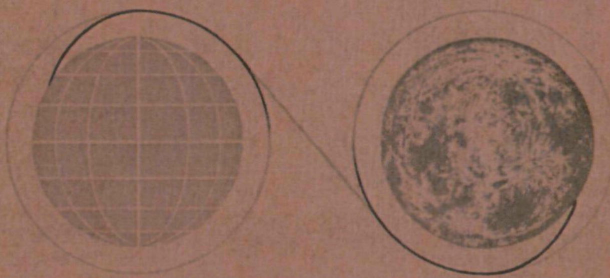
CONFIDENTIAL

Grumman Design 378B



Apollo Extension Systems—Lunar Excursion Module
Phase B Final Report

U. S. Government Agencies and Contractors Only

Vol. IV Phase II Laboratory Design Analysis Summary (U)

CONFIDENTIAL

CONFIDE[redacted]

C66-00093

Copy No. 11

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

U. S. Government Agencies [redacted]

by

Grumman Aircraft Engineering Corporation
Bethpage, New York

This document con[redacted]s information affecting the national defense of the United States within [redacted]meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794, th[redacted]nsmission or revelation[redacted]f which in any manner to an unauthorized person i[redacted]ohibited by law.

G[redacted]p 4 D[redacted]ent
Dow[redacted]raded at 3-Y[redacted]Intervals
[redacted]eclassified after 1[redacted]ears

Vol. IV Phase II Laboratory Design Analysis Summary

Contract No. NAS 9-4983
ASR 378B

8 December 1965

[redacted]

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*

TABLE OF CONTENTS

(Note: Tables and Figures are grouped at the rear of each major subsection.)

1. INTRODUCTION

This volume describes the study of the use of an Apollo LEM as an orbital laboratory to provide experiment support for mission durations of up to forty-five days. This vehicle, to be operated in conjunction with an "AES" Command and Service Module, is known as the Phase II Lab.

The preliminary design data which are provided are intended to permit the selection by NASA of a Phase II Lab Configuration.

The following vehicle-level ground rules were observed during this study. Additional subsystem-level ground rules and assumptions are included in the subsystem and system sections:

- The Phase II Lab shall be a conversion from the LEM design in an optimum manner commensurate with study guidelines and constraints.
- The Phase II Lab shall be operated with the "AES" CSM for a maximum of 45 days earth orbit utilizing a Saturn I-B or Saturn V launch vehicle.
- The Phase II Lab shall require minimum spacecraft modifications and shall utilize Apollo and Gemini hardware wherever feasible.
- The vehicle shall require minimum modifications to Ground Support Equipment, Acceptance Checkout Equipment, and the Manned Spaceflight Network.
- Modifications and development must be compatible with the launch schedule as defined in ML-65-1.
- The specific modifications required to accomplish rendezvous and/or split launch are not included in the vehicle design.
- The orbital characteristics of the Phase II Lab missions are as described in Table II (Revision L) of the Blue Book.

The definition of the Phase II Lab is not based upon any specific experiment or group of experiments. The requirements of the vehicle subsystems for experiment support have been selected from a broad survey of the proposed missions and from data available from the first Phase of this study, (Apollo Extension System - Earth Orbit Mission Study - Addendum I to Contract NAS 9-3681).

The analysis of the vehicle is divided into the appropriate subsystem and system areas. Each of the subsystems includes a description of selected configuration choices. These choices include a "recommended", a "baseline", and certain "alternate" choices. The "recommended" choice describes the configuration which now appears most attractive on an overall vehicle basis and is reported on in the third section of each subsystem. The "baseline" configuration is that configuration upon which the PDP costing was based and appears in the fourth section of each subsystem. The various alternates appear in succeeding sections of each subsystem and are presented as possible candidates for NASA selection. "Per flight modifications" are included, where appropriate, as changes to the vehicle which may be attractive only for specific flights. A tabular listing of these choices, together with other descriptive information, is included in the Configuration Summary.

2. CONFIGURATION SUMMARY

2.1 INTRODUCTION

This section summarizes the recommended and baseline Phase II Lab configurations and the subsystem alternates which were studied during the contract period. The definition of these configurations is based on the following:

- NASA ground rules as defined in the Work Statement and Blue Book
- Results of Phase A studies, Contract NAS 9-3681
- Subsystem and system studies
- Vehicle design and integration studies
- Compatibility with "AES" Command and Service Module

The vehicle level ground rules that were observed during the study are defined in the Introduction, Section 1. The mission analysis and supporting studies are described in detail in Sections 3 through 6.

2.2 ASSUMPTIONS

Gross vehicle design assumptions used during the study are summarized by subsystem in Table 2.2.-1. These assumptions are based upon the established ground rules, upon discussions with NASA personnel and upon vehicle design requirements as described in the Blue Book.

2.3 RECOMMENDED CONFIGURATION

The recommended Phase II Lab (Fig. 6.2-1) is a LEM with modifications needed to provide (1) a mission duration capability of 45 days (2) an experiment support capability and (3) compatibility with the AES Command and Service Module. The specific subsystems requiring modification are the electrical power, environmental control, stabilization and control, instrumentation, reaction control and the structural changes associated with these modifications. Minor modifications have also been made to crew provisions, communications and displays. No main propulsion capability is carried. Main propulsion tanks, including the descent tanks, have been deleted. All modifications or changes, with reference to the present LEM configuration are listed in Table 2.3-1 and are described in detail in Sections 4, 5 and 6. Summary descriptions are presented below. A level I functional block diagram of the recommended Lab subsystem interfaces is shown in Fig. 2.3-1.

2.3-1 Electrical Power

The housekeeping energy for the 45 day mission, including an allowance for growth and distribution buses is 755 kw-hrs. Since this requirement exceeds that which can reasonably be supplied by batteries, fuel cells have been chosen as the power source. The housekeeping energy, including fuel cell parasitics, is 1004 kw-hr.

The Allis Chalmers 2 kw nominal design fuel cell has been selected. Two of these fuel cells are mounted in the aft equipment bay of the Lab and provide a peak power output of 4400 w.

The cryo tanks used to supply reactants to these cells are the CSM "AES" tanks. One each hydrogen and oxygen tanks contain 144 lb H_2 and 1375 lb O_2, respectively. These reactants supply a total of 1680 kw-hrs for a typical mission. The energy available for experiments therefore is 676 kw-hrs. Since the average power of the mission requires reactant flow rates that are approximately double that specified as "minimum allowable" for these tanks, no reactant loss due to boil off is anticipated.

The cells are actively cooled using 60 sq ft of radiator area to accommodate peak and normal heating loads.

2.3.2 Environmental Control

During the 45 day orbital mission duration, the temperature variations of the various components and subsystems within the vehicle will be controlled by the Heat Transport Section using a 60 sq ft space radiator in combination with supplemental water boiling. The ECS radiator consists of four 15 sq ft panels mounted on opposite sides of the descent stage. The control section provides sufficient flexibility such that no thermal constraints are imposed upon the vehicle even under extreme environmental conditions.

These radiators, with a LEM type water boiler, can accommodate about 3.1 kw of experiment load in addition to the housekeeping power. The total system capacity for experiment cooling is approximately 834 kw-hr.

The Atmosphere Supply and Pressurization Control Section provides for airlock re-pressurizations using the same regulation and delivery equipment as is used on the LEM. A LEM ascent GOX tank functions as an accumulator to supply oxygen from the EPS cryo tanks. Gaseous nitrogen is stored in the LEM descent GOX tank and is sufficient, in combination with the available oxygen, to pressurize the airlock 44 times.

Experiments may be integrated onto existing cold plate areas within the cabin (500 sq in.) or onto existing cold rails in the aft equipment bay.

Mounting of experiments outside the vehicle is compatible with the planned ECS system up to the thermal load limits previously described.

2.3.3 Stabilization and Control

The Lab carries a stabilization and control section for the purpose of providing attitude hold during orbital operations. On the basis of power, operating life, and thermal considerations, the LEM Abort Guidance and Control Section has been selected over the Primary Navigation, Guidance and Control Section. Some modifications are required however to reduce the amount of propellant consumed during undisturbed limit cycle operation. These changes include a modification to the Rate Gyro Assembly to provide an increased sensitivity to determine vehicle rates and a modification to the Attitude and Translation Control Assembly. To compensate for system drift, it is necessary to "update" the attitude reference system on a periodic basis. This may be done in the Lab by interfacing the Alignment Optical Telescope to the Abort Electronics Assembly. This interface consists of adding a star catalog to the AEA program and implementing the AOT signals into the Data Entry and Display Assembly. These changes, as well as the changes to the RGA and ATCA, are carried as part of the recommended configuration.

Additional sensors, such as horizon scanners or star trackers, may not be required on every flight. As such, they are not carried as part of the Lab.

2.3.4 Instrumentation

A data handling section has been added to the Lab to provide for recording, storage and transmission of experimental data. The section consists of a modified LEM Pulse Code Modulator and Timing Electronics Assembly (PCMTEA) and two modified CSM type tape recorders.

The recorders are modified to (1) operate from LEM single Phase AC power (2) provide increased digital data handling capacity by converting 4 analog tracks to digital and (3) increase output dump rate to 409.6 kb/sec. The PCMTEA is modifed such that the low bit rate is changed from the 1.6 kb/sec to a 12.8 kb/sec format. In this mode of operation each tape provides 4 hrs of recording at maximum tape density and a data compression of 32 to 1. The PCMTEA high bit rate remains at 51.2 kb/sec and provides one hour of recording per tape (data compression eight to one). Each of the above modes dumps data at 409.6 kb/s and requires 8 min transmit time per tape. Because of the digital track modification, the recorders run at half speed.

It is anticipated that this capability will meet the requirements of every Phase II mission.

2.3.5 Reaction Control

The LEM now carries two sets of RCS tanks. To provide sufficient capacity to meet the anticipated needs of the Phase II Lab, two additional sets have been added. These tanks are carried in the aft equipment bay in areas made available by the deletion of ascent propulsion components. Since the O/F ratio of the RCS engine during minimum impulse bit firing is considerably less than that for which the tanks are sized, it is desirable to, in effect, reverse the fuel and Ox tanks. This change, together with the added tanks, produces a usable tank capacity of 1048 lb. This quantity will provide a capability of 0.3 deg limit cycling for the entire mission, with ideal rate sensing, provided no disturbance torques are present.

2.4 BASELINE CONFIGURATION

The baseline configuration is summarized in Table 2.3-1, as changes from the LEM configuration. The principal difference between this configuration and the recommended is that no airlock was carried, the CSM "Housekeeping" cryo tanks were used, a capability to provide descent propulsion was required, and the P&W fuel cells were used. Other changes were generated from the fact that the baseline configuration was mated to CSM which did not have a regenerable CO_2 removal system and did not have a two gas cabin atmosphere.

2.5 ALTERNATE CONFIGURATIONS

In arriving at the recommended Lab configuration, alternate methods of achieving the mission requirements were studied. The candidates studied are summarized by subsystem in Table 2.5-1.

2.5.1 Stabilization and Control

The most significant alternates considered to provide the attitude hold requirement are the Primary Navigation, Guidance, and Control Section (PGNCS), momentum exchange devices, and the present LEM Abort Guidance and Control Section (AGS) - un-modified.

The PGNCS can provide the attitude hold capability while consuming a minimum of reaction propellant. It also possesses a capability for attitude reference updating and could provide local vertical hold if required. The disadvantages of this system are that it requires 240 w more power, has a lower operating lifetime, and prevents the installation of experiment cooling loads on the back cabin bulkhead.

Momentum exchange devices, such as control moment gyros, inertia wheels, or fluid flywheels, provide reduction in the amount of RCS propellant required for long duration pointing. Preliminary sizing of a control moment gyro system indicates that it requires 144 w of power, weighs around 480 lb, and has a diameter of 2.7 ft.

The LEM AGS may be used unmodified if its inability to sense reduced vehicle rates can be tolerated. This inability might be allowed if, (1) the duration required for fine attitude control is less than 6 days or (2) if the vehicle disturbance torques are quite large. Since many of the missions, as presently understood, do not satisfy either of these conditions, a modified AGS has been recommended.

2.5.2 Environmental Control

The alternates studied include the use of a separate cooling loop for experiments, the deletion of the suit circuit assembly, and the elimination of the airlock.

A separate cooling loop may be desirable for experiments that have restrictive temperature requirements and therefore should not be subjected to the temperature variations that occur in the "housekeeping" loop. This separate loop could use components presently used in the LEM secondary coolant loop.

The suit circuit assembly is retained in the recommended configuration specifically to support egress/ingress procedures during extra vehicular operations. This assembly provides suit cooling while transitioning to the backpack and also provides a capability to purge the suit of N_2 before the suit pressure is dropped to 3.7 psi. The suit circuit assembly could be eliminated if this support was provided by the CSM suit system. This method creates an additional interface to the CM but provides a usable volume increase of 12 cu ft.

Transition to the backpack without suit circuit support requires development of new checkout procedures, review of comfort and reliability standards and may entail modification to the suit and/or backpack.

The airlock provides a vehicle weight saving of 100 lb based on a design requirement of 44 egress operations. Should the number of extravehicular operations be significantly less than this, it may be desirable to delete the airlock. The effect of cabin depressurization upon overall laboratory operations must also be considered.

2.5.3 Electrical Power

Both the Pratt & Whitney and General Electric fuel cells have been examined. These power supplies have been compared with the Allis Chalmers on the basis of performance, weight, and reliability. Although each of the three candidates are considered satisfactory, the General Electric design introduces a cooling system penalty and also requires four cells instead of two. The Pratt and Whitney cell has poorer step lead performance and, because of a larger and heavier design, does not lend itself to easy integration into the vehicle. The energy available for experiments is 625 kw-hr for the GE and 691 kw-hr for the P&W as opposed to 676 kw-hr for the Allis Chalmers design. The overall evaluation shows the AC fuel cell to be the most desirable design for the Phase II Lab.

2.5.4 Vehicle Design

Several airlock designs are presented for the Lab. Two of these configurations involve the use of expandable structure and are attached to the front face of the vehicle. These so called "front hatch" designs are advantageous in that the astronaut enters the airlock through the front hatch and can wear a "checked out" back pack. One of these two designs is a common design with the Shelter. The disadvantage of these types is that they must be retracted when not in use because of the severe visibility restrictions created while extended.

The third type of airlock investigated is a rigid design which occupies the descent stage center bay in an area made available by the deletion of the main propulsion function. Access to this airlock is made through the "ascent stage" opening in the aft cabin floor. This chamber, 47 inches in diameter, affords several advantages over the front hatch design. It offers, in effect, another 85 sq ft of pressurized cabin volume when not being used as an airlock and can also serve as a docking tunnel for rendezvous flights. A disadvantage is created because of the restricted entry hatch diameter (requiring backpack donning within the chamber) and because the design is not common with the Shelter. Although an airlock is part of the recommended configuration, no specific selection has been made as yet.

2.6 POTENTIAL MODIFICATIONS PER FLIGHT

Per flight modicications include the use of the "low profile" descent stage, the incorporation of additional RCS tankage, the use of descent propulsion, the use of additional storage boxes, and the incorporation of the viewfinder.

The recommended configuration is compatible with each of these except the use of descent propulsion. This modification requires the relocation of the cryo tanks. Also, the feasibility of controlling the combined LEM-CSM during descent engine firing has not been established.

The use of the low profile descent stage is compatible with the AES cryo tank installation, but may require reconfiguration of the "standard" radiator panels.

The per flight changes are not included in the vehicle design since their incorporation is strongly mission dependent. These modifications, as listed in Table 2.5-1, are discussed in the appropriate subsystem sections.

Table 2.2-1

PHASE II LAB
GUIDELINES AND ASSUMPTIONS

Item	
Environmental Control	• The CSM ECS Shall Provide For The Removal Of Carbon Dioxide. Excess Water Vapor, Odors, Trace Contaminants And Particulate Matter From The Combined CM Lab Atmosphere During Routine Flight • The CSM Shall Provide All Water Required By The Crew For Drinking, Food Preparation And Personal Hygiene. • The Lab Shall Provide For Recharging The PLSS • The Lab Shall Provide For The Exchange Of Cabin Atmosphere Between The Lab And CM As Required To Maintain The Former At Acceptable Humidity, Temperature And Carbon Dioxide Concentration Levels • For Phase II Missions, The Atmosphere Shall Be 5 psia, 70% Oxygen 30% Nitrogen. Ambient Storage Of Inert Gas Shall Be Employed. A Capability Shall Exist For Alternative Operation At 5 psia Pure Oxygen • Lab Metabolic And Leakage Gas Requirements Shall Be Supplied By The CSM • There Shall Be No Requirement That One Crew Member Be In A Pressure Suit At All Times • The CSM Shall Incorporate A Two Bed Thermal Swing Molecular Sieve For Carbon Dioxide Removal • An Airlock And Associated Support Equipment Shall Be Integrated Into The Phase II Lab • Crew Metabolic Heat Loads Are Apportioned As Follows: CSM ECS: All Latent Metabolic+Sensible Metabolic Produced By CM Occupants Lab ECS: Sensible Metabolic Produced By Lab Occupants • The Lab Airlock Is Decompressed To Effect Egress And Is Unpressurized During EVA Experiments Only • There Are No Fluid Hardware Interfaces Between The Lab And CSM • The Lab ECS Returns Cabin Gas To The CSM At The Same Temperature At Which It Is Supplied (Nominally 75 ± 5°F). • The Lab Suit Circuit Performs Carbon Dioxide, Excess Moisture, Odor And Particulate Matter Removal Functions In Support Of Airlock Operations Only (i.e., PLSS Transition) • No Restrictions Are To Be Placed On Vehicle Orientation Due To Thermal Control Restraints • An Active Thermal Control System Will Be Used For Vehicle Heat Rejection

Table 2.2-1 (cont.)

	• Overboard Venting Of Cryogenic Oxygen And Hydrogen Is To Be Avoided • Only Water Generated By The Fuel Cells That Is Not Required For Any Other Purpose Is To Be Used In Water Sublimators. • Minimum Modification From Flight To Flight Overrides Optimization For Any Particular Flight • The NAA AES Cryogenic Storage Tanks Shall Be Used If Thet Satisfy The Phase II Lab Missions
Instrumentation	• The Lab Module Carries Its Own Communications And Data Handling System • There Will Be No Data Interface Between The Lab And The CSM • Video Transmission Will Be Through The CMS-Band Link (Real Time Only) • Any Changes In The Operational Measurements Shall Not Exceed The Present Lunar LEM Measurements • Maximum Utilization Of The Crew For Redundancy Monitoring And Failure Mode Corrections/Operations Will Be Used • All Operational Data Will Be Presented To The Ground Line-Of-Sight Mission Phases Only (Real Time) • There Will Not Be Any On-Board Recording Capability For Operational Data • All Vendor Supplied Experiments Will Provide Their Own Signal Conditioning Compatable With The AES Experiment Acquisition System • Experiment Data Will Be On-Board Recorded During Periods Of Flight Not Covered By Line-Of-Sight • Experiment Data Set-Up, Pre Or Post Calibration And Operation Will Be On-Board Controlled And Will Not Require Any Ground Uplink Support Capabilities • Experiments Requiring Analog Data Recovery Will Utilize The Analog Portion Of The Experiment Tape System • All Experiment Data Will Be Considered "Passive" For Ground Reduction (Not Requiring Real Time Display) On-Board Display Of Selected Experiment Parameters Will Be Available To The Astronauts • The Data Record, Dump Or Re-Dump Requirements Will Be The Responsibility Of The Astronauts And Will Not Require Any Ground Uplink Control
Electrical Power Supply	• No Interchange Of Electrical Power Between The CSM And The Lab • Use Existing Cryogenic Tank Designs • Design Power Profile - a. 7.5% Distribution Losses For All Loads b. 20% Growth Allowance For All Loads

Table 2.2-1 (cont.)

	c. Load Values Based On LEM Current Status Or Latest Vendor Test Data d. Housekeeping Power Provides For Rate Stabilization Only e. 19,350 n.mi Synchronous Earth Orbit With A 1080 hr Orbit Mission Time • Fuel Cells Started Prior To Launch • Experiment Energy Available Made Equal To AES Cryogenic Tank Capacity Energy Minus Housekeeping Energy • Voltage At Fuel Cell Terminals - 28 To 32.5
Propulsion	• Ascent And Descent Propulsion Subsystems Will Be Deleted
Structure	• No Holes In The Pressure Shell • No Modification To Ascent And Descent Primary Structure • The Retention Of Existing Piping And Wiring • Maintain Commonality Of Subsystems Between Vehicles • No Changes To The Spacecraft LEM Adapter (SLA) • Location Of Subsystem Additions To Retain Many Of The GSE Servicing Requirements In The SLA • Experiments Will Be Mounted To The Vehicle At Existing Hardpoints
Stabilization & Controls	• All Translation And Orbital Maneuvering Capability Will Be Supplied By The CSM • The Lab Will Provide The Orbital Attitude Hold Capability Within The Limits Of The Recommended Configuration Capability Beyond These Limits Will Be Supplied By The Experiment Package • There Is No Electrical Interface For Control Between The Lab And The CSM • All Missions Have RCS In The Lab • There Is No Main Propulsion System In The Lab • The Lab Must Include A Capability To Provide An Inertial Reference • The Addition Of External Sensors Such As Hoizon Scanners Are Experiment Dependent And, As Such, Are Not Included In The Vehicle Design • Since There Is No Requirement For Translational Capability, Consideration Of Rotations Resulting from Translation Thrusting Along the ±Y Or ±Y Axes Are Omitted
Crew Provisions	• The CM Will Be The Crew Living Quarters • The Phase II Lab Will Be Used Mainly As A Laboratory • The CM Will Be Used As Crew Shelter During Unusual Radiation Or Meteoroid Activity

Table 2.2-1 (cont.)

	• CM ECS Shall Incorporate A Two-Bed Thermal Swing Molecular Sieve For CO_2 Removal. The Present LiOH System Shall Be Retained As A Backup For Emergencies And For Pressure Suit Operations • An Airlock Will Be Incorporated • The Spacecraft Will Normally Carry A Three Man Crew, With No More Than Two Men In The Lab At One Time • There Shall Be No Requirement That One Crew Member Will Be In A Pressure Suit At All Time • Untreated Biological Wastes Shall Not Be Allowed To Become Free Residue In Space • The Waste Management, Waste Disposal Systems, Personal Hygiene, Exercise, Rest, Medical And Recreation Equipment Is Assumed To Be Located In The CM • Crew Members Will Sleep In A Soft Suit On The CM Couches. The Space Suits Will Normally Be Dried, Serviced And Stowed On The Couches. • Food For The Mission In Excess Of Three Man-Days Will Be Stored In The Lab • Food Preparation And Consumption And Water Management And Supply For Crew Use Equipment Will Be Accomplished In The CM • Food Quantity Shall Be Based On An Individual Calorie Intake Of 3000 K Calories Per Man Per Day • Rechargeable Batteries Will Be Used For The PLSS • Each Crew Member Requires A New Constant Wear Garment (CWG) Every Two Days • One Pressure Garment, One Liquid Cooled Garment, One Helmet And One Thermo-Meteoroid Garmet Are Located In The CM Storage Containers • No CM-LiOH Cartridges Will Be Carried In The Lab
RCS	• The Lab Shall Be Used Exclusively For Attitude Hold • Two Deadzone Settings Are Available: ±.3 deg and ±.5 deg • Gyro Rate Threshold Sensitivity Is Compatible With The Vehicle Mass Properties Unless Otherwise Specified • CSM RCS Shall Be Used For Transit And Orbital Slewing Functions Including Rolling Operations • The Marquardt 100 lb Thruster Performance Is As Follows: Minimum Impulse (Standard Condition) = .75± .15 lb sec Specific Impulse (At Minimum Impulse) = 130 sec O/F Ratio (At Minimum Impulse) = 1.3 • Engine Life Time Specifications: Burning Time = 1000 sec Total; 500 sec, Steady State; 500 sec Min Impulse Cycling Maximum Number of Cycles - 10,000 • Unmodified Propellant Tank Capacity Is 423 lb Of Usable Propellent • Modified (Interchanged Propellant Tanks) Tank Capacity Is 524 lb Of Usable Propellant

Table 2.2-1 (cont.)

Communications	• There Are No TV Or Data Uplink Requirements • All Three Astronauts Will Have Continous Audio Capabilities • EVA Communication To The CSM Or Lab Will Be Via The VHF Link • Earth S-Band Communication Link Is Always Available Regardless Of The Intercommunications Mode • Lab Status Data Will Be Transmitted To The Ground During Line-Of-Sight Mission Phases • There Is No Data Interface Between The CSM And Lab • Lab Communications And Telemetry Subsystems Are Not Dependent On CSM • TV Transmission Will Be Via The CSM S-Band Link To Earth (Real Time Only) • TV Requirements Will Be Satisfied By The Present Apollo GFE TV Camera. This Camera Will Be Deployed From The CSM Through The Hatches To The Lab, With The Power Cable Extending From The Camera To The CSM S-Band Subsystem • There Will Be A Hardline Intercommunications System Between The CSM And Lab. The Hardline Can Be Used When The Lab Is Depressurized
Displays & Controls	• The Required Lab Displays Should Be Incorporated With A Minimum Of Modification To The Existing Console Layout • Maximum Use Should Be Made Of LEM Type Controls And Displays For Modifications
Mass Properties	• Experiment Weight Is Not Included In The Baseline Or Recommended Laboratory Weights • Water, Oxygen, LiOH And PLSS Batteries For 16 And 44 EVA's Are Provided By The Baseline And Recommended Labs Respectively • Food And CSM LiOH For 44 Days Are Carried In The Baseline Lab • Food For 44 Days Is Carried In The Recommended Labs • Experiment Weight Must Include The Following Dependent Items In Addition To The Experiment Itself - Supports And Mounts - Micrometeroid And Thermal Shielding - Signal Conditioning And Sensors - Electrical Wiring - Controls And Displays - GN&C For Special Requirements - Electrical Power, Propellant, Oxygen And Water (And Associated Hardware) For Requirements In Excess Of Above

Table 2.2-1 (cont.)

- AES (CSM) Maximum Volume Cryogenic Tanks (1 Hydrogen And 1 Oxygen) Plus Allis-Chalmers Fuel Cells Utilized In The Recommended Configuration Result In 676 kw-hrs Of Available Experiment Energy; AES (CSM) Housekeeping Cryogenic Tanks (2 Hydrogen And 2 Oxygen) Plus Pratt & Whitney Aircraft Fuel Cells Utilized In The Baseline Configuration Result In 654 kw-hrs Of Available Experiment Energy

Table 2.3-1

RECOMMENDED VS. BASELINE CONFIGURATION

Vehicle	Recommended Configuration			PDP Baseline Configuration		
Item / Change	Removed	Modified	Added	Removed	Modified	Added
1.0 Structure (Ascent) (Descent)	•Ascent Engine Cover •Propellant Tank Supts •Water Tank Supports •Battery Supports •GOX Tank Supports •Prop. Tank Shielding •Base Heat Shield* •Battery Supports		•Airlock (No Specific Recommendation) •GOX Tank Supports •SOX & SH_2Tank Supts. •Fuel Cell Supts. •RCS Tank Supts. •Radiator Supts. •Lower Deck Insulation •Water Tank Supts.	•Ascent Engine Cover •Propellant Tank Supts •Water Tank Supports •Battery Supports •GOX Tank Supports •Prop. Tank Shielding •Base Heat Shield* •Battery Supports	•M/M Shielding •M/M Shielding	•Mid Section Canister •GOX Accum. Supports •SOX & SH_2 Tank Supts. •Fuel Cell Supts. •RCS Tank Supts. •Radiator Supts. •Lower Deck* Insulation •Water Tank Supts.
2.0 Stabilization & Controls	•GDA •DECA	•AEA (Software change to accomodate star catalogue) •Modify RGA to provide lower rate •Change rate gain in ATCA to insure one pulse limit cycle		•DECA*		
3.0 Navigation & Guidance	•Landing Radar •Rendezvous Radar •IMU •LGC •PTA •PSA •CDU			•Landing Radar •Rendezvous Radar* •IMU* •LGC* •PTA* •PSA* •CDU* •DSKY*	•AEA	
4.0 Crew Provisions		•Revise External lighting •Add furnishings	•Provide capability for .44 backpack recharges (assume rechargable batteries) •Airlock--suit loop in •Add battery charger		•Revise External lighting •Add furnishings	

*Vehicle Must Be Capable of Retaining All Items Marked With Asterisk

Table 2.3-1 (cont.)

Vehicle	Recommended Configuration			PDP Baseline Configuration		
Item / Change	Removed	Modified	Added	Removed	Modified	Added
4.0 Crew Provision (cont'd)	•Lunar Speciman Return Containers •Still Camera •EVA Life Line •Water Probe and Holster		•Change backpack battery capability to 44 (assume rechargeable) (°2 batts) •Provide 66 const. wear garments •Extra flood lights •2 work tops & work top lights •Dome Light •1 seat •1 LEM voice rec. (total--2)			
5.0 Environmental Control	•LEM Water Tanks •Secondary Glycol Loop •One Water Boiler •Ascent Stage GOX Tank	•Glycol Pump •Cabin Fans (to provide for duct losses)	•ASA Bypass •Suit Circuit Interface to Airlock •CSM/Lab Recirc Duct •1 'Fuel Cell' Type Water Management Tanks •2 30 ft^2 Radiator Panels (A) •Fuel Cell Coolant Loop •Two Gas Airlock System	•LEM Water Tanks •Secondary Glycol Loop •One Water Boiler •2 A/S GOX Tanks	•Glycol Pump	•CSM/Lab Recirc Fan Assy •2 'Fuel Cell' Type Water Management Tanks •2 30 ft^2 Radiator Panels (A) •16 PLSS LiOH Cartridges
6.0 Landing Gear		•Remove Completely			•Remove Completely	
7.0 Instrumentation			•1 Modified PCM (B) •2 CSM Type Recorders Modified to provide 409 kb/s dump digital track mod and Single Phase AC OP.		•PCM	•1 Modified PCM (B) •2 CSM Type Recorders

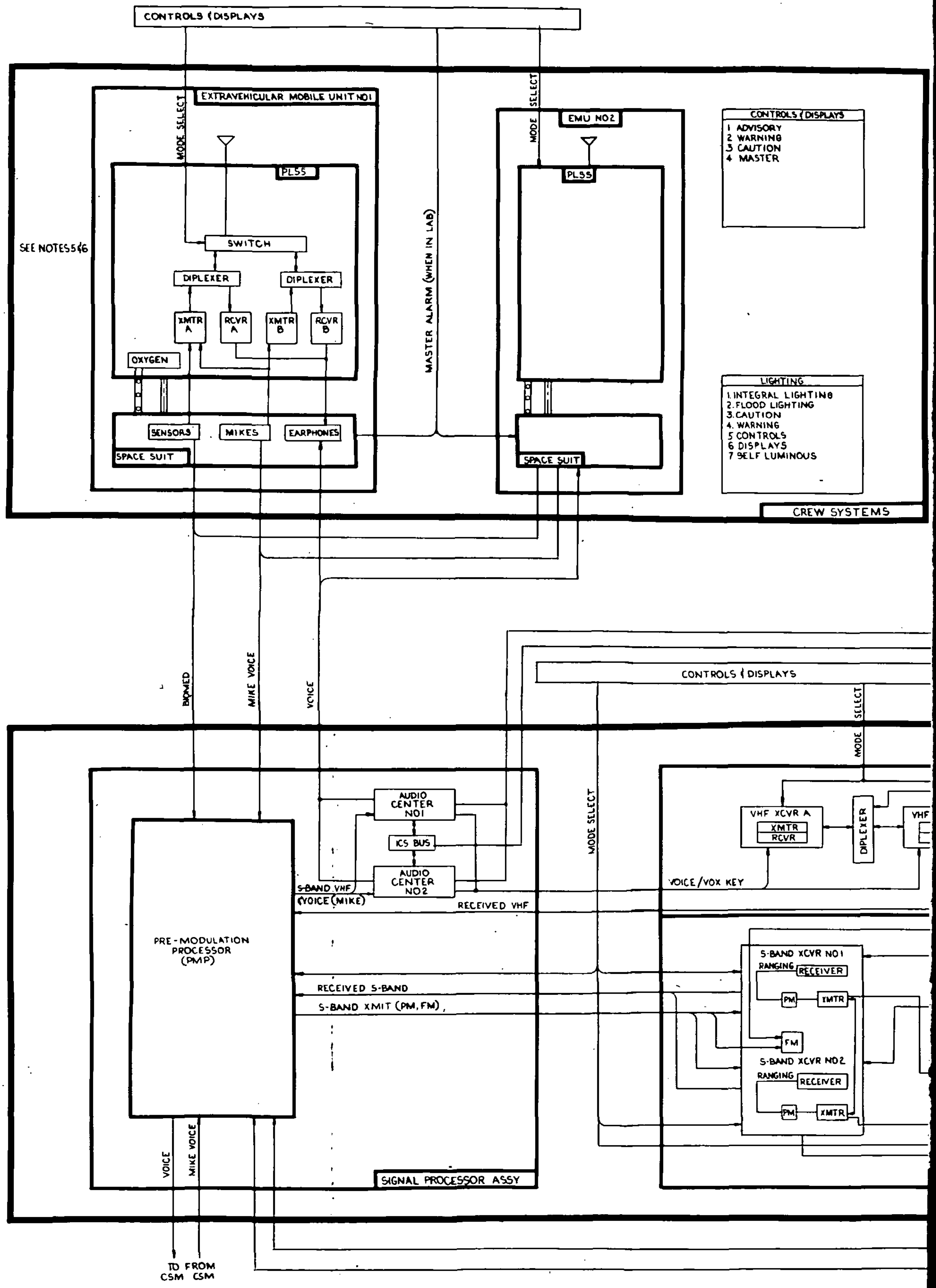
(A) 180° Apart
(B) Experiment Data Sensors, Experiment signal conditioning and power to operate same are considered to be an experimenter's responsibility

Table 2.3-1 (cont.)

Vehicle	Recommended Configuration			PDP Baseline Configuration		
Item / Change	Removed	Modified	Added	Removed	Modified	Added
8.0 Electrical Power Supply	•LEM Batteries & ECA's	•Wiring	•Fuel Cell ECA's •Peaking Battery ECA •2 AC Fuel Cells •2-30 ft^2 Radiators (A) •1 Peaking Battery •1 AES H_2 Tank •1 AES O_2 Tank	•LEM Batteries	•Wiring	•2 P&W Fuel Cells •2-25 ft^2 Radiators (A) •1-7 KW Hr Peaking Battery •2 CSM 'Housekeeping' H_2 Tanks •2 CSM 'Housekeeping' O_2 Tanks
9.0 Propulsion	•Ascent Engine •Ascent Prop System •Ascent He System •Descent Engine •Descent He System •Descent Prop Tanks •Descent Prop Plumbing			•Ascent Engine •Ascent Prop System •Ascent He System •Ascent Cont & Elect •Descent Engine* •Descent He System* •Descent Prop Tanks* •Descent Prop Plumbing*		
10.0 RCS		Interchange fuel and ox lines at tank outlets	•2 Oxidizer Tanks •2 Propellant Tanks •2 He Tanks •All Associated Plumbing		Interchange fuel and ox lines at tank outlets	•2 Oxidizer Tanks (C) •2 Propellant Tanks •2 He Tanks •All Associated Plumbing (D)
11.0 Communications	•S-Band Erect Antenna •VHF Erect Antenna	•SPA mod-provide for hardline intercom	•Hardline Intercom •Interface 409.6 Kb/s Data Channel Into FM Modulator	•S-Band Erect Antenna •VHF Erect Antenna		•Hardline Intercom
12.0 Displays & Controls	•ACA (1) •TCA (1) •FDA I (1) •GASTA •DSKY •Ascent Eng. Controls •Battery Controls •Descent Eng. Controls •Radar displays	•DEDA •Audio Control •Explosive Devices	Controls for Fuel Cells, cryo tanks and hardline intercom. •Crew Safety Displays •Quantity Gage RCS •Data Handling Controls and displays •Control for peaking battery	•ACA (1) •TCA (1) •FDAI (1)	•Revise EPS, Comm •Controls	Controls for Fuel Cells, cryo tanks and hardline intercom.

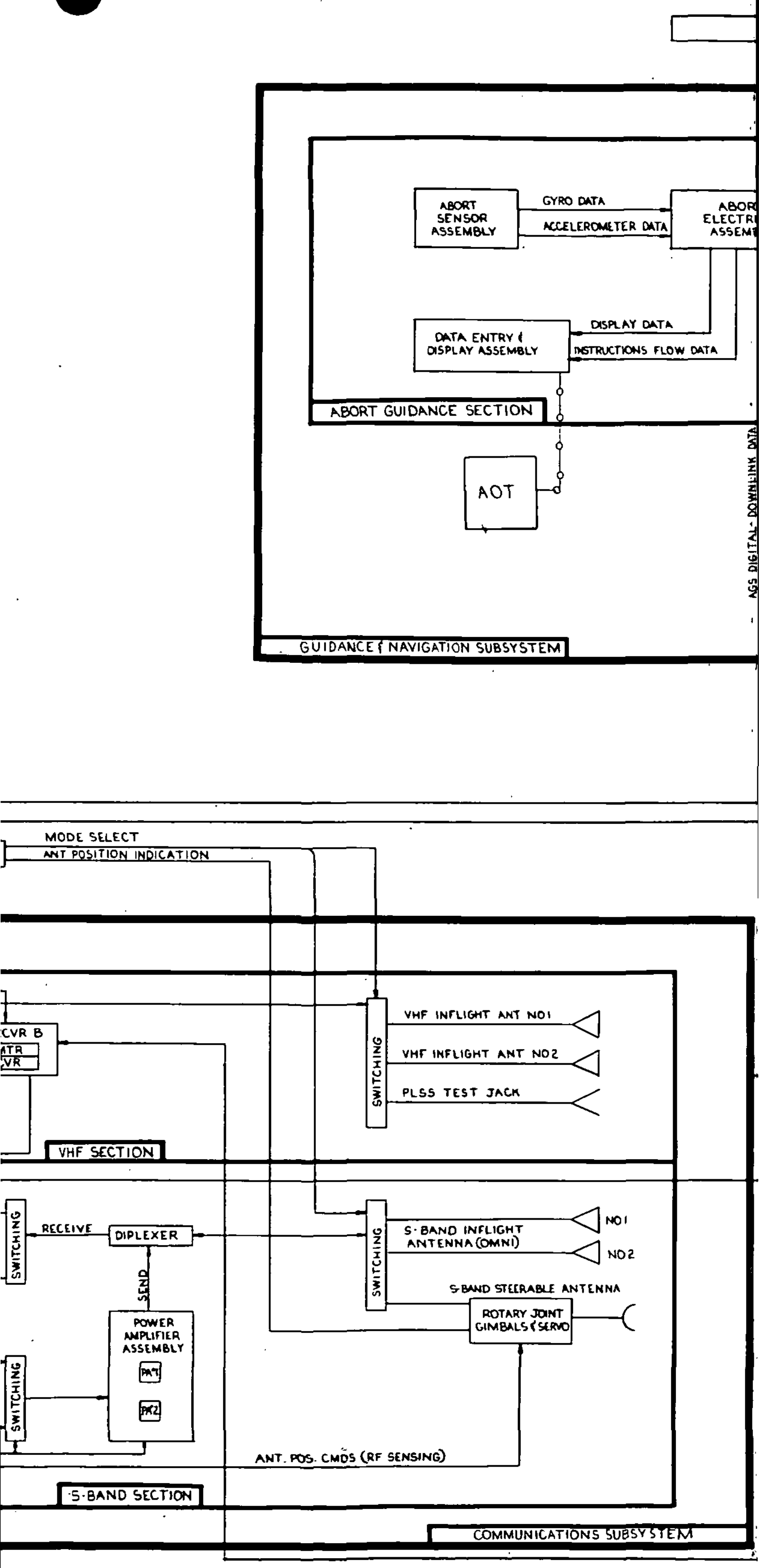
*Vehicle Must Be Capable of Retaining all Items marked With Asterisk

(C) Double the LEM capacity
(D) Reverse fuel and oxidizer line connections.



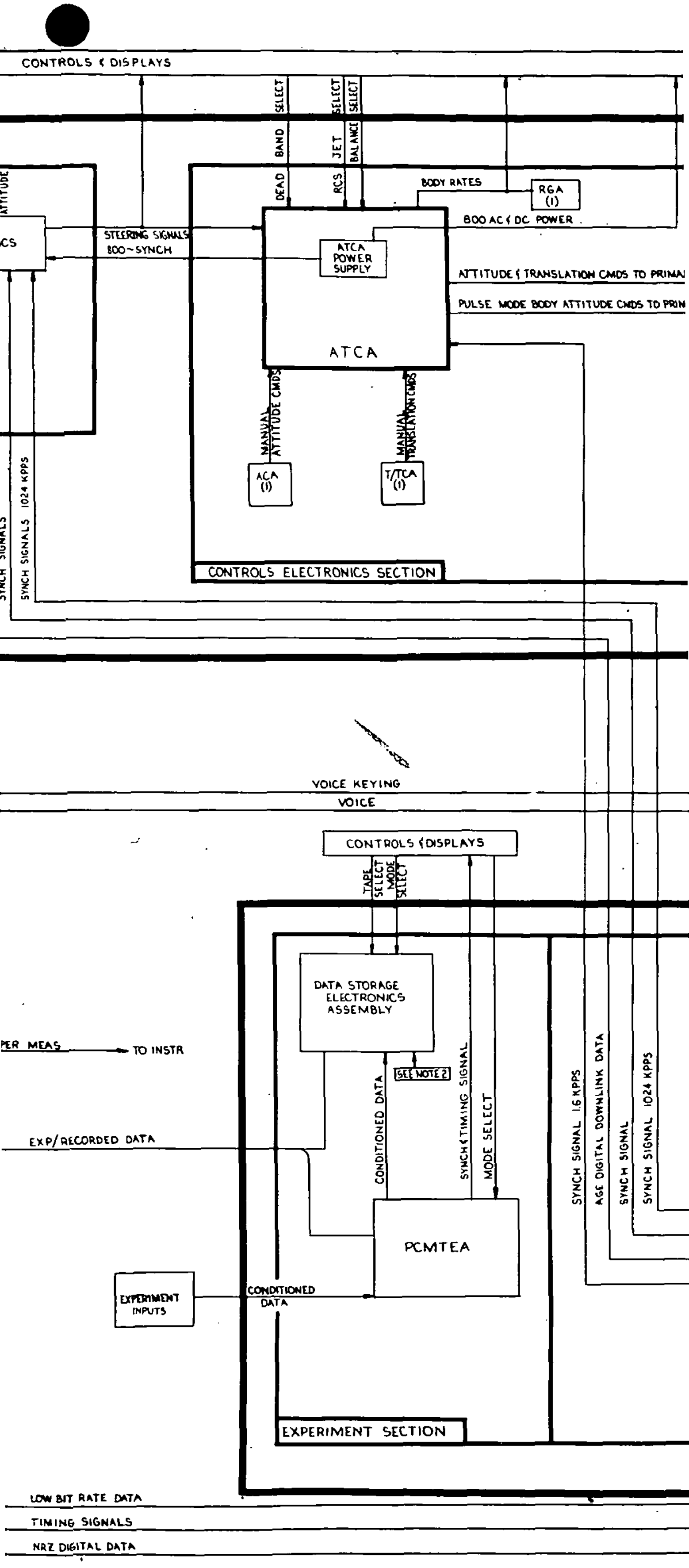
CONTROLS & DISPLAYS
EXTRAVEHICULAR MOBILE UNIT NO1
MODE SELECT
PLSS
SWITCH
DIPLEXER
DIPLEXER
XMTR A
RCVR A
XMTR B
RCVR B
OXYGEN
SENSORS
MIKES
EARPHONES
SPACE SUIT
SEE NOTES 5 & 6
MASTER ALARM (WHEN IN LAB)
EMU NO2
MODE SELECT
PLSS
SPACE SUIT
CONTROLS & DISPLAYS
1 ADVISORY
2 WARNING
3 CAUTION
4 MASTER
LIGHTING
1. INTEGRAL LIGHTING
2. FLOOD LIGHTING
3. CAUTION
4. WARNING
5 CONTROLS
6 DISPLAYS
7 SELF LUMINOUS
CREW SYSTEMS
BIOMED
MIKE VOICE
VOICE
CONTROLS & DISPLAYS
MODE SELECT
MODE SELECT
AUDIO CENTER NO1
ICS BUS
AUDIO CENTER NO2
S-BAND VHF
(VOICE (MIKE)
RECEIVED VHF
PRE-MODULATION PROCESSOR (PMP)
RECEIVED S-BAND
S-BAND XMIT (PM, FM),
VHF XCVR A
XMTR
RCVR
DIPLEXER
VHF
VOICE/VOX KEY
S-BAND XCVR NO1
RANGING
RECEIVER
PM
XMTR
FM
S-BAND XCVR NO2
RANGING
RECEIVER
PM
XMTR
VOICE
MIKE VOICE
SIGNAL PROCESSOR ASSY
TO CSM
FROM CSM

2.3-1A
(1)


ABORT SENSOR ASSEMBLY
GYRO DATA
ACCELEROMETER DATA
DATA ENTRY & DISPLAY ASSEMBLY
DISPLAY DATA
INSTRUCTIONS FLOW DATA
ABORT GUIDANCE SECTION
AOT
GUIDANCE & NAVIGATION SUBSYSTEM
MODE SELECT
ANT POSITION INDICATION
VHF INFLIGHT ANT NO1
VHF INFLIGHT ANT NO2
PLSS TEST JACK
SWITCHING
VHF SECTION
RECEIVE
DIPLEXER
SEND
POWER AMPLIFIER ASSEMBLY
PA1
PA2
S-BAND INFLIGHT ANTENNA (OMNI)
NO1
NO2
S-BAND STEERABLE ANTENNA
ROTARY JOINT GIMBALS & SERVO
ANT. POS. CMDS (RF SENSING)
S-BAND SECTION
COMMUNICATIONS SUBSYSTEM

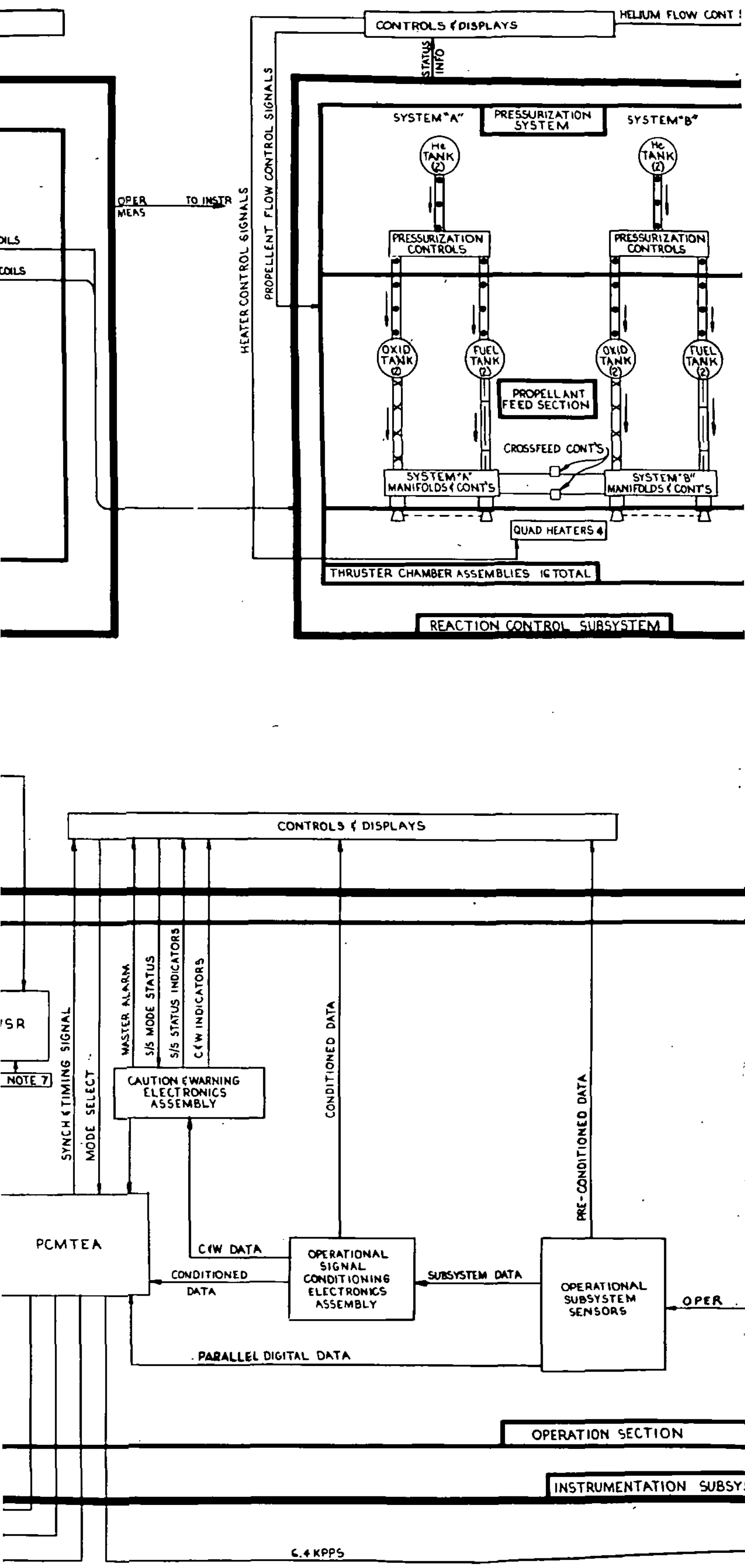
2.3-1A

(2)



CONTROLS & DISPLAYS
SELECT
BAND
DEAD
SELECT
JET
RCS
SELECT
BALANCE
ATTITUDE
CS
STEERING SIGNALS
800~SYNCH
BODY RATES
RGA (1)
800 AC & DC POWER
ATCA POWER SUPPLY
ATTITUDE & TRANSLATION CMDS TO PRIMA
PULSE MODE BODY ATTITUDE CMDS TO PRIN
ATCA
MANUAL ATTITUDE CMDS
MANUAL TRANSLATION CMDS
ACA (1)
T/TCA (1)
SYNCH SIGNALS
SYNCH SIGNALS 1024 KPPS
CONTROLS ELECTRONICS SECTION
VOICE KEYING
VOICE
CONTROLS & DISPLAYS
TAPE SELECT
MODE SELECT
DATA STORAGE ELECTRONICS ASSEMBLY
PER MEAS
TO INSTR
SEE NOTE 2
CONDITIONED DATA
SYNCH & TIMING SIGNAL
MODE SELECT
EXP/RECORDED DATA
PCMTEA
SYNCH SIGNAL 1.6 KPPS
AGE DIGITAL DOWNLINK DATA
SYNCH SIGNAL
SYNCH SIGNAL 1024 KPPS
EXPERIMENT INPUTS
CONDITIONED DATA
EXPERIMENT SECTION
LOW BIT RATE DATA
TIMING SIGNALS
NRZ DIGITAL DATA

23-14
(3)



CONTROLS & DISPLAYS
HELIUM FLOW CONT
STATUS INFO
PROPELLANT FLOW CONTROL SIGNALS
HEATER CONTROL SIGNALS
OPER MEAS
TO INSTR
SYSTEM "A"
PRESSURIZATION SYSTEM
SYSTEM "B"
He TANK (2)
PRESSURIZATION CONTROLS
OXID TANK (2)
FUEL TANK (2)
PROPELLANT FEED SECTION
CROSSFEED CONT'S
SYSTEM "A" MANIFOLDS & CONT'S
SYSTEM "B" MANIFOLDS & CONT'S
QUAD HEATERS 4
THRUSTER CHAMBER ASSEMBLIES 16 TOTAL
REACTION CONTROL SUBSYSTEM
CONTROLS & DISPLAYS
SR
NOTE 7
SYNCH & TIMING SIGNAL
MODE SELECT
MASTER ALARM
S/S MODE STATUS
S/S STATUS INDICATORS
C&W INDICATORS
CAUTION & WARNING ELECTRONICS ASSEMBLY
CONDITIONED DATA
PRE-CONDITIONED DATA
PCMTEA
C&W DATA
CONDITIONED DATA
OPERATIONAL SIGNAL CONDITIONING ELECTRONICS ASSEMBLY
SUBSYSTEM DATA
OPERATIONAL SUBSYSTEM SENSORS
OPER
PARALLEL DIGITAL DATA
OPERATION SECTION
INSTRUMENTATION SUBSYS
6.4 KPPS

2.3-1A

(4)

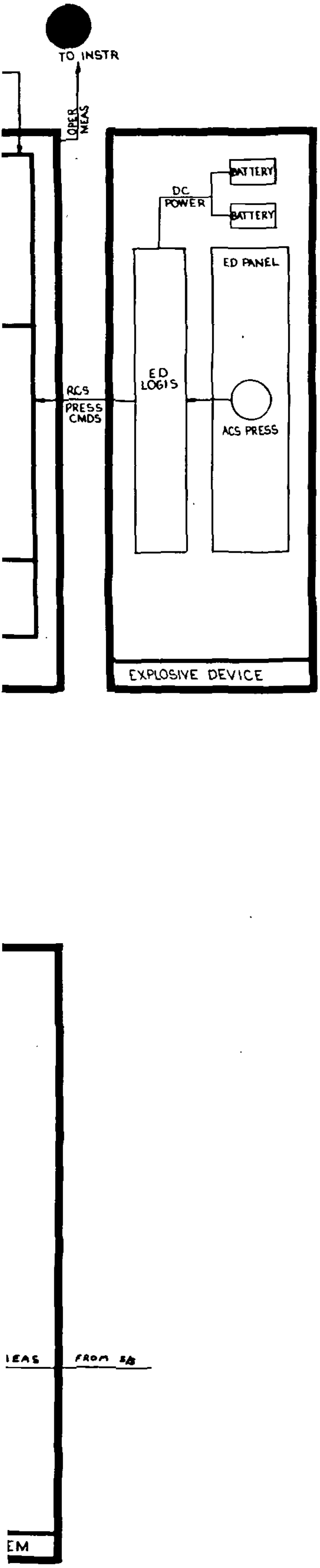
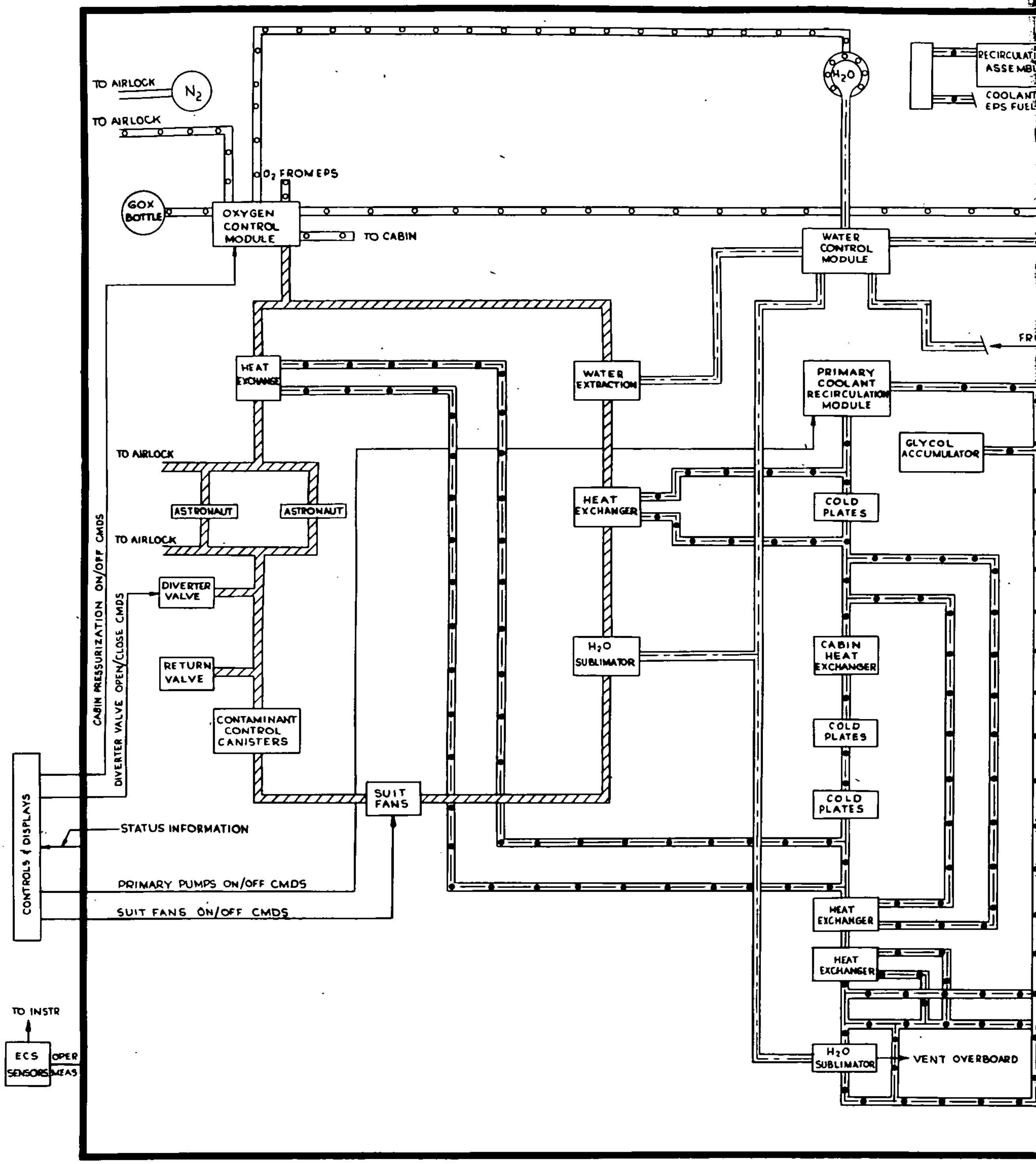


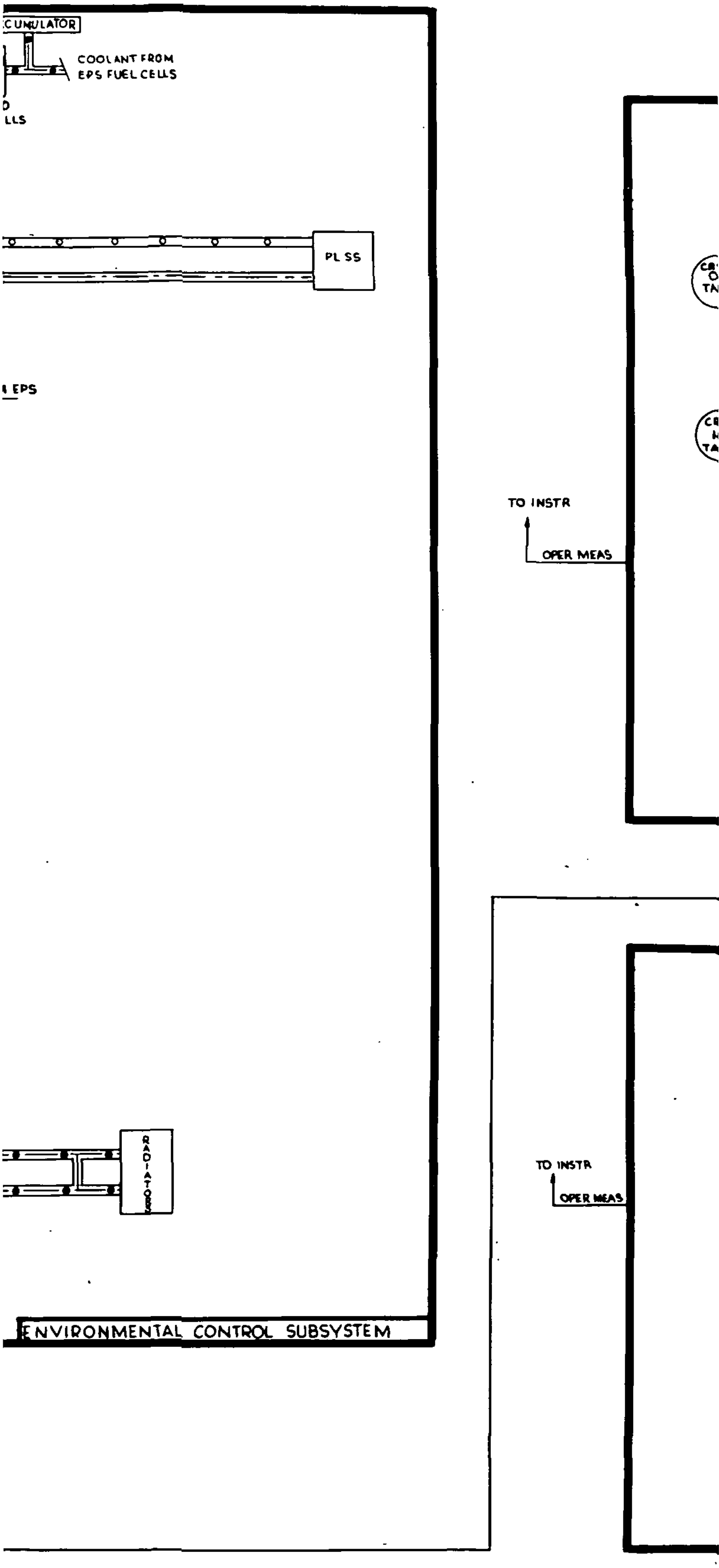
Fig. 2.3-1 Phase II Lab Level I Functional Block Diagram (Sheet 1 of 2)

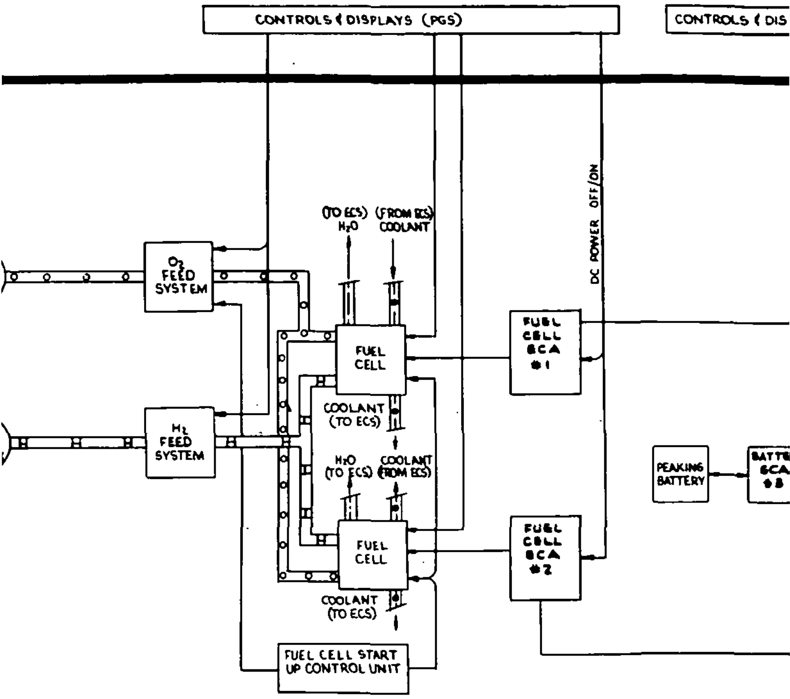
A 5

Grumman


TO AIRLOCK
N2
TO AIRLOCK
O2 FROM EPS
GOX BOTTLE
OXYGEN CONTROL MODULE
TO CABIN
H2O
RECIRCULAT
ASSEMBL
COOLANT
EPS FUEL
WATER CONTROL MODULE
FR
HEAT EXCHANGER
WATER EXTRACTION
PRIMARY COOLANT RECIRCULATION MODULE
GLYCOL ACCUMULATOR
TO AIRLOCK
ASTRONAUT
ASTRONAUT
TO AIRLOCK
HEAT EXCHANGER
COLD PLATES
CABIN PRESSURIZATION ON/OFF CMDS
DIVERTER VALVE OPEN/CLOSE CMDS
DIVERTER VALVE
RETURN VALVE
H2O SUBLIMATOR
CABIN HEAT EXCHANGER
CONTAMINANT CONTROL CANISTERS
COLD PLATES
SUIT FANS
COLD PLATES
CONTROLS & DISPLAYS
STATUS INFORMATION
PRIMARY PUMPS ON/OFF CMDS
SUIT FANS ON/OFF CMDS
HEAT EXCHANGER
HEAT EXCHANGER
TO INSTR
ECS SENSORS
OPER MEAS
H2O SUBLIMATOR
VENT OVERBOARD

2.3-1b


COOLANT FROM
EPS FUEL CELLS
PLSS
TO INSTR
OPER MEAS
TO INSTR
OPER MEAS
RADIATORS
ENVIRONMENTAL CONTROL SUBSYSTEM



ELECTRICAL POWER SUBSYSTEM

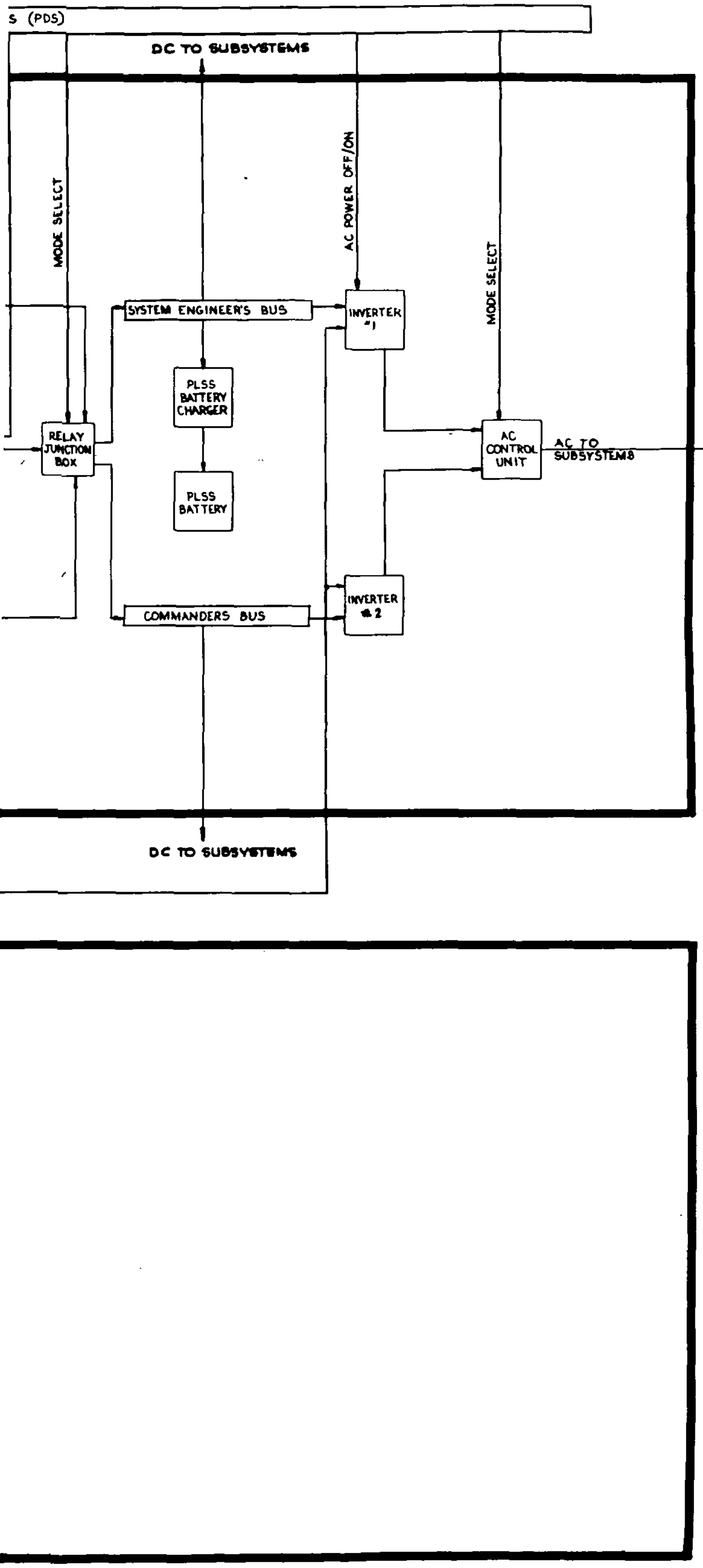
6.4 KPPS

STRUCTURES

SEE NOTES 1 & 4

2-3-1b

(B)


S (PDS)
DC TO SUBSYSTEMS
MODE SELECT
AC POWER OFF/ON
MODE SELECT
SYSTEM ENGINEER'S BUS
INVERTER #1
PLSS BATTERY CHARGER
PLSS BATTERY
RELAY JUNCTION BOX
AC CONTROL UNIT
AC TO SUBSYSTEMS
INVERTER #2
COMMANDERS BUS
DC TO SUBSYSTEMS

J-3-1B

9

NOTES

IS A TENTATIVE FUNCTIONAL DIAGRAM OF THE
PHASE II LAB

?E ARE TWO DATA STORAGE UNITS IN
DSEA

AES PHASE II LAB VEHICLE MUST BE CAPABLE OF RETAINING
FOLLOWING:
STRUCTURS - BASE HEAT SHIELD, LOWER-DECK INSULATION
STABILIZATION & CONTROLS - GDA & DECA
NAVIGATION & GUIDANCE - IMU, LGC, PTA, PSA, CDU
CONTROLS & DISPLAYS - DSKY

OR MODIFICATIONS TO STRUCTURES - AIRLOCK ADDED, M/M
.LDING MODIFIED & LANDING GEAR REMOVED

ITIONS TO THE BASIC LEM CONFIGURATION FOR CREW PROVISIONS
BACKPACK LIOH CARTRIGES
OD FOR 44 DAYS
ATTERY CHARGER
SEAT
DOME LIGHT
EXTRA FLOOD LIGHTS
2 WORK TOPS & WORK TOP LIGHTS
66 CONST WEAR GARMENTS
BACKPACK BATTERY CAPABILITY MOD. TO 44

ETIONS TO THE BASIC LEM CONF. FOR CREW PROVISIONS
M LIOH CANISTERS
UNAR SPECIMAN CONTAINERS
TILL CAMERA
EVA LIFE LINE
WATER PROBE AND HOLSTER

TAINS TWO VSR'S (ONE SPARE)

ABBREVIATIONS

= OPERATIONAL
= MEASUREMENTS
= GASEOUS OXYGEN
= SIMPLEX
= ALIGNMENT OPTICAL TELESCOPE
= COMMANDS
= WATER
= OXYGEN
= CONTROLS & DISPLAYS
= ATTITUDE & TRANSLATION CONTROL ASSEMBLY
= DESCENT ENGINE CONTROL ASSEMBLY
= SYNCHRONIZATION
= SIGNAL
= VERY HIGH FREQUENCY
= EXPERIMENT
= ELECTRICAL CONTROL ASSEMBLY
= DIRECT CURRENT
= ALTERNATING CURRENT
= COMMAND SERVICE MODULE
= ANNUNCIATOR
= INFORMATION
= VOICE STORAGE RECORDER
= PORTABLE LIFE SUPPORT SYSTEM
= SUBSYSTEM
= HELIUM
= INDICATOR
= CAUTION & WARNING
= TRANSLATION CONTROL ASSEMBLY
= ATTITUDE CONTROL ASSEMBLY
= RATE GYRO ASSEMBLY
= ASSEMBLY
= TRANSMITTER
= RECEIVER
= TRANSCEIVER
= POWER AMPLIFIER
= PHASE MODULATION
= FREQUENCY MODULATION
= INTERNAL COMMUNICATIONS SYSTEM
= DISPLAY KEYBOARD
= INSTRUMENTATION SUBSYSTEM
= CONTROLS
= NON RETURN TO ZERO
= VOICE OPERATED SWITCH
= COUPLING DATA UNIT
= DUPLEX
= EXTRA VEHICULAR MOBILE UNIT
= PULSE CODE MODULATION
= POWER SERVO ASSEMBLY

SYMBOLS

OXYGEN LINE
WATER LINE
OXIDIZER LINE
COOLANT LINE
HELIUM LINE
FUEL LINE
CONDITIONED OXYGEN LINE
HYDROGEN LINE
MECHANICAL LINKAGE

Fig. 2.3-1 Phase II Lab Level I Functional Block Diagram (Sheet 2 of 2)

5

Grumman

Table 2.5-1

Phase II Lab

CANDIDATE CONFIGURATIONS

Item	Candidate Configurations	Per Flight Modifications
Structure (Vehicle Design)	• LEM Structure With AC Fuels Integrated Into Aft Equipment Bay Including - Expandable Front Hatch Airlock (Cylindrical) Or: - Rigid Descent Stage Airlock Or: - Expandable Front Hatch Airlock (Shelter Design) • Use of P&W Fuel Cells • Use of GE Fuel Cells • Alternate Radiator Installations and Variable Radiator Area Designs	• Incorporation of Viewfinder • Descent Stage Compartment • Descent Stage Airlock-(Docking Tunnel) • Additional RCS Propellant • Low Profile Descent Stage
Stabilization & Controls	• Modified Abort Guidance System With Changes to RGA and ATCA • Unmodified Abort Guidance System • Modified Abort Guidance System Deriving Rate Information From ASA • Modified Abort Guidance System With New RGA Assembly • Use of Primary NAV Guidance System • Modify Jet Logic to Use All Thrusters • Use of Other Torque Generating Devices • Use of Low Level Thrusters	• Reduce Narrow Deadband To 0.1 deg
Crew Provisions	• Basic LEM With Changes Consistent With Other Subsystems And Additional Storage of Expendables External To The Vehicle • Lab With Descent Stage Airlock-Docking Tunnel	• Additional Storage Boxes • Descent Stage Compartment

Table 2.5-1 (cont.)

Item	Candidate Configurations	Per Flight Modifications
Crew Provisions (cont.)	• Lab With Front Hatch Airlock (Cylindrical) And Desc Stage Compartment • Lab With Front Hatch Airlock (Shelter) And Desc Stage Compartment • Lab With Suit Loop Removed And Addition Of A Rear Facing Console	
Environmental Control	• Active System With 60 sq ft Radiators, Combined ECS & EXP Cooling Loop, 2 Gas Airlock Press System, Separate F.C. Cooling Loop • Same As Above Except One Gas System With No Airlock • Use of Separate Cooling Loop For Experiments • Deletion Of Suit Circuit Assembly (ARS) • Deletion of Airlock - Two Gas Cabin Repress System	
Instrumentation	• LEM Operational System With Data Handling System Using CSM Recorders Modified For Single Phase Operation, Output Of 409.6 kbps, Conversion Of 4 Analog Tracks To Digital, And Half Speed Mod. PCM Low Bit Rate Converted To 12.8 kbps • LEM Operational System With Data Handling System Using CSM Recorders Modified For 409.6 kbps. PCM Low Bit Rate Is Converted To 12.8 kbps • LEM Operational System With Data Handling System Using CSM Recorders Modified For Single Phase Operation And Output of 409.6 kbps.	
Electrical Power Supply	• AC Fuel Cells With AES Cryo Tanks & 5 kw-hr Peaking Battery; 60 sq ft Radiator • P&W Fuel Cells With CSM House-keeping Tanks; 50 sq ft Radiator • Use Of GE Fuel Cells	

Table 2.5-1 (cont.)

Item	Candidate Configurations	Per Flight Modifications
Propulsion	• Not Applicable (No Main Propulsion In Labs)	• Use of Descent Propulsion
RCS	• Double LEM RCS Tankage With Fuel And OX Lines Reversed • Use of Low Level Thrusters • Multiple RCS Feed Systems	• Additional RCS Tankage
Communications	• Hardline Intercom And Additional FM Data Channel-409.6 kbps • Hardline Intercom And Additional PM Data Channel (Mod Spa) • Coupled S-Band In Flight Antennas • S-Band Transceiver Cycling • Addition Of Internal TV Jack	
Displays And Controls	• Basic LEM Displays And Controls Modified As Appropriate	

3. MISSION ANALYSIS

3.1 MISSION OBJECTIVES

The Phase II Laboratory will be utilized in conjunction with an Apollo CSM to perform manned Earth and Lunar orbital experimentation missions. The Phase II Lab will be required to perform at its nominal design performance level for durations up to 45 days.

The Lab flights, each one at a specific orbital altitude and inclination, will be required to actively support extensive orbital experiments and observations conducted in the Lab in the areas of:

- Basic scientific research
- Applied science and technology
- Engineering validation of design configurations
- Testing and qualification of crews, systems, subsystems and components for space missions.

In supporting this activity, the Lab is required to provide electrical power, attitude hold, data handling, and other support functions to enable crewmen to perform the in-orbit experiments.

3.2 GROUND RULES AND ASSUMPTIONS

The following ground rules and assumptions were utilized in the selection of the basic Phase II Laboratory configuration:

- Lab shall provide attitude hold capability with no control interface with the CSM. Slewing capability will be provided by the CSM. Lab attitude shall not be constrained by temperature control of the spacecraft.
- Lab will provide oxygen (GOX) for repressurization, leakage and recharging PLSS.
- No crew system water to be carried in the Lab except that required to recharge PLSS.
- Lab will provide atmosphere circulation between modules.
- No communications interface with CSM except for TV camera and intercom hardline.
- No power interface with CSM. Lab provides own power for housekeeping activities and experiments.

- Lab carries LiOH (PLSS), and food in excess of three man days.
- Descent propulsion system is not required.
- Illumination, radiation and meteoroid environment shall not inhibit or constrain any LAB mission.
- Provisions shall be made to support EVA excursions throughout the mission duration.

3.3 ANALYSIS

3.3.1 General

The detailed study of the Phase II Lab missions has resulted in a determination of the experiment-related average power and energy requirements. These are listed in Table 3.3-1 for Lab flights. It is noted in Paragraph 5.1 that the Lab can provide 676 kw-hrs for experiment support including operation of experiment dependent subsystems. This amount of energy will meet the requirements of the Lab missions as they are defined in the Phase A Final Report, Addendum 1.

3.3.2 Subsystem Experiment Support - General

Laboratory attitude hold and stability requirements were prepared for all Lab missions for sizing of the S & C and RCS systems, in accordance with the ground rule that the Lab provide orbital attitude hold control and pointing capability for mission experimentation. Attitude hold is provided about all three principal axes within two deadzone limits: ±5.0 deg and ±0.3 deg as discussed in Paragraphs 4.3 and 5.4. Figure 3.3-1 shows the RCS propellant flow rates for undisturbed limit cycle operation. The existing LEM deadband limits of 5 and 0.3 deg are shown for various rate threshold limits. The present rate threshold limitation (0.01 deg/sec) is shown along with the recommended "design goal" value of 0.001 deg/sec. The minimum impulse line represents the limitation on the system caused by RCS thruster sizing. These data are derived from an extensive analysis shown in Paragraph 4.2. It is noted that the capacity of the RCS thrusters is doubled for the Lab missions.

Figure 3.3-2 illustrates the depletion of available experiment energy as a function of attitude hold duration for the AGS and the PGNCS. Figure 3.3-3 summarizes the energy required for data handling. The energy available for Lab experiments must therfore consider these aforementioned subsystem dependent requirements.

In addition, the communication requirements over the housekeeping allowance must be considered. Figures 3.3-4 and 3.3-5 summarize the communication energy requirements for the 200 and 19,350 n.mi Lab orbits, respectively, as a function of duty cycle and mission duration.

An investigation into the egress-ingress capability of the Lab involving PLSS recharges and cabin/airlock repressurizations was performed and a detailed discussion of this investigation is presented in Paragraph 5.2.3.4. Weight and volume allocations have been made for 44 backpack batteries and 44 LiOH canisters. Additional batteries may be carried at a weight penalty of 5 lb each and additional LiOH canisters may be carried at 4.5 lb each.

It is normally assumed that, during EVA activity by one crew member, a second crew member is operating from the suit loop on standby within the Lab cabin. This operation involves 152.2 w power expenditure to operate the suit loop fan. This penalty is also considered as experiment dependent subsystem operation.

3.3.3 Subsystem Experiment Support - Sample Calculation

The following procedure is suggested for determining the energy penalty for experiment dependent subsystem operation:

- Sample Mission - Synchronous Orbit
  - o Mission duration- 45 days
  - o Attitude Hold Duration- 120 hr
  - o Communication Time- 50% of Mission Duration
  - o EVA Time (suit loop operation)- 5 hr
  - o Data Transmission- 50% (same as communication time)
- Calculation
  - o Energy available (Fig. 3.3-2) = 630 kw-hr
  - o Penalty for data handling (Fig. 3.3-3)(600 hr record-50% transmission) = 46.5 kw-hr
  - o Penalty for Communications (Fig. 3.3-5) 41 kw-hr - housekeeping allow = 1.4 kw-hr (39.6 kw-hr)
  - o Penalty for suit loop operation 125 w x 5 hr .76 kw-hr
  - o Net available for experiments = 581.34 kw-hr

3.3.4 Environmental Protection Requirements

3.3.4.1 Micrometeoroid Hazard Evaluation

3.3.4.1.1 Environment. The micrometeoroid environment used is that defined by LEM specification LSP-470-1A. The sporadic flux is presented as an average isotropic flux that is constant throughout the regions of space applicable to the AES missions. It is modified only by the planetary shielding factor determined by each mission's trajectory. Shower meteoroids are not included.

3.3.4.1.2 Approach. LEM specification LSP-470-1A presents criteria for defining the micrometeoroid protection provided by single and double skin areas against both primary (sporadic) and secondary micrometeoroids. It does not contain criteria for handling configurations with more than two skins or double skins with small separation distances. Such situations were conservatively analyzed by omitting the thinnest skins until the configuration fitted the LEM specification. The analysis was performed for the recommended version of the Lab configuration, with no micrometeoroid shielding assumed in addition to that provided for the LEM.

Many approximations had to be made to estimate the meteoroid protection provided by the complicated Lab structure of spherical and cylindrical shapes enclosed by flat surfaces. Since the penetration mechanics for the back-up skin are strongly dependent on this skin's distance from the bumper skin, the critical areas exposed to meteoroids by spherical and cylindrical tanks were divided into two sections: (1) the cap area which is an area of the tank closest to the bumper, and (2) the donut area which is a section of the tank area adjoining the cap. The distance from the bumper to each section's point of closest approach was used to ensure conservative calculations (Fig. 3.3-6).

The critical areas were also sized by their cone of exposure to the isotropic flux. A very conservative 2π solid angle was applied in most cases. A nominal critical area was added to include the effect of such miscellaneous terms as black boxes, wiring and tubing.

Though shielding of the descent stage by ascent stage structure, and vice versa, was incorporated, shielding by the CSM was not included to make the calculations applicable to missions in which the Lab and CSM may separate.

3.3.4.1.3 Computer Program. The Lab basic design was described in terms of critical areas, exposure periods, skin thicknesses and skin separation distances, and the information fed into the computer program which contained the LEM protection criteria. When a particular combination of skin thicknesses and separation distance for a specified critical area resulted in the bumper skin too thin to melt the micrometeoroid, the size of the micrometeoroid was reduced to the melting point and the probability of such a particle impacting during the mission was determined.

The program evaluates both an existing vehicle's structure for the probability that it will not be damaged by micrometeoroids during its mission, and can be used to determine those locations where shielding would be most efficiently applied.

3.3.4.1.4 Micrometeoroid Hazard Results. The results of four missions evaluated for a basic Lab configuration are presented in the following table. Mission success is defined as the probability that the Lab will survive 45 days with no penetration of any component required for mission operation. Crew safety is defined as the probability that no pressurized tank or the cabin will be punctured, and it is assumed that the Lab cabin is manned for 45 days in earth orbit and 28 days in lunar orbit.

Mission	Crew Safety	Mission Success
200 n.mi Earth Orbit	.99873	.99848
Synchronous Earth Orbit	.99810	.99772
20 n.mi Lunar Orbit	.99898	.99878
80 n.mi Lunar Orbit	.99886	.99863

The radiators are not included in these numbers because they will require protection. Without protection they have a mission success probability of .98985. With 40 mil aluminum strips covering the tubing, the probability increases to .999374. The weight of the aluminum stripping is 7 lb. By shaping the strips into a bumper, this probability should increase further. The crew safety and mission success numbers are sufficiently high such that additional shielding in areas other than the radiators does not seem to be required.

3.3.4.2 Radiation Environment

3.3.4.2.1 Introduction. The radiation environment assumed for the Lab missions consists of both the Earth's trapped radiation belt and solar flare particles for the polar and synchronous Earth orbit missions; and trapped radiation belt particles for the low inclination orbit missions. For lunar missions, only the solar flare events were considered. The solar flare model used was obtained from LSP-470-1A.

3.3.4.2.2 Solar Flares. The effect of solar flares on the polar, synchronous and lunar orbit missions would be to either (1) cause mission abort if the flare were of sufficient intensity to cause the crew in the CM to receive their allowable emergency dose (500 RAD skin dose), or (2) postpone the scheduling of crew activities if the intensity of a flare were such that the crew would receive a dangerous dose in the Lab but would be relatively safe within the CM. The latter situation is more likely since the ratio of dose received in the CM to dose received in the Lab is approximately 1/20. This assumes an equivalent shielding effectiveness of 1 lb/ft^2 for the Lab and 10 lb/ft^2 for the CM. Estimates were made of the probability of mission abort and the probability of rescheduling crew activities, due to solar flare activity, for a 45 day mission. The results are shown in the following table. The reschedule probability is smaller for polar orbits than either synchronous or lunar orbit because the spacecraft is protected by the Earth's magnetic field during a portion of each orbit.

Effect of Solar Flares

Lab Mission Duration (Days)	Probability of Affecting Mission			
	Polar		Synchronous & Lunar	
	Abort	Reschedule	Abort	Reschedule
7	0.001	0.015	0.001	0.03
14	0.002	0.03	0.002	0.06
45	0.006	0.09	0.006	0.18

The probability of having to abort a polar, synchronous or lunar orbit mission due to solar flare activity is relatively low. However, the flare activity could cause a delay in the crew's Lab activities for a period of 48 hr, which is the approximate duration of a high intensity solar flare.

For the lunar orbit missions, an abort might be initiated even if the allowable crew dose limit were not exceeded. This is due to a combination of reasons, among them the inability to predict solar flare intensities in advance, the fact that large solar flare events tend to occur in multiples, and, the relatively long transearth coast times.

3.3.4.2.3 Radiation Belts. A literature search has indicated that there is a wide variation in the predicted dose rates from the Earth's trapped radiation belts. These variations are mostly due to the uncertainty in the rate of decay of the artificial electron belt at low orbital altitudes, and the large fluctuations that have been observed in the electron fluxes at higher orbital altitudes due to extraterrestrial disturbances. An estimate has been made of the effect of the trapped radiation belt for a 200 n.mi, 30 deg inclination orbit as being representative of the environment to be encountered by an Earth orbiting Lab. The dose rates would be reduced by about a factor of two for a 200 n.mi polar orbit. No consistent estimates were available of the dose rates that would be encountered in a synchronous orbit. The allowable doses in the radiation belts were taken to be the allowable average yearly exposure values of 233 RAD skin dose and 27 RAD dose to the eyes from LSP-470-1A. Estimates of the average dose in a 200 nautical mile, 30 deg, inclination orbit within the Lab range from one to four RAD per 24 hour day. The upper limit of four RAD per day was chosen to be conservative. Preliminary crew time line analysis has indicated that no crew member would spend more than 6 hr consecutively per day inside the Lab. Thus the average daily 24 hour dose rate inside the Lab becomes one RAD/day. The accumulated dose inside the CM would be of the order of 0.1 RAD per day yielding a total daily dose of 1.1 RAD per day in orbit. Therefore, the allowable skin dose would be exceeded after about 210 days in orbit and the allowable eye dose would be exceeded after about 24 days in orbit. The eyes can be comparatively easily shielded using goggles. The amount of eye protection required as a function of the desired increase in allowable exposure time is shown in Fig. 3.3-7. For example, the addition of approximately 0.020 in. of glass would be sufficient to permit a 45 day orbital mission without exceeding the allowable eye dose.

3.3.5 Simulation Requirements

The increased inertia of the combined CSM/Lab relative to the LEM, and RCS propellant consumption considerations, dictate the need for improved attitude rate sensitivity sensing (in the range of 0.001 deg/sec). The method selected to solve the rate gyro threshold sensitivity problem should be verified by simulation.

In addition, the following alternatives, if adopted, could require simulation support:

- Modify Abort Sensor Assembly (ASA) and Abort Electronics Assembly (AEA) to provide lower rate threshold.
- Provide new Rate Gyro Assembly (RGA) to provide lower rate threshold.
- Retain Primary Navigation and Guidance in lieu of the Abort Guidance System.
- Install Control Moment Gyros and/or inertia wheels to provide accuracy levels and reaction jet fuel savings.

Systems simulation may also be required to verify results of fuel cell evaluation studies, and to verify performance of the selected fuel cell system.

3.4 MISSION DESCRIPTION

The AES Phase II Lab will be required to perform up to 45-day manned experiment missions in the following orbital modes:

- Earth Low Inclination Orbit
- Earth Polar Orbit
- Earth Synchronous Orbit
- Lunar Polar Orbit

Mission profiles are shown in Tables 3.4-1 through 3.4-4.

3.4.1 Earth Low Inclination Orbit

a) A two stage Saturn 1B is used to launch an unmanned Lab into a 200 n. mi 28.5 deg inclined circular orbit. A CSM is then launched by a two stage Saturn 1B into a similar orbit to achieve rendezvous, docking and crew transfer. A 45 day experimentation mission is then conducted.

b) A three stage Saturn V vehicle launches the CSM-Lab II directly into a 200 n. mi 28.5 deg inclined circular orbit.

3.4.2 Earth Polar Orbit

A three stage Saturn V vehicle is used to launch the CSM-Lab in a south-easterly direction from KSC. A yaw-steering maneuver is initiated at the beginning of second stage flight to obtain a 200 n. mi polar orbit of 90 deg inclination. The launch azimuth and magnitude of the yaw rate will be selected to minimize launch vehicle impact hazards to populated areas. Minimizing launch vehicle impact hazards may also require yaw-steering during first stage burn. A capability to achieve an 83 deg retrograde orbit shall also be provided.

3.4.3 Earth Synchronous Orbit

The CSM-Lab is launched by a three stage Saturn V into a 100 n. mi 28.5 deg inclined circular parking orbit. The SIVB stage is re-ignited at the fourth descending nodal crossing to perform a 2 deg plane change and simultaneously initiate a Hohmann transfer to synchronous orbital altitude of 19,350 n. mi. At apogee, the SIVB stage is again ignited to perform a plane change of 17.5 deg and partially circularize the orbit (perigee = 5,140 n. mi). The CSM then transposes and docks to the Lab and the SIVB is jettisoned. Upon completion of one orbit at apogee the SPS is utilized to inject the CSM-Lab into the final, circularized equatorial synchronous orbit.

3.4.4 Lunar Polar Orbit

A three-stage Saturn V launch vehicle launches the CSM-Lab into essentially the same trajectory as the current Apollo to a point near the moon (to be determined). At this point a small Δv is applied to obtain the desired lunar orbital inclination. Near pericynthion a retro or braking maneuver is performed to place the spacecraft into lunar orbit. At completion of the 28 day orbital stay the spacecraft will perform a multiple or single impulse transearth trajectory, whichever is optimum. The single impulse trajectory could be similar to the current Apollo mission except it will probably occur at a different lunar orbital location. The multi-impulse trajectory is currently envisioned as a two-impulse trajectory with one impulse in orbit and the second at the "moon's sphere of attraction". Reentry and recovery are similar to that of the current Apollo mission. Anytime abort will be retained where possible. However, free return is not a trajectory requirement.

3.5 MISSION TIMELINES

A detailed analysis of Flight 513, the first Phase II Laboratory mission of 45 days duration as defined by the LEM for AES Blue Book, was conducted to check mission related effects upon the Lab system configuration and to develop a representative mission time line in terms of crew scheduling and experiment equipment duty cycles for a Lab mission.

Flight 513 has been treated as a primary biomedical and behavioral experiment flight. The basic experiments involve biomedical and behavioral phenomena associated with prolonged weightlessness. In addition, space science experiments related to radiation, magnetic field lines and the generation of comet-like particle clouds will be accomplished. Also, operational tests of sensors of the Earth's atmosphere and the collection of meteorological data are to be performed as shown in the mission timelines. Table 3.5-1 lists the various experiment requirements and mission parameters for this particular flight. The energy requirement for this mission is 136.2 kw-hr based on experiment equipment utilization only.

All the experiments except the 0802 series have been scheduled to meet their designated frequencies. The total time devoted to experimentation is 1300 out of a possible 1335 man-hrs. The biomedical/behavioral series developed by Grumman during Phase A was used as the primary experiment objective. A complete description is provided in Volume 1, Section 1 of the Phase A Final Report, Addendum 1. A summary of Flight 513 experiment and crew duty cycle for 45 days is tabulated in Table 3.5-2. This is based on an analysis of crew scheduling and duty cycles. The basic data for the experiments to be conducted on Flight 513 were extracted from Volume 4 of the Addendum 1 report. Experiment requirements and parameters were somewhat modified because of commonality of equipment, length of mission and return payload requirements as well as variations in primary emphasis of the experimentation.

The mission timelines indicating the power, pointing and stability requirements during the experiment equipment duty cycling for Flight 513 is shown in Table 3.5-3. These profiles are representative of the full 45 day mission for experiments only and were utilized to verify Lab subsystem sizing study results.

3.5 MISSION TIMELINES (Continued)

General housekeeping and initial Lab systems checkout information is provided in Table 3.5-4. Also listed is the time required to conduct systems check and status monitoring as well as space suit and PLSS check out and final Lab shutdown time.

The Lab system check and status monitoring time (averaging 6 min at 2 hr intervals for entire mission) is based on Table 4.4-7 which tabulates the required housekeeping activities and subsystems to be checked. The spacesuit and PLSS checkout time is accomplished prior to every EVA. It is noted that the EPS fuel cells are purged during every third subsystem status check or once every 6 hr.

Table 3.3-1

ELECTRICAL ENERGY REQUIRED FOR PHASE II LAB'S EXPERIMENTS
(Based on Phase A Study)

Flight No.	Avg Exp Power Delivered, watts	kw-hr for Exp
218	62	67
219	162	175
221	90	97
516	535	578
518	487	525
521	108	117
523	368	397
229	412	445
LOS w/o mapping radar	---	274
LOS with mapping radar	---	611

NOTE: Flight 230 is not an applicable Phase II Lab design candidate since it consisted of a descent stage only.

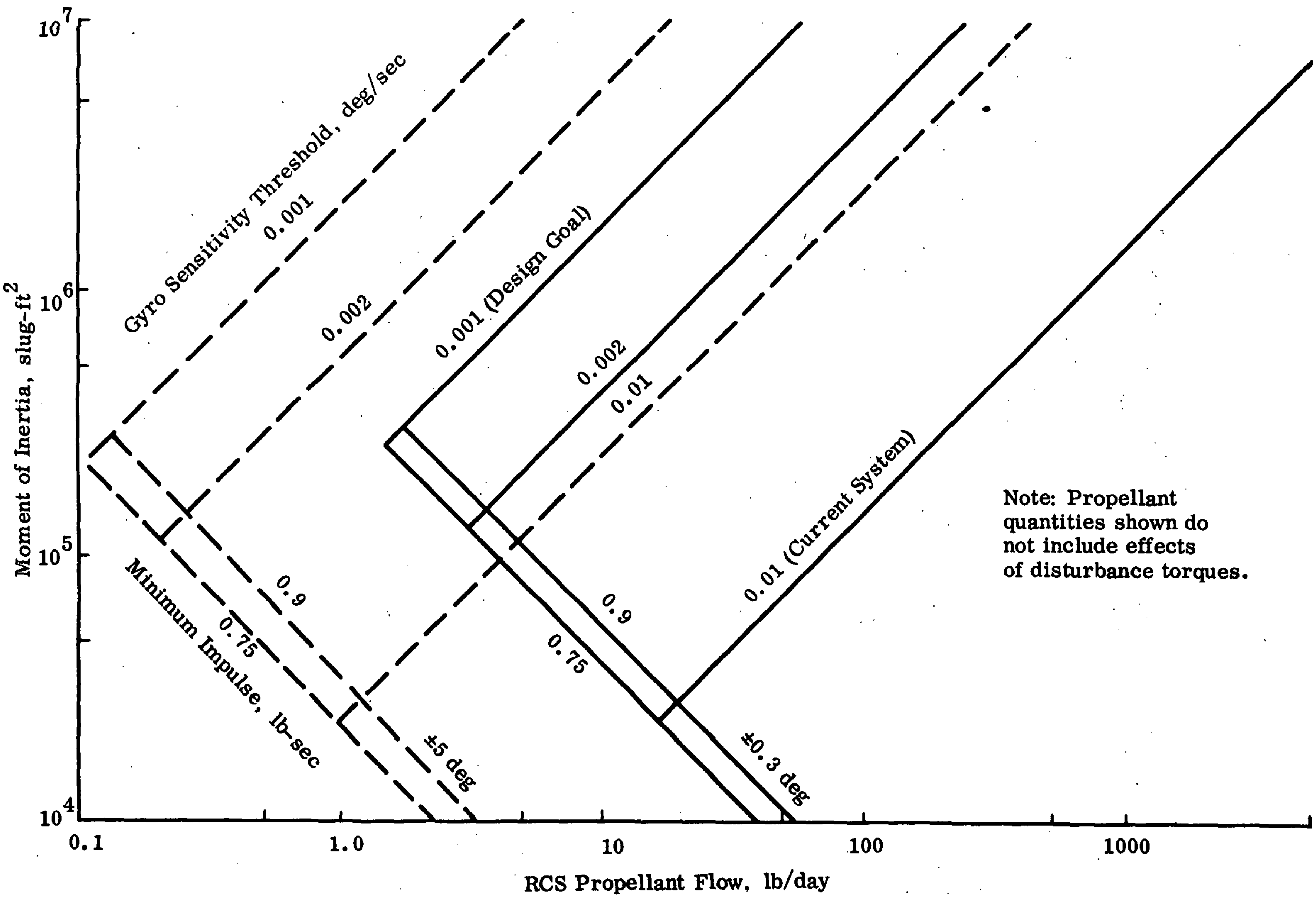


Fig. 3.3-1 Undisturbed Limit Cycle RCS Propellant Flow

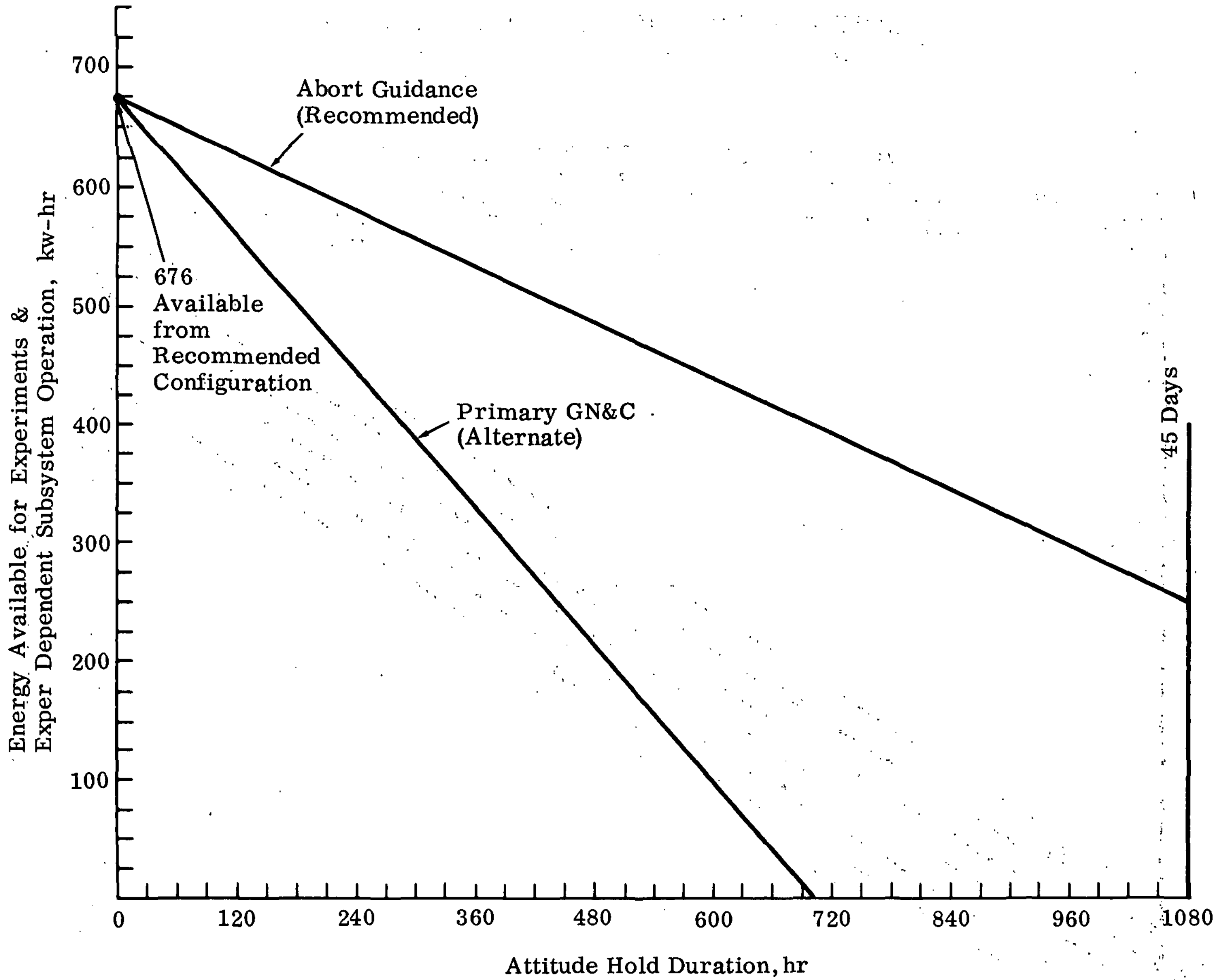


Fig. 3.3-2 Energy Available for Experiments vs Attitude Hold Duration

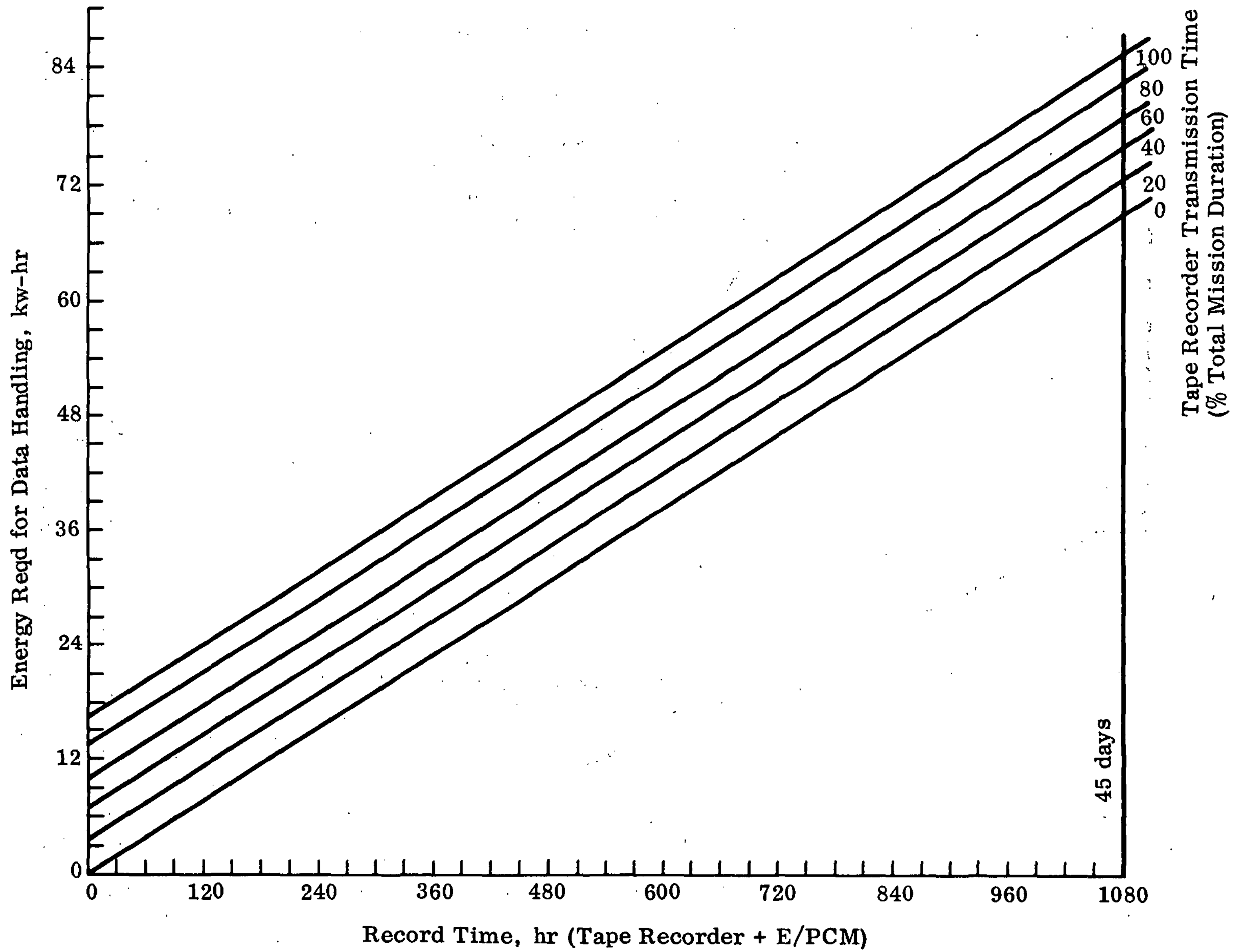


Fig. 3.3-3 Energy Required for Data Handling

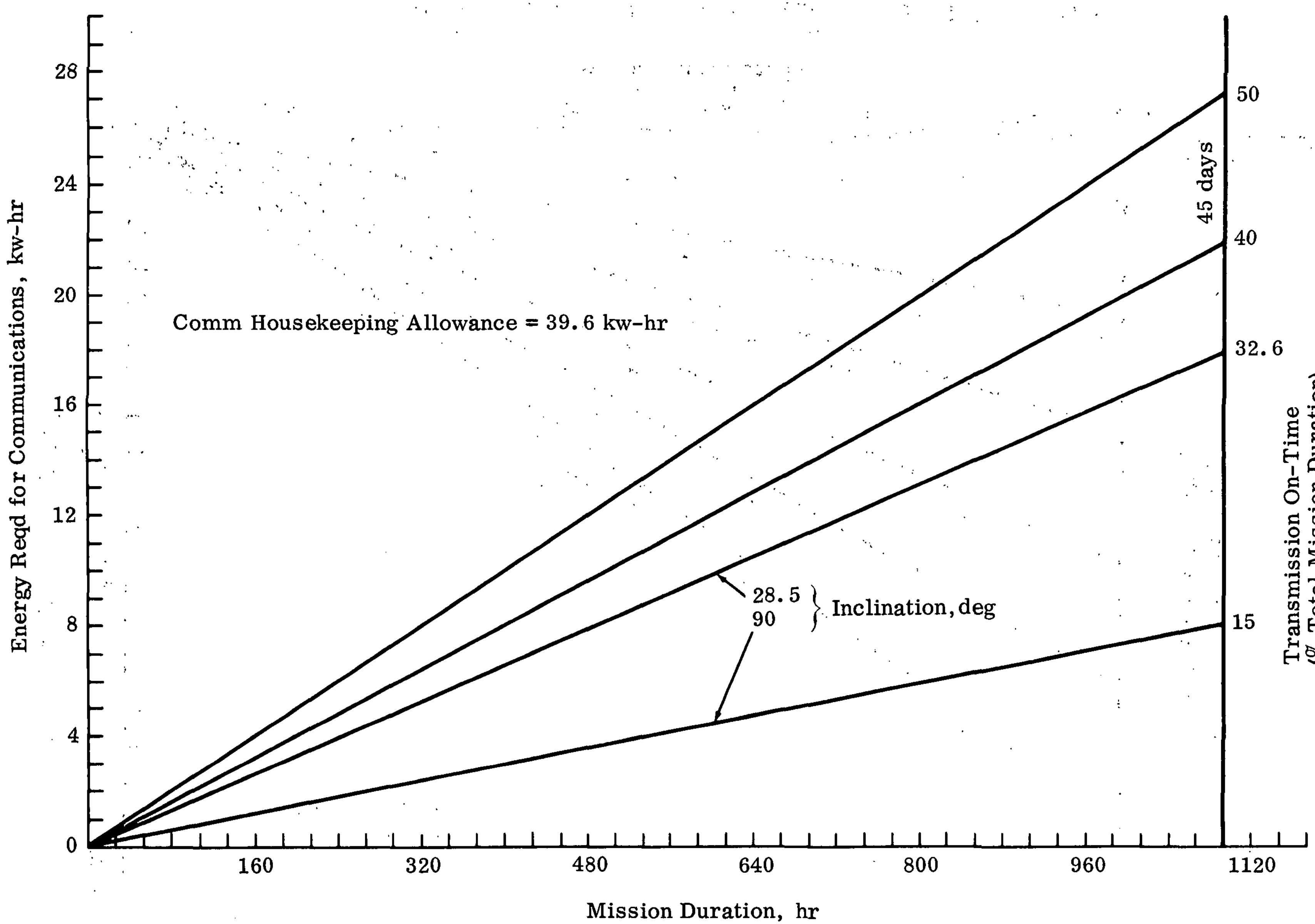


Fig. 3.3-4 Energy Required for Communications, 200 N mi Orbit

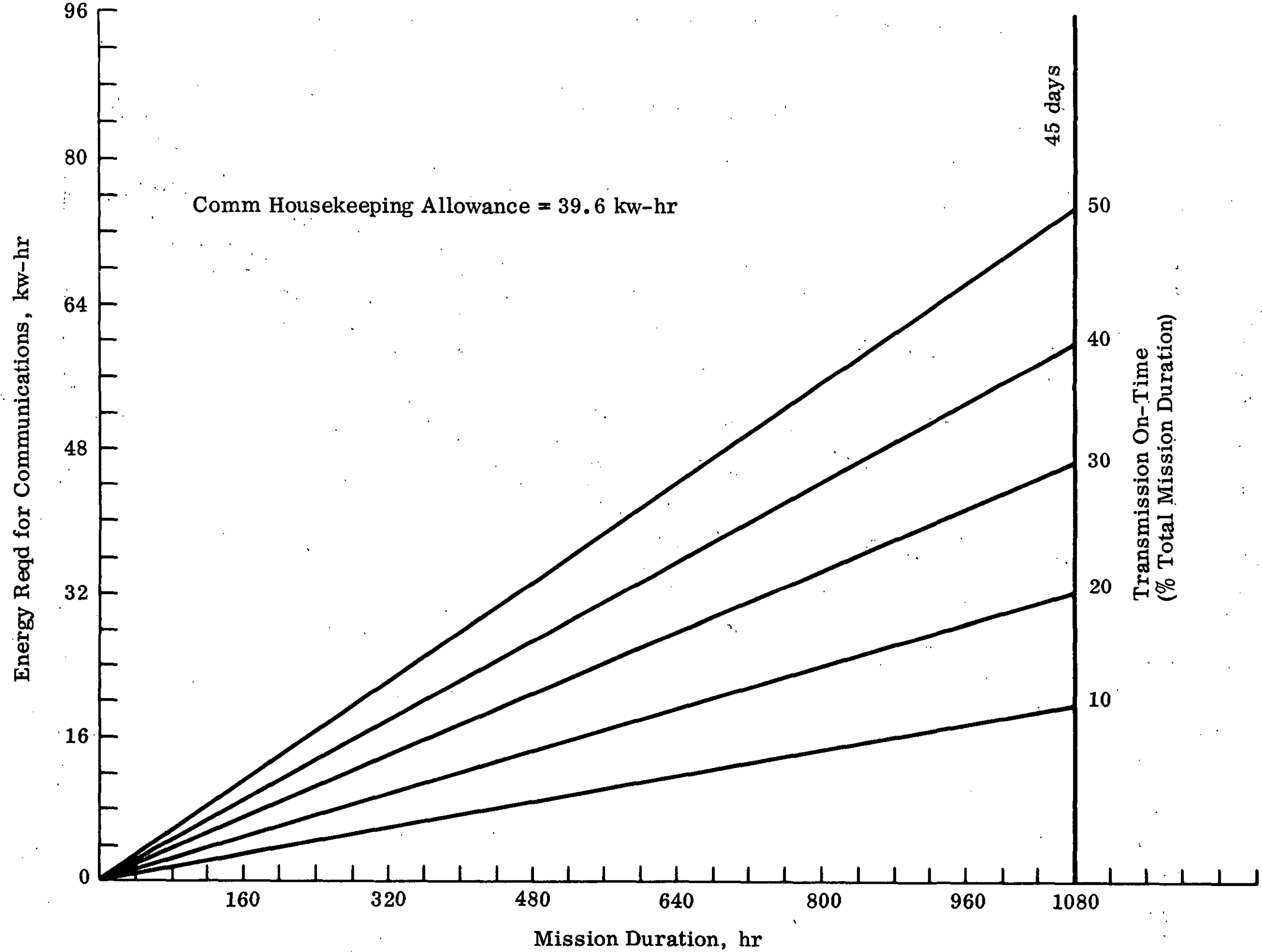


Fig. 3.3-5 Energy Required for Communications, 19, 350 N mi Orbit

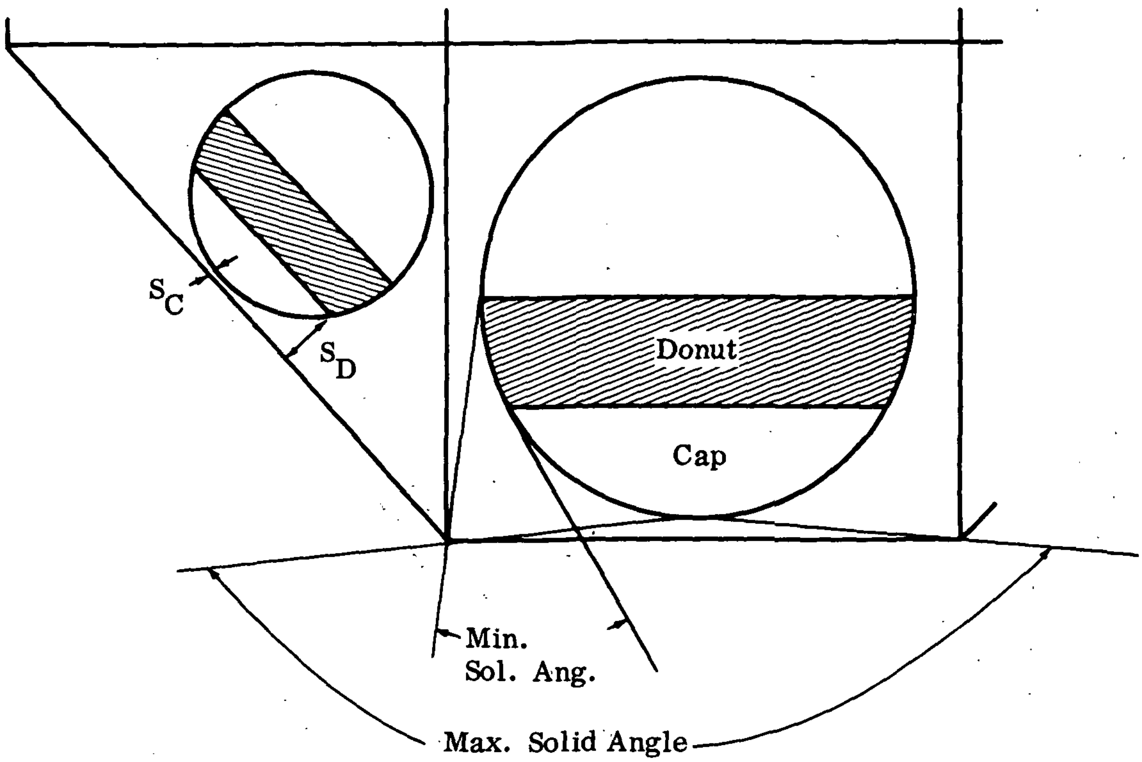


Fig. 3.3-6 Critical Area Sectioning

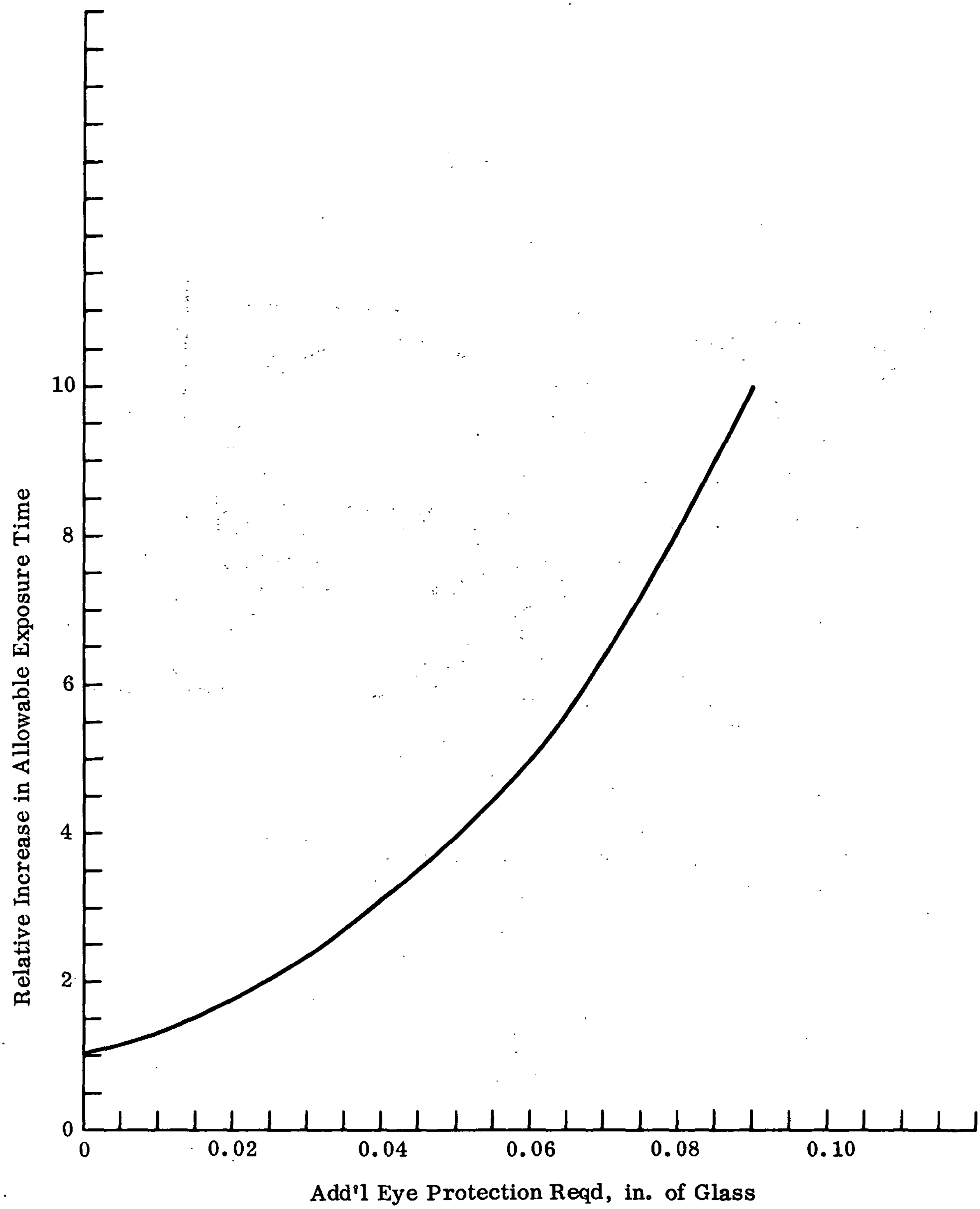


Fig. 3.3-7 Eye Protection Required vs Increase in Rad Exposure Time

Table 3.4-1

MISSION PROFILE LOW INCLINATION EARTH ORBIT

Low-Incl, 28.5 deg; Alt, 200 n.mi

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
1. Saturn 1B Ascent to Orbit (LEM Lab) a) S-1B Firing b) S-IVB Firing c) LES-B.P. Jettison	00:12:00	• Demonstrate integrated mission control. Applicable during all phases thru CSM-Lab docking.
2. Earth Orbit Coast S-IVB Stabilization a) Subsystems status check	03:00:00	• Demonstrate operation of modified LEM systems after being subjected to boost environment.
3. S-IVB Lab Separation a) SLA petal deploy b) LMP initiates Sep. c) LMP shuts down S/S	00:20:00	
4. Earth Orbit Storage (Lab Unstabilized) a) LMP activates S/S for status checks.	To Be Determined	• Demonstrate ability of LEM Lab FCS, EPS, Inst. & Comm. equipment to perform during unmanned orbital storage.
5. Saturn 1B Ascent to Orbit (CSM & Crew) a) Same as 1a & b b) LES Jettison	00:12:00	
6. Earth Orbit CSM C/O	00:30:00	
7. CSM-S-IVB Separation	00:05:00	
8. CSM Rendezvous with Lab	Variable	
9. CSM Active Docking a) LMP stabilizes Lab b) CSM docks	00:15:00	• Demonstrate unmanned LEM Lab FCS ability to operate after orbital storage and effect docking with a manned CSM.

Table 3.4-1 (cont)

Mission Phase	Nom Phase Time, Hr: min: sec	Objectives Supported
10. Lab C/O a) Crew transfer b) Lab C/O	01:30:00	
11. Earth Orbit Lab Experiment Operations: Typical a) Biomedical & behavioral studies b) EVA studies c) Radiation monitoring	14 days 336:00:00	• Evaluate extra vehicular crew operations. • Evaluate Lab data management system. • Demonstrate capability of modified LEM ECS & crew provisions to support life. • Demonstrate performance of modified LEM structure & insulation.
12. Lab shutdown and equipment and data transfer to CSM	01:30:00	
13. Preparation for CM entry a) Lab jettison b) SPS deorbit maneuver c) SM Jettison	00:10:00	
14. Entry	00:11:00	
15. Parachute Descent	00:07:00	
16. Post landing through S/C retrieval	Variable	

Table 3.4-2

MISSION PROFILE EARTH POLAR ORBIT

Incl, 90 deg; Alt, 200 n. mi

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
1. Saturn V Ascent to Polar Orbit a) S-1C Firing b) S-11 Firing (Yaw Steering) c) LES Jettison d) S-IVB Firing (Yaw Steering)	00:16:30	• Demonstrate LEM Lab Structural integrity after Saturn V yaw steering maneuvering to effect a polar orbit.
2. Orbit Coast - S-IVB Stabilized a) CSM C/O	03:00:00	
3. CSM Transposition & Docking a) CSM S-IVB Separation b) CSM Transposition c) CSM-LEM Lab Docking d) LEM Lab S-IVB Separation	00:30:00	
4. LEM Lab C/O a) Crew Enters Lab b) Activation & C/O of Lab Subsystems	02:00:00	• Demonstrate performance of modified LEM S/S after being subjected to boost environment.
5. Earth Polar Orbital Lab Experiment Operations: Typical a) Biomedical & behavioral studies b) Lunar survey equipment C/O (Earth mapping) c) Weather studies	14 days 336:00:00	• Evaluate EVA crew operations. • Demonstrate the Earth pointing capability of Lab flight control system. • Demonstrate the performance of the modified LEM structure & insulation over a 14-day Earth orbital mission. • Evaluate radiations levels throughout mission duration. • Demonstrate the capability of the modified LEM ECS and crew provisions to support life over a 14 days Earth orbital mission.

Table 3.4-2 (cont.)

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
6. LEM Lab shutdown & equipment and data transfer to CSM.	01:30:00	• Evaluate the LEM Lab data management system. • Demonstrate compatibility of LEM Lab with MSFN for polar orbital operations.
7. Preparation for CM re-entry a) Lab jettison b) Service propulsion deorbit maneuver c) SM jettison	00:10:00	
8. Entry	00:11:00	
9. Parachute descent	00:07:00	
10. Post landing through S/C retrieval	Variable	

Table 3.4-3

MISSION PROFILE EARTH SYNCRONOUS ORBIT

Incl, Zero; Alt, 19,350 n. mi.

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
1. Saturn V Ascent to 100 n. mi. Parking Orbit 28.5 Deg. Inclin. a) Launch azimuth 90 Deg. b) S-1C Firing c) S-11 Firing d) LES Jettison e) S-IVB Firing f) Parking Orbit insertion	00:10:00	
2. Earth Parking Orbit (1-1/4 Orbits) a) CSM Systems Check b) Preparation for transfer orbit Insertion	01:50:00	
3. Transfer Orbit Insertion a) S-IVB Restart b) Orbit Transfer & Partial Plane Change	00.06.00	
4. Transfer Orbit Coast to 19,350 n. mi.	05:15:00	
5. S-IVB Restart to do Partial Plane Change & Circularize at Synch. Alt.	00:02:00	
6. Transposition & Docking a) CSM S-IVB Separation b) CSM Transposition & Docking with Lab. c) LAB-S-IVB Separation	00:30:00	

Table 3.4-3 (cont.)

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
7. CSM Firing to Complete Plane Change and Circularization. (NOTE: May need to wait for one orbit)	00:01:30	
8. Lab C/O a) Crew transfer to Lab b) Activation and C/O of Lab S/S.	01:30:00	• Demonstrate operation of modified LEM S/S after being subject to boost environments.
9. Earth synch. orbit Lab experiment operations: typical a) Biomedical & behavioral studies b) Astronomical studies and observations c) Small maneuverable satellite studies.	14 days	• Demonstrate LEM Lab thermal control. • Demonstrate compatibility of LEM Lab with MSFN for synch. orbit mission. • Evaluate radiation levels. • Evaluate extra vehicular crew operations. • Evaluate LEM Lab data management systems. • Demonstrate capability of the modified LEM ECS and crew provisions for 14 day mission. • Demonstrate earth pointing capability of LAB FCS.
10. LEM Lab shutdown & equipment and data transfer to CSM.	01:30:00	
11. Preparation for CM reentry a) Lab jettison b) Service propulsion deorbit maneuver c) SM jettison	05:30:00	

Table 3.4-3(cont.)

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
12. Entry	00:11:00	
13. Parachute descent	00:07:00	
14. Post-landing through S/C retrieval.	Variable	

Table 3.4-4

MISSION PROFILE LUNAR POLAR ORBIT

Incl, 90 deg; Alt, 80 n. mi

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
1. Saturn-V Ascent to Parking Orbit (100 n. mi.) a) S-1C Firing b) S-11 Firing c) LES Jettison d) S-IVB Firing e) Parking Orbit Insertion	00:10:00	
2. Earth Parking Orbit a) CSM C/O b) Preparation for Translunar Insertion	02:12:00	
3. Translunar Insertion a) S-IVB Restart	00:10:00	
4. Translunar Coast a) CSM-S-IVB Separation b) Transposition & Docking c) CSM/Lab-S-IVB Separation d) 1st Mid-course Correction e) 2nd Mid-course Correction f) 3rd Mid-course Correction	60:15:00	
5. Lunar Orbit Insertion a) SPS Firing	00:05:00	
6. Lab C/O in Lunar Orbit a) Crew transfer to Lab b) Activate & C/O of Lab systems	01:30:00	• Demonstrate operation modified LEM systems after boost environments.

Table 3.4-4 (cont.)

Mission Phase	Nom Phase Time, hr: min: sec	Objectives Supported
7. Lunar Orbit Lab Experiment Operations: Typical a) Biomedical & behavioral studies b) Lunar photographic studies c) Lunar oriented experiments	14 days 336:00:00	• Evaluate radiation and micrometeorite levels in low inclination lunar orbit. • Demonstrate CSM-LEM Lab 1 mission compatibility for lunar mission thermal vacuum environment. • Evaluate LEM Lab data management systems.
8. LEM Lab shutdown and equipment and data transfer to CSM	01:30:00	
9. Transearth Injection a) Jettison Lab b) SPS firing	00:05:00	
10. Transearth Coast a) 1st midcourse correction b) 2nd midcourse correction c) 3rd midcourse correction		
11. SPS Deorbit a) SPS Firing b) SM Jettison	00:05:00	
12. Entry	00:11:00	
13. Parachute Descent	00:07:00	
14. Post-landing through S/C Retrieval	Variable	

Table 3.5-1

PHASE II LAB EXPERIMENT REQMTS, FLIGHT 513*

Exper No & Title	Wt, lb	Vol, cu ft Int	Vol, cu ft Ext	Power, watts Avg	Power, watts Pk	Energy, kw-hr	Point'g Accur'y deg	Stab Reqmts, deg/sec	Orient'n Direct'n	Experiment Length hr	Experiment Freq, no.	No. Men	Special Reqmts & Remarks
0103-0203 Biomed/Behavior	380	28.3	-	110	600	109.7	N/A	N/A	N/A	VAR.	207	1 or 2	Human perf test panel incl.
0501 Radiation Monitor	46	1.1	0.6	6.3	-	6.8	N/A	N/A	N/A	Cont.	Daily	3	10 min/man/day check
0502 Mag Field Lines	312	0.4	4.6	10.	150	1.4	0.5	5.0	MFO	135.	270	1	Mag field orientat'n
0503 Comet-like Clouds	157	1.8	4.7	63.	-	0.8	2°/5°	1°-5°	PCO	12.	4	1	Particulate cloud orient'n
0802A IR Radiometer	303	2.5	12.8	30	30	1.8	5.0	1.0	EO	60.	180	1	E-O cryo cooling
0802B IR Spectromtr	432	2.0	8.4	170	170	7.7	5.0	0.5	EO	45.	270	1	Scanning
0802C uWave Spect	150	1.5	5.0	95	95	2.1	0.5	0.5	EO	22.5	90	1	EO

Table 3.5-1 (cont.)

Exper No & Title	Wt, lb	Vol, cu ft		Power, watts		Energy, kw-hr	Point'g Accur'y deg	Stab Reqmts, deg/sec	Orient'n Direct'n	Experiment		No. Men	Special Reqmts & Remarks
		Int	Ext	Avg	Pk					Length hr	Freq, no.		
0802D Proto Star Trkr	60	0.7	3.5	50	50	.05	0.5	0.15	IO	0.1	6.	1	IO
1507 EVA Assy Ops	870	2.0	40.	150	1500	5.8	2.0	0.2	Var.	39.	13.	2	EVA Obsvr All men awake 1/2 LiOHs incl.
TOTALS	2710	40.3	79.6			136.2							

*
- Alt:200 n.mi
- Incl:83 deg Ret.
- No Men:3
- No. days:45
- Primary biomed/behavioral

Table 3.5-2

FLIGHT 513 MISSION DEFINITION SUMMARY

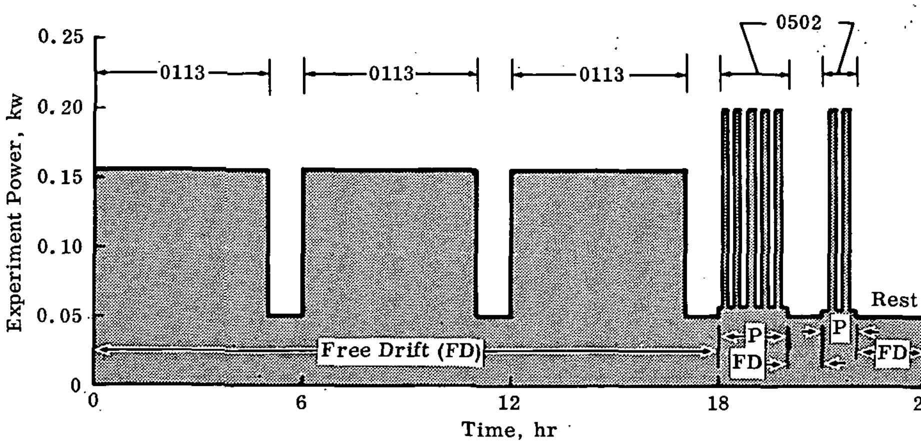
Exper. No.	Occurrence Day No.	Total Times Perf/ Mission	No. Men Reqd	Exper Time/Test		Total Exper Man-hr/Mission				Total Exper Man-hr/Mission	
				Setup Time, min	Test Time min	Crewman 1	Crewman 2	Crewman 3	Total	Achvd	Spec'd
0100	All Except Day 40	Var	2	Var	Var	230	230	230	690	690	690
0200	" "	Var	1 or 2	Var	Var	102	102	103	307	307	307
0501	1 thru 45	135	1	---	10	7.5	7.5	7.5	22.5	22.5	22.5
0502	1 thru 45	270	1	10	30	45.10	45.10	45.10	135.0	135.0	135.0
0503	13,19,28,33, 34, 40	6	1	60	120	6.0	6.0	6.0	18.0	12.0	12.0
0802	12,13,15,18-22, 25,28,33,34,40, 42,44	265	1	5-10	13.0-26.0	19.5	19.5	22.5	61.5	61.5	Note 2
1507	13,19,20,25,26, 28,34,40,41,44	10	2	60	120	21.0	21.0	18.0	60.0	60.0	78.0
EVA LiOH (Note 1)	7,13,19,25,32 39	6	2	20	40	2.0	2.0	2.0	6.0	4.5	4.5
					TOTALS	433.0	433.0	434.0	1300.0		

- Work Day Time on Duty, hr
  - Max: 12
  - Avg: 10
  - Min: 6
- Total EVA Man-hr: 66
- Var: Variable

Notes: (1) Half of the LiOH EVAs are accomplished in Exper. 1507.
(2) Required as frequently as possible during good visibility.

Table 3.5-3

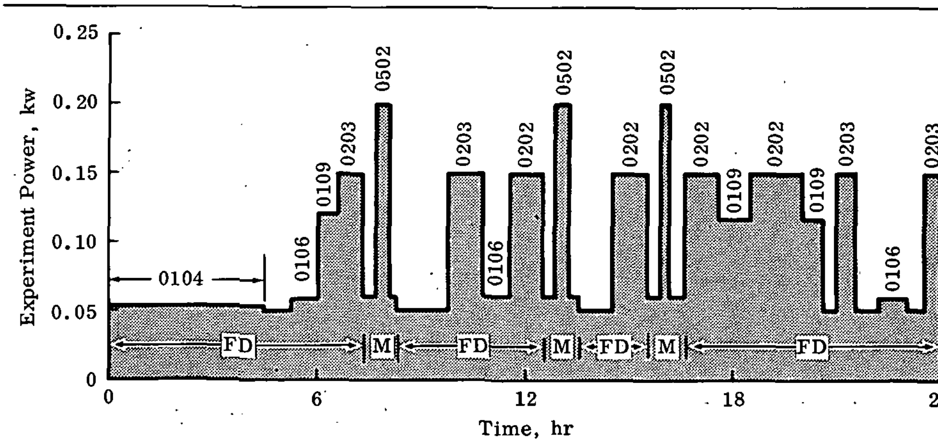
FLIGHT 513 EXPERIMENT MISSION TIMELINES



A. Day 3, 10, 17, 24, 31, 38 & 45

Stability Reqmts: 5.0 deg/sec

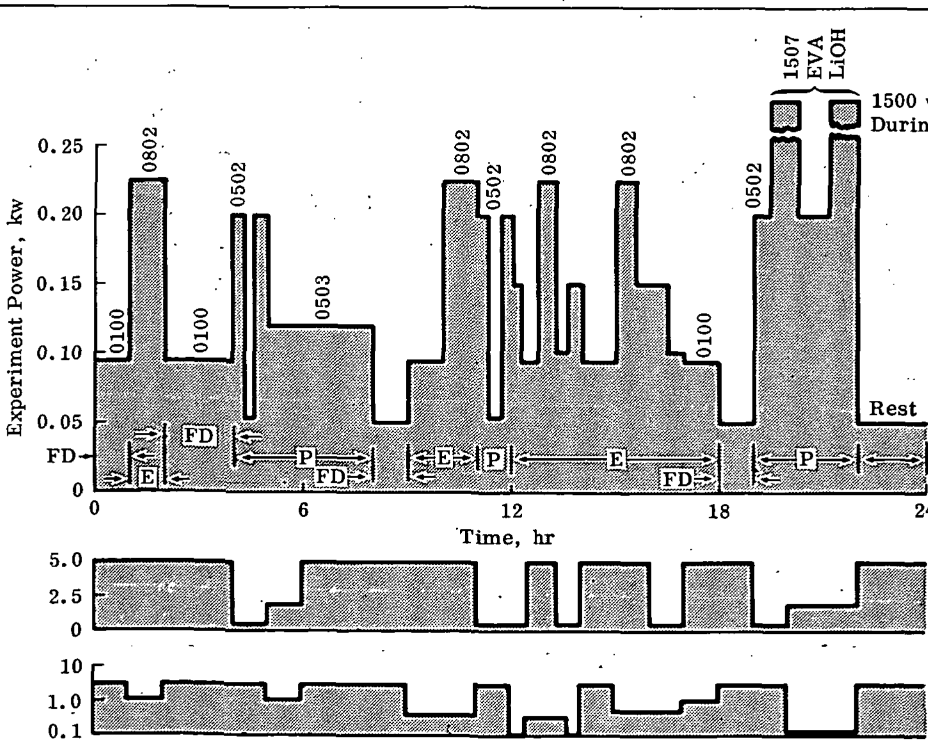
Pointing Accuracy Reqmts: Free Drift, ±5.0 deg
: P(Phenomena Oriented), ±0.5 deg



B. Day 1, 2, 4-9, 11, 12, 14-16, 18, 21-23, 27, 29, 30, 32, 33, 35-37, 39, 42, 43

Stability Reqmts: 5.0 deg/sec

Pointing Accuracy Reqmts: Free Drift, ±5.0 deg
: M(Magnetic Field Orientation), ± 0.5 deg



C. Day 13, 19, 20, 25, 26, 28, 34, 40, 41, & 44

E: Earth Orientation
P: Phenomena
FD: Free Drift

Table 3.5-4

HOUSEKEEPING & SYSTEMS CHECKOUT TIMELINE

Event Time or Start Time Hr: Mins: Sec.	Mission Event	Event Duration
00: 00: 00	Astronaut(s) Enter Lab.	4 min. -00 sec.
00: 04: 00	CSM-LAB Communication Check	3 min. -30 sec.
00: 07: 30	Activate C&W System	0 min. -30 sec.
00: 08: 00	Power Dist. Status Check	2 min. -00 sec.
00: 10: 00	Activate and Checkout Lighting	1 min. -00 sec.
00: 11: 00	Activation of Sensors & Displays	0 min. -20 sec.
00: 11: 20	Check Propellants; Gases & Fluid Status	2 min. -00 sec.
00: 13: 20	Initial Status Check of ECS	7 min. -30 sec.
00: 20: 50	Transfer Equipment to Lab. (PLSS, Hand Cameras, Accessories, etc.)	4 min. -10 sec.
00: 25: 00	Deployment of S-Band Antenna	0 min. -30 sec.
00: 25: 30	Communication and Instrumentation Checkout	12 min. -00 sec.
00: 37: 30	Completion of ECS Checkout	10 min. -00 sec.
00: 47: 30	Checkout of SCS & RCS System	19 min. -00 sec.
01: 06: 30	LAB Subsystem Initial Checkout and Activation Completed	
xx 00: 00	LAB Subsystem Status Monitoring	6 min. -00 sec.
xx 06: 00	(Performed at approximately two hrs. interval for entire flight)*	
	Pressurized spacesuit & PLSS checkout for every EVA	20 min. -00 sec.
45th day	LAB II Shutdown and Astronaut exit to CSM	15 min. -00 sec.

*Purge EPS Fuel Cells Every 3rd Subsystem Status Check

4. SYSTEMS ENGINEERING

4.1 THERMODYNAMICS

4.1.1 Ground Rules and Assumptions

- The NAA AES cryogenic storage tanks should be used if they will satisfy the Phase II Lab Mission.
- No restrictions are to be placed on vehicle orientation due to thermal control restraints.
- An active thermal control system will be used for vehicle heat rejection.
- Overboard venting of cryogenic oxygen and hydrogen is to be avoided.
- Only water generated by the fuel cells that is not required for any other purpose is to be used in water sublimators.
- Minimum modification from flight to flight overrides optimization for any particular flight.

4.1.2 Background Data and Analysis

4.1.2.1 Thermal Environment

The thermal environment comprises the direct solar radiation, reflected albedo radiation, and direct I-R radiation incident on the vehicle surfaces. The intensity of thermal radiation depends on the orbit, vehicle orientation, and the location of the sun relative to the orbital plane. The angle between the solar vector and the orbital plane, θ_s, varies as a function of the orbit inclination, the date, and time of launch. The tabulation below shows the possible range of θ_s for each of the Phase II Lab flights. In addition, the maximum possible temperature of a surface in thermal equilibrium with the radiation environment is shown for a typical skin surface, $\alpha/\epsilon = 0.8$, and a typical radiator surface $\alpha/\epsilon = 0.2$.

Orbit Alt.n.mi/inclination, deg	Oriented	θ_s, deg	Max. Temperature, °F		Radiator Max. Avg. Absorbed Radiation* Btu/hr/ft^2
			$\alpha/\epsilon = .8$	$\alpha/\epsilon = .2$	
200/28.5	Earth or Space	-62	228	62	44
19350/0	Earth or Space	-23.5	213	16	40
200/-83	Earth or Space	-90	228	62	60
80/90.	Lunar or Space	-90	230	210	65.5

* Based on the recommended radiator configuration. The orbital average of two radiator units located on opposite sides of the vehicles.

In Table 4.1-1, the orbital average of incident thermal radiation is presented for a number of surfaces. Solar, albedo, and I-R radiation intensities are shown for both earth and space oriented Labs in earth orbits with varying solar angle, θ_s. Also shown is a moon oriented lunar orbit with the solar vector in the orbital plane.

An indication of the variation in incident radiation throughout an orbit is given in Fig. 4.1-1A and 4.1-1B. They show the variation in the thermal environment of upward and downward directed surfaces, for earth and lunar orbits respectively. In both cases, the solar vector is in the orbital plane. This condition produces the maximum variation during an orbit.

The thermal environment in the synchronous orbit is primarily due to solar radiation. At this orbital altitude the levels of albedo and I-R radiation do not exceed 2 Btu/hr/ft^2. Hence the major factor is the surface orientation relative to the solar vector. Shadowing by the earth for up to 5% of the orbit is also possible. Figure 4.1-2 shows the percentage time in sunlight for the 200 n.mi earth orbit and 80 n.mi lunar orbit as well as for the synchronous orbit.

4.1.2.2 Vehicle Heat Loads

Heat loads are imposed on the vehicle by four primary sources: fuel cell heat rejection, electrical power dissipation in the housekeeping and experiment loops, metabolic loads due to the crew, and the external environment. The power profiles used to establish min/max loads on the cooling loops were supplied by EPS and are presented in Fig. 5.1-1 and 5.1-2. Table 5.1-1 presents a distributional power requirement list. Using this list the following table was formulated to allocate cooling loads to various vehicle sectors.

Distribution of Electrical Power Dissipation

Location	Avg Btu/hr Min	Avg Btu/hr Max
Low Temp Electronics	580	580
Battery	34	34
Pump	136	136
Cabin Air	681	1188
High Temp Electronics	930	2595
Metabolic Load	600	600
Structural Heat Leak	-1366	0

The values for the structural heat leak presented above were obtained by considering the assumed structural load variations for the ascent stage and experiments. A tabulation for the ascent stage loads is presented below: (+ is gain to vehicle; - is lost by vehicle to space).

Vehicle Area	Max Sun Btu/hr	No Sun Btu/hr
Skin	-270	-450
Window	shade up: +530 shade down: 0	shade up: -180 shade down: 0
Top Tunnel Covered (Non-docked configuration)	+ 5	- 27
RCS	+88**	- 52*
Antenna, and other areas	+40	- 70

** 23 Watts of heat supplied to two Cold Clusters
* 46 Watts of heat supplied to all four clusters

Thus the Lab will have a structural heat loss varying from approximately 100 Btu/hr for a condition of maximum sun light with the window shades closed, to approximately 700 Btu/hr for the minimum sun light condition with the shades open. In addition it was estimated that the experiments hung off the Labs could cause the Lab to gain 100 Btu/hr or lose 666 Btu/hr. Thus, the overall estimated heat leak will vary from 0 to -1366 Btu/hr.

The fuel cell heat loads are discussed in detail in the next section with the thermal evaluation of the candidate fuel cells.

4.1.2.3 Fuel Cells Thermal Evaluation

The electrical power for the vehicle will be supplied by either General Electric, Pratt and Whitney, or Allis Chalmers fuel cells. Each of these systems has been evaluated with respect to its heat generation characteristics, environmental temperature requirements, launch pad thermal control, storage and remote start-up requirements, and optimum cooling loop design. All three fuel cell designs have been found to be thermally compatible with the mission requirements of the vehicle. The general characteristics of all three fuel cells are summarized in Fig. 4.1-3.

4.1.2.3.1 Heat Generation. Hydrogen-oxygen fuel cell efficiency has a theoretical upper limit of 0.83 with all the remaining energy of reaction appearing as heat. The practical efficiency of a fuel cell is governed by its polarization characteristics. These are different for each cell design but, are, in all cases, sensitive to cell operating temperature. Higher temperature cells tend to be more efficient. The heat generation characteristics of the A-C, GE, and PWA fuel cells are shown in Fig. 4.1-3A. The 400°F PWA design is the most efficient and the 205°F A-C design and the 120°F GE design decrease in efficiency in that order. There is a plateau in the PWA heat rejection curve caused by dissipation of parasitic power, the fuel cell pumps, etc., into the FCA cooling loop. All of the heat generated in the fuel cell is removed by the vehicle-supplied thermal control system.

4.1.2.3.2 Environmental Temperature Requirements. When operating in vacuum, the GE and AC fuel cells may be placed in thermal environments of -60°F to 150°F and -120°F to 185°F respectively without damage. There is no dependency upon heat exchange with the environment for survival. The PWA fuel cell uses a radiant heat exchange with the environment to cool its control components. Therefore the cell must be placed in an environment of 30°F to 130°F, which has to be guaranteed by the vehicle. Unless a restriction is placed upon the location of the fuel cells in the vehicle, there are portions of the mission during which the fuel cell compartment will exceed 130°F. If a random location is assumed, the anticipated heat load from the PWA fuel cells is 300 Btu/hr/FCA. This heat load results in a weight penalty of 19 lb to the Lab ECS loop.

4.1.2.3.3 Launch Pad Thermal Control. Launching the Lab with operating fuel cells requires that adequate ground cooling be supplied to the Lab on the pad. The GE fuel cell is a low temperature unit and is compatible with the existing LEM air conditioning system. The A-C fuel cell also does not require any changes to the air conditioning system. However, this cell requires approximately 5 lb of external insulation to reduce the conductive heat losses to a level compatible with its internal heater size. The PWA fuel cell uses super-insulation which is not highly effective at one atmosphere pressure. The heat loss from this unit is, therefore, much larger than the

300 Btu/hr FCA encountered in flight. PWA has estimated it at 1500 Btu/hr FCA at Std sea level conditions. This heat loss is beyond the capabilities of the existing LEM air purge, but the heat must be removed to prevent damage to the fuel cell controls and to the vehicle. Therefore, the launch pad air conditioning must be supplemented with an additional cooling air flow rate of approximately 20 lb/min. The fly-away weight penalty for the ducting, umbilical connection, etc. needed for this system is 10 lb.

4.1.2.3.4 Cooling Loop Considerations - Vehicle thermal control loops have been weight optimized for each fuel cell in conjunction with the vehicle electrical power profile as shown in Fig. 5.1-2. Radiators have been sized based on the most advantageous inlet and outlet temperature for each fuel cell with a by-pass control system used as required in order to enhance the design.

Water sublimation to augment the radiators during high heat rejection periods was considered as a variable in the study. Water-boiloff vs radiator area tradeoff curves are presented in Fig. 4.1-4. The radiator weight including all plumbing and structural support is estimated at 2 lb/ft^2. Detailed radiator characteristics are also presented for all three systems based on the use of 850 lb of free water from the fuel cells. These data are presented to illustrate "minimum" radiator comparisons. The final design selected, as discussed in Paragraph 4.1.3.2, is an all radiator design.

4.1.2.4 Equipment Temperature Specifications

Listed below are equipment temperature specifications for key items requiring thermal control. In general all other equipment either rejects heat passively or is cold plated in the ECS loop.

Item	Temperature °F Min	Temperature °F Max
RCS Propellant	40	100
Cabin Air	70	80
RCS Engine (Propellant Valves)	35	175
Battery surface Temp	40	80
Water Tanks	40	165
Abort Sensor Assembly (operating)	119.1	120.1
(storage)	105	120
Inertial Measuring Unit* (operating)	134.9	135.1
(storage)	120	135

* IMU not carried on recommended configuration

4.1.2.5 Equipment Heater Requirements

Various external antennas, and the RCS Clusters, will require heat when exposed to space and not in use or receiving radiant energy from the sun or planetary bodies. Heat is also needed to maintain the navigation and guidance equipments above their recalibration temperatures when not in use.

- RCS Cluster Heater Requirements: The cluster oxidizer valves must be maintained above minimum temperature of 35°F, to prevent the propellant in them from freezing. The electrical heat required for each cluster valve is a function of how much heat is conducted and radiated from the cabin to the cluster can. As the cabin temperature rises, more heat is transferred from the cabin and the electrical heat required diminishes. Figure 4.1-5 shows the heater requirements as a function of cabin temperature, for a condition of no external heat flux. When the cluster is in direct sun light, no heater power is required. It is estimated that for the Labs the average heater power required for all four clusters is 30 w, assuming that two out of four clusters are in the sun at any one time.
- S-Band Steerable Antenna - The S-Band Antenna, when not in use, requires heater power to maintain the antenna's steering components above the low temperature survival limit. Components such as servomotors, electronic equipment and gimbal mechanism must be maintained above -65°F. It is estimated that 5 w of heater power are required to accomplish this during the condition of zero external heat flux. When the antenna is in direct sunlight, no extra heat is required.
- Navigational Equipment - In the LEM, the IMU and the ASA are both located above the cabin. Though not exposed to space, they require precise thermal control when in use (+0.1°F) and close temperature control when not in use. Both units utilize gyro-systems and accelerometers that are extremely temperature-sensitive. If the temperature drops below 120°F on the IMU and 105°F on the ASA, the units will go out of calibration. In the basic LEM, temperature control of the IMU and ASA in the non-operating mode is achieved 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 cooling loop. For the Lab, a bypass valve will be incorporated into the cooling loop, to by-pass the IMU and ASA when the units are not operating. The IMU and ASA are conductively coupled to the cabin structure. Figure 4.1-6, shows the heater power required by the IMU and ASA to maintain them above their recalibration points, as a function of cabin temperature. The losses to the vehicle skin are minimized by a blanket of 20 layers of aluminized mylar insulation between the units and the vehicle skin. Heater power required for the ASA and IMU, for two cabin temperatures, is tabulated below:

Equipment	Heater Power (watts)	Temperature (°F)
Average Cabin Temperature 70°F		
IMU*	9.5/8.5	135/120
ASA	5/4	120/105
Average Cabin Temperature 40°F		
IMU*	13/11.4	135/120
ASA	7/6	120/105

* *IMU not carried in recommended configuration*

4.1.2.6 Passive Temperature Control

The equipment located in the aft bay lends itself quite readily to passive or semi-passive cooling. About 600 Btu/hr could be rejected in this manner. This would decrease the housekeeping experiment loop radiator area by five to ten sq ft; a minimal saving. At the same time the continuous passive rejection of heat from the aft bay would reduce the minimum load on the radiator. The end result is a large increase in the required radiator turn-down ratio. The increased complexity in the radiator control system more than offsets any savings obtained by passive heat rejection.

4.1.2.7 Cryogenic Storage

Investigations were made into the basic thermodynamic considerations involved in the design and performance of vapor cooled cryogenic tankage. This effort was required for two reasons: 1) to provide the ability to make accurate estimates of vapor cooled tank performance at other than the design point condition; 2) to provide information that would allow Grumman to recommend a cryogenic tank vendor if existing tanks had been found unsatisfactory for the Phase II. Lab.

On the basis of these studies, several important statements can be made with respect to the vapor cooled storage tanks being considered for the AES mission:

- At low receiver surface temperatures (about 350°R and below) discrete radiation shields will thermally outperform conductive type insulation.
- Vapor cooling is about twice as effective when applied to radiative rather than conductive heat leaks, ie., vapor cooling will be more effective with discrete radiation shields than some types of superinsulation.
- A vapor cooled tank designed with a predominantly radiative heat leak that meets N.A.A. requirements (170°F environment) will have one half the design value heat leak in a 40°F environment. The Lab can supply this environment for two sets of AES tanks. The power available for experiments is tripled without resorting to overboard venting. A vapor cooled tank with a predominantly conductive heat leak would require a 312°R (-148°F) environment to achieve the same result.

Of the vendors contacted during the Phase B study effort (Bendix, Beech, and AiResearch), Bendix was deemed to have the best potential design considering thermodynamic principles.

4.1.2.8 Space Radiator Development

4.1.2.8.1 Radiator Requirements. A large range of heat rejection requirements exists for any Phase II Lab flight. Also, a large variation in average heat rejection levels exists between the various flights. Requirements are further complicated by large variations of environmental influx introduced by different orbits and vehicle orientation.

Moderating the severity of the radiator max/min operating range requirements are four factors:

- Excess water is available from the fuel cells to reduce the maximum radiator cooling requirement, thus reducing the required operating range.

- Modulaization of the radiator allows a crude tailoring of radiator area to the required heat rejection of each specific flight.
- A large thermal inertia exists within the system which moderates the instantaneous or steady state extremes in required heat rejection range.
- Radiator area applied to opposite sides of the vehicle reduces the average maximum environmental influx to the radiator.

As applied to Lab space radiators, the max/min heat rejection requirements for steady state conditions is referred to as Turn Down Ratio (TDR). This is defined by the equation:

$$TDR = \frac{Q_{max} - Q_{H_2O\ Boil} + A_{rad}\, q_{envt\ max}}{Q_{min} + A_{rad}\, q_{envt\ min}}$$

Where

Q_{max} = maximum equipment heat generation

Q_{min} = minimum equipment heat rejection

Q_{H_2O} Boil = quantity of heat that can be accommodated by water boiling

A_{rad} = radiator area

q_{envt} = specific rate of heat absorbed by radiators from the environment.

TDR can also be considered as the maximum to minimum internal load that can be handled by a radiator while viewing an absolute zero temperature environment. The present definition of loads indicates that for any particular flight a radiator TDR design requirement of greater than 11:1 could exist. It represents the requirement before the following moderating factors are applied:

- Applying radiator area on both sides of vehicle
- Water utilization
- Thermal Inertia
- Modularization

Employment of the modular radiator concept reduces the control system TDR to approximately 11:1. Utilizing excess fuel cell water will reduce the TDR requirement to about 10:1. Splitting the total radiator area requirement into two half areas and applying them on diametrically opposed sides of the vehicle reduces the maximum environmental influx on the total area to 60 Btu hr/ft^2 from the 100 Btu hr/ft^2 that would exist if the entire area were on one side of the vehicle. The effect of this is to reduce the TDR requirement to about 6:1. The effect of the thermal inertia is to reduce the total rediator area required and hence the TDR. The quantitative definition of the TDR after consideration of thetransient effects will reduce this requirement to an estimated 4-5:1.

An engineering factor that may further moderate the magnitude of the TDR is to integrate the heat rejection requirements of the fuel cells with those of the ECS and experiments.

Growth loads will not be firmly defined for a considerable time; failure mode operation can increase TDR; and reasonable tolerances must be factored into hardware designs. Consequently, for purposes of evaluating the applicability of various control approaches, a design objective of 10:1 was established. This represents sufficient allowance for growth and contingencies to assure development of a control approach that will meet the present and future requirements.

4.1.2.8.2 The Modular Radiator Concept. Adopting the building block (modular) concept of radiator sizing for the various flights results in minimizing development time and cost. Ultimately a single size module will evolve which will be compatible with a single control system. The only variation from flight to flight will be in the number of modules employed. The control system will be compatible with any number of modules. This is now a design objective for the radiator system and unless it penalizes the design, it will be adopted as a system design constraint.

4.1.2.8.3. Radiator Control Concept. A number of approaches to radiator control have been investigated to determine their applicability. The concepts considered cover a large number of control methods, capable of development within the time available. Those evaluated and determined to be inadequate, due either to insufficient TDR or poor recovery characteristics, are: uncontrolled radiators, radiator bypass, regenerator control, selective stagnation, louvers, venetian blinds and vehicle orientation control. LTV was given a contract to investigate non-mechanical control concepts, including the LTV selective stagnation concept and Grumman valve stagnation concept for TDR and recovery characteristics. The final report covering this study is included under separate cover. From the LTV and Grumman studies, three systems were selected which are compatible with all thermal requirements and constraints. Two of these are discussed below; the third is presented with the recommended configuration.

- "Window Shade" Control: This control system approach to achieving high TDR is based on covering that quantity of radiator area not required for heat rejection with a shade of H film superinsulation. The achievable TDR is determined by the heat leakage through and around the shade when it fully covers the radiator.

  It was recognized that several potential mechanical problem areas exist with this concept. Consequently Grumman has instituted a company-funded applied research effort to define and resolve these areas. The first area of concern is the possibility of cold welding of the H film sheet to itself in the high vacuum environment. The second area of investigation is the fatigue life of the film stressed by 45 days of cycling on and off a driver. A mechanical feasibly rig is now in design and fabrication to investigate these and related potential problem areas.

  A desirable feature of this and the "barn door" control discussed below is that minimum temperature levels in the fluid loop can be maintained at virtually any level desired. Therefore, the choice of transport fluid need not be directed by space radiator considerations. This approach readily offers the desired TDR's for the Lab.

- "Barn Door" Control: A concept of control that offers TDR potential equal to or greater than the window shade is one where rigid panels expose or cover the radiator surface. As with the window shade approach, the limitation on TDR is dictated by the heat leakage through and around the door shield when in a closed position.

Minimum fluid temperature can be selected at any level desired so fluid choice need not be dictated by radiator design considerations.

Control components of the shade and door actuators are mechanically similar. As will be shown in a later section, the total radiator subsystem including the accommodation of modularization is similar for both approaches.

A mechanical design description of the door control including a design drawing of the actuator doors, and mechanical linkages can be found in paragraph 6.2.6 of this report. The complete scheme uses simple and feasible state-of-the-art technology at the basic component level. However, because the approach is new in concept, proof of feasibility and a development program are required.

Several attractive characteristics of this control system that are unique to the approach are:

- A single actuator mechanism on one side of the vehicle serves from one to four modules.
- "Doors" can be non-thermal panels or active radiator panels depending on the mission dictated requirements. Thus up to 60 sq ft of radiator surface area is available on each quarter panel of the descent stage.

A summary tabulation of the status of the various control concepts considered for this application is included as Table 4.1-2.

4.1.2.8.4 Radiator System Dynamic Response. Utilization of mechanical means of obtaining required TDR is accomplished in a complete operational subsystem loop as shown in Fig. 4.1-7.

If the Barn Door capacity control approach is used, the schematic would be as shown in Fig. 4.1-7. One actuator services each bank of up to four modules on a side.

If the shade approach is employed the schematic would differ to the extent that each module would have a separate shade actuator.

A dynamic analysis of the mechanical control approach was performed utilizing an analog computer. The description of the analog system that was simulated is contained in paragraph 4.1.3 of this report.

The following characteristics of the control system were employed.

Thermostatic Flow Proportioner:	$\pm$ 10°F full travel
Thermostatic Door Actuator:	Full closed at 30°F Full open at 50°F

A deliberate attempt was made to uncover system instability. Large instantaneous changes in equipment loads and environment loads on either side of the vehicle were applied, sequentially and simultaneously. Loads were applied and removed. Time constants different from ideal were studied. Absolutely no instability or incipent instability was uncovered for any case.

A typical self-explanatory mission time trace demonstrating system reaction to various applications of loads is included as Fig. 4.1-7. This illustrates the responsiveness of the system in maintaining the required temperature levels and the complete stability existing at all times.

4.1.3 Recommended Configuration

Pertinent design features of the recommended configuration are listed in Table 4.1-3. A discussion in some detail of the specific areas is presented in the following paragraphs.

4.1.3.1 Cryogenic Tankage: Selected Design

The NAA AES tanks have been selected for the storage of cryogenic oxygen and hydrogen in the Lab. A fully loaded tank system with the selected fuel cells has the ability to supply 1680 kw-hr of energy and 221 lbs of ECS oxygen. See Table 4.1-4 for tank specifications as supplied by NAA.

The minimum Lab housekeeping power is 440 watts. This power requires a hydrogen flow rate of 0.052 lb/hr. The maximum flow rate due to the heat leak only in the Lab environment will be 0.047 lb/hr. Therefore, the AES tanks are suitable for the proposed Phase II Lab missions. No venting of hydrogen must be considered. Combined fuel cell and ECS requirements also negate overboard venting of oxygen.

4.1.3.2 Active Thermal Control System

Thermal control of the vehicle and dissipation of the heat load is accomplished by two cooling loops; one for the fuel cells and one for the combined housekeeping and experiments. The radiator area for each loop is 60 sq ft and is made up of four 15-sq ft modules. Two modules, operating as one unit, are located 180 deg. apart from the other two modules. Provisions are incorporated, for those missions that have higher ECS loads and thus require more than 60 sq ft of radiator area, to add one or two modules to each side of the vehicle. Figure 4.1-8 shows the capacity of different radiator areas when subjected to varying amounts of external absorbed radiation.

Figure 4.1-9 shows the system configuration for the cooling loops. The radiator unit (two modules) contains two fluid flow paths. One flow path is a single tube near an outer edge of the panel; the other consists of a series of parallel tubes. A modulating valve positively controls the quantity of flow to the two flow paths. The valve is controlled by a downstream fluid mix temperature sensor. At minimum load, all the fluid is directed through the single tube flow path, while the tubes in the other path stagnate. Upon application of increased load, destagnation takes place sufficiently fast to keep the equipment within the temperature limits.

The flow proportioner valve compensates for a condition where the radiator unit on one side of the vehicle has a large value of absorbed external radiation while the other radiator unit has a low value. When this occurs, the proportioner will decrease the flow to the side with the high absorbed external radiation and direct more flow to the side in the colder environment. This is accomplished by sensing the fluid temperauures out of the radiator units and proportioning the flow to hold essentially equal temperatures.

The function of the regenerative heat exchanger is to keep the fluid temperature supplied to the load from falling below the allowable level under low load conditions. At maximum load, the regenerator is bypassed.

The design inlet and outlet temperatures for the radiators of the two cooling loops are different and therefore, the allowable extremes in performance capability are also different. This allowable performance is referred to as "turn down ratio" and is defined in paragraph 4.1.2.8. On a per unit area basis minimum heat rejection of a fuel cell radiator module is 14 Btu/hr/ft^2. The maximum heat rejection value is 208 Btu/hr/ft^2. Thus, the turn down ratio available is 208 divided by 14, i.e., 14.8. The min/max heat rejection values for the ECS loop radiator modules are 14 and 116.7 Btu/hr/ft^2, respectively. Therefore, the available turn down ratio is 8.3.

Sufficient turn down ratio is available in the fuel cell modules to handle the min/max fuel cell heat rejection for any Phase II Lab flight. Therefore, no supplementary water boiling is required in this loop.

The ECS loop is capable of handling the maximum average orbital loads without the use of water boiling. Peak loads above the maximum average orbital loads will exceed the radiator capacity and are handled by water boiling. 740 lb (min) of free fuel cell water are available for this cooling and will handle 217 kw-hr of energy.

4.1.3.2.1 <u>Radiator Analysis: Basic Module.</u> The ability of a space radiator to reject heat is dependent on several variables. The more important factors and the values of these factors appropriate to the basic radiator module are listed below.

o Emmittance (ϵ) :	0.9
o Solar Absorbtance (α) :	0.18
o Panel thickness - inches:	0.02
o Fin Effectiveness:	0.96
o Design fluid inlet temp:	100°F
o Design fluid outlet temp:	40°F

The external, orbital average, incident heat flux is presented in paragraph 4.1.2.1 for various orbital flights and vehicle surfaces. The above information in conjunction with Fig. 4.1-10 can be used to determine radiator heat dissipation per unit area for any flight and radiator orientation. Hence, a knowledge of the heat load to be dissipated leads to the minimum radiator area required for that particular flight. The actual radiator on the vehicle will consist of the minimum number of modules that will provide the required area, thus it is slightly over sized. The basic module area is 15 sq ft and was selected on the basis of the maximum size module which can be placed on the descent bay panel behind the landing strut and still allow placement of two modules on any of the four descent bay quadrants.

4.1.3.2.2 <u>Integrated Housekeeping - Experiment Cooling Loop</u>. The following paragraphs present a description of the integrated housekeeping experiment cooling loop, a discussion of hardware changes, and the results of a steady state analysis of variables which could be typical of a mission. The system configuration and hardware is the same as LEM except for the following:

- Number 209 water boiler is removed
- A radiator and regenerative heat exchanger is added
- The circuit fluid is changed from 35% glycol/65% water; to 62.5% glycol/37.5% water
- The Number 224 water boiler incorporates a control system
- Removal of the suit circuit ECS function requires that the CSM ECS handle the latent metabolic load generated in the Lab cabin.

The maximum orbital average absorbed radiation used in this particular study was 35 Btu/hr/ft^2. Higher or lower values of the absorbed radiation would increase or decrease respectively the required radiator area as noted in Fig. 4.1-8. The regenerative heat exchanger consists of two #204 LEM heat exchangers with a dry weight of approximately 6.4 lb.

The system is shown schematically on Fig. 4.1-11. Temperatures throughout the system are shown for maximum average and minimum average loads. Minimum average load values are shown bracketed. The capacity of the system is adequate without the use of the water sublimator. Water is boiled when loads greater than that defined by maximum average load are experienced.

Under maximum average load, the system is capable of holding a 75°F cabin temperature. This load corresponds to zero structural heat leak, 529w electrical housekeeping, 800 w experimental and 600 Btu/hr sensible metabolic load.

If the structural heat leak were increased to 500 w, the minimum average load would decrease. For the cabin to remain at 75°F, an increase in the effectiveness of both regenerative heat exchangers would be required. This could be accomplished by adding one #204 LEM heat exchanger to each of the regenerative heat exchangers. The weight increase would be approximately 6.4 lb.

An alternate to the proposed system is shown schematically on Fig. 4.1-12. The radiator is located in its own fluid loop, and connected to the main circuit by means of a transport fluid heat exchanger which would replace the regenerative heat exchanger. A pump is incorporated to circulate the transport fluid.

The transport fluid is selected solely to satisfy radiator requirements rather than compromising the fluid to satisfy both the radiator and the main fluid loop. The transport fluid could be Refrigerant 21 which has very low freezing point. Thus, this system allows larger radiator turn down ratios. Increased turn down ratio would would allow maintaining a 75°F cabin at lower minimum loads, implying that larger structural heat leaks would be permissible.

The penalty of this system, compared to the proposed system is a weight increase of 3.2 lb in the heat exchanger and a weight of 6.8 lb for the transport fluid pump. In addition, the required power draw of 44 w represents a weight penalty of 70 lb. The overall weight penalty of this alternate system is approximately 80 lb which must be evaluated in the light of its much better turndown ratios.

4.1.3.2.3 Performance of a Radiator in Off-Design Conditions. Having selected a radiator for a particular design condition, it is necessary to determine its performance during off-design conditions to insure that the system remains operational throughout a mission. The lower limit to the amount of heat that the radiator is allowed to reject is dictated by the desired recovery characteristics. The maximum turn down ratio may or may not permit freezing of the transport fluid in the radiator. This is dependent upon the control system and radiator design characteristics, the transport fluid, and rate of change of radiator fluid inlet temperature with the application of maximum load. Transient recovery characteristics can be controlled to a large extent by tube spacing with a negligible effect on weight.

Figure 4.1-13 shows the steady state performance characteristics of a typical radiator module in the ECS loop. During by-pass operation, with no absorbed external radiation, the radiator rejects 14 $Btu/hr/ft^2$ and has a radiator outlet temperature of -30°F. Flow and fluid viscosity considerations preclude operation at lower outlet temperatures. Hence, this establishes the minimum radiator operating condition. The maximum heat rejection from the design conditions is 116.7 $Btu/hr/ft^2$; and the turn down ratio available from a single module, therefore, is 8.3.

The minimum heat rejection rate (14 $Btu/hr/ft^2$) of a basic module will be the same in the fuel cell loop as it is in the ECS loop. Maximum heat rejection however, is 208 $Btu/hr/ft^2$ and the turn down ratio available is 14.8.

4.1.3.2.4 System Operation with Radiators in Parallel. The radiator units operate in parallel, receiving fluid from a common header and returning fluid to a common header. The flow proportioning valve divides the flow so that the difference in temperatures leaving the units is within a specified range, and directs the larger percentage of the fluid to the unit in the colder environment.

Figure 4.1-14 is the characteristic of any radiator with an emissivity of 0.9 and an efficiency of 0.96. The upper half of the figure is plotted for a fluid inlet temperature of 560°F and the lower half for 540°F. Plots for any fluid inlet temperature can be plotted and thus Fig. 4.1-14 shows only two of a complete family of plots.

The use of Fig. 4.1-14 in evaluating radiator performance is a rather rapid iterative procedure and its use is described below. Assume two radiators, each with an area of 60 sq ft, are required to reject 6120 Btu/hr. One radiator absorbs 26 $Btu/hr/ft^2$ of external heat and the second absorbs 106 $Btu/hr/ft^2$ of external heat. The total flow to the two radiators is 250 lb/hr and the fluid specific heat is .87 Btu/lb°F. By using the bottom plot we are assuming that the fluid inlet temperature is 540°F. Enter the plot with an externally absorbed heat of 26 $Btu/hr/ft^2$, move vertically up to the working line and then horizontally to an assumed exit temperature of 510°F. Then move vertically from this point and read $\frac{\text{Flow rate x spacific heat}}{\text{area}}$ of 2.92. Calculate the flow through this radiator as

$$\frac{\text{Flow rate x specific heat}}{\text{area}} \times \frac{\text{area}}{\text{Specific Heat}} = 2.92 \times \frac{60}{0.87} = 200.$$

The flow rate through the second radiator is 250-200 = 50 lb/hr. Now calculate $\frac{\text{Flow rate x specific heat}}{\text{area}}$ for the second radiator as $\frac{50 \times 0.87}{60} = 0.724$. Enter the curve at an externally absorbed heat of 106 Btu/hr/°F, move vertically upward to the working curve. Draw a horizontal line through this intercept. Now enter the curve with the

$\frac{\text{Flow rate x specific heat}}{\text{area}}$ value of 0.724, and move vertically downward to the horizontal line. Read this intercept at a fluid exit temperature of 520°F. The difference in fluid exit temperatures is 520°F-510°F = 10°F which is within the acceptable band. If this temperature difference exceeded 10°F then the process would be repeated assuming various exit temperatures (different from 510°F) until the temperature difference was within 10°. At this point, check the heat rejected from each radiator to see that the sum equals the required rejection of 6120 Btu/hr. For the first radiator Q = 200 lb/hr x 0.87 (540-510) = 5250 Btu/hr and for the second rediator Q = 50 x 0.87 (540 - 520) = 870 Btu/hr for a total of 6120 Btu/hr which fulfills the requirement. If the sum of the heat rejected for the two radiators did not equal the requirement, then the complete procedure would be repeated on different plots (different fluid inlet temperatures) until the requirement is met.

4.1.3.2.5 Radiator Transient Analysis. A transient thermal analysis of the entire ECS loop has been performed on the analog computer. The study had a two fold objective. The first was a stability study of the "barn door" radiator control system (Paragraph 4.1.2.8.4). The second was to determine the combined effect of equipment thermal inertia and external absorbed radiation on the ECS loop temperatures. Due to the thermodynamic similarity between the barn door and valve stagnation radiator control systems the results apply for both systems. Earth and lunar orbits were evaluated. The characteristics of the ECS loop as programmed for the computer are listed below:

- Total fluid flow rate - 250 lb/hr
- Specific heat of fluid - 1 Btu/°F lb
- Total thermal capacitance of all equipment equal to 200 Btu/°F taken as a single capacitance
- Overall heat transfer coefficient of 267 Btu/hr°F between the equipment and fluid
- An on-off electrical load of 8000 Btu/hr
- Two radiator units 60 sq ft each, located 180 deg apart
- Simulated external absorbed radiation for max/min radiator orientation
- Linear thermal control flow proportioning and radiator valve with 2°F hysterisis

The radiator doors varied linearly from full open at 0°F to full closed at -20°F. The flow proportioning valve varies the flow to each radiator unit from 5% to 95% of the total flow. Whenever the outlet temperature of radiator (A) is 10°F or more above that of radiator (B) 95% of the total flow is directed to radiator (B). When the outlet temperature of (A) is 10°F or more below that of (B) 5% of the total flow is directed to (B). Intermediate conditions vary linearly between these limits.

Figures 4.1-15 and 4.1-16 indicate that the electrical equipment mass and fluid mixed temperatures with an electrical load of 8000 Btu/hr vary as follows for the orbital conditions considered:

- Equipment Temperature °F

	Max	Min
o Lunar Orbit		
Case I	100	70
Case II	80	60

	Max	Min
o Earth Orbit		
Case I	80	76
Case II	52	50

• Fluid Mixed Temperature 0°F

	Max	Min
o Lunar Orbit		
Case I	84	28
Case II	60	20
o Earth Orbit		
Case I	62	40
Case II	24	19

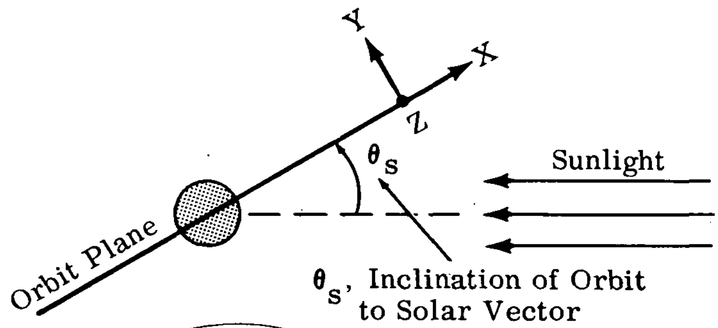
The results indicate small temperature variations both in the equipment being cooled and in the mixed fluid exiting the radiator system. The analysis also indicates that a unit of minimum mass in the present system under the most severe lunar orbit would not vary more than ±28°F while the main equipment temperature varies ±15°F. The stabilizing effect of the thermal capacitance of the equipment validates the use of orbital average absorbed radiation for radiator sizing analysis.

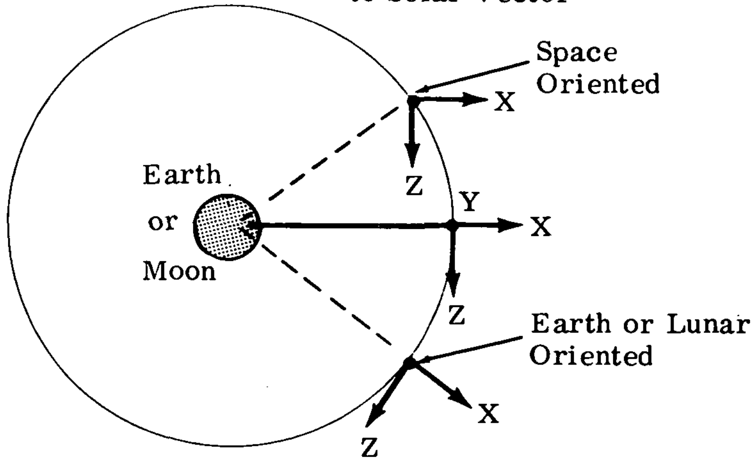
4.1.4 Baseline Thermal Control Configuration

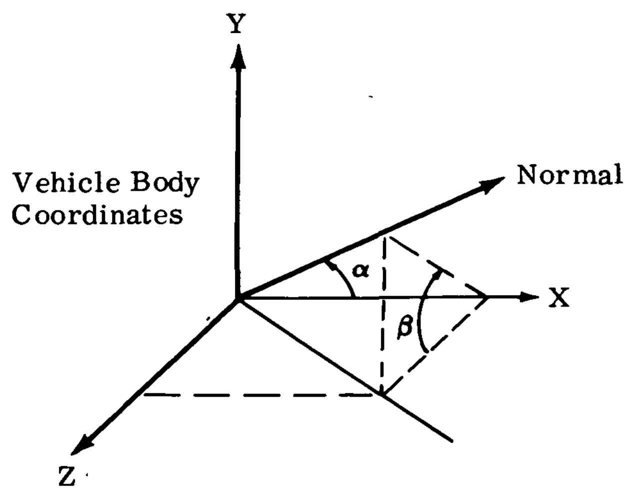
This configuration is the same as the recommended except that P&W fuel cells are used instead of AC. Use of P&W fuel cells will require modification of the existing LEM launch pad air conditioning systems. Additional cooling air, about 20 lb/min is required to provide proper thermal control. Provision of the required in-flight thermal environment represents a weight penalty of about 19 lb to the ECS loop. See Table 4.1-3 for a summary of this configuration.

4.1.5 Alternate Configuration - GE Fuel Cells

Same as the recommended configuration except that GE fuel cells are used instead of AC. The fuel cells will require approximately 75 sq ft of radiator surface and a supplementary water boiler. See Table 4.1-3 for a summary of this configuration.







Altitude,
Orbit
θ_s, deg

Surface Orientation, deg	
α	β
45	0
	45
	90
	135
	180
	225
	270
	315
90	0
	45
	90
	135
	180
	225
	270
	315
135	0
	45
	90
	135
	180
	225
	270
	315
0	-
180	-

Average Incident Radiation to Sa

n mi →	200			200			200
	Earth (Earth-Oriented)			Earth (Earth-Oriented)			Ea
→	Zero			30			60

Solar Radiation	Albedo Radiation	Direct IR Radiation	Solar Radiation	Albedo Radiation	Direct IR Radiation	Solar Radiation
134.118	2.089	2.546	117.519	1.811	2.546	70.53
119.892	2.081	2.546	56.578	1.647	2.546	0.
99.698	2.072	2.546	23.039	1.576	2.546	0.
119.895	2.081	2.546	56.581	1.647	2.546	0.
134.121	2.089	2.546	117.522	1.811	2.546	70.53
119.855	2.081	2.546	158.937	1.966	2.546	177.38
99.636	2.072	2.546	177.703	2.027	2.546	235.23
119.852	2.081	2.546	158.934	1.966	2.546	177.38
93.493	16.659	20.290	84.053	14.438	20.290	58.27
66.129	16.636	20.291	18.142	13.711	20.291	0.
0.053	16.611	20.286	0.	13.401	20.291	0.
66.128	16.636	20.290	18.142	13.711	20.291	0.
93.492	16.659	20.290	84.054	14.438	20.290	58.27
66.091	16.636	20.290	115.895	15.142	20.291	157.48
0.	16.610	20.286	138.243	15.426	20.290	279.28
66.091	16.636	20.291	115.894	15.142	20.291	157.48
39.923	37.643	45.858	37.572	32.627	45.858	32.79
25.684	37.635	45.858	9.865	31.769	45.858	0.
5.475	37.626	45.858	0.	31.411	45.858	0.
25.680	37.635	45.858	9.863	31.769	45.858	0.
39.919	37.643	45.858	37.570	32.627	45.858	32.78
25.667	37.634	45.858	45.751	33.474	45.858	101.89
5.462	37.625	45.858	40.843	33.823	45.858	159.74
25.670	37.634	45.858	45.753	33.474	45.858	101.89
140.949	0.	0.	122.078	0.	0.	70.49
7.731	50.280	61.253	9.011	43.580	61.253	17.11

ellite Surfaces for One Orbit

Table 4.1-1

INCIDENT THERMAL R

th (Earth-Oriented)		200 Earth (Earth-Oriented) 90			80 Lunar (Lunar-Or Zero	
					Incident Radia in Btu/hr-sq f	
Albedo Radiation	Direct IR Radiation	Solar Radiation	Albedo Radiation	Direct IR Radiation	Solar Radiation	Albedo Radiatio
1.054	2.546	0.031	0.190	2.546	136.012	0.244
0.786	2.546	0.	0.006	2.546	120.885	0.243
0.680	2.546	0.	0.	2.546	99.693	0.241
0.786	2.546	0.	0.006	2.546	120.887	0.243
1.054	2.546	0.031	0.190	2.546	136.014	0.244
1.338	2.546	221.952	0.644	2.546	120.846	0.243
1.461	2.546	313.888	0.902	2.546	99.631	0.241
1.338	2.546	221.953	0.644	2.546	120.844	0.243
8.386	20.291	0.023	1.289	20.286	97.845	2.551
7.166	20.291	0.	0.196	20.291	69.207	2.546
6.671	20.290	0.	0.000	20.290	0.055	2.540
7.166	20.291	0.	0.196	20.290	69.206	2.546
8.386	20.290	0.022	1.289	20.286	97.844	2.551
9.646	20.291	313.884	3.060	20.290	69.168	2.546
10.178	20.290	443.900	4.050	20.290	0.	2.540
9.646	20.291	313.885	3.060	20.291	69.168	2.546
18.939	45.858	0.031	2.589	45.859	44.181	6.154
17.470	45.858	0.	1.018	45.858	29.040	6.152
16.866	45.858	0.	0.437	45.858	7.836	6.150
17.470	45.858	0.	1.018	45.858	29.037	6.152
18.939	45.858	0.031	2.589	45.858	44.178	6.154
20.425	45.858	221.952	4.430	45.858	29.023	6.152
21.045	45.858	313.888	5.263	45.858	7.820	6.150
20.425	45.858	221.953	4.430	45.858	29.026	6.152
0.	0.	0.023	0.	0.	140.942	0.
25.294	61.253	0.023	3.392	61.253	11.068	8.357

DIATION

nted)

on

	200 Earth (Space-Oriented) Zero			200 Earth (Space-Oriented) 30		
Direct IR Radiation	Solar Radiation	Albedo Radiation	Direct IR Radiation	Solar Radiation	Albedo Radiation	Direct Radiat
3.324	190.276	7.142	24.718	169.477	6.199	24.71
3.302	190.278	6.108	23.237	100.329	5.014	23.2
3.277	190.228	5.296	22.078	71.634	4.165	22.0
3.302	190.156	6.116	23.237	100.203	5.019	23.2
3.324	190.104	7.153	24.718	169.299	6.207	24.71
3.302	190.103	6.116	23.237	238.447	5.603	23.2
3.276	190.153	5.296	22.078	267.142	5.044	22.0
3.302	190.225	6.108	23.237	238.573	5.597	23.2
34.745	0.122	19.264	24.718	0.125	16.699	24.71
34.667	0.124	17.741	22.078	0.	14.672	22.0
34.567	0.053	16.542	20.200	0.	13.353	20.2
34.667	0.	17.754	22.078	0.	14.680	22.0
34.745	0.	19.281	24.718	0.	16.712	24.71
34.666	0.	17.753	22.078	97.664	16.107	22.0
34.565	0.	16.541	20.200	138.243	15.369	20.2
34.666	0.049	17.741	22.078	97.841	16.096	22.0
83.800	0.	33.466	24.718	0.	28.999	24.71
83.735	0.	32.433	23.237	0.	27.390	23.2
83.686	0.	31.622	22.078	0.	26.419	22.0
83.735	0.	32.443	23.237	0.	27.396	23.2
83.800	0.	33.480	24.718	0.	29.009	24.71
83.733	0.	32.442	23.237	0.	28.830	23.2
83.683	0.	31.621	22.078	0.	28.392	22.0
83.733	0.	32.433	23.237	0.	28.822	23.2
0.	268.972	2.655	24.718	239.553	2.309	24.71
113.715	0.	39.886	24.718	0.	34.555	24.71

	200 Earth (Space-Oriented) 60			200 Earth (Space-Oriented) 90		
IR on	Solar Radiation	Albedo Radiation	Direct IR Radiation	Solar Radiation	Albedo Radiation	Direct IR Radiation
8	114.171	3.635	24.718	0.204	1.433	24.719
8	0.	2.622	23.239	0.	0.489	23.241
8	0.	1.974	22.078	0.	0.210	22.079
7	0.	2.623	23.237	0.	0.488	23.238
8	113.964	3.637	24.718	0.	1.431	24.719
8	253.638	3.636	23.239	221.913	2.503	23.240
8	311.553	3.493	22.078	313.950	3.060	22.079
7	253.785	3.634	23.237	222.115	2.504	23.238
7	0.146	9.704	24.717	0.201	1.435	24.719
9	0.	7.726	22.080	0.	0.212	22.081
6	0.	6.647	20.215	0.	0.000	20.213
7	0.	7.726	22.077	0.	0.211	22.077
7	0.	9.707	24.717	0.	1.433	24.719
9	197.380	10.198	22.080	313.742	3.063	22.081
6	279.284	10.141	20.215	443.900	4.034	20.213
7	197.587	10.194	22.077	314.028	3.065	22.077
8	0.	16.802	24.718	0.080	1.438	24.719
8	0.	15.055	23.239	0.	0.492	23.240
8	0.	14.190	22.078	0.	0.212	22.079
7	0.	15.056	23.237	0.	0.491	23.238
8	0.	16.804	24.718	0.	1.436	24.719
8	25.502	17.538	23.239	221.789	2.510	23.241
8	83.417	17.612	22.078	313.826	3.068	22.079
7	25.649	17.535	23.237	221.991	2.511	23.238
7	161.318	1.384	24.718	0.088	1.431	24.719
7	0.	20.006	24.718	0.	1.438	24.719

Table 4.1-2

RADIATOR CONTROL SYSTEMS

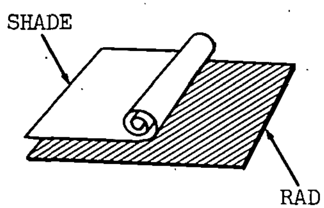
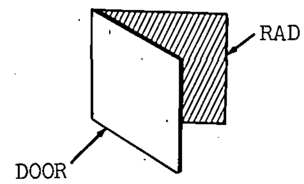
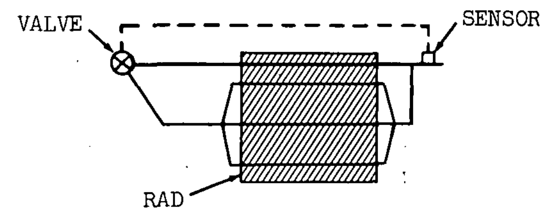
Type	Window Shade	Barn Door	Valve Stagnation	
Illustration				
Fluid	Any	Any	H_2O/ Glycol	Freon 21
TDR Available	30+	30+	8 - 9	15 - 20
Recovery Time, hr	Follows Load	Follows Load	2 - 12	.5
Constraints on Tube Arrangement	None	None	Parallel Tubes As Shown	
Advantages	• High TDR • Use Any Fluid	• High TDR • Use Any Fluid • Mulitple Modules • Use One Actuator • Door May Also be Radiator	• No Moving Parts • Multiple Modules Can Use One Stagnation Valve	• No Moving Parts • Multiple Modules Can Use One Stagnation Valve
Disadvantages	Moving Parts	Moving Parts	Requires Regenerative Heat Exchanger	Requires Separate Radiator Loop
State of the Art (SOTA)	Cold Welding of Shade & Fatigue Are Unknown	New System Actuator is SOTA	New System Valves are SOTA	New System Valves are SOTA
Present Development Effort	Grumman-Funded Feasibility Rig In Design	Design Feasibility Estabilished; Development Program to Start in Phase C.	Feasibility Rig in Design; Development to Start in Phase C.	

Table 4.1-3

THERMAL CONTROL CONFIGURATION

● Common Characteristics

- Cryogenic Tanks	Hydrogen	Oxygen
Selected Configuration	One)NAA-AES	One)NAA-AES
Usable Fluid lbm	144.5	1375
Dry Wt, lbm	290	395
Wet Wt, lbm	441.5	1840
Min. Flow @ 130 lbm/hr	0.047	0.47
Vent Requirements	None	

- An Integrated ECS-Experiment Cooling Loop
- A Separate Fuel Cell Cooling Loop
- Modular Radiator Concept

● Basic Radiator Modular Characteristics

α	ϵ	Area, sq.ft.	Panel Thickness, in.	Fin Effectiveness	Max Sys Wt, lbm/sq ft
.18	.19	15	.02	.96	2.0

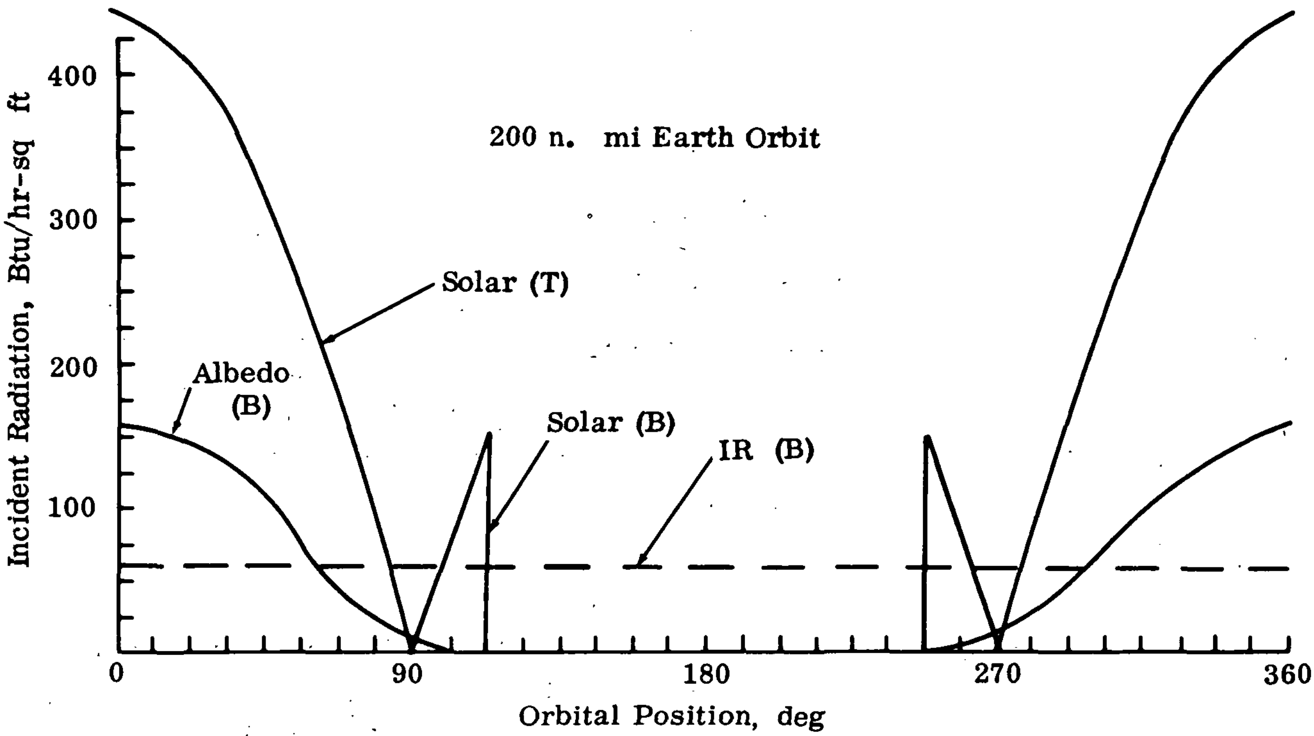
Cooling-Loop Characteristics	ECS			Fuel Cell		
	Recommended	Baseline	Alternate	Recommend	Baseline	Alternate
Fuel Cell				AC	P & N	GE
Area, sq ft	60	60	60	60	60	75
Control System		Valve Stagnation				
Location		Descent Stage				
Transport Fluid		62.5% Glycol, 37.5% Water				
Max. Heat Rejection (Zero Absorbed) Btu/hr	7200	7200	7200	12480	12360	12100
Design Inlet Temp, °F	100	100	100	185	195	120
Design Outlet Temp, °F	40	40	40	136	110	110
Turn Down Ratio Reqd.	4.5	4.5	4.5	10.4	5.6	10.05
Turn Down Ratio Avail	8.3	8.3	8.3	14.8	14.2	11.1
Est. Recovery Time, hr	2-3	2-3	2-3	3-4	1-2	4-6

Free Water Available for Thermal Control, 850 lbm (Nominal)

Table 4.1-4

NAA AES CRYOGENIC STORAGE TANKS

	Vessel Sizes	
	LOX	LH_2
Outer		
Diameter, in,	41.5	41.5
Overall Length, in.	39.74	59.44
Elliptical Contour	1.43 to 1	1.43 to 1
Cylindrical Length, In.	10.1	29.8
Temperature, °F	170	170
Outer Area, sq ft	27	52
Inner		
Volume, cu ft	20.25	34.2
Fluid Weight (usable),lb	1375	144.2
Total		
Weight (Al outer, 718 inner),lb	395	290
Pressure, psia	1000	300
Residual, %	5	5
Min. Flow at 170°F, lb/hr	0.50	0.05



Key B: Bottom Surface
T: Top Surface

Note: Solar Vector Parallel To Orbital Plane

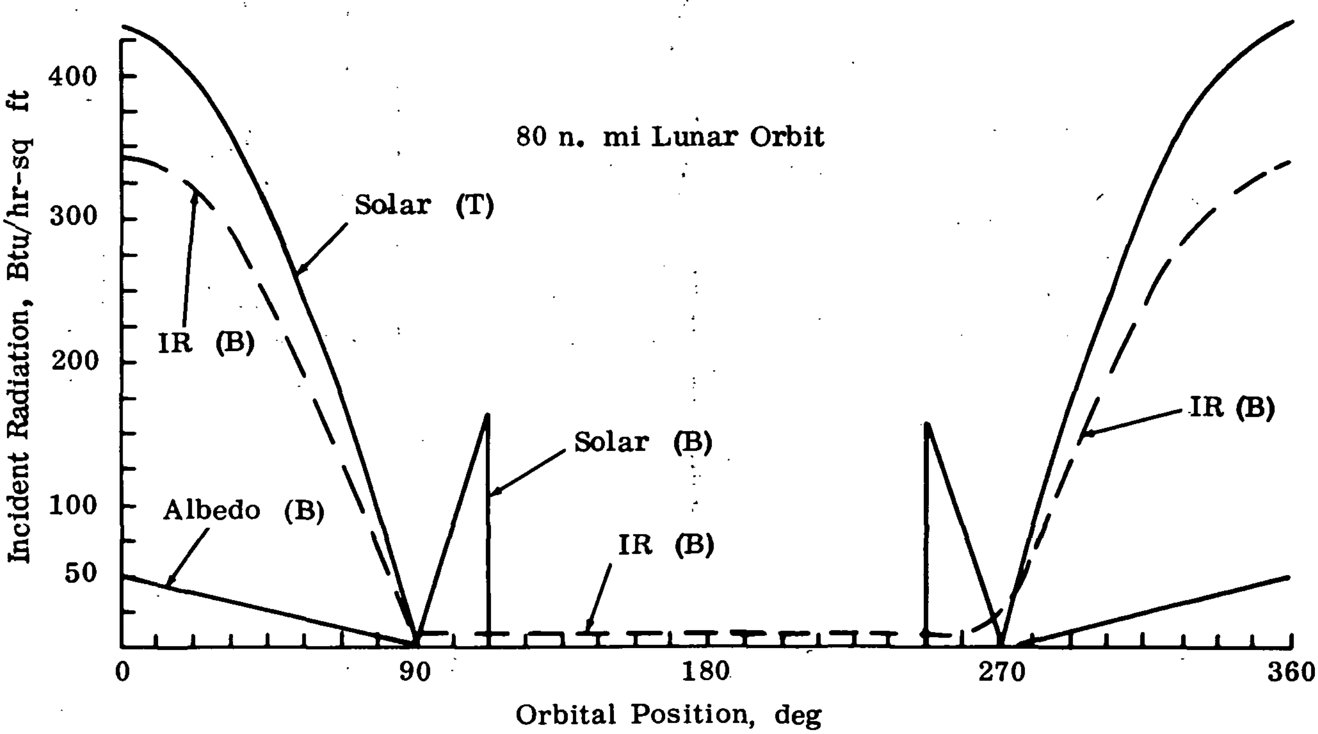


Fig. 4.1-1 Variation in Thermal Environment

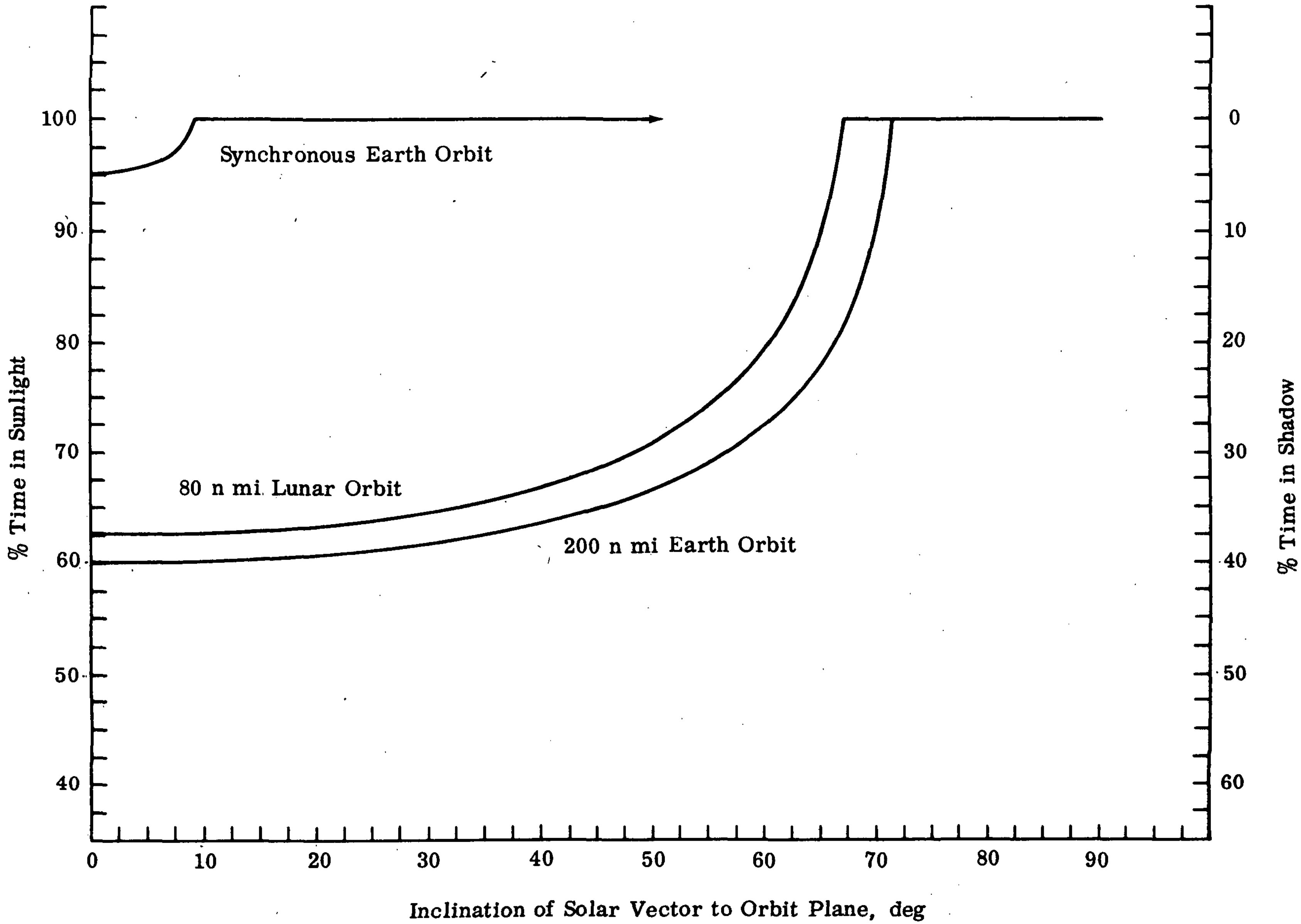
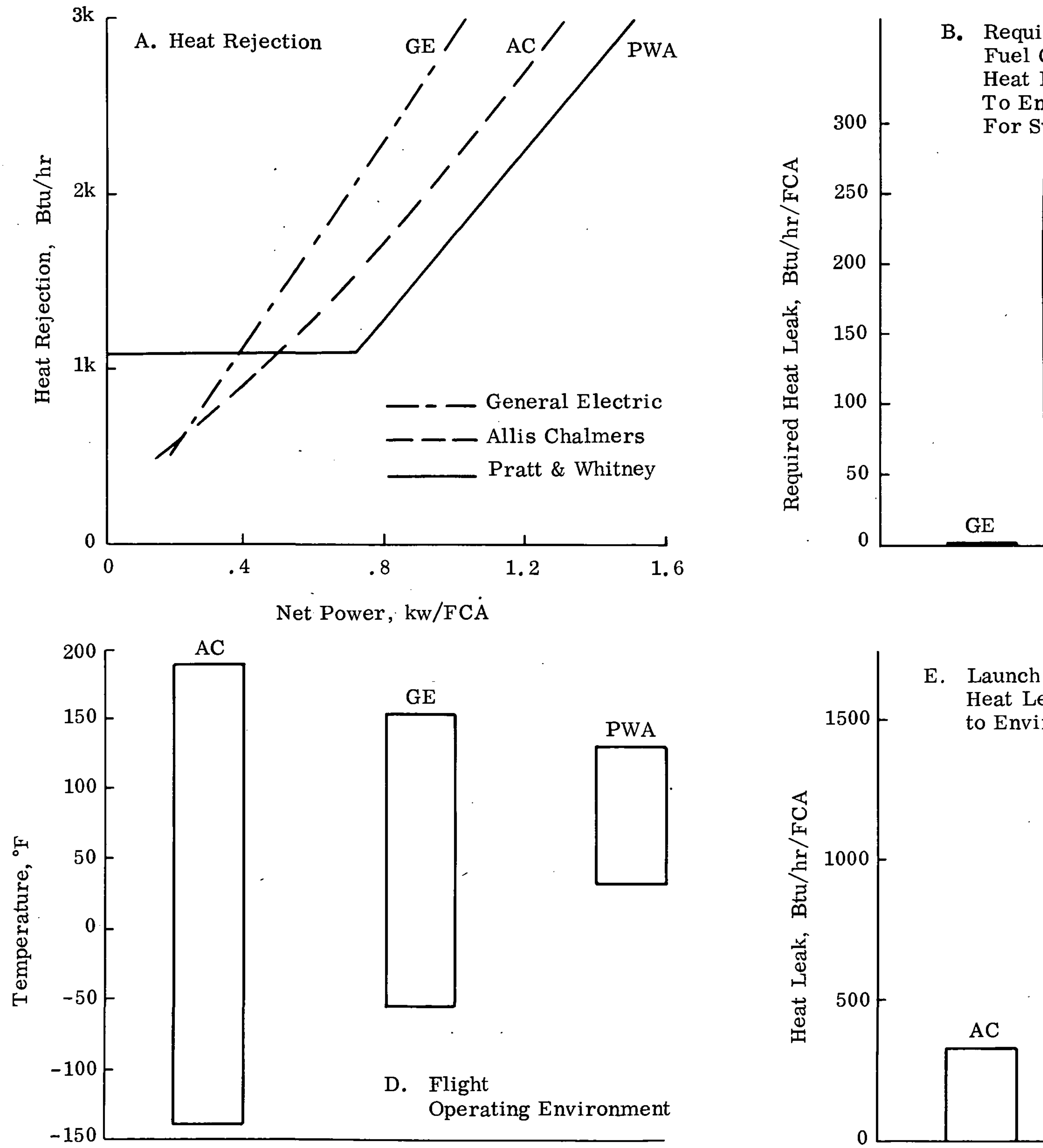
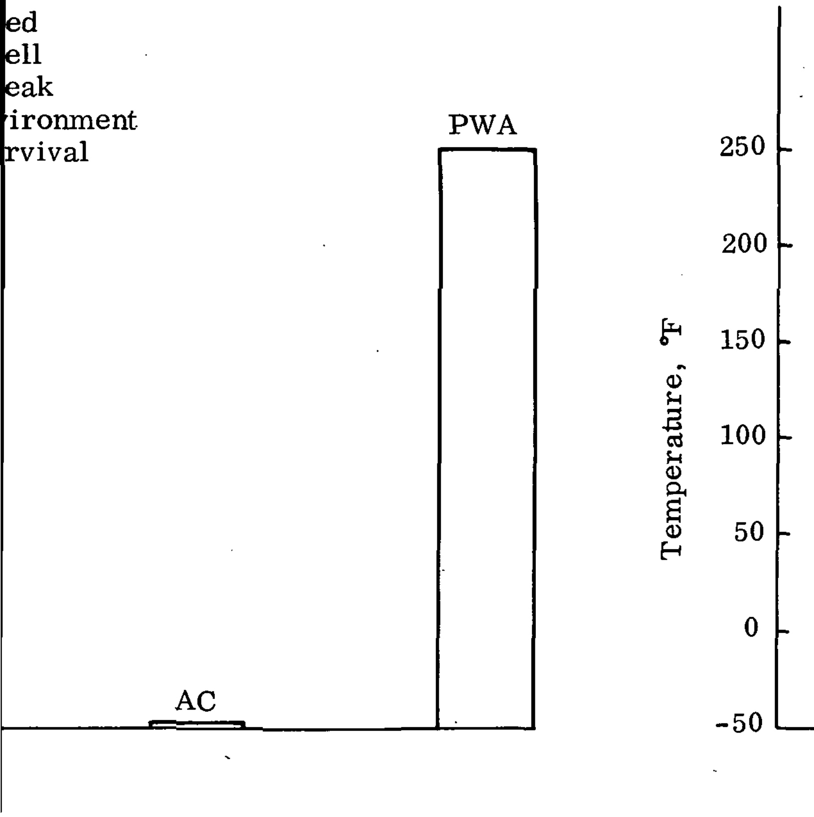


Fig. 4.1-2 % of Time in Sunlight

25


A. Heat Rejection
Heat Rejection, Btu/hr
3k
2k
1k
0
0
.4
.8
1.2
1.6
Net Power, kw/FCA
GE
AC
PWA
General Electric
Allis Chalmers
Pratt & Whitney
B. Requi
Fuel (
Heat l
To En
For S
Required Heat Leak, Btu/hr/FCA
300
250
200
150
100
50
0
GE
Temperature, °F
200
150
100
50
0
-50
-100
-150
AC
GE
PWA
D. Flight
Operating Environment
E. Launch
Heat Le
to Envi
Heat Leak, Btu/hr/FCA
1500
1000
500
0
AC


ed
ell
eak
vironment
rvival
PWA
AC
Temperature, °F
250
200
150
100
50
0
-50

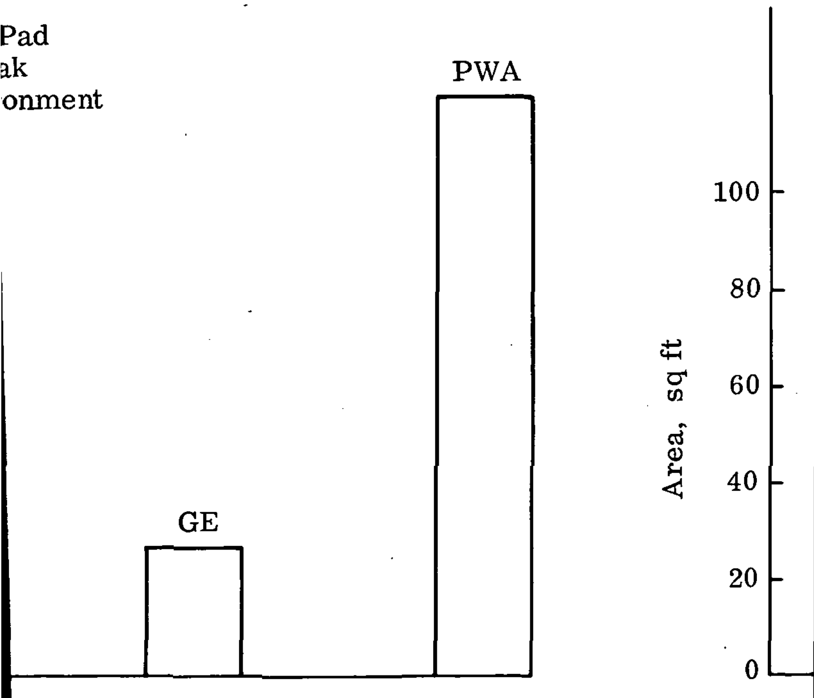
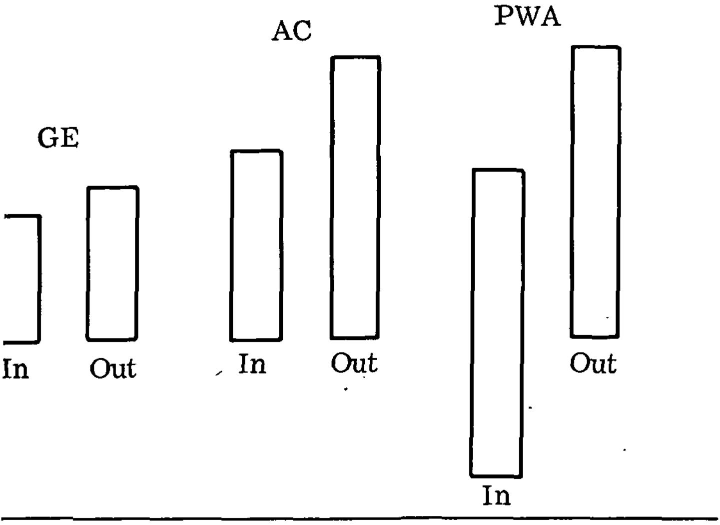
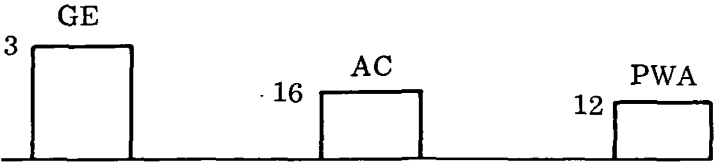

Pad
ak
onment
PWA
GE
Area, sq ft
100
80
60
40
20
0

Fig.

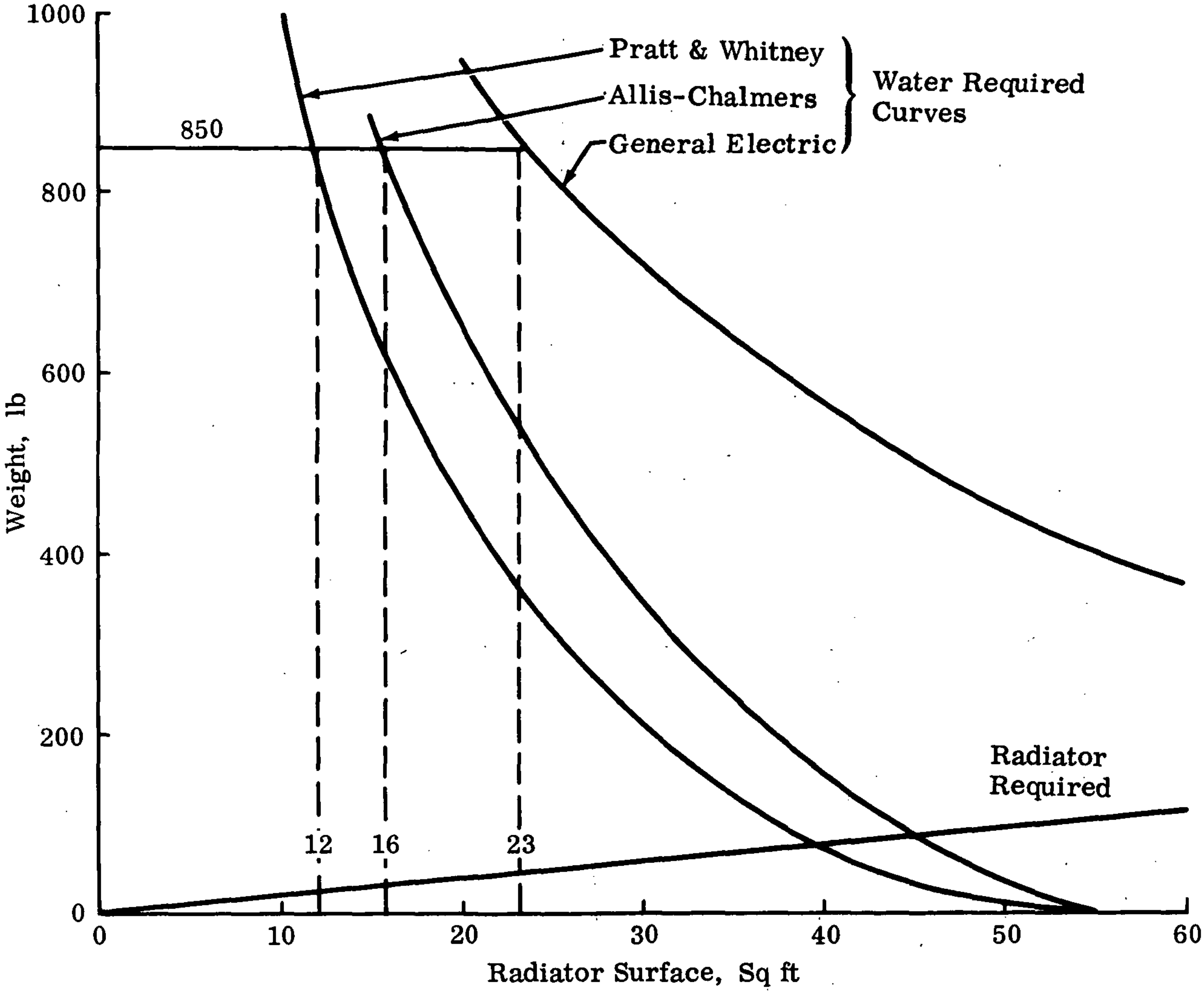
C. Coolant Temperature Ranges



F. Required Radiator Area with 850 lb H_2O Boil Off



1-3 Fuel Cells - General Characteristics



	Allis-Chalmers	Pratt & Whitney	General Electric
Inlet Temp, °F	185	195	120
Outlet Temp, °F	136	110	110
Peak Power, Kw	3.5	3.5	3.3
Peak Heat, Btu/hr	8700	7600	9600
Radiator Capacity,** Btu/sq ft	150	133	97
Water Boil-off, lb	850	850	850
Radiator Surface,* sq ft	16	12	23

*Radiator sized based on 850 lb H_2O boil-off.

**Based on the radiator viewing a 450°R sink

Fig. 4.1-4 Phase II Apollo Applications Fuel Cell Radiator and Water Requirements

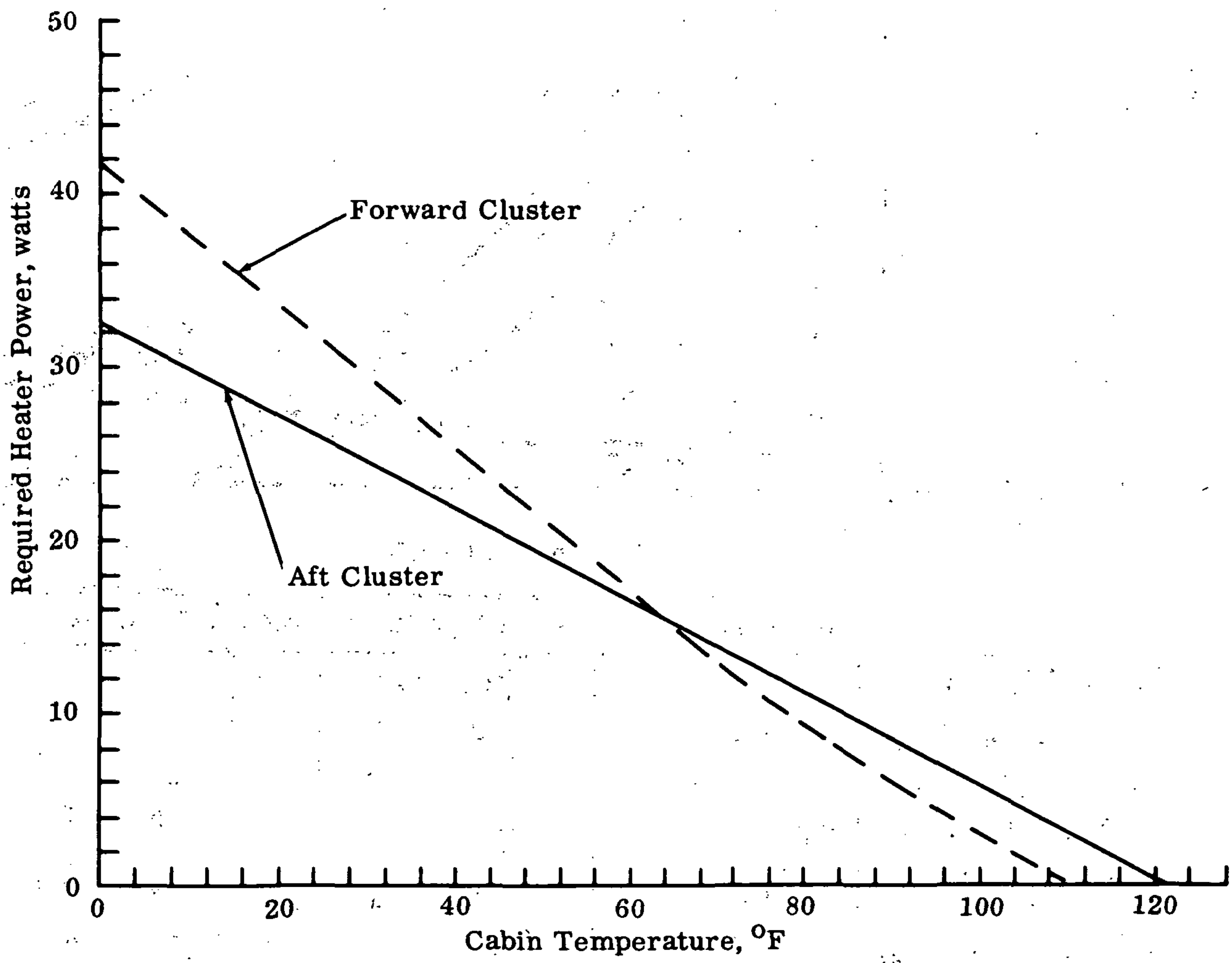


Fig. 4.1-5 RCS Heat Requirements

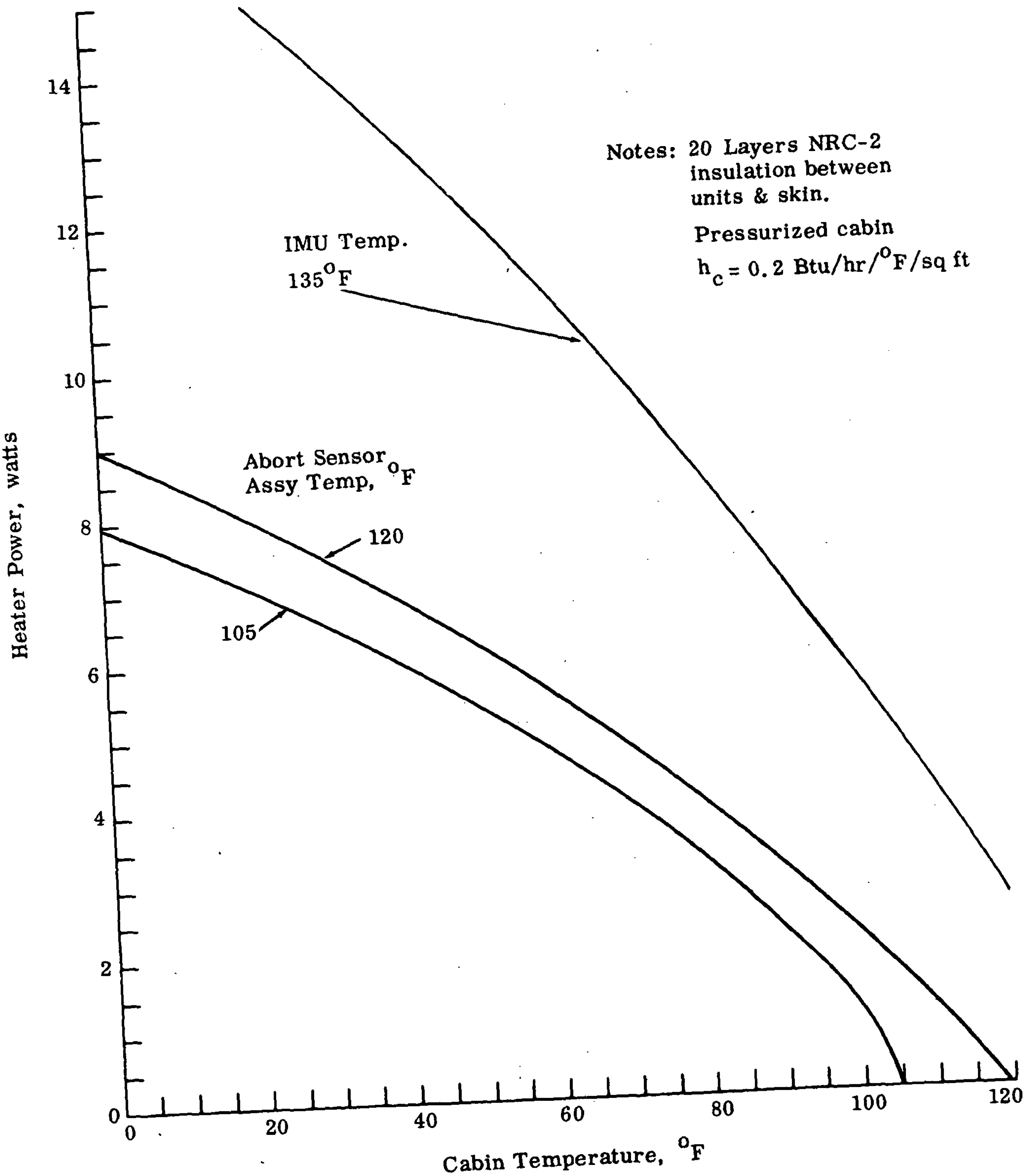
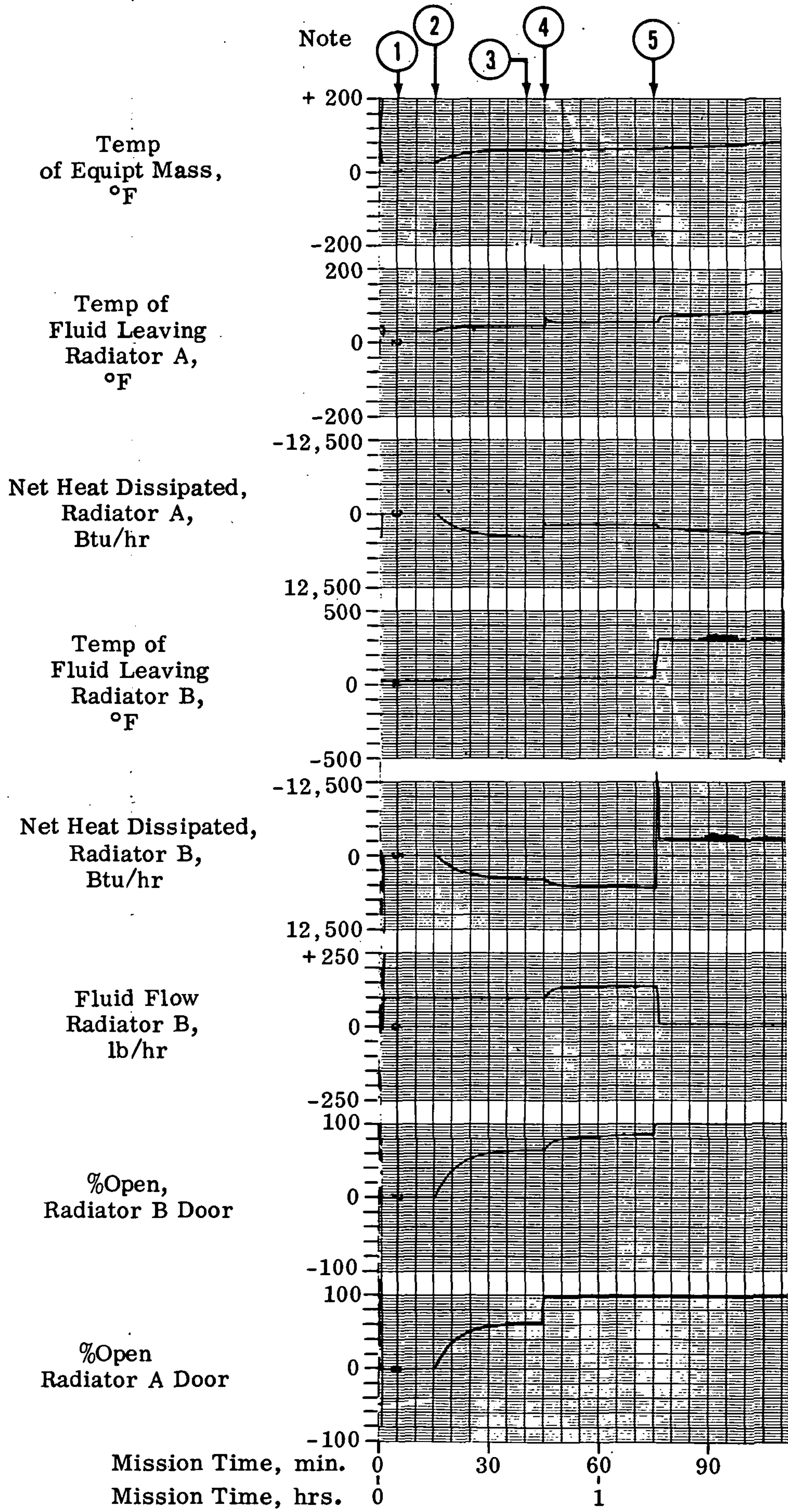
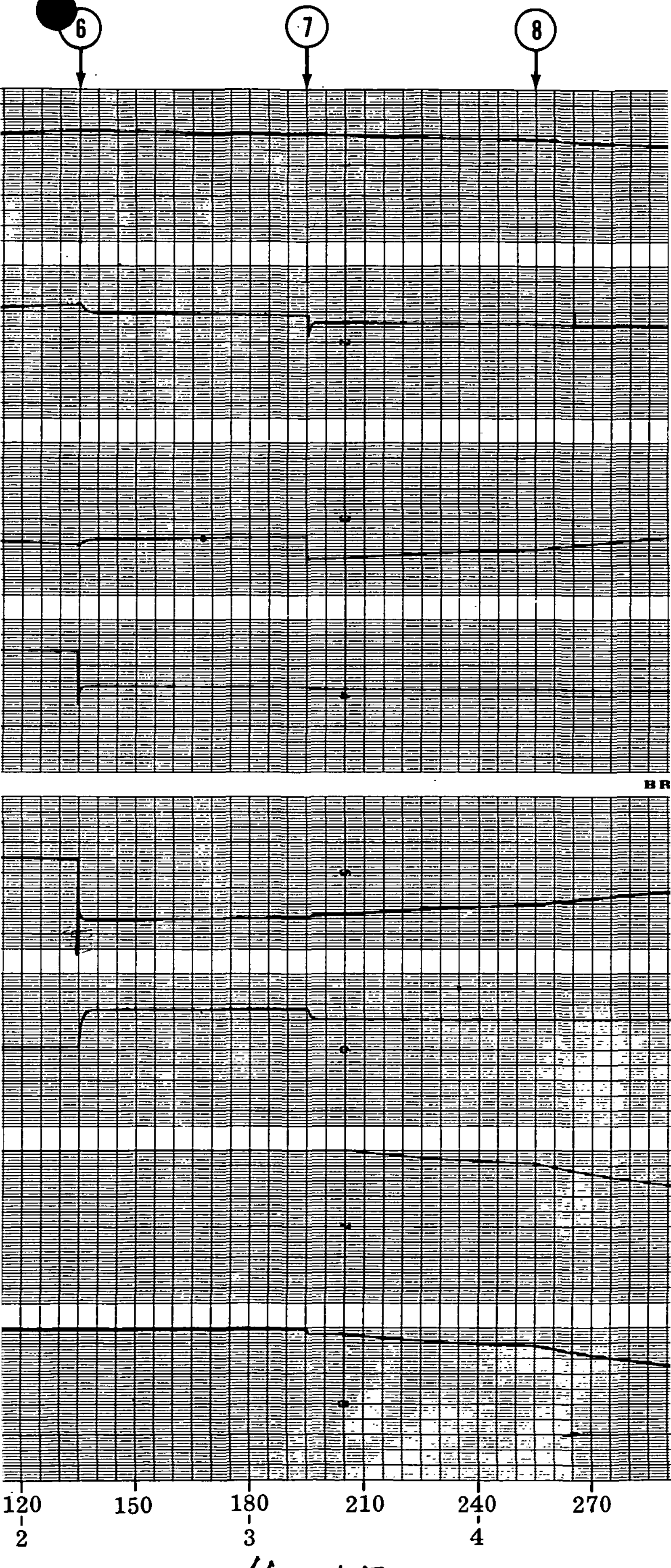


Fig. 4.1-6 IMU-ASA Heater Power

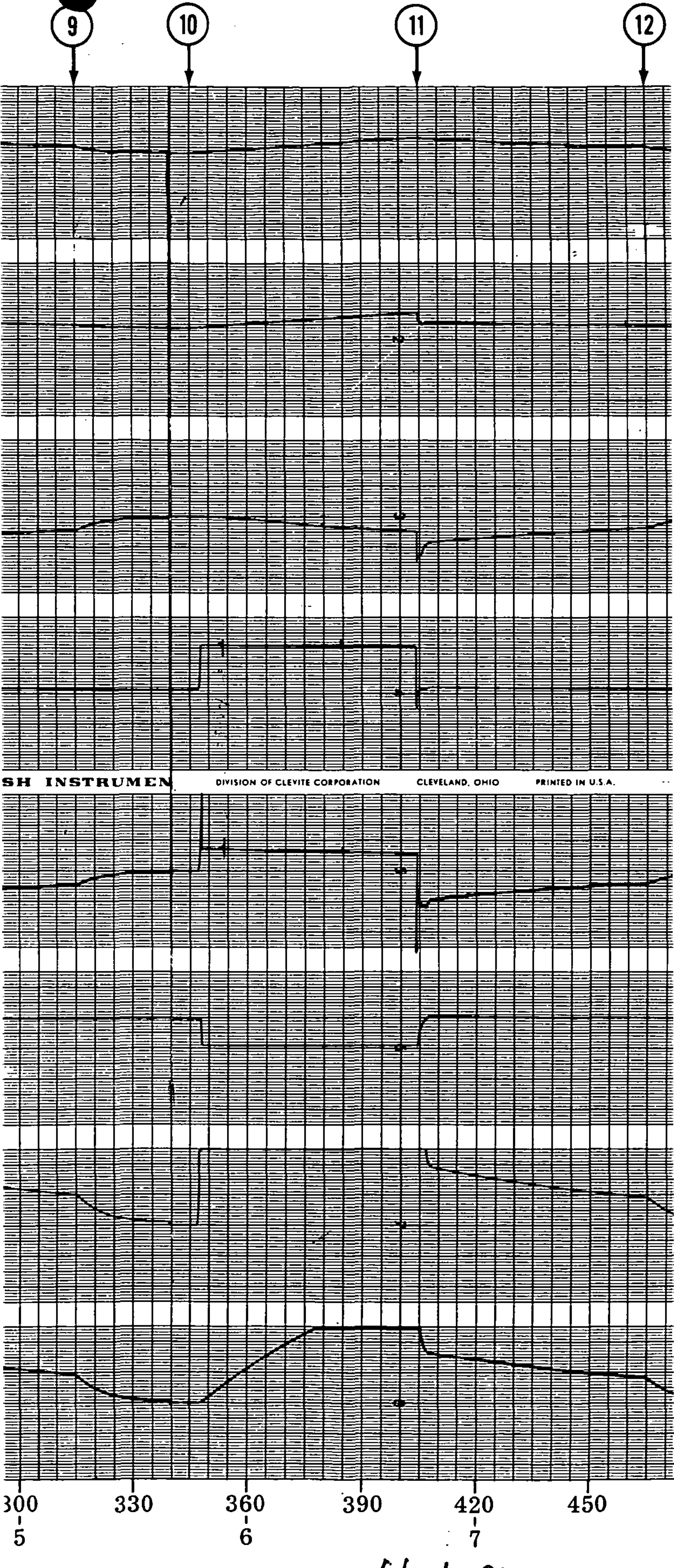

Note
1
2
3
4
5
Temp of Equipt Mass, °F
+ 200
0
-200
Temp of Fluid Leaving Radiator A, °F
200
0
-200
Net Heat Dissipated, Radiator A, Btu/hr
-12,500
0
12,500
Temp of Fluid Leaving Radiator B, °F
500
0
-500
Net Heat Dissipated, Radiator B, Btu/hr
-12,500
0
12,500
Fluid Flow Radiator B, lb/hr
+ 250
0
-250
%Open, Radiator B Door
100
0
-100
%Open Radiator A Door
100
0
-100
Mission Time, min.
0
30
60
90
Mission Time, hrs.
0
1

4.17 (1)



4,1-7

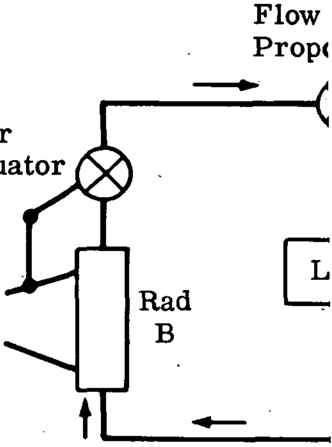
s - Ba[illegible] Door Space Radiator with Thermostatic Door &



4,1-7

3

DEFINITION OF SYSTEM



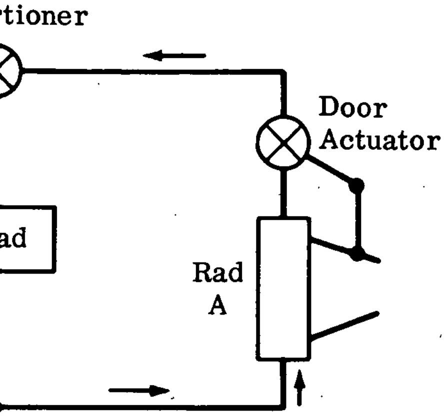
- Hysteresis: Door Actuators & Flow Prop
- Time Constant - Door Actuators = 1 min
- Time Constant - Flow Proportioner = 5 n
- Time Constant - Equipment Mass (Load)
- Door Closed Fully at 30°F, Open Fully a
- Proportioner: 50%/50% Flow Split At 0°
- Flow Proportioner Full Closed Leakage

NOTES

1. No Load, Doors Closed, Temp. Level =
2. 8000 Btu/hr Equipment Load Applied at 1
   This is done to reach steady state quickl
   10 times as long.
3. Incorporate Full Mass.
4. Apply Instantaneous Full Normal Sun En
5. Apply Instantaneous Full Moon Environm
6. Instantaneously Remove Full Moon Envir
7. Instantaneously Remove Full Sun Enviro
8. Instantaneously Remove 8000 Btu/hr Equ
9. Reduce Mass Time Constant to 1/10 to A
10. Apply Instantaneously 8000 Btu/hr Equip
    A, Full Moon Environment Load on B, S
    Constant.
11. Remove Equipment Load, & All Environ
12. Reduce Mass Time Constant To 1/10 To

180
8

EMPLOYED IN ANALYSIS



rtioner ± 2°F

n
45 min
50°F
ΔT, 95%/5% At 10°F ΔT
ate = 5%

2°F
/10 Real Time Constant. (1/10 Mass.)
- otherwise problem would have taken

ronment Load On Radiator A (80 Btu/hr-sq ft).
nt Load on Radiator B (330 Btu/hr-sq ft).
nment, Load from Radiator B.
nent Load from Radiator A.
oment Load.
hieve Steady State Quickly.
ent Load, Full Sun Environment Load on
nultaneously at 45-min Equipment Time

ent Loads Instantaneously & Simultaneously.
chieve Steady State Quickly.

Fig. 4.1-7 Control System Synthesis

(5)

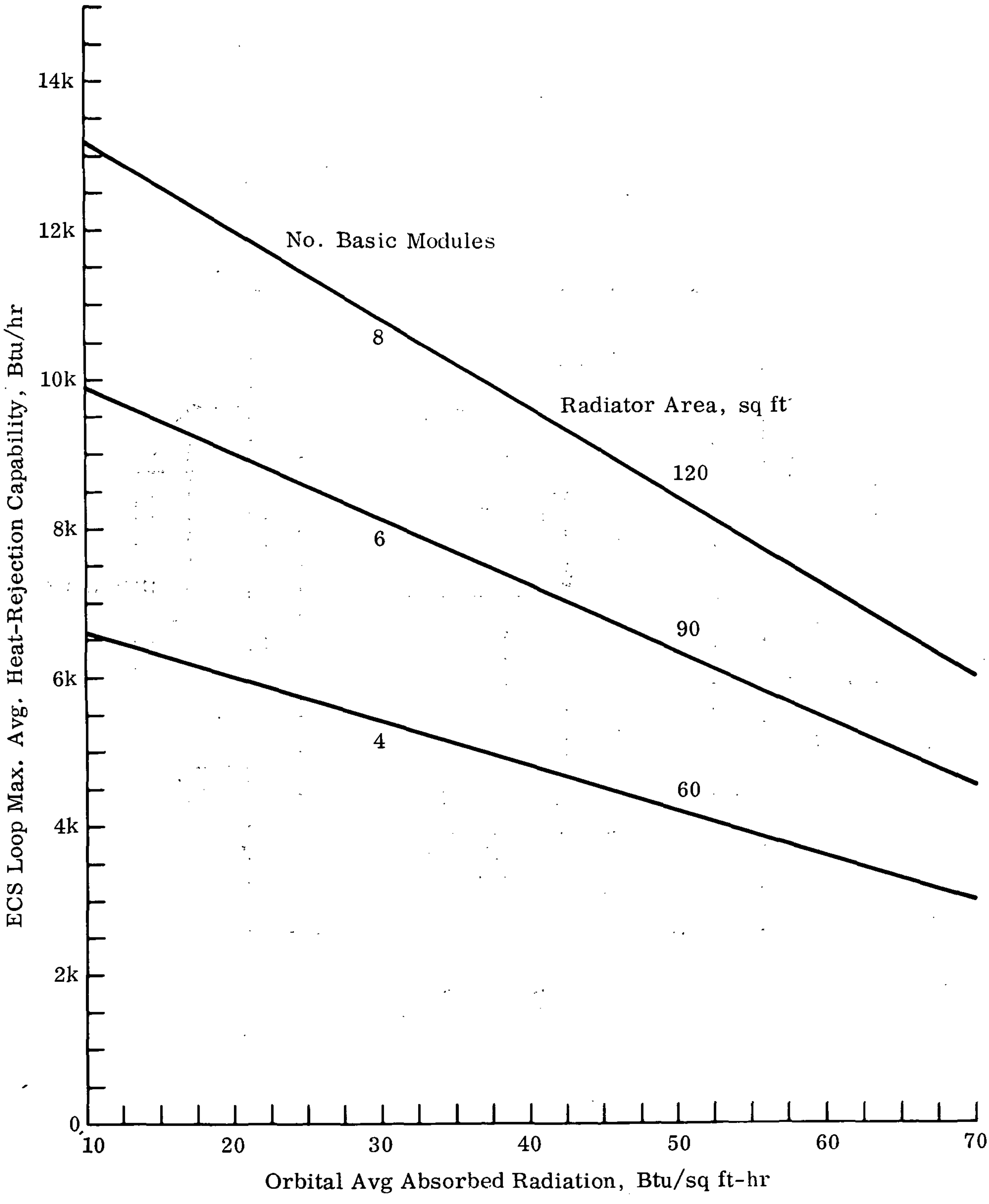


Fig. 4.1-8 ECS Loop Radiator Capability

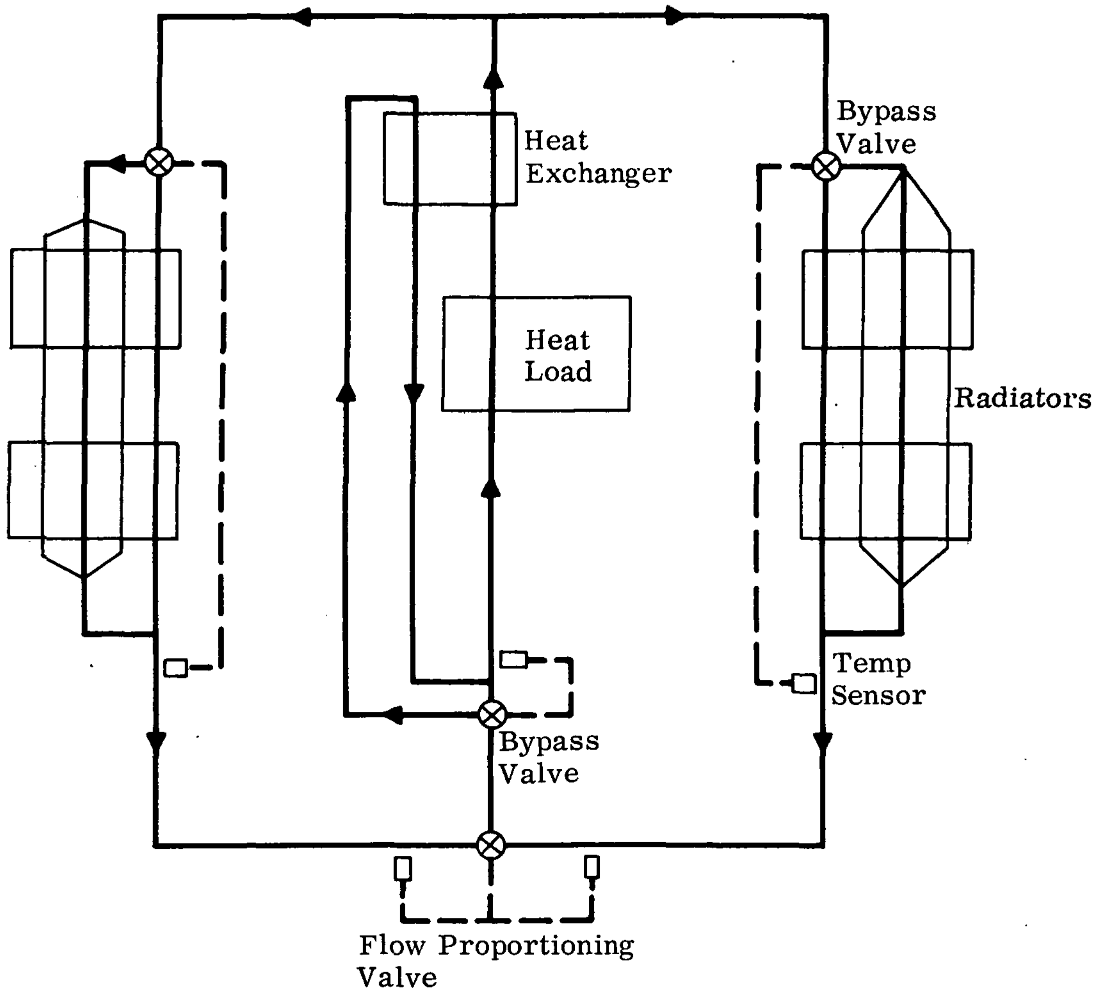


Fig. 4.1-9 Recommended Thermal Control System Schematic

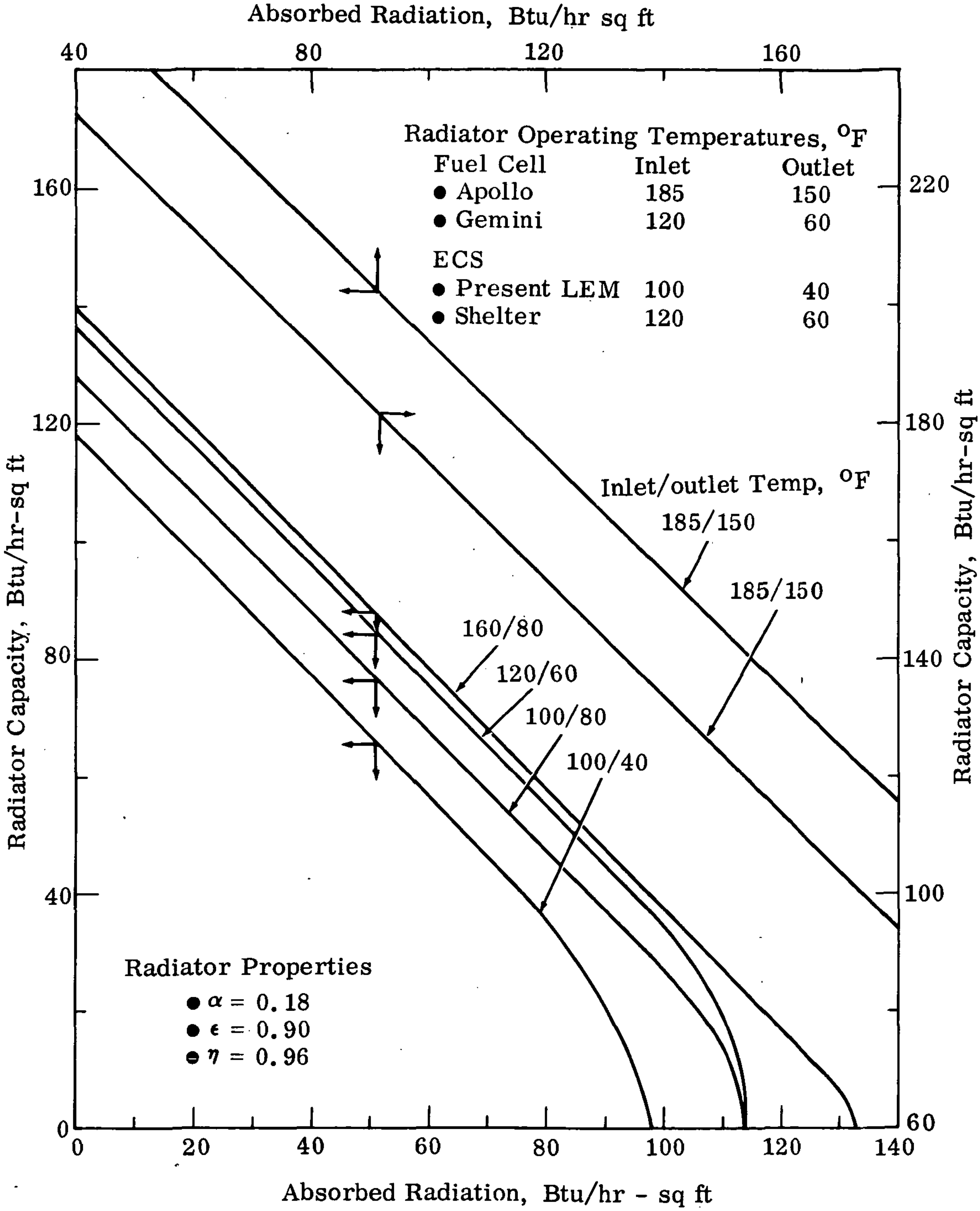


Fig. 4.1-10 Radiator Sizing Curve

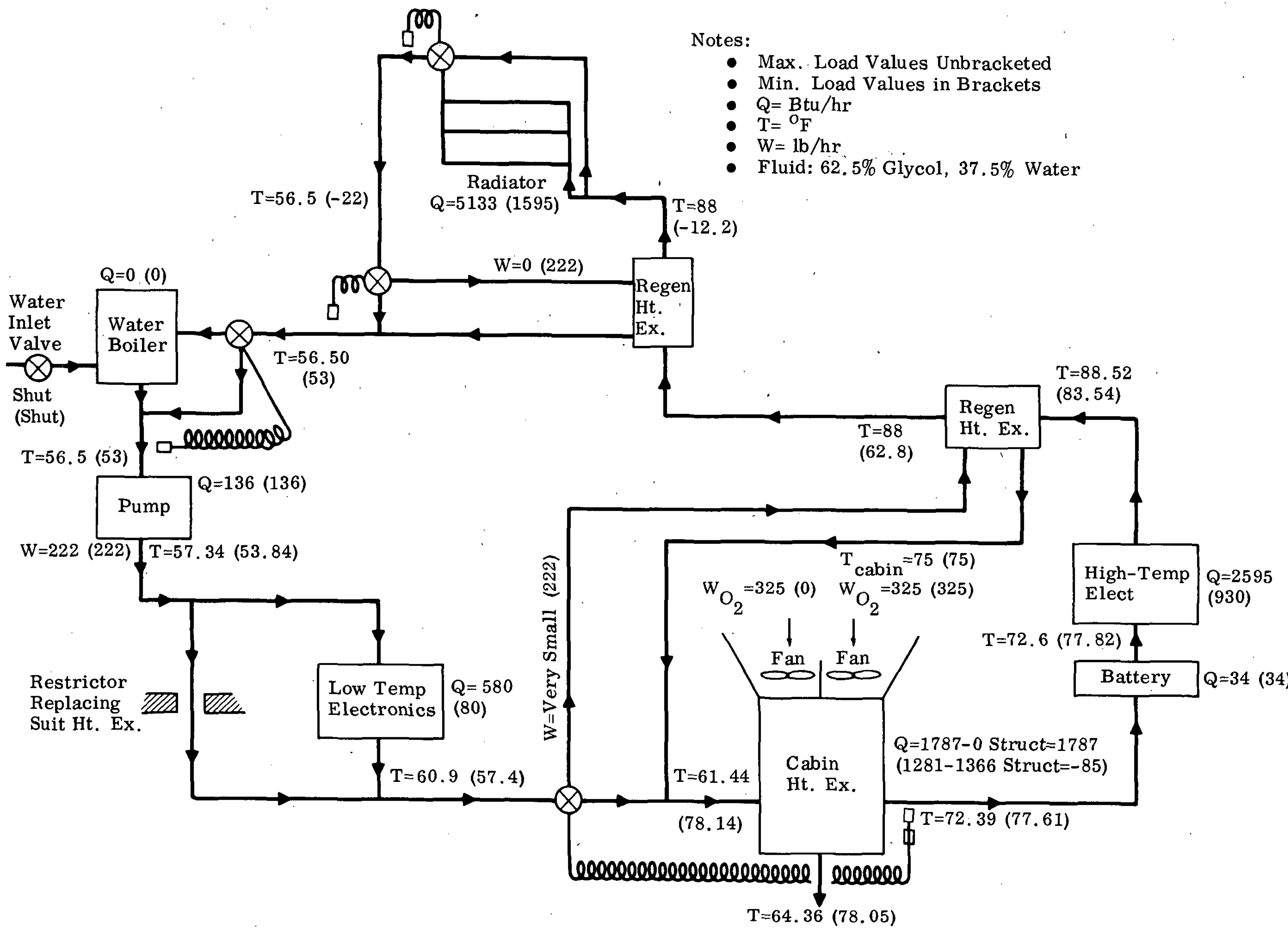


Fig. 4.1-11 Recommended ECS Loop

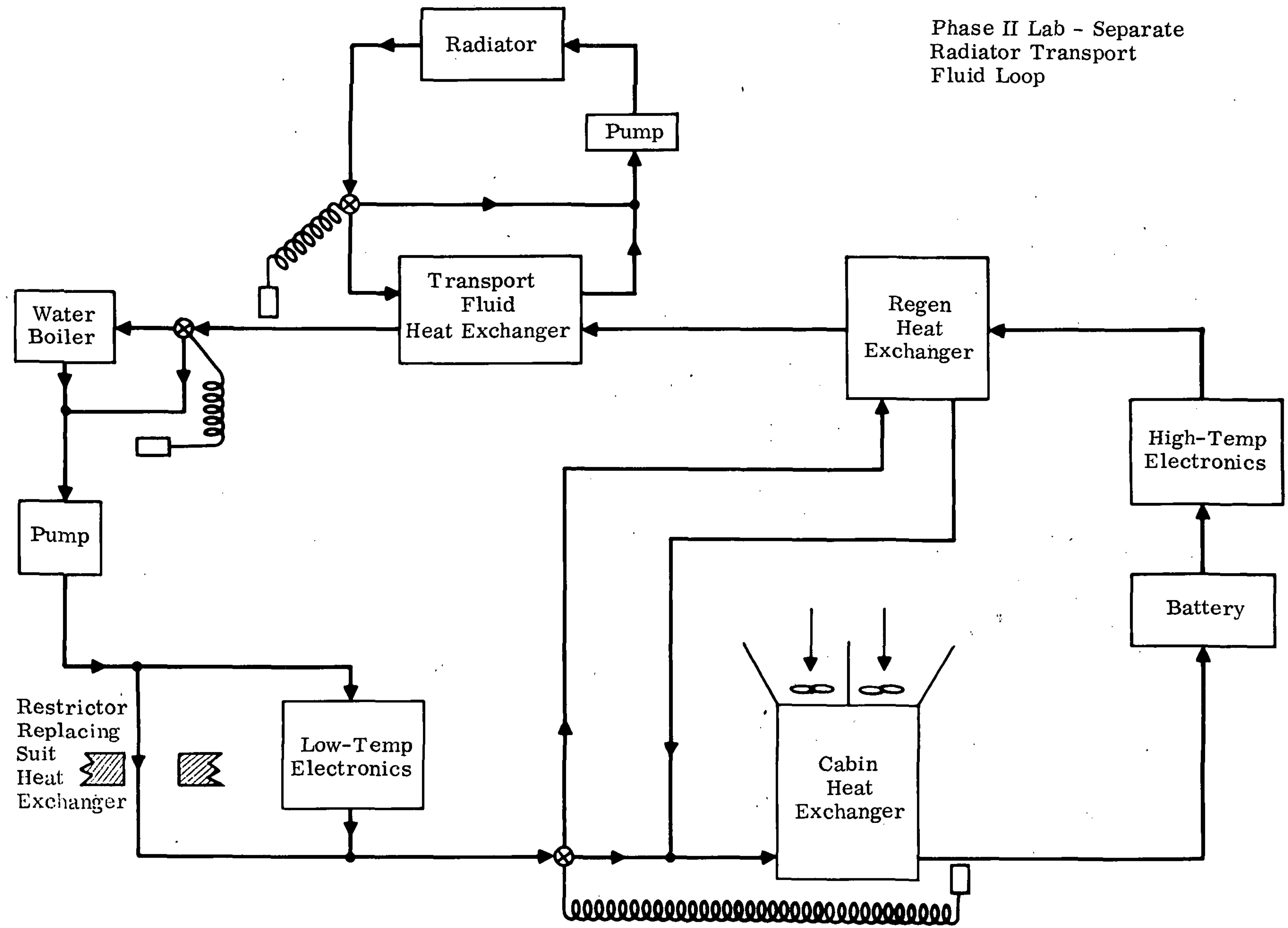


Fig. 4.1-12 Alternate ECS Loop

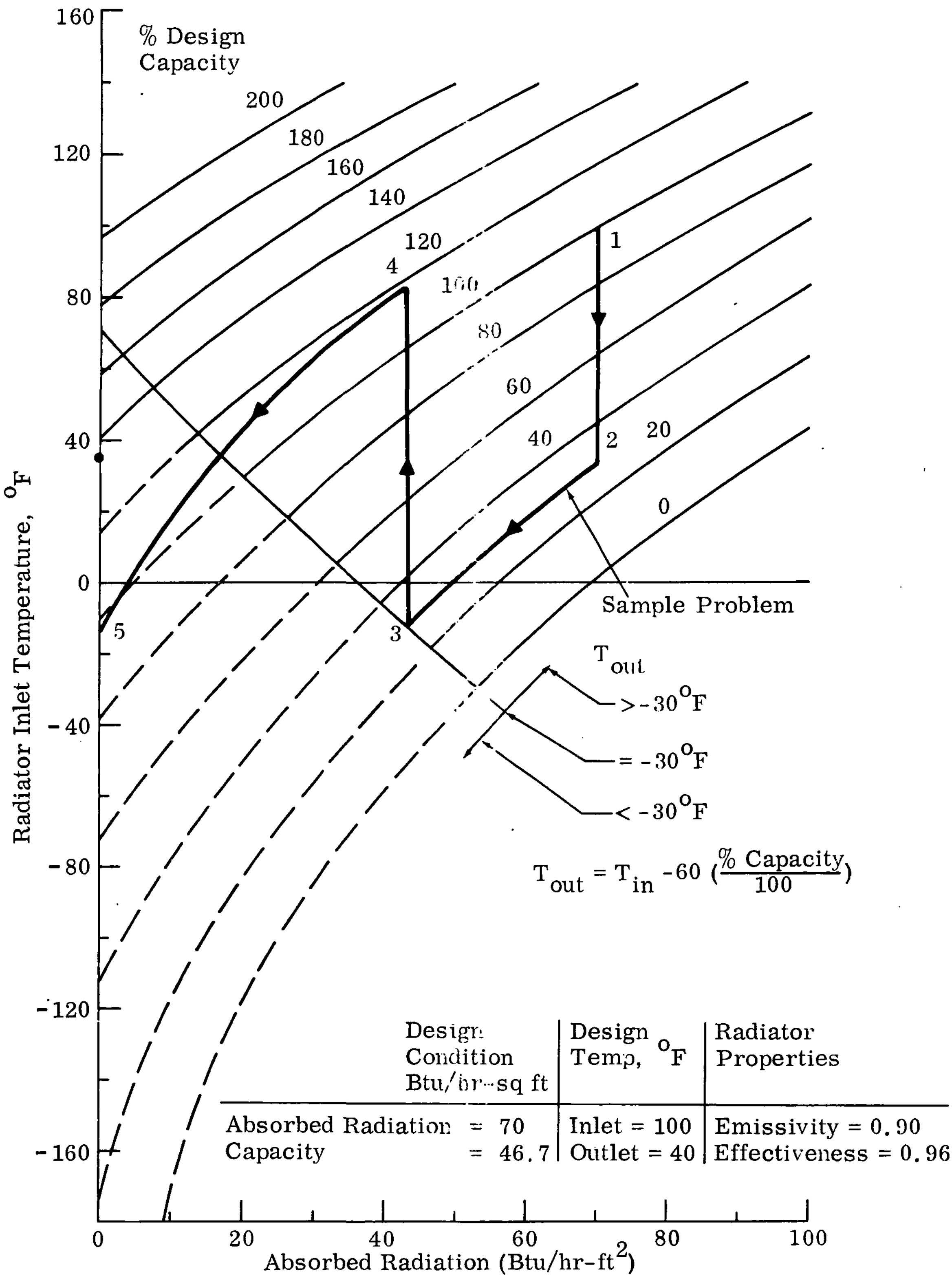
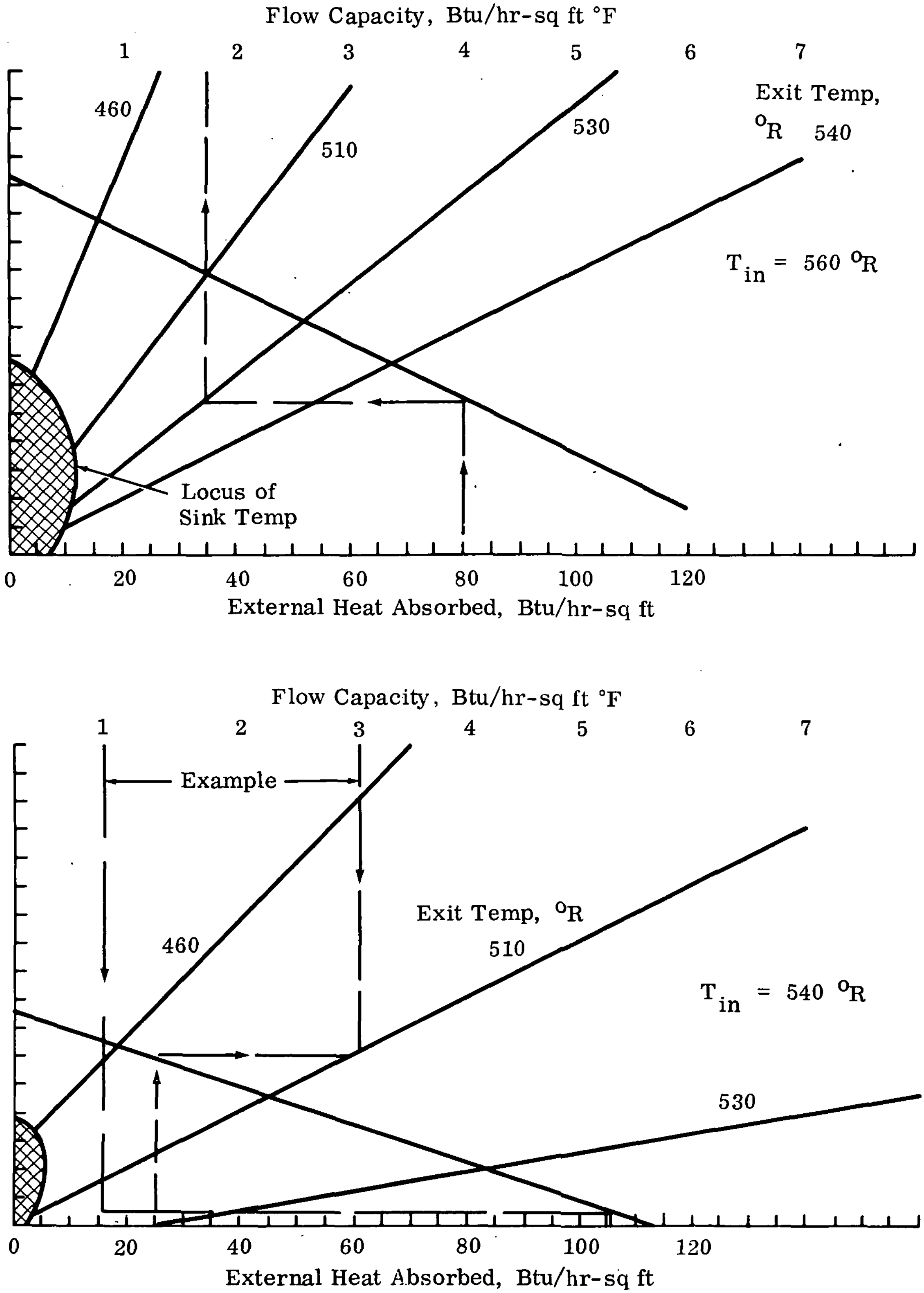
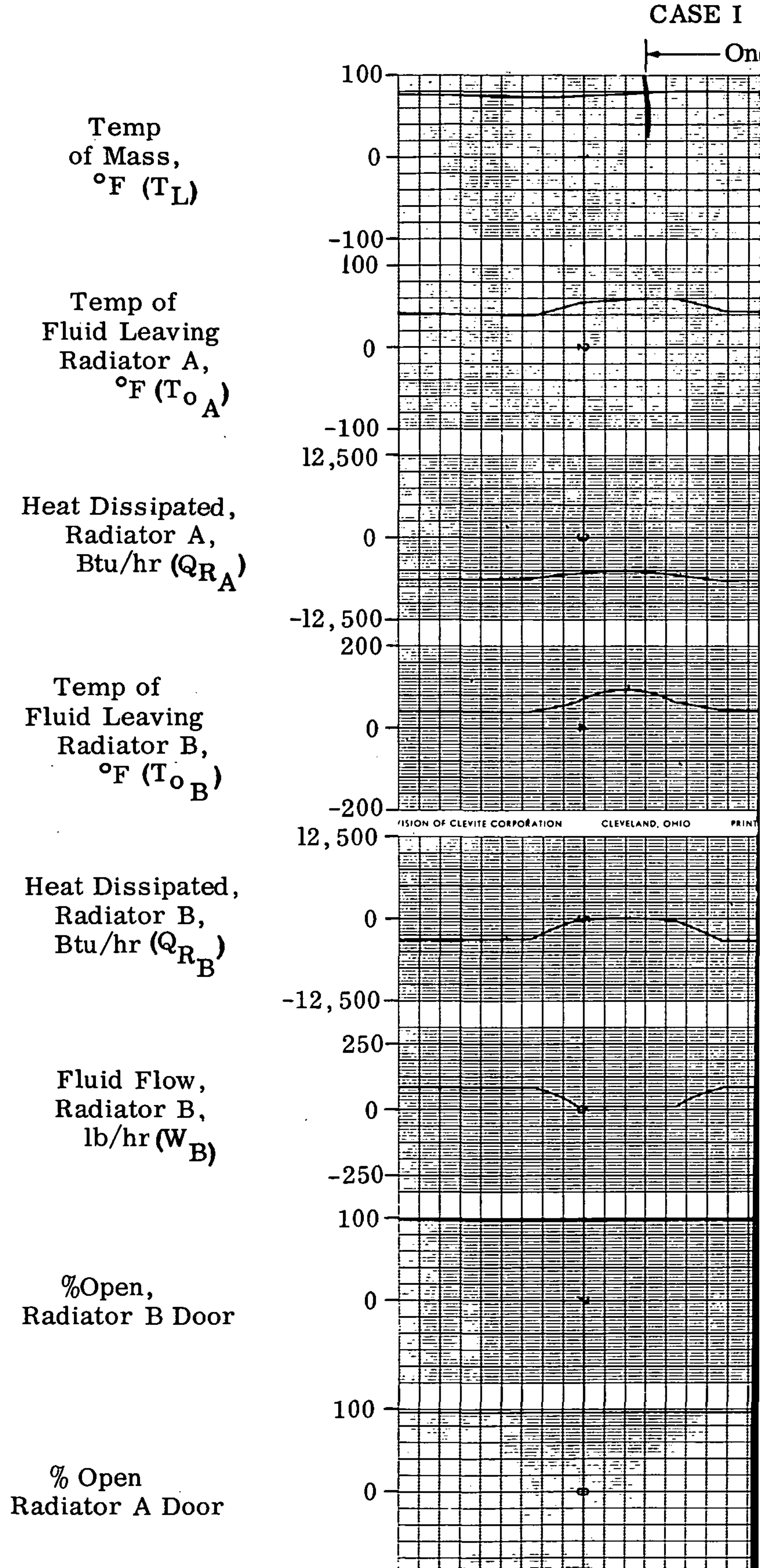


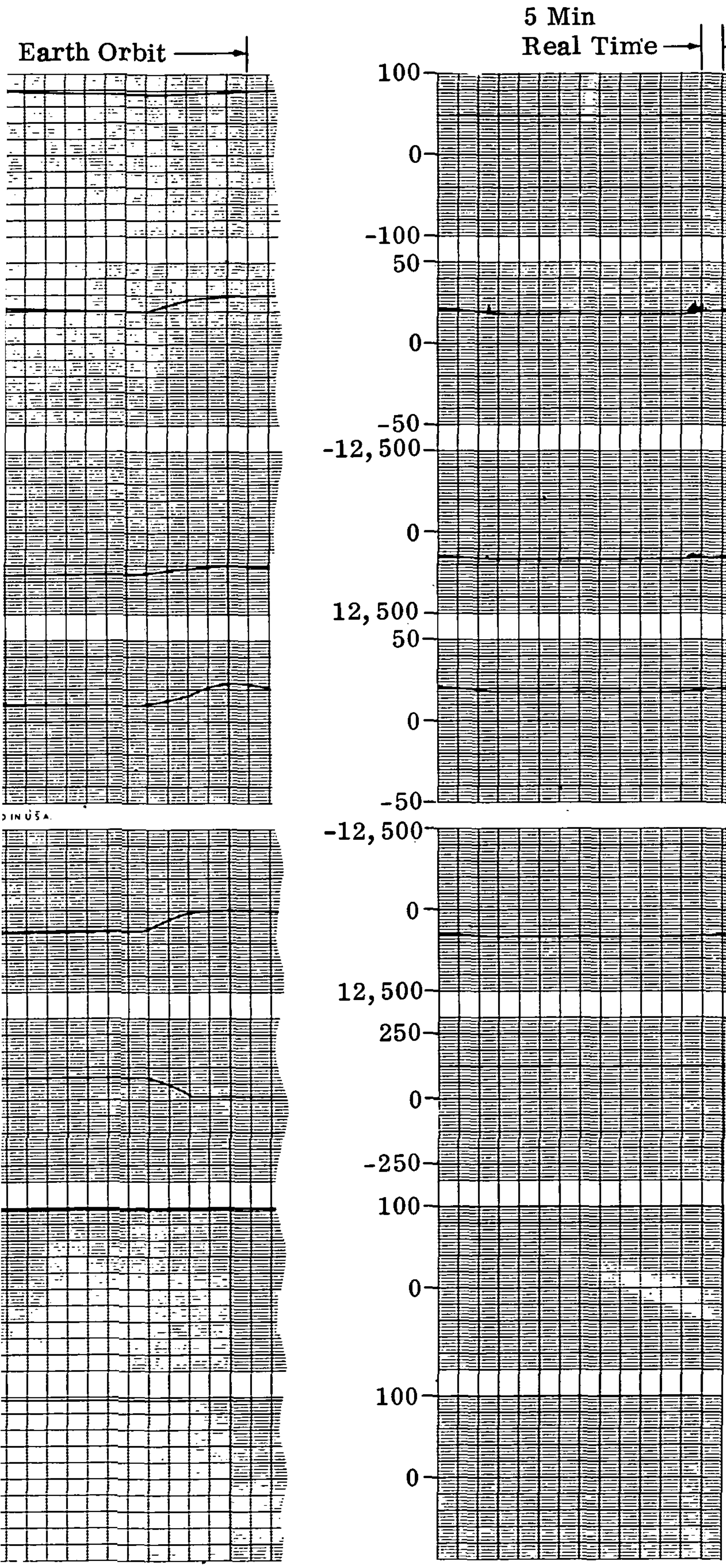
Fig. 4.1-13 Radiator in By-Pass Operation



Radiator Flow Capacity

Fig. 4.1-14 Radiators in Parallel


CASE I
On
100
0
-100
Temp of Mass, °F (T_L)
100
0
-100
Temp of Fluid Leaving Radiator A, °F (T_{o_A})
12,500
0
-12,500
Heat Dissipated, Radiator A, Btu/hr (Q_{R_A})
200
0
-200
Temp of Fluid Leaving Radiator B, °F (T_{o_B})
ISION OF CLEVITE CORPORATION
CLEVELAND, OHIO
12,500
0
-12,500
Heat Dissipated, Radiator B, Btu/hr (Q_{R_B})
250
0
-250
Fluid Flow, Radiator B, lb/hr (W_B)
100
0
%Open, Radiator B Door
100
0
% Open Radiator A Door


Earth Orbit
5 Min
Real Time
100
0
-100
50
0
-50
-12,500
0
12,500
50
0
-50
-12,500
0
12,500
250
0
-250
100
0
100
0
IN U.S.A.

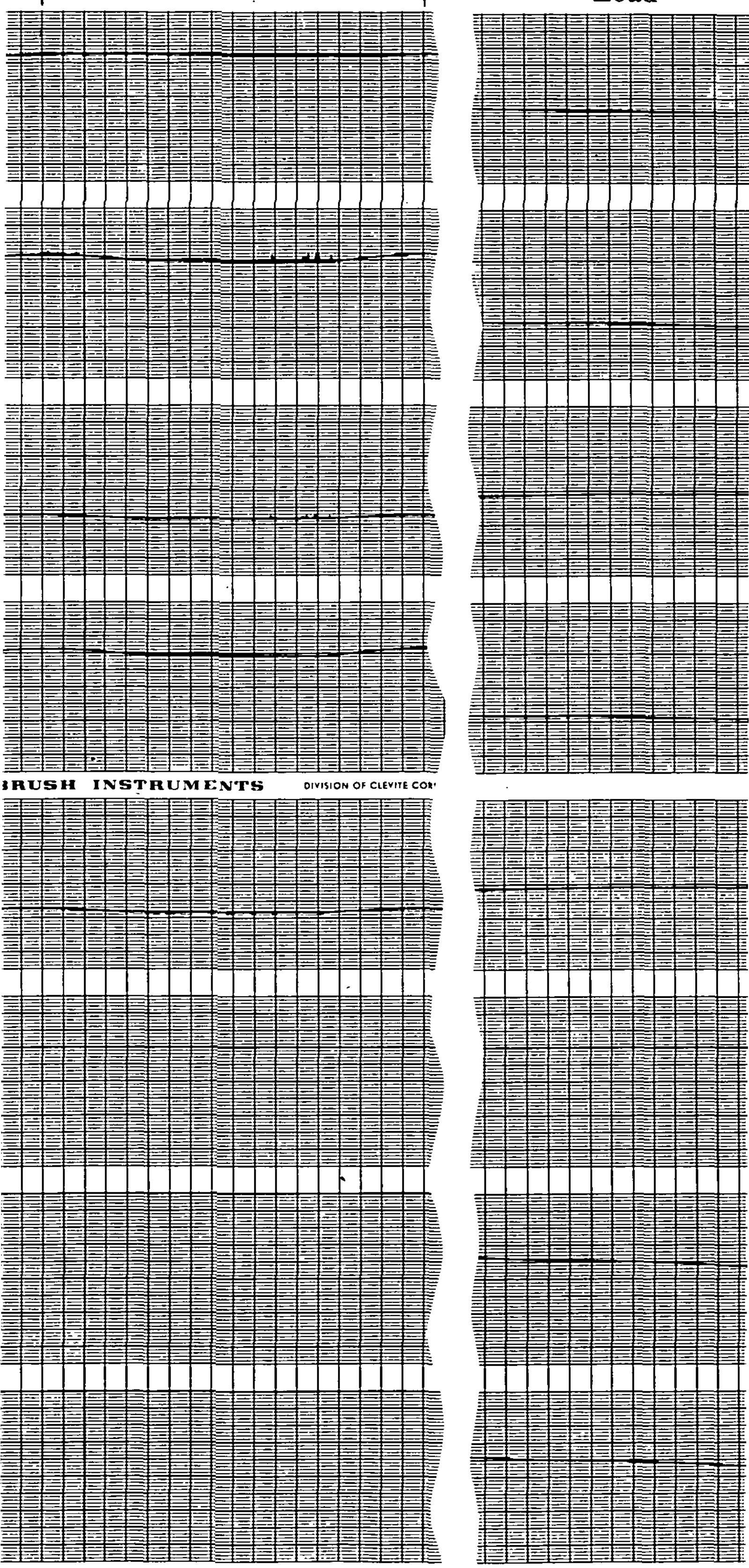
4.1-15

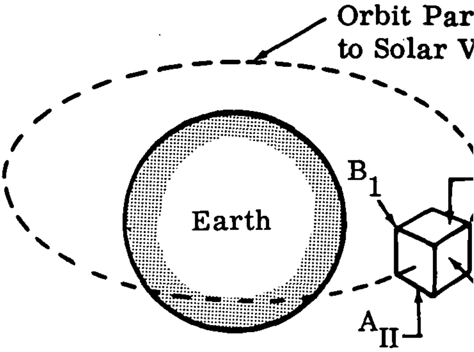
(2)

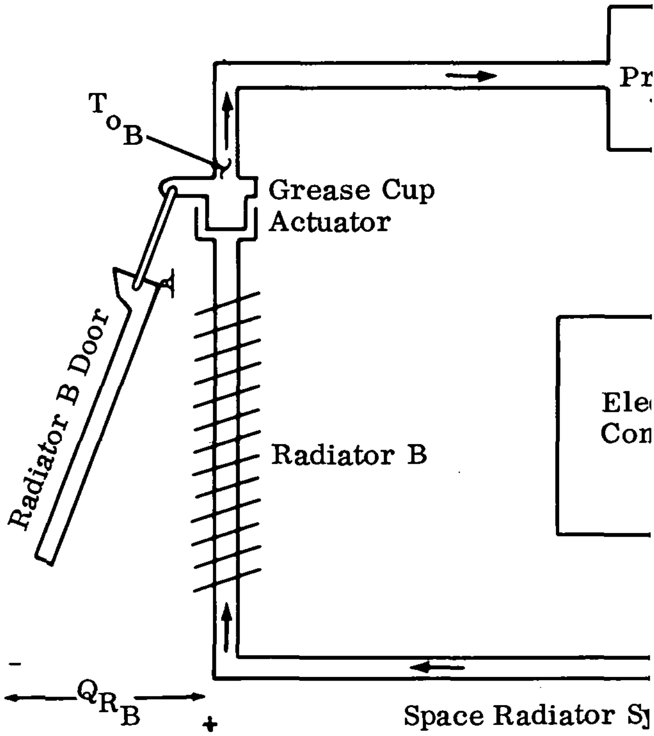
CASE II

One Earth Orbit

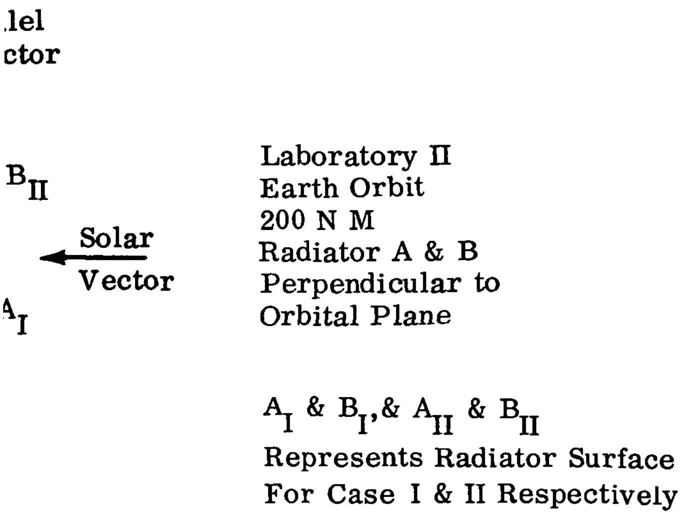
6th Rev After Zero Electrical Load

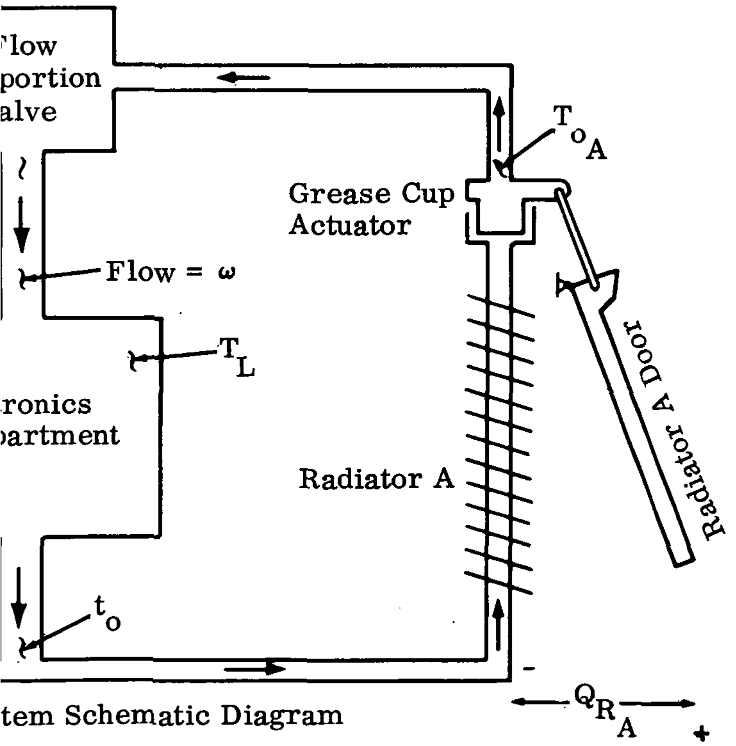






Space Radiator Sy

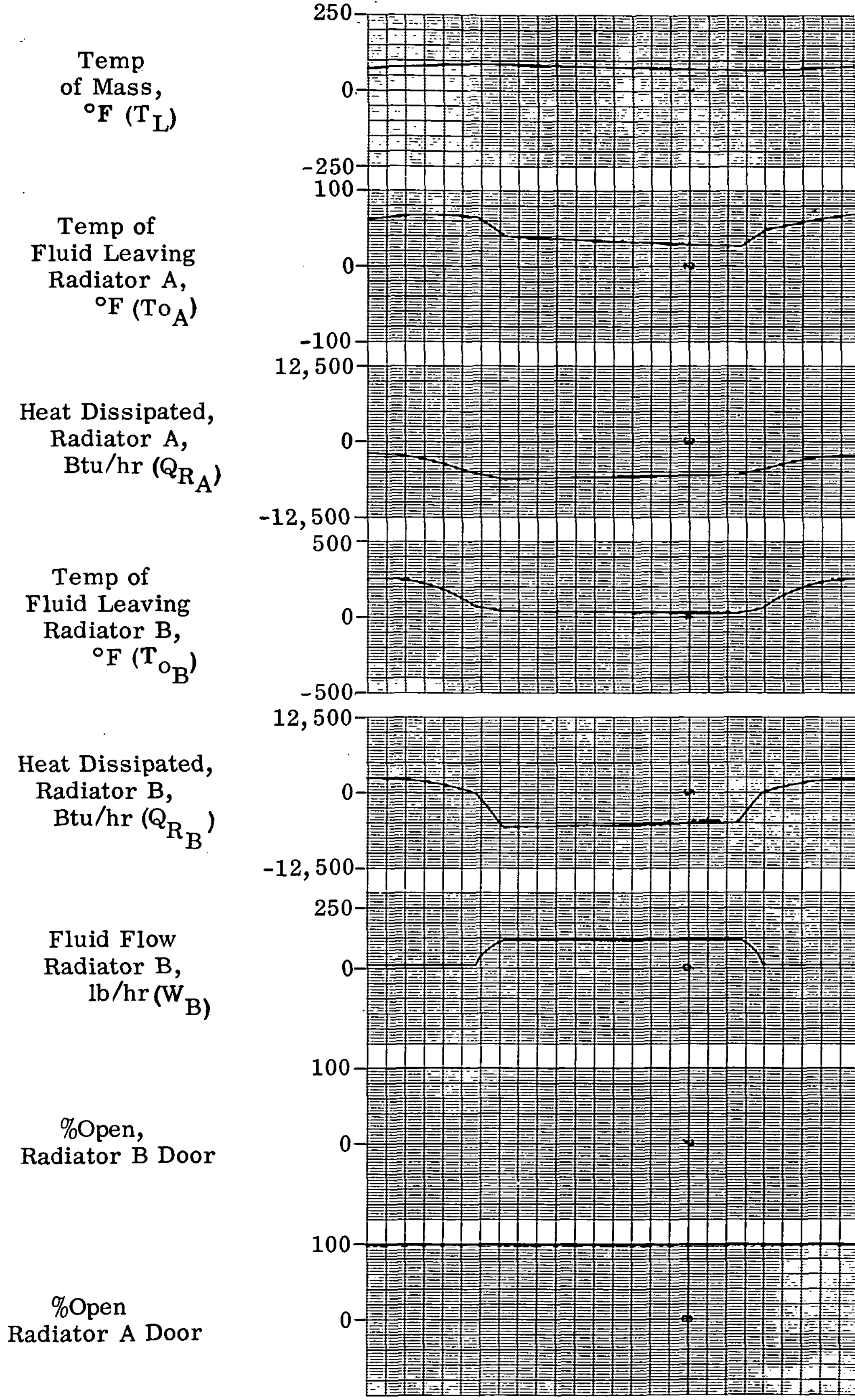




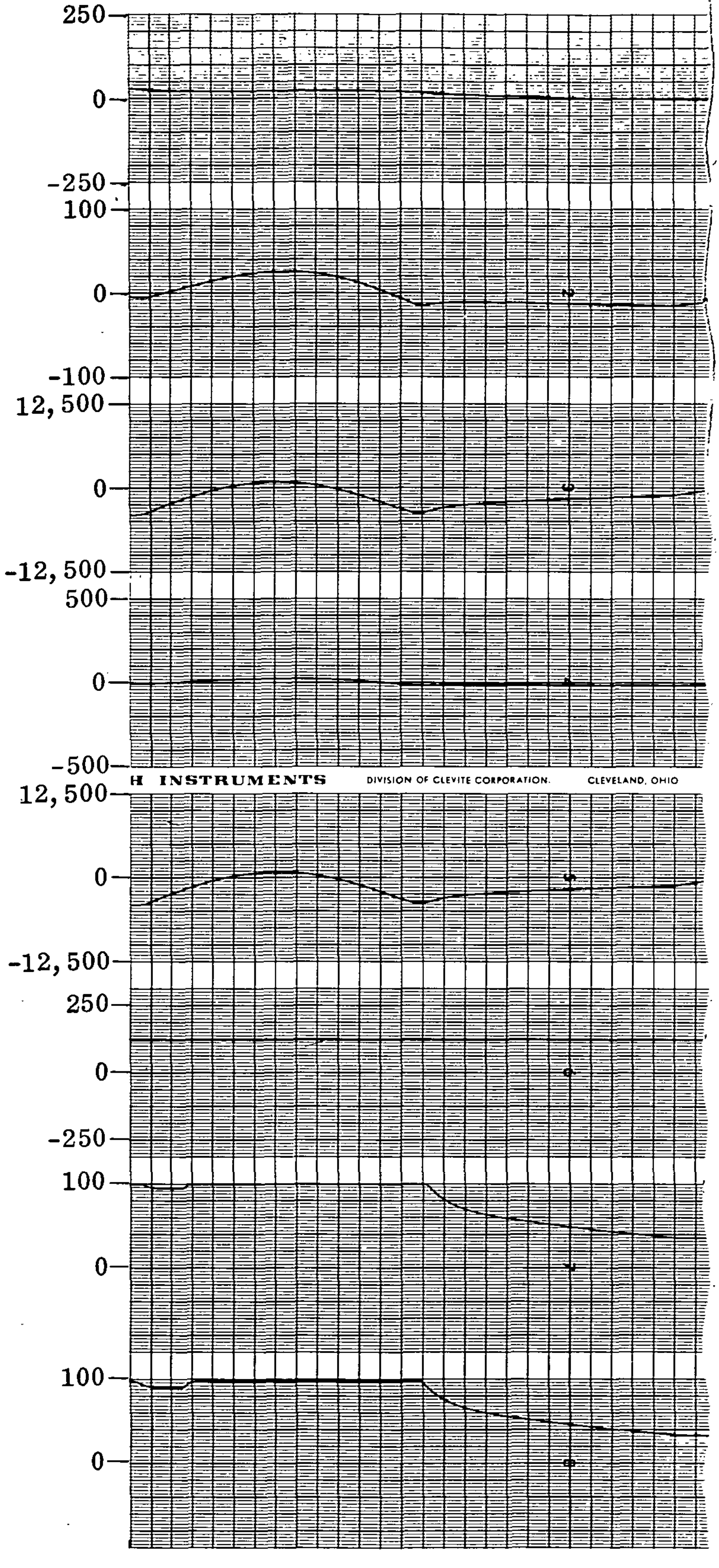
tem Schematic Diagram

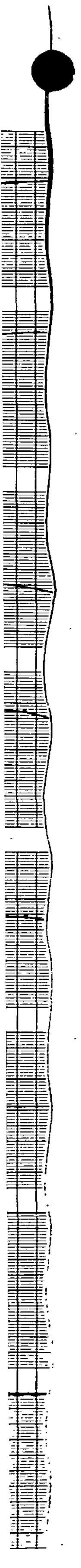
Fig. 4.1-15 Radiator Transients

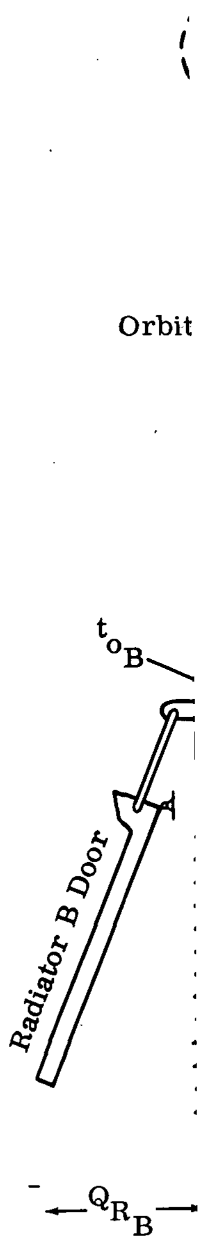
CASE I


Temp of Mass, °F (T_L)
250
0
-250
Temp of Fluid Leaving Radiator A, °F (To_A)
100
0
-100
Heat Dissipated, Radiator A, Btu/hr (Q_R_A)
12,500
0
-12,500
Temp of Fluid Leaving Radiator B, °F (T_o_B)
500
0
-500
Heat Dissipated, Radiator B, Btu/hr (Q_R_B)
12,500
0
-12,500
Fluid Flow Radiator B, lb/hr (W_B)
250
0
%Open, Radiator B Door
100
0
%Open Radiator A Door
100
0

CASE II

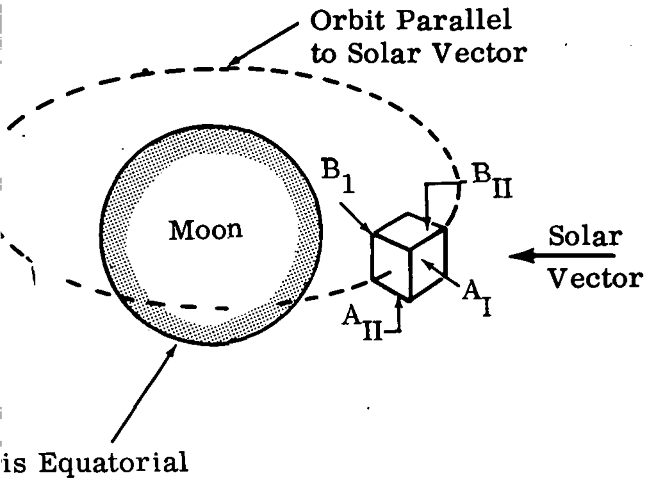






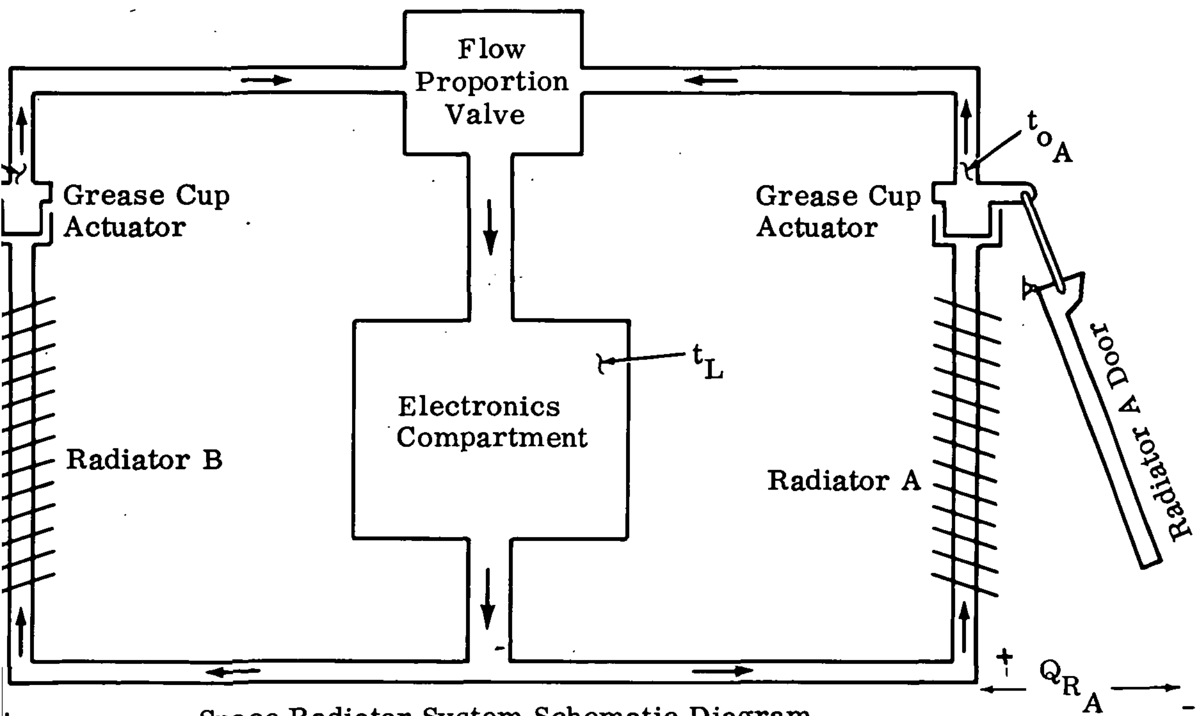
4.1-16

(2)



Laboratory II
Lunar Orbit
80 N M
Radiator A & B
Parallel to
Orbital Plane

A_I & B_I, & A_{II} & B_{II}
Represent Radiator Location
For Case I & II Respectively



Space Radiator System Schematic Diagram

Fig. 4.1-16 Radiator Transients

3

4.2 INTEGRATED GUIDANCE AND CONTROL

4.2.1 Assumptions

Major assumptions made in defining the IGNC for the Phase II Labs were:

- All translation and orbital maneuvering capability will be supplied by CSM.
- The Lab will provide the orbital attitude hold capability within the limits of the recommended configuration. Capability beyond these limits will be supplied by the experiment package.
- There is no electrical interface for control between the Lab and the CSM.
- All missions have RCS in the Lab.
- There is no main propulsion system in the Lab. Since there is no requirement for translational capability, consideration of rotations resulting from translation thrusting along the ±Y or ±Z axes was omitted.

4.2.2 Background Data

4.2.2.1 Control System

The block diagram of the control system is shown in Fig. 4.2-1. This control system corresponds to the LEM-AGS control system configuration. The results of various analyses performed to define control system capabilities are presented herein, and are based upon the characteristics of RCS given in Ref. 4.2-1. The location and numbering sequence for the RCS thrusters is shown in Fig. 4.2-2.

Disturbance torques generated by crew motions are expected to produce vehicle transients of relatively short duration and will result in small incremental changes in orientation. Proper scheduling of crew activities should minimize the significance of these disturbances. However, the composite of unidirectional and cyclical external disturbance torques is expected to have a significant effect on mission duration.

The cyclical and unidirectional disturbance torque components and their effects on IGNCS design are mission and configuration dependent. However, preliminary analysis of the effects of these disturbance torques on mission propellant requirements has dictated the need for examining momentum exchange devices and other RCS thrusters.

4.2.2.2 Environmental Disturbance Torques

A preliminary analysis of the external disturbance torques affecting the Lab in Earth orbit has been performed. Gravity gradient and aerodynamic torques were estimated to be the most significant. Magnetic disturbance torques are dependent upon vehicle shape, ambient field, location and magnetic qualities of ferromagnetic elements stored in the vehicle and the induced fields due to electrically powered components. Therefore, computing a reasonable estimate of the magnetic torque is not feasible at this time, since the field-producing components cannot be located adequately in a vehicle configuration which is not fully defined.

For purposes of defining reference torques for the Lab, a configuration showing high moments of inertia was used. This configuration is shown in Fig. 4.2-3. Moments of inertia about the X, Y, and Z body axes were estimated to be 40629, 237531 and 235721 slug-ft^2, respectively. Five percent of the Z-axis moment of inertia (11786 slug-ft^2) was used as an estimate of the cross-product of inertia.

A peak gravity gradient torque of 0.374 ft-lb can be expected for this vehicle in an inertially oriented mode. Half of the peak value (0.187 ft-lbs) is assumed to be the most probable average value. The peak aerodynamic torque is 0.079 ft-lb; the average value is taken as half the peak value, or 0.040 ft-lbs. The figures for aerodynamic torque include a factor of five to account for diurnal and seasonal variations in dynamic pressure. The following summarizes the torque environment for the reference flight with the vehicle in a fixed inertial orientation.

Source	Average (ft-lbs)	Peak (ft-lbs)
Gravity Gradient	0.187	0.380
Aerodynamic	0.040	0.079
TOTAL	0.227	0.388 (RSS)

For an inertially-oriented vehicle, the procedure used to obtain the total from all sources is similar to that used in the definition of the torque environment of the OAO. Average values are summed, but peak values are computed on a root-sum-squared basis since it is probable that each component of torque will not peak at the same time point in the orbit.

For the case where the reference flight is oriented to within ±5 deg of the local vertical (assumed dead band limits) the maximum bias torque due to the gravity gradients will be 0.0295 ft-lbs. Aerodynamic torques which result from an angle of attack corresponding to the ±5 deg deviation from the local vertical are negligible, compared to the gravity gradient torque.

Based on the analytical model, the following hold for the characteristics of the gravity gradient torques:

- The total gravity torque vector always lies in the horizontal plane, (i.e., the plane normal to the local vertical direction) and is dependent upon the angles between the vehicle principal axes of inertia and the local vertical.
- The maximum torque occurs when the minimum moment of inertia axis is at an angle of 45 degrees from the vertical.
- An attitude which places two of the vehicle principal axes in the horizontal plane and the third along the vertical will result in zero gravity gradient torque.

Figure 4.2-4 indicates the torque-producing effects of variations in vehicle attitude relative to the local vertical. These curves have been developed for general application to any vehicle in a 200 n. mi altitude circular orbit. In generating the data for Fig. 4.2-4, cross products of inertia were assumed to be zero. Rotations about the vehicle's X axis were not considered. Fig. 4.2-5 demonstrates the cyclic characteristics of the gravity gradient torque for the reference vehicle, held in an inertial orientation.

The aerodynamic torques shown in Fig. 4.2-6 and 4.2-7 were calculated for various AES configurations using a free molecule flow analysis. Aerodynamic pressure and shear stresses were calculated based on incremental surface area elements of the idealized vehicle configuration shown in Fig. 4.2-3. The analysis includes the effects of structural shadowing of the aerodynamic flow.

The solid and dashed curves of Fig. 4.2-7 represent the aerodynamic torque variation for the maximum and minimum X-axis excursion of the vehicle cg, measured from the base of the CM. Computation of the torque profile was based on the ARDC 1962 standard atmosphere. However, the dynamic pressure can be assumed to be at least five times the standard dynamic pressure at 200 n. mi due to:

a) diurnal atmospheric bulge
b) seasonal variations
c) density changes caused by solar activity

Until a more detailed review of research in the area of atmospheric variations can be performed, a confidence factor of five is applied to the aerodynamic torques for purposes of computing propellant requirements.

Maximum aerodynamic torques are experienced at attitudes which place the vehicle's X axis normal to the relative wind (assumed to lie at the intersection of the horizontal plane and the plane of the orbit). Minimum aerodynamic torques are experienced when the vehicle's X axis is parallel to the relative wind.

4.2.2.3 Orbital Decay

The orbital decay of the Lab stored in orbit is a consideration that could affect GN&C requirements. If orbital decay is severe, stabilization of the vehicle and a subsequent reset of the orbit using the GN&C system would required. Fig. 4.2-8 shows the initial Lab circular orbit altitude required to achieve a 200 n. mi orbit after 60 days as a function of the ballistic parameter, W/C_DS. Fig. 4.2-9 presents the ballistic parameters for several CSM-LEM Lab configurations. For the Lab alone, a ballistic parameter of no less than 30 is expected. Since W/C_DS will never be less than 30, the maximum initial orbital altitude can be as low as 210 n. mi. This will assure a 200 n. mi altitude for up to 60 days.

4.2.2.4 Ground Tracking Coverage for Earth Orbital Missions

Analyses were performed to determine tracking station coverage in terms of time of entrance to and exit from the station coverage. This data was generated for several typical AES earth orbit missions. The following assumptions were made:

- Parking orbit insertion is taken as mission initiation.
- Thrusting maneuvers involving Hohmann transfers to the higher operational orbits were not considered.
- All orbits were assumed circular.

The eleven Near Space Instrumentation Facility Stations were included in the tracking model. For polar orbit missions, the Fairbanks, Alaska site also was included. Table 4.2-1 presents typical output data for 14 orbits, assuming 28.5 deg inclination, 200 n. mi altitude orbit. Additional data has been compiled for as many as 50 orbits. An evaluation of this data can be found in Volume XVI.

4.2.2.5 Analysis of Communications Between a Lunar Orbiter and Earth Tracking Stations

Data were generated to determine the tracking station communication capability of a vehicle in a lunar polar orbit, and of one in a low inclination, retrograde lunar orbit. An important parameter considered was the interruption of communications by lunar occultations of the vehicle.

The JPL Space Trajectory Program was used to generate time histories for a vehicle in both of the orbits described above. In addition, the program generated the rise and set times of the vehicle relative to five tracking stations, and the times of occultation of the vehicle by the moon.

The evaluation of these data is presented in Volume 16 "PRELAUNCH AND MISSION OPERATIONS".

4.2.3 Recommended Configuration

The recommended attitude control system configuration, which provides for flexibility and future growth, consists of the following LEM assemblies:

- Abort Sensor Assembly (ASA)
- Abort Electronics Assembly (AEA)
- Modified Rate Gyro Assembly (RGA) *
- Attitude and Translation Control Assembly (ATCA)
- Attitude Controller Assembly (ACA)
- Reaction Control System (RCS)
- Translation Controller Assembly (TCA)

A block diagram of this attitude control system is presented in Fig. 4.2-1. The 16 RCS thrusters, which provide the required control torques, are located and numbered as shown in Fig. 4.2-2. The characteristics assumed for the thrusters are given in Ref. 4.2-1.

Ref. 4.2-2 and 4.2-3 were used to establish jet selection for rotational control about a desired axis (Table 4.2-2). The symbolic logic showing routing of signals is presented in Fig. 4.2-10-a and 4.2-10-b. Note that since main engine signals are nonexistent, rotation about Y (pitch) and Z (roll) axes for the recommended configuration is restricted to two-jet operation. Similarly, since no Y or Z translation commands are assumed, X (Yaw) axis rotation will also be restricted to a two-jet operation.

Propellent flow rates for limit cycle operation using this logic are presented in Fig. 4.2-11, 4.2-12, and 4.2-13 for the non-disturbed condition (normal) and in the presence of external disturbance torques. Typical limit cycles for normal and disturbed conditions are shown in Fig. 4.2-14. Fig.4.2-13 is included to show the system propellant flow rate for extremely small disturbance torques. It should be noted that the minimum point shown on these curves is dependent upon control system dead-band and vehicle moment of inertia. This point can be extracted from Fig. 4.2-15 for various values of vehicle moment of inertia and control system deadband for the minimum impulse limit cycle depicted in Fig. 4.2-14-c. The dotted portion of Fig. 4.2-13 represents the transition from a disturbed limit cycle (Fig. 4.2-14-c) to a normal limit cycle (Fig. 4.2-14-a). Fig. 4.2-16 and 4.2-17 present the remaining torque-disturbed limit cycle characteristics which are required to completely define the disturbed limit cycle (Fig. 4.2-14-c) parametrically. Similarly, Fig. 4.2-18 presents the normal limit cycle period (Fig. 4.2-14-a) which, in conjunction with Fig. 4.2-11, defines the normal limit cycle characteristics parametrically.

- - - - - - -

* RGA modified to sense rates of $(3.25/I_m)$rad/sec., where I_m is maximum moment of inertia in slug-ft^2.

The discussion of the recommended configuration has assumed two-jet rotation about all vehicle axes. An impending change to LEM is to perform all yaw rotations using four jets. This change will be accomplished by causing relay K3 in Fig. 4.2-10-b to be de-energized at all times. This would increase yaw axis propellant flow rates by a factor of four.

4.2.4 Baseline Configuration

The baseline configuration attitude control system is identical to that of the recommended configuration except that the present LEM RGA, with an 0.01 deg/sec threshold, is used. This will yield a normal limit cycle of the type depicted in Fig. 4.2-14-b, with the propellant flow rates indicated in Fig. 4.2-19. The increasing rather than decreasing propellant flow rate as a function of vehicle moment of inertia is attributed to the inability to sense rates less than 0.01 deg/sec.

It can be seen by comparing Fig. 4.2-11 and 4.2-19 that a severe penalty is paid in terms of required propellant, if the present RGA is used. However, disturbed-limit-cycle propellant flow rate is still obtained from Fig. 4.2-12, but the flow rate for extremely small torque disturbances cannot be defined as was done for the recommended configuration (Fig. 4.2-13).

4.2.5 Alternate Configuration - Modify ASA and AEA to Provide Rate Information

The feasibility of this approach, based upon deriving rate from attitude information using the AEA, has not been verified for the rate threshold being considered (0.001 deg/sec). Additional analyses are being performed, but the approach does not look promising. This approach, which would require hardware modification of the AGS, is competitive with the alternate discussed below.

4.2.6 Alternate Configuration - Use of PGNCS in Lieu of AGS.

The LEM abort GNC system is the recommended configuration because it is functionally adequate, requires less power, is lighter and has a higher design operating life (5000 hr vs 2000 hr for the PGNCS). However, the inherent capabilities of the PGNCS, (Ref 4.2-4), afford considerably more mission planning flexibility and some significant advantages when overall control system requirements (including RCS functions) are considered. Tables 4.2-3 and 4.2-4 summarize some of the more significant characteristics.

It can be seen that the PGNCS has the inherent capability of providing low rate thresholds which will result in a near-minimum impulse limit cycle, at all vehicle inertias, in the absence of external torques. Undisturbed limit cycle propellant flow rates and periods for this configuration are shown in Fig. 4.2-11 and 4.2-8. Provision is also made for adjusting (maximizing) electrical thruster signal pulse width to compensate for disturbance torques about the Y and Z axes. This will tend to maximize the I_{sp}. The propellant flow rates, therefore, will approach the ideal values shown in Fig. 4.2-12 (without making any system changes).

The most severe limitation in planning the use of PGNCS is its design operating life of 2000 hr. At present, no attempt has been made to assess the improvement in reliability that might be achieved by use of replaceable spares or by redesign of critical elements.

It is understood that AC Spark Plug is currently studying such approaches under contract to NASA. It is assumed that pertinent results from these studies will be made available in timely fashion to the AES associate contractors (Grumman). A considerable improvement in reliability for both the AGS and the PGNCS is possible if the failure rates of elements not essential to the Lab missions as currently defined are excluded.

Scheduling (availability) of PGNCS for missions is also an important consideration which must be assessed by NASA. The schedule does indicate, however that a considerably larger amount of test data (and time) should have been accumulated for the PGNCS prior to the scheduled launches of early Phase II Labs. Thus, it is expected that a higher level of confidence in this equipment will exist at that time. As the AGS design reaches maturity, a crossover point is anticipated, beyond which the AGS should be able to demonstrate better reliability than the PGNCS at higher confidence levels.

4.2.7 Alternate Configuration - Logic Modification

The recommended configuration, using the LEM ATCA jet select logic, will use only eight RCS thrusters to maintain attitude hold; i.e., the other eight RCS thrusters will never be used (Fig. 4.2-11-a and 4.2-10-b). A modification of the jet select logic to allow selection of alternate jet pairs will yield improved mission reliability because of the control redundancy obtained. This modification has no impact on the limit cycle characteristics of the recommended configuration, described in Paragraph 4.2.3.

4.2.8 Alternate Configuration - Use of Other Torque Generating Devices

Reaction torques in a momentum exchange device are generated by changing the angular momentum of a component of the device (through the relationship: torque = time rate of change of component's angular momentum = component's inertia x time rate of change of component's angular velocity).

If the disturbing torques have a non-zero average, the angular momentum will continue to increase until design limits are exceeded. In this case the angular momentum must be periodically dumped, and the system must be reset. The best known means of accomplishing reset is by using RCS jets.

Three momentum exchange devices that are considered to be feasible for application to the Phase II Lab are inertia wheels, fluid flywheels, and twin control moment gyros. Each device contains sensors to detect angular errors, amplifiers to obtain the proper signal levels, and motors which act as torque generators. A set of three inertia wheels or three fluid flywheels, with spin axes mutually perpendicular, or a set of six control moment gyros (two counterrotating gyros for each axis) provides three axis control.

In an inertia wheel device, a torque generator acts to increase or decrease the angular velocity of a high-inertia wheel to provide changes in angular momentum. In a fluid flywheel device, fluid is driven around a torus by a pump, and angular momentum changes are effected by changing the fluid's velocity. A control moment gyro's angular momentum is changed by varying the orientation of the gyro spin vector. Because of the laws governing gyroscopic motion, the input or error sensitive axis, the gyro spin axis, and the torquer or output axis are mutually perpendicular. Therefore two counterrotating gyros are used for control about each axis; torques about the output axes and null-position spin axes cancel each other, and the resultant change in total angular momentum takes place solely about the disturbance torque input axis, which is independent of gyro motions.

The feasibility of using control moment gyros has been demonstrated by analysis and simulation.

A preliminary study has shown that for sinusoidal disturbance torque with a maximum value of 1 ft-lb, gyro wheels having a maximum angular momentum capability (individually) of 500 ft-lb-sec will provide adequate control. Problems involved in angular momentum dumping have not yet been studied. No definite conclusion as to the superiority of this momentum exchange method over the others has been arrived at to date.

Table 4.2-5 lists some of the advantages and disadvantages of each attitude control method discussed above, from the performance and mechanical implementation points of view. Paragraph 5.3 presents preliminary estimates of the power, size and weight for a control moment gyro system.

4.2.9 Alternate Configuration - Use of Low Level Thrusters

Table 4.2-6 compares control system performance in limit cycle operation, when various thrusters with characteristics other than those of the present LEM RCS are used. Assumptions made in the analysis are as follows:

- normal limit cycle operation; i.e., ideal rate sensors are assumed
- only two-thruster pure couple rotations occur
- moment arm is the same for all thrusters
- minimum vehicle rate change ($\Delta \dot{\theta}$ min) is given by

$$\Delta \dot{\theta}_{min} = \frac{2\, I_{T_{min}} L}{I} = K\, I_{T_{min}} \qquad (1)$$

where

$I_{T_{min}}$ = minimum thruster total impulse - (lb-sec)
L = thrust moment arm - (ft)
I = vehicle moment of inertia - (slug-ft^2)
K = $\frac{2L}{I}$ = constant for all thrusters

- normal limit cycle propellant flow rate ($\dot{w}$) is given by

$$\dot{w} = \frac{I_{T_{min}}^2\, L}{\Omega\, I\, Isp_{min}} = A\, \frac{I_{T_{min}}^2}{Isp_{min}} \qquad (2)$$

where

Ω = control system deadband - (rad)
$I_{sp_{min}}$ = thruster minimum specific impulse - (sec)
$A = L/\Omega I$ = constant for each thruster.

Note that thruster number one is the present LEM RCS component, given as a reference base.

If thruster number three (Table 4.2-6) is used on the Phase II labs in the attitude hold mode of operation, normal limit cycle propellant flow rate can be reduced to 1/259 = 0.0039 times that of the recommended AGS configuration. However, use of thruster number three would require even further improvement in the AGS-RGA over that recommended. In fact, capability must be provided to sense rates which are 1/15 = 0.067 times the recommended AGS rate capability to completely realize the potential propellant savings. It is possible that the PGNCS, unmodified, may be capable of operating at the required low rates, but such capability has yet to be demonstrated.

In constant-torque-disturbed limit cycle operation, the AGS, with the required rate sensing capability discussed above, will be most efficient if thruster number two is used. This occurs because the AGS generates a minimum impulse torque-disturbed limit cycle for the disturbance torque levels being considered, and the value of $I_{sp_{min}}$ is the largest for thruster two. This can be seen from the equation for constant-torque-disturbed limit cycle propellant flow rate, which is

$$\dot{w} = \frac{T_D (T_C - T_D)}{T_C L I_{sp_{min}}} \qquad (3)$$

where

T_D = constant disturbance torque level - (ft - lb)

T_C = control torque - (ft - lb) .

Equation 3 can be approximated by

$$\dot{w} = \frac{T_D}{L I_{sp_{min}}} \qquad (4)$$

if $T_D \ll T_C$ = L x Thrust Level

(which is the case for all thrusters considered in Table 4.2-6 and for disturbance torque levels predicted).

The constant-torque-disturbed minimum impulse limit cycle period (T) is given by

$$T = \frac{2 \, IT_{min} \, L \, T_C}{T_D (T_C - T_D)} \approx \frac{2 \, IT_{min} \, L}{T_D} \qquad (5)$$

Therefore, thruster number one (the present LEM thruster) will have the largest disturbed limit cycle period for a given constant disturbance torque level (i.e., thruster number one will be subjected to the lowest number of thruster operations for a given T_D).

The above discussion can be summarized as follows:

- thruster number three will yield the best possible normal limit cycle operation
- thruster number two yields the minimum propellant flow rate for the constant-torque-disturbed limit cycle
- thruster number one will yield the minimum number of thruster operations for any constant-torque-disturbed limit cycle

A selection of any one thruster or combination of thrusters will require additional studies. The studies will consider each of the combinations with respect to performance, power, reliability, and weight requirements.

4.2.10 Discussion of Configuration Choices

These studies have verified that the Apollo LEM IGNCS equipment can meet the basic requirements for Lab missions as presently defined. From an overall cost effectiveness standpoint, a modified version of the LEM abort guidance system is recommended. It provides the desired capability of holding attitudes established by the CSM, weighs less and requires less power than the PGNCS, has a design operating life of 5000 hr as compared to 2000 hr for the PGNCS, and the AGS elements required to provide the specified attitude hold feature represent the least severe developement challenge.

However, the major control problem will be that associated with the management of momentum exchange phenomena. Thus, any meaningful analysis will be highly dependent on adequate mission/experiment definition and precise knowledge of the vehicle geometry and equipment distribution. Consideration of such factors has underscored the significance of considering detailed dynamic characteristics of control elements such as the rate gyro and the RCS thrusters in computing parametric curves for propellant flow rates. On the basis of such results, several alternates to the recommended configuration were presented.

The most significant issues are those relevant to a choice between the AGS and the PGNCS. The latter offers considerably more capability than has been currently specified. It also offers more flexibility and growth potential in accommodating changes to the mission plan or experiment requirements. Greater utilization of this potential possibly could be realized if the opportunity for improved insight to the PGNCS design and into the LGC program structure was afforded Grumman.

The initial edge in confidence level that the PGNCS appears to have is felt to be temporary and would probably diminish as the AGS reaches greater design maturity. However, should "sparing" become desirable, it might be feasible to realize some support of the CSM system with elements from the LEM system. "Sparing" has not been considered to date.

The greatest improvement in reliability can be achieved by judicious scheduling of equipment duty cycles. For instance, the duty cycle of either the AGS or the PGNCS attitude reference equipments could be reduced by making use of the rate gyros in the rate command mode. Thus, a thorough cost effectiveness review depends upon availability of schedules and other mission/experiment planning factors which must be weighed in making decisions on the following factors:

- Automatic Star Tracker <u>or</u> AOT
- Selection of IGNCS configuration from alternates presented
- Selection of alternate torque generators to replace or supplement the present LEM RCS system
- Define specific reference missions <u>in detail</u> so attitude profiles can be optimized to allow effective control (or use) of all external and internal torques.
- Identification of significant design constraints which will have significant impact upon design analyses (i.e., CSM RCS thermal design considerations)
- Philosphy on items such as "sparing"

Grumman will use these inputs to perform more detailed system performance analyses based upon consideration of detailed dynamic characteristics of all control elements and preparation of an internal torque summary. This will allow appropriate updating and release for approval of specifications for the operational functional and performance requirements for the Phase II Laboratory IGNCS.

Rev	Time In hr	min	Time Out hr	min	Span, min	Station
1	0,	1.10	0,	8.67	7.56	GUAYMAS S-BAND
	0,	4.29	0,	11.84	7.55	CORPUS S-BAND
	0,	8.29	0,	15.85	7.56	CCTMA FPS-16
	0,	8.88	0,	16.42	7.54	BAHAMA
	0,	12.16	0,	18.88	6.72	BERMUDA FPS-16
	0,	13.98	0,	20.65	6.66	ANTIGUA FPS-16
	0,	28.97	0,	34.83	5.86	ASCENSION FPS-1
	1,	0.67	1,	8.12	7.45	CARNARVON FPS-1
	1,	26.66	1,	34.17	7.51	HAWAII FPS-16
2	1,	38.68	1,	46.24	7.56	GUAYMAS S-BAND
	1,	41.87	1,	49.43	7.56	CORPUS S-BAND
	1,	45.92	1,	53.03	7.11	CCTMA FPS-16
	1,	46.49	1,	53.77	7.28	BAHAMA
	1,	51.19	1,	53.93	2.74	BERMUDA FPS-16
	1,	51.21	1,	58.71	7.50	ANTIGUA FPS-16
	2,	5.63	2,	13.04	7.41	ASCENSION FPS-
	2,	39.16	2,	44.11	4.95	CARNARVON FPS-
	2,	50.62	2,	57.33	6.71	GUAM
	3,	4.51	3,	11.61	7.10	HAWAII FPS-16
3	3,	16.25	3,	23.67	7.42	GUAYMAS S-BAND
	3,	19.60	3,	26.43	6.83	CORPUS S-BAND
	3,	24.94	3,	28.26	3.32	CCTMA FPS-16
	3,	25.30	3,	29.32	4.02	BAHAMA
	3,	30.11	3,	34.46	4.35	ANTIGUA FPS-16
	3,	45.02	3,	49.13	4.11	ASCENSION FPS-
	4,	27.80	4,	35.06	7.26	GUAM
	4,	42.58	4,	49.37	6.79	HAWAII FPS-16
4	4,	54.44	4,	59.93	5.49	GUAYMAS S-BAND
	6,	6.98	6,	11.64	4.65	GUAM
	6,	20.14	6,	27.50	7.36	HAWAII FPS-16
5	7,	57.72	8,	4.93	7.21	HAWAII FPS-16
6	9,	24.45	9,	27.75	3.30	GUAM
	9,	37.82	9,	39.26	1.44	HAWAII FPS-16
7	10,	17.88	10,	24.09	6.20	ASCENSION FPS-
	11,	0.81	11,	7.50	6.70	GUAM
8	11,	54.84	12,	2.24	7.40	ASCENSION FPS-
	12,	38.04	12,	45.40	7.36	GUAM

Table 4.2-1

G STATION COVERAGE

Rev	Time In hr min	Time Out hr min	Span, min	Station
9	13, 35.21	13, 36.79	1.58	ASCENSION FPS-16
	14, 18.65	14, 19.51	0.86	GUAM
10	15, 14.33	15, 20.83	6.50	CANARY S-BAND
11	16, 39.92	16, 46.41	6.49	ANTIGUA FPS-16
	16, 51.14	16, 58.67	7.54	CANARY S-BAND
	17, 29.24	17, 34.31	5.07	CARNARVON FPS-16
12	18, 15.94	18, 19.85	3.92	BAHAMA
	18, 16.87	18, 24.30	7.43	ANTIGUA FPS-16
	18, 19.50	18, 23.59	4.09	BERMUDA FPS-16
	18, 28.69	18, 36.24	7.55	CANARY S-BAND
	19, 5.30	19, 12.75	7.46	CARNARVON FPS-16
13	19, 48.65	19, 53.29	4.64	CORPUS S-BAND
	19, 51.35	19, 58.17	6.81	CCTMA FPS-16
	19, 51.44	19, 58.71	7.27	BAHAMA
	19, 55.17	20, 2.08	6.91	BERMUDA FPS-16
	19, 55.46	20, 1.37	5.92	ANTIGUA FPS-16
	20, 6.26	20, 13.79	7.53	CANARY S-BAND
	20, 42.88	20, 50.30	7.42	CARNARVON FPS-16
14	21, 22.03	21, 28.35	6.32	GUAYMAS S-BAND
	21, 24.50	21, 31.82	7.32	CORPUS S-BAND
	21, 28.34	21, 35.88	7.55	CCTMA FPS-16
	21, 28.77	21, 36.32	7.54	BAHAMA
	21, 32.23	21, 39.58	7.35	BERMUDA FPS-16
	21, 34.22	21, 38.99	4.77	ANTIGUA FPS-16
	21, 44.11	21, 50.57	6.45	CANARY S-BAND
	22, 20.68	22, 28.03	7.35	CARNARVON FPS-16
	22, 49.36	22, 52.25	2.90	HAWAII FPS-16

- Node: 178.58
- Alt: 200 n. mi
- Incl: 28.5 deg

Table 4.2-2

THRUSTER IGNITION FOR ROTATIONAL CONTROL

Type of Signal	Thrusters Used for Response	Mode
Single Axis		
Q_1	9, 14	Two-Jet Rotation
Q_2	10, 13	
R_1	5, 10	
R_2	6, 9	
P_1	7, 15	
P_2	3, 11	
Q_1	2, 5, 9, 14	Four-Jet Rotation
Q_2	1, 6, 10, 13	
R_1	1, 5, 10, 14	
R_2	2, 6, 9, 13	
P_1	4, 7, 12, 15	
P_2	3, 8, 11, 16	
Combined Rotations		
Q_2 R_1	1, 6, 10, 13 & 1, 5, 10, 14	All Modes
Q_2 R_2	1, 6, 10, 13 & 2, 6, 9, 13	
Q_1 R_1	2, 5, 9, 14 & 1, 5, 10, 14	
Q_1 R_2	2, 5, 9, 14 & 2, 6, 9, 13	

Table 4.2-3

ATTITUDE CONTROL SYSTEM PERFORMANCE
DURING UNDISTURBED LIMIT CYCLES

	• No Main Engine Thrust • No Exterior Torques • Attitude-Hold Mode of Operation	Control System* Present Primary	 Present Abort
I = 24,000 Slug-ft.²	RCS Jet Pulses/sec	2	Up to 4
	Max Angular Rate in Symmetrical Limit Cycle, deg/sec	0.0086	Up to 0.0173
	Period, min/cycle	2.46	Down to 1.34
	Avg Propellant Consumption, lb/min	0.011	Up to 0.041
I = 200,000 Slug-ft.²	RCS Jet Pulses/sec	2	Up to 18
	Max Angular Rate in Symmetrical Limit Cycle, deg/sec	0.00097	Up to 0.0097
	Period, min/cycle	21.3	Down to 2.58
	Avg Propellant Consumption, lb/min	0.00124	Up to 0.097
	Minimum Predictable or Measurable Angular Rate, deg/sec	Zero (Limited by drift rate of primary sys & dig comptr sealing)**	0.01
	Error Sources	Errors in RCS jet thrust could cause larger limit cycles & higher propellant consumption.**	Rate gyro threshold & resolution
	Possible Changes for Improved Performance at High Vehicle Inertias	None anticipated.**	Decrease rate gyro resol. inaccuracies & thresh. Increase rate gain to 8.0
	Type of Change	-	Hardware
	Limiting Factor if System	Computer calculation interval.**	PRM threshold & D-A converter resolution**

*System Deadband = 0.3 deg
Min. RCS jet output pulse = 0.6 lb-sec
For Abort Sys:
Min PRM output pulse length = 0.01 sec
Rate gain = 1.5

LMO 500-339

**Requires further study.

PGNCS

1. More severe penalties in weight, power, thermal areas than AGS.

2. Better rate derivative capability ... can obtain better limit cycle performance without hardware change (i.e., software only). Causes "optimum" convergence (for a combined minimum fuel and time performance criterion) from any point in the phase plane to a closed limit cycle.

3. Compensates for torque disturbances about Y and Z axes, affording reduction of 2:1 in propellant flow rates.

4. Changes in deadband and logic will essentially require software modification which could be accomplished on a "per mission" basis.

5. Has extensive capability beyond the baseline attitude hold requirement, such as the following:

   - Capable of self-alignment to stellar-inertial reference, and could afford degraded alignment of CSM attitude reference via voice link.
   - May have adequate inherent capability for tracking, local vertical--may simplify interface and negate need for horizon scanner or other external sensor.
   - Affords added flexibility for mission concepts requiring storage of Lab in Earth orbit.

6. If prelaunch testing is limited to 1,200 hr, the design operating life of 2,000 hr leaves 800 hr for Lab mission. Preliminary reliability studies to investigate simplification and deletion of circuitry, etc. are possible in light of Phase I Lab requirements. This should make reliability figures compare favorably with those for AGS. Proper scheduling should preclude any conflict with the 30-day recalibration requirement.

7. Considerable lack of information --It is assumed the major performance limitation is lack of all-attitude capability, however, other performance capabilities to be established are as follows:

   - Performance at low angular rates
   - Performance over long periods of time
   - Effect of RCS jet thrust level errors (could cause multiple-pulse limit cycle)
   - Effect of undetected jet failures (stability)

8. Anticipate higher level of confidence (than LEM AGS) for early need dates on Phase I Labs due to commonality with and prior flight experience (scheduled for) the CSM Apollo PGNCS Earth orbital missions.

TABLE 4.2-4

: AGS FOR LABORATORY APPLICATION

A G S

1. Lighter, requires less power than PGNCS.

2. Requires modification of RGA and ATCA gain change to provide propellant consumption comparable to PGNCS for undisturbed limit cycle operation.

3. No logic to permit widening electrical pulses in presence of disturbance torques...costs propellant penalty.

4. Changes in deadband, gain and modification to obtain 2 - jet control about X-axis require hardware changes.

5. Must modify AEA to include star catalog if self alignment is desired. If NASA decides to make the AST a part of the basic LEM, the AEA must be modified to accommodate the AST hardware interface.

6. Requires external sensors and additional ATCA hardware interface change to accommodate same to provide local vertical tracking. This is expected to be a relatively simple interface.

7. Must modify Program Reader Assembly (PRA) for use in Earth orbital storage concept.

8. Design operating life is 5000 hr--Preliminary reliability studies indicate simplification and deletion of circuitry, etc. are possible in light of Phase I Lab requirements. Reliability projections compare favorably with data available for PGNCS. Proper scheduling should preclude conflict with maintainability requirements.

9. Performance data in presence of noise, effect of D/A converters and other AEA delays on performance must be established in the future. Problem similar to that for PGNCS.

10. Anticipate lower level of confidence (than PGNCS) for early need dates due to limited test experience. Ultimately, the AGS should be able to yield higher levels of confidence and reliability due to relative simplicity in mechanization as compared to PGNCS.

11 Use of AGS permits use of cold plate areas in cabin provided by deletion of PGNCS components.

Table 4.2-5

COMPARISON OF ATTITUDE CONTROL TECHNIQUES

Technique	Advantages	Disadvantages
RCS Jets (Present LEM)	• Simple in comparison to other actuation systems • Many performance analyses completed on LEM project • No reset device necessary as there is no saturation • No cross-coupling effects with proper nozzle alignment	• System limited by propellant weight to short-duration missions with restricted reqmts • Fine degree of accuracy cannot be maintained without large propellant expenditure
Inertia Wheels	• Relatively simple in comparison to other momentum-exchange devices • High-accuracy control can be maintained • Considerable experience with this type of control accrued on OAO project	• Coarse & fine control reqd when fine-pointing accuracy is desired • Wheels heavy in comparison to other momentum-exchange devices • Gyro cross-coupling effects can exist • RCS jets needed for reset
Fluid Flywheels	• Extremely flexible & simple mech design make this system independent of vehicle configs • Extremely rapid response capability • High-torque ability with potential low-torque ability, giving it single-system applicability	• State-of-art relatively undeveloped; such problems as "resetting" yet to be solved • RCS jets needed for reset • Gyro cross-coupling effects can exist
Twin Control-Moment Gyros	• Exhibits rapid high torque response to correct for internal movement of equipt & personnel • Inherently stable & fail-safe in closed-loop operation	• Highly complex • Efficiency varies inversely with gyro offset angle • Reset logic must be examined • RCS jets needed for reset • Gyro cross-coupling effects can exist

Table 4.2-6

COMPARISON OF LOW-LEVEL & PRESENT LEM THRUSTERS

		Thruster No. 1 (LEM)	2	3	4
	Nominal Thrust Level, lb	100	22	5	5
	Minimum Total Impulse, lb-sec	0.75	0.22	0.05	0.35
	Minimum Specific Impulse,	130	210	150	180
Undisturbed Limit-Cycle Operation	$\dot{\omega}/A = I^2_{T(min)}/I_{SP(min)}$	$432x10^{-5}$	$23x10^{-5}$	$1.67x10^{-5}$	$68x10^{-5}$
	Factor by which AGC rate-sensing capabilities must be improved*	1.0(nom)	3.4	15	2.14
	Factor by which propellant flow is reduced	1.0(nom)	18.8	259	6.35
Constant-Torque Disturbed Limit-Cycle Operation (with AGS)	$\dot{\omega}/D = 1/I_{SP(min)}$	0.0077	0.00477	0.00666	0.00556
	$T/B = 1/I_{T(min)}$	1.333	4.55	20	1.15
	Factor by which propellant flow is reduced	1.0(nom)	1.62	2.86	1.39

*Beyond rate requirement established in ENG-AES/IOM-65-110, "AES Labs: Estimated RCS Propleeant Flow Rates and Limit Cycle Periods for AES Labs Using LEM Abort Guidance System and LEM Reaction Control Subsystem", R. Edelmann, 20 Oct. 1965.

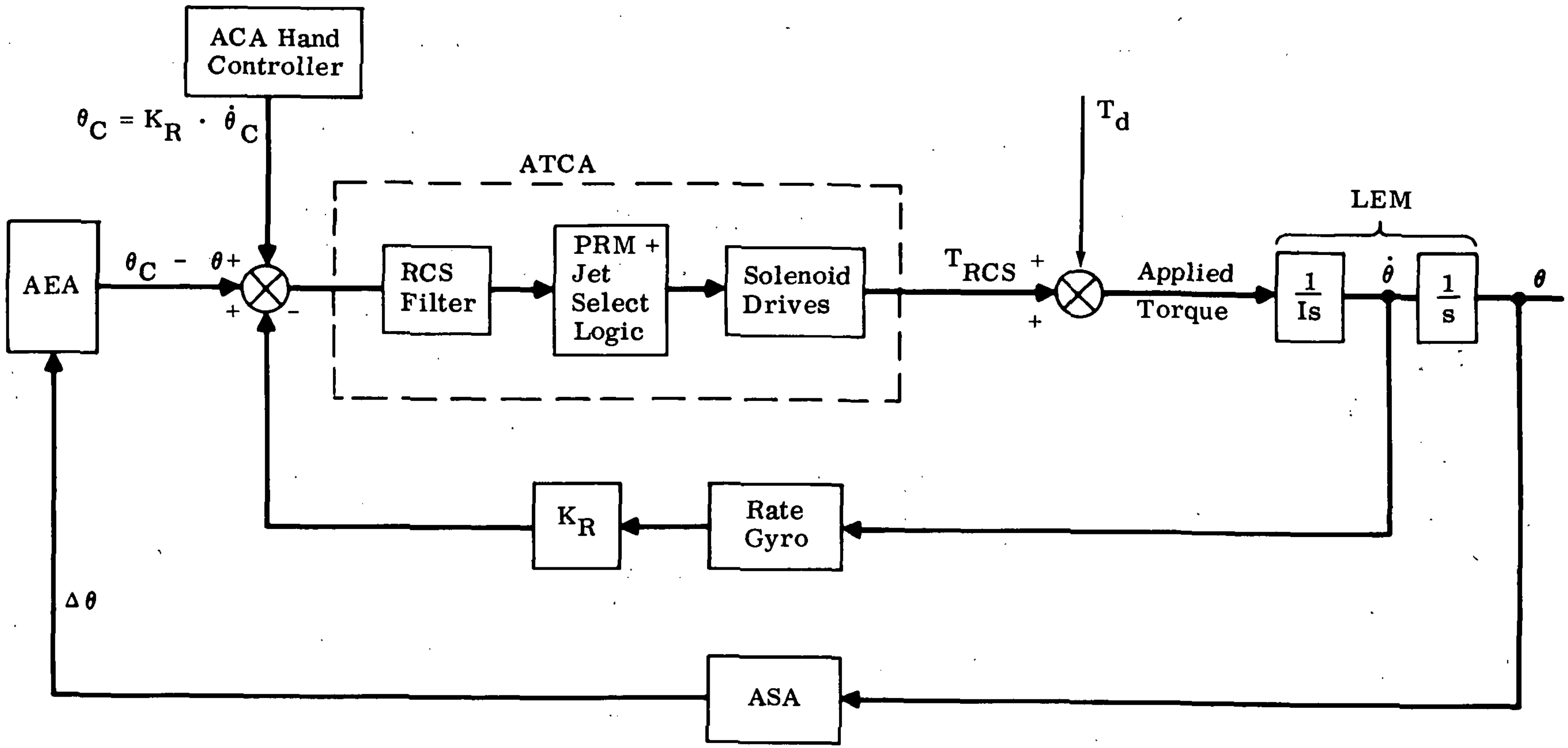


Fig. 4.2-1 AGS Control System

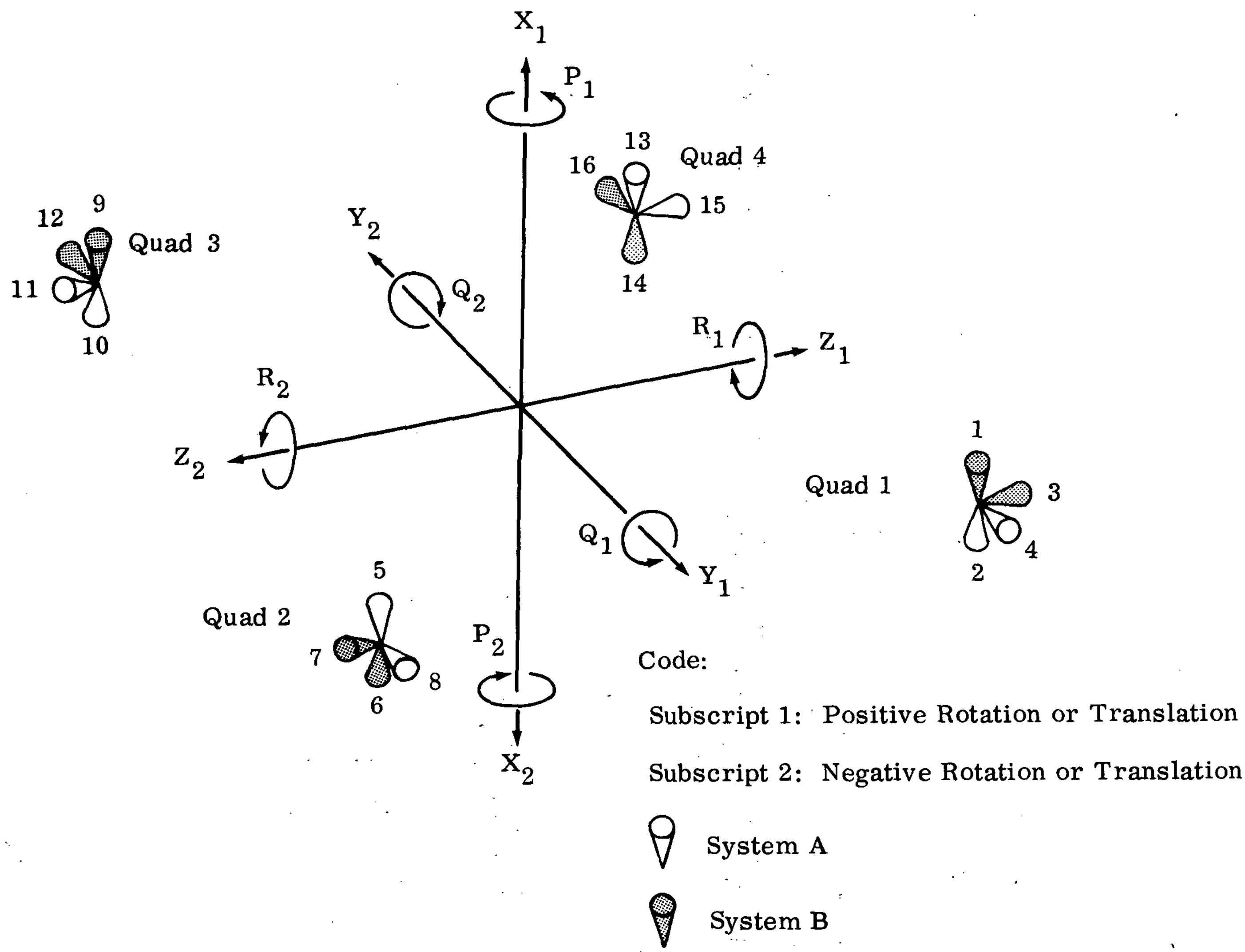


Fig. 4.2-2 RCS Jet Thruster Configuration

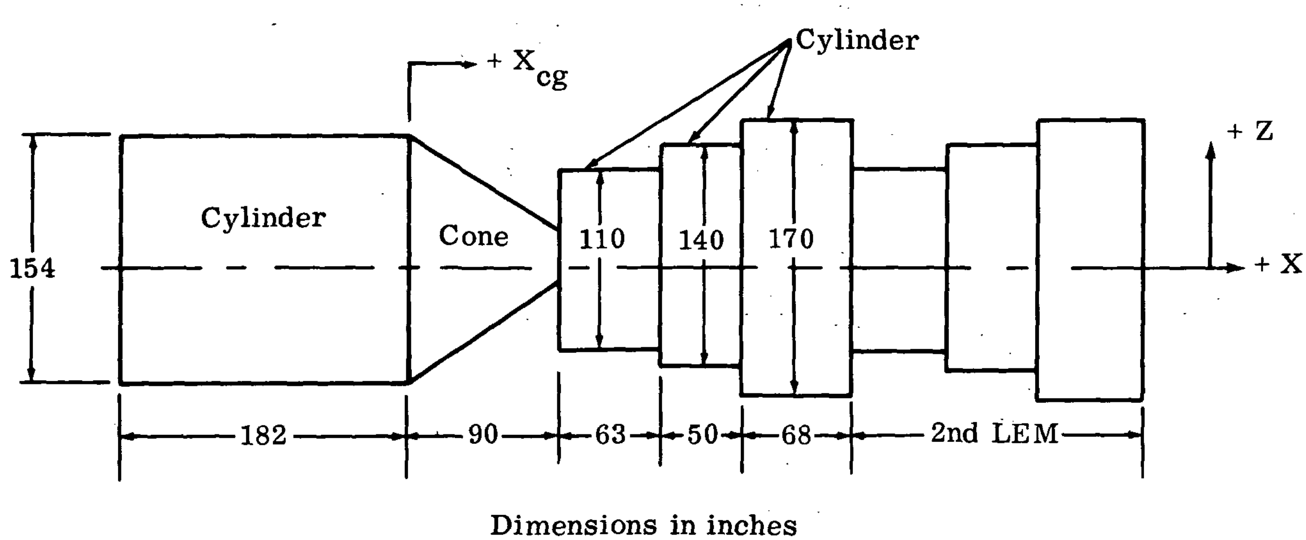


Fig. 4.2-3 Idealized AES-LEM-LAB Configuration

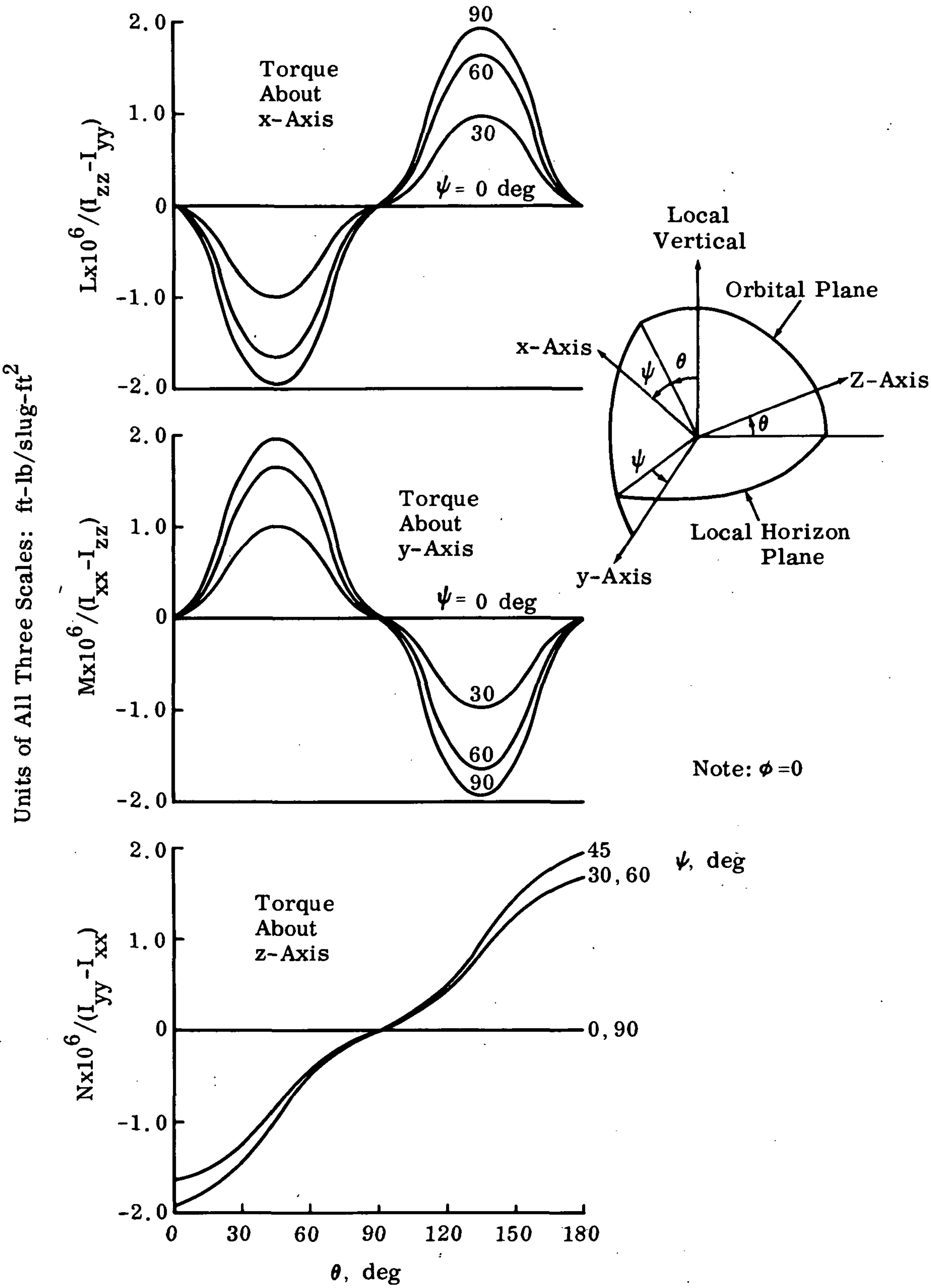
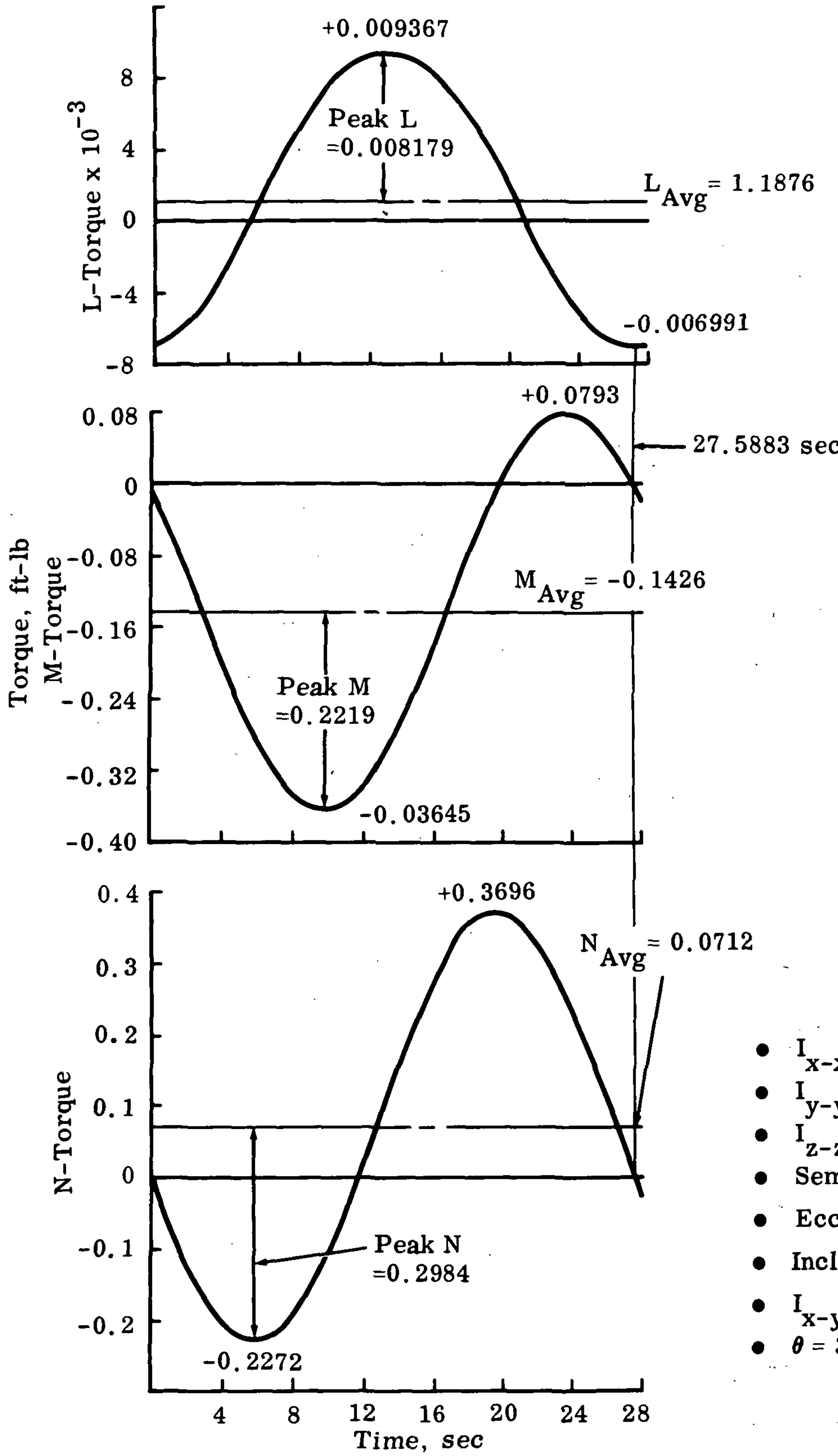


Fig. 4.2-4 Gravity Gradient Torques Parameter



Notes:

- I_{x-x} = 40,629 slug-ft^2
- I_{y-y} = 237,530 slug-ft^2
- I_{z-z} = 235,720 slug-ft^2
- Semi-major Axis = 2.2142×10^7 ft
- Eccentricity = zero
- Inclination = 28.5 deg
- $I_{x-y} = I_{y-z} = I_{z-x}$ = zero
- $\theta = 30$, $\psi = 90$, ϕ = zero deg

Fig. 4.2-5 Gravity Disturbance Torques

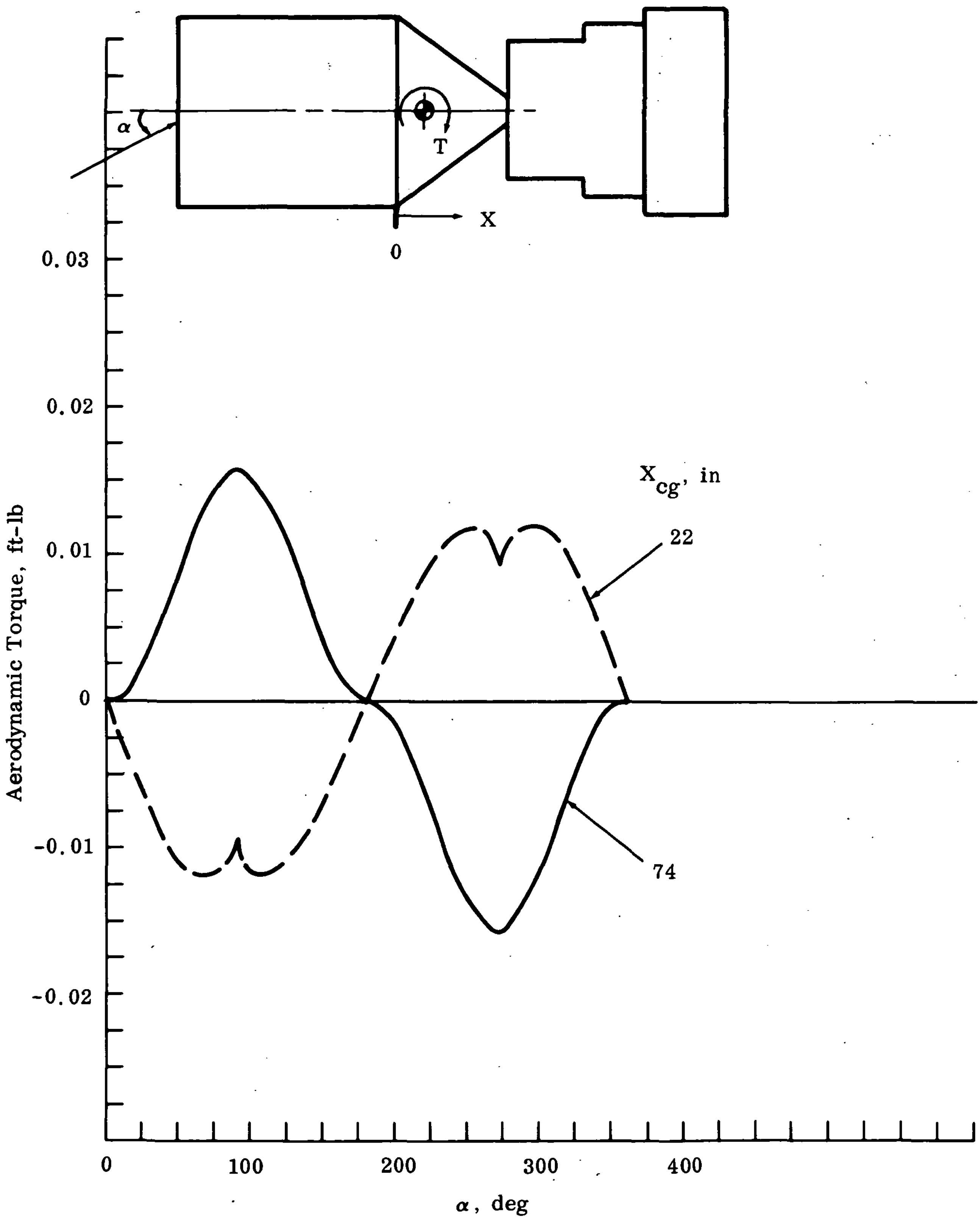


Fig. 4.2-6 Aerodynamic Torques

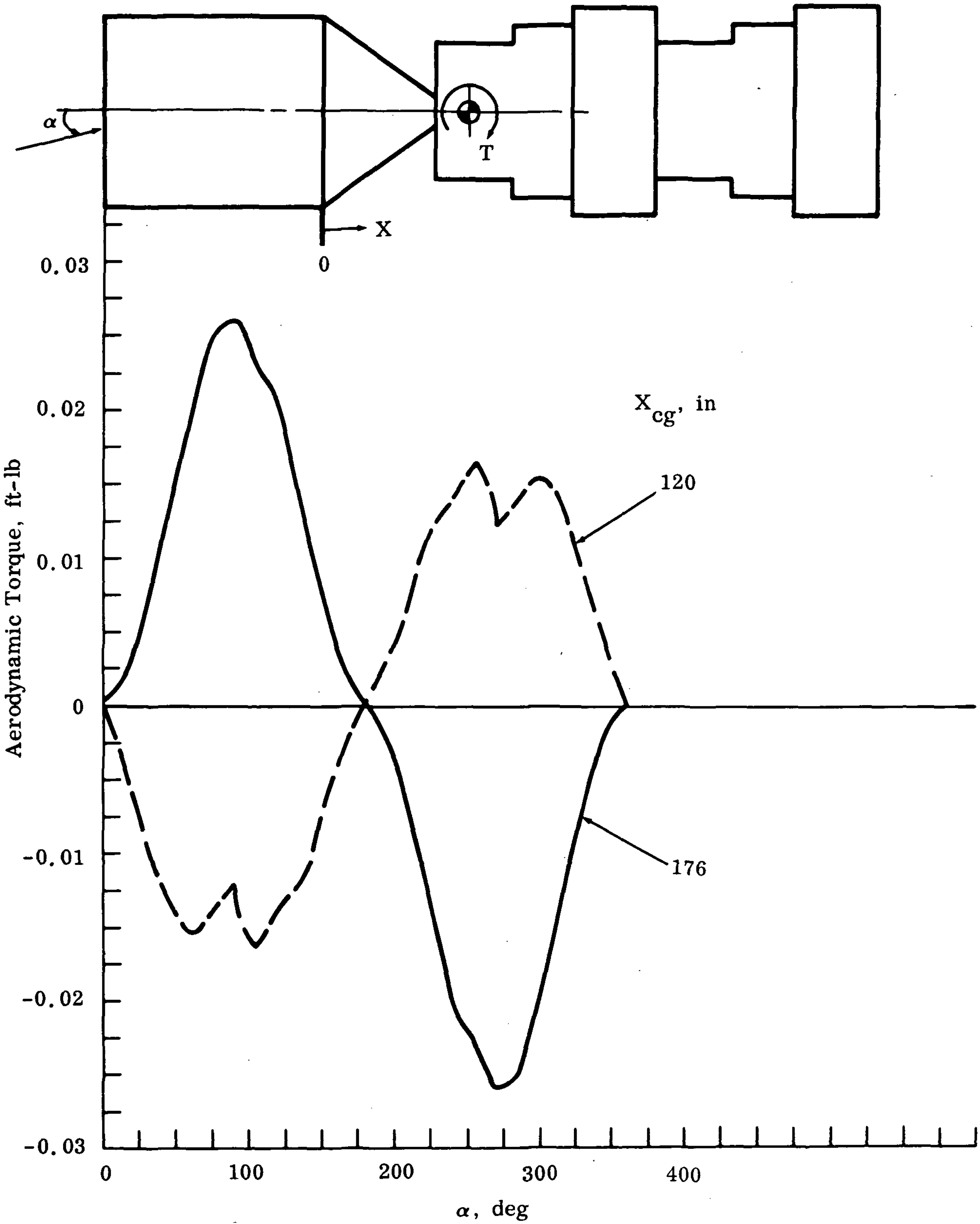


Fig. 4.2-7 Aerodynamic Torques

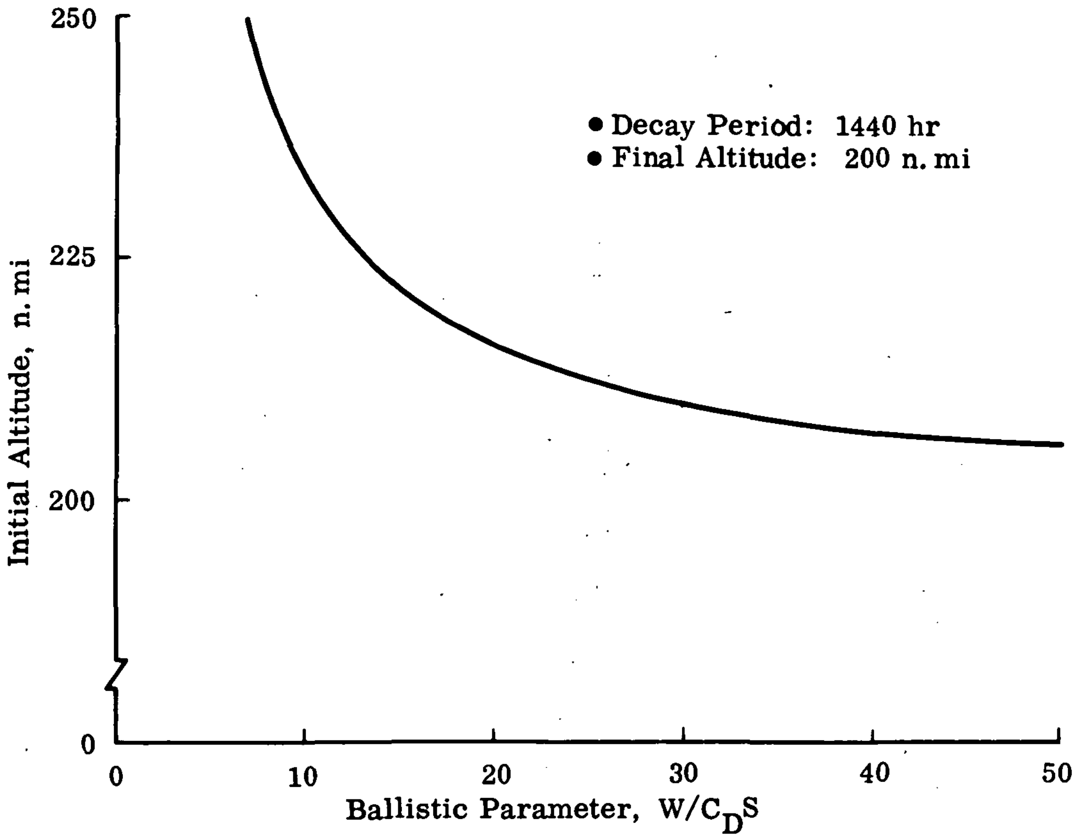


Fig. 4.2-8 Orbital Decay, Earth LEM Lab

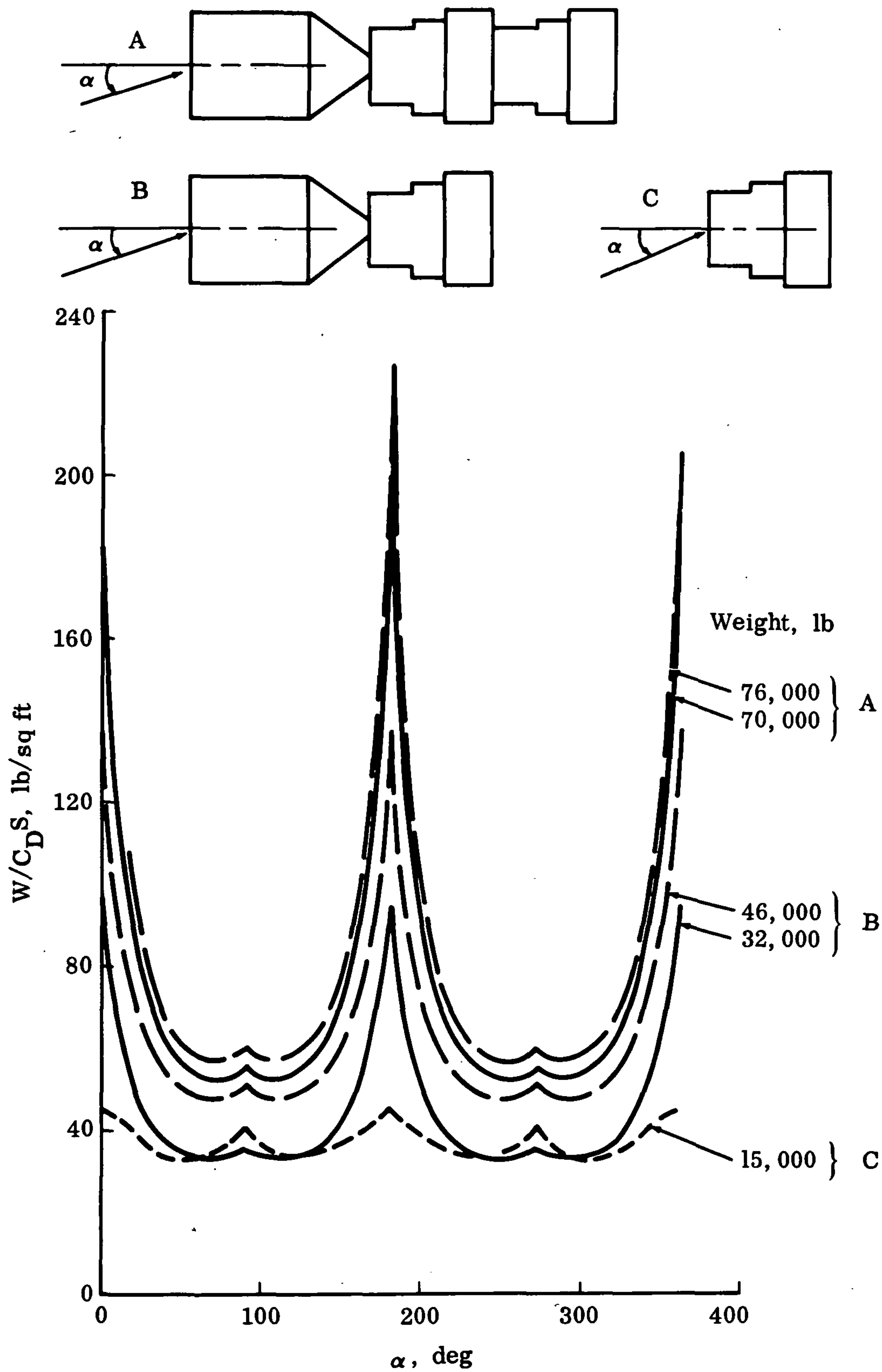


Fig. 4.2-9 Ballistic Parameters for Several CSM-LEM Configurations

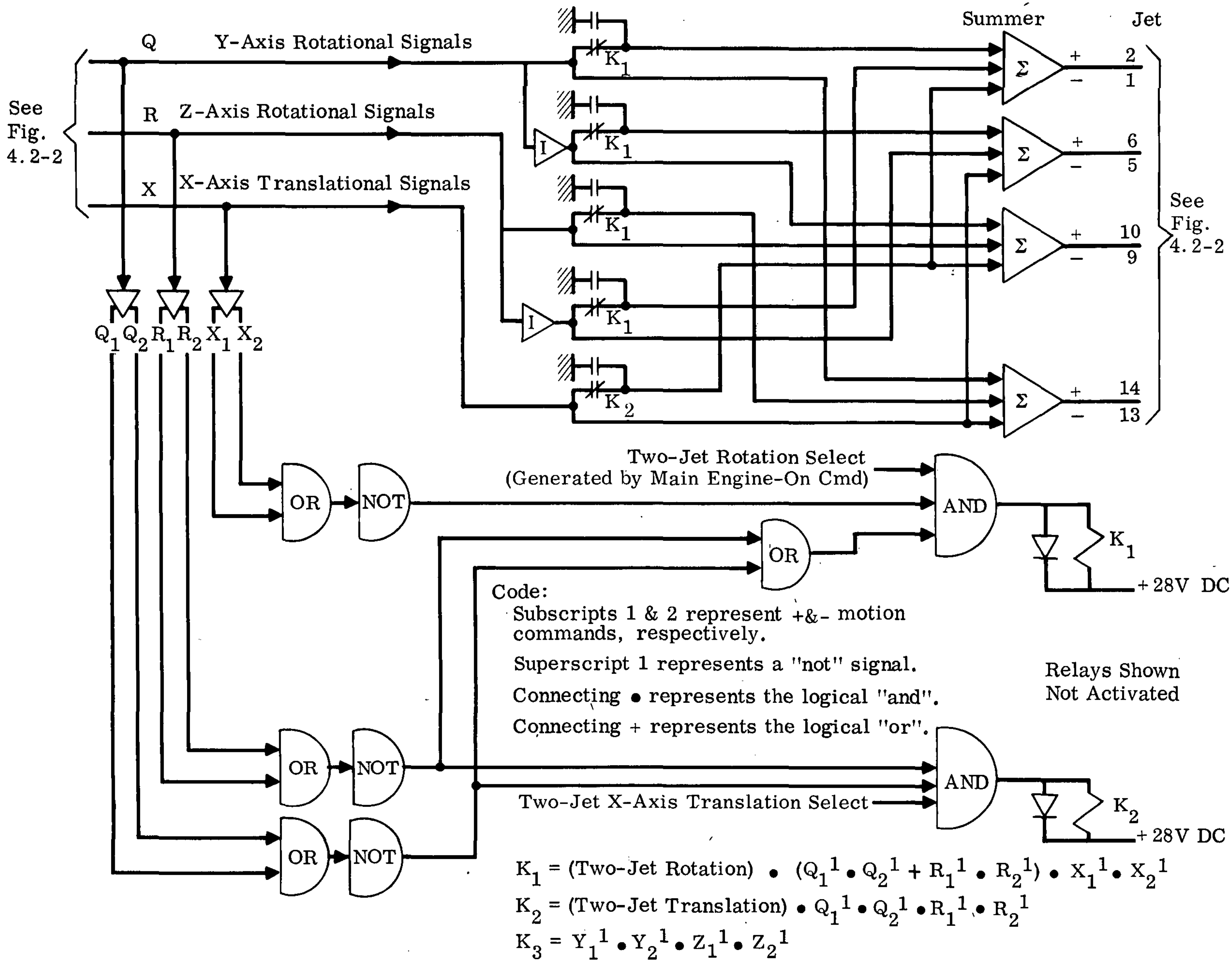


Fig. 4.2-10a Symbolic Logic RCS Vert Jet Select Attitude & Translation Control

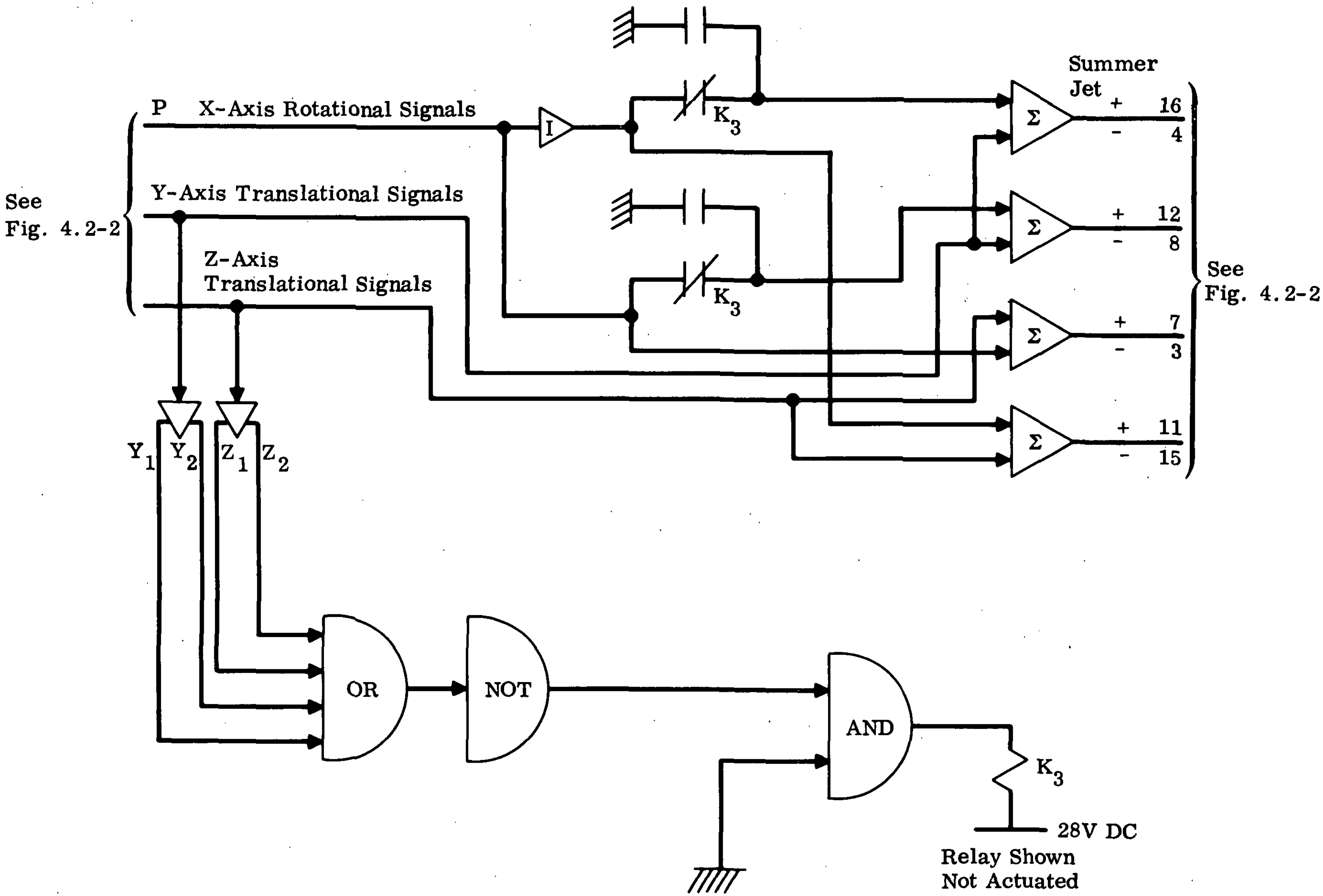


Fig. 4.2-10b Symbolic Logic RCS Horiz Jet Select Attitude & Translation Control

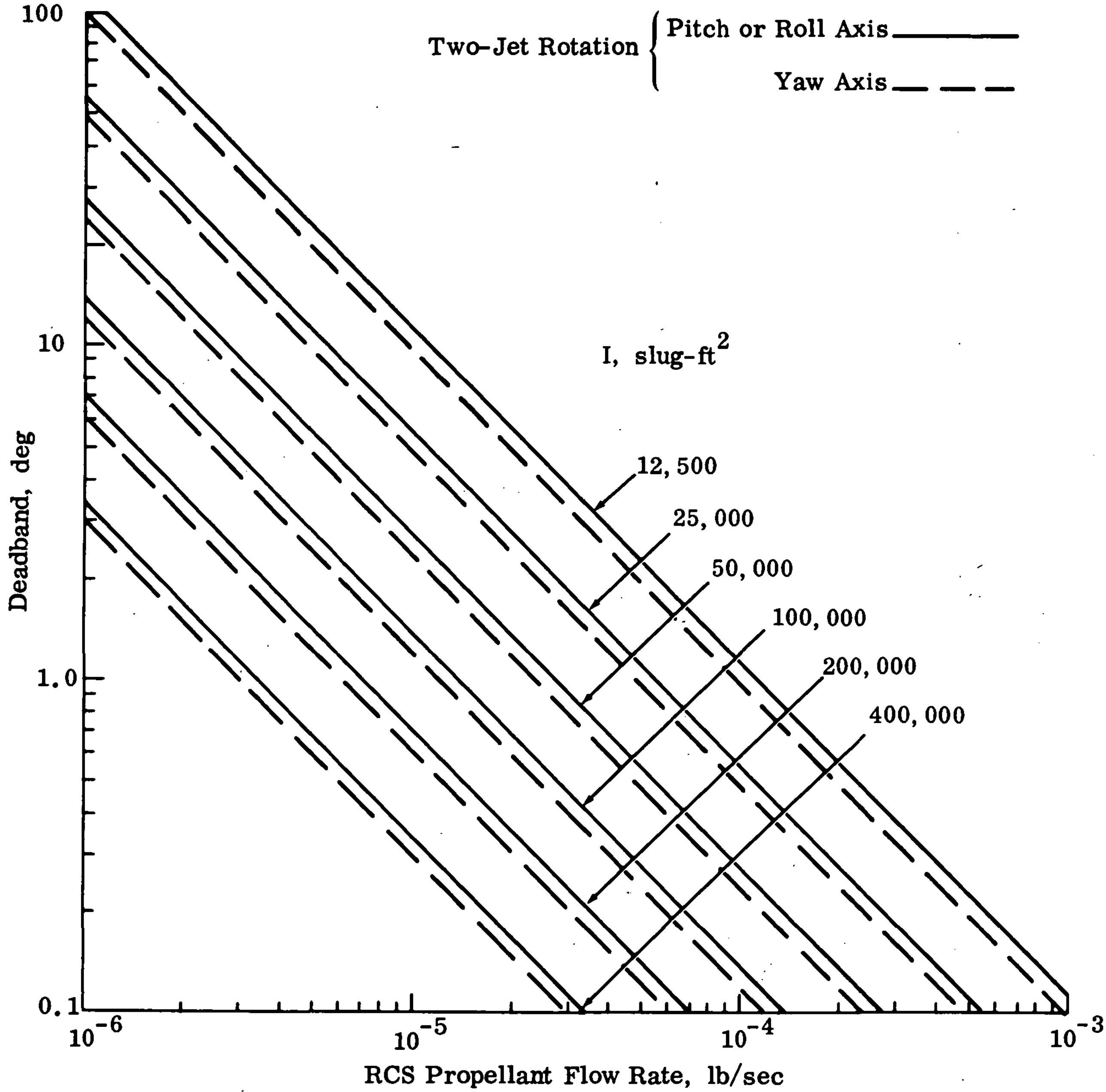


Fig. 4.2-11 Normal Limit Cycle Propellant Flow Rate

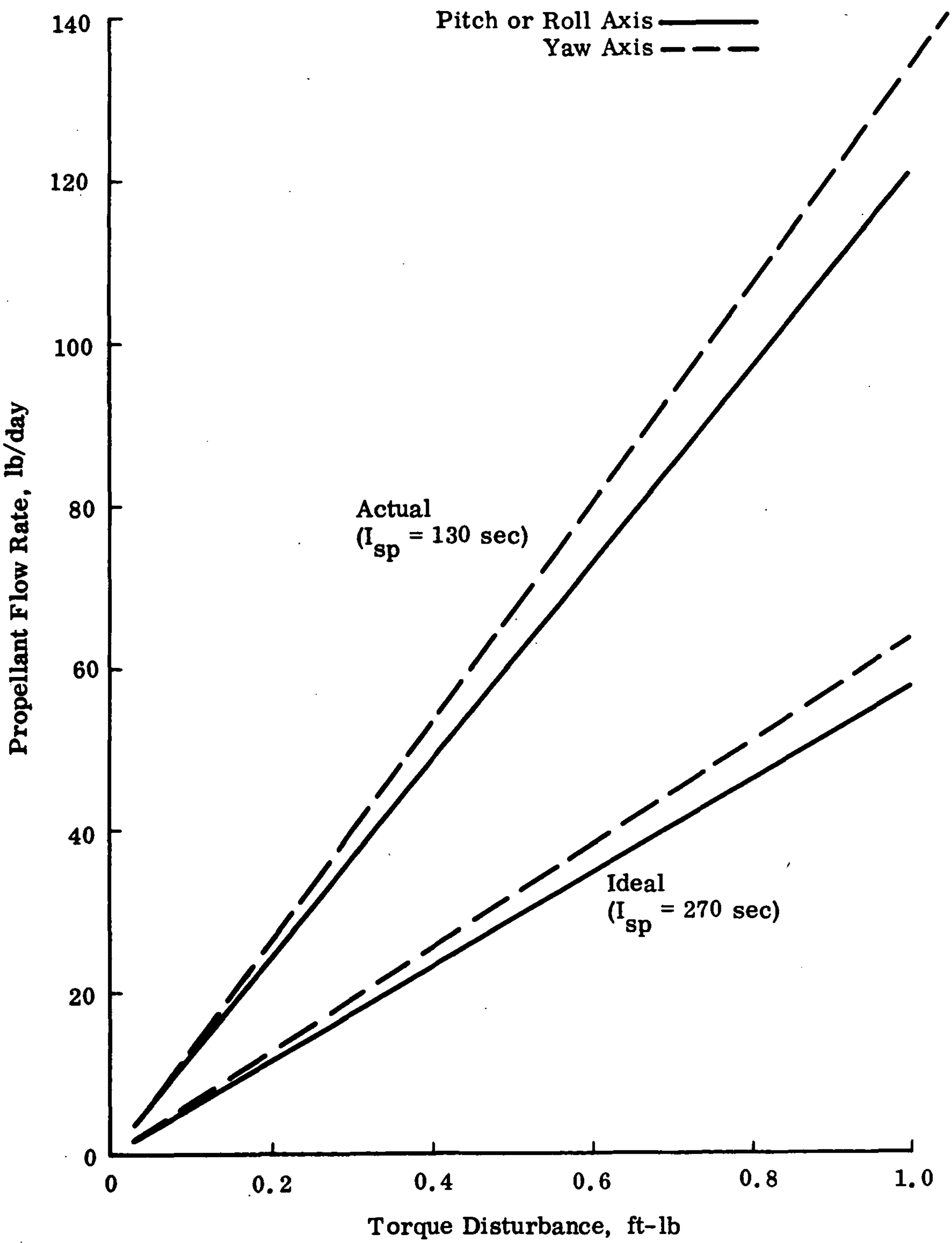


Fig. 4.2-12 Torque Disturbance vs Propellant Flow Rate

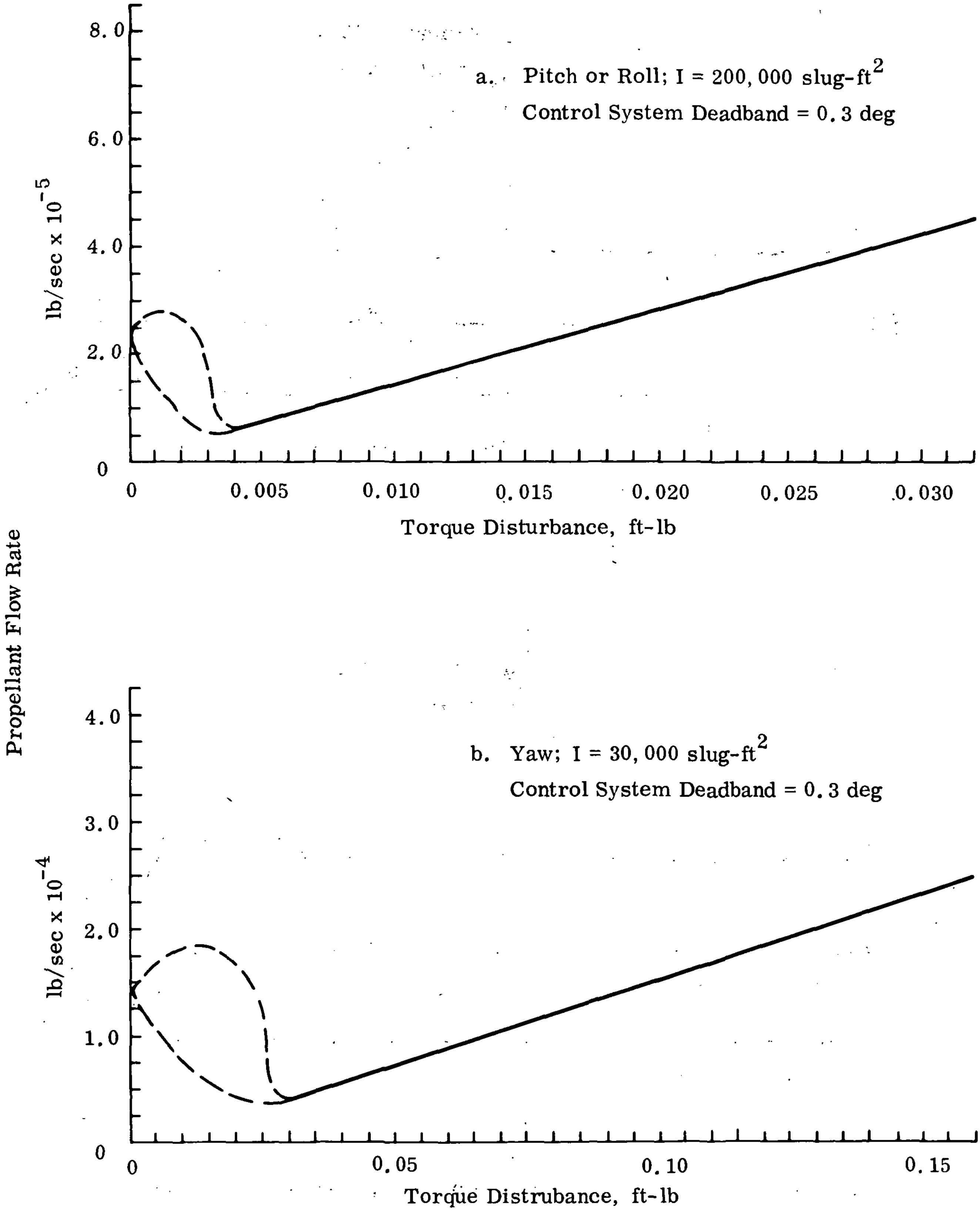
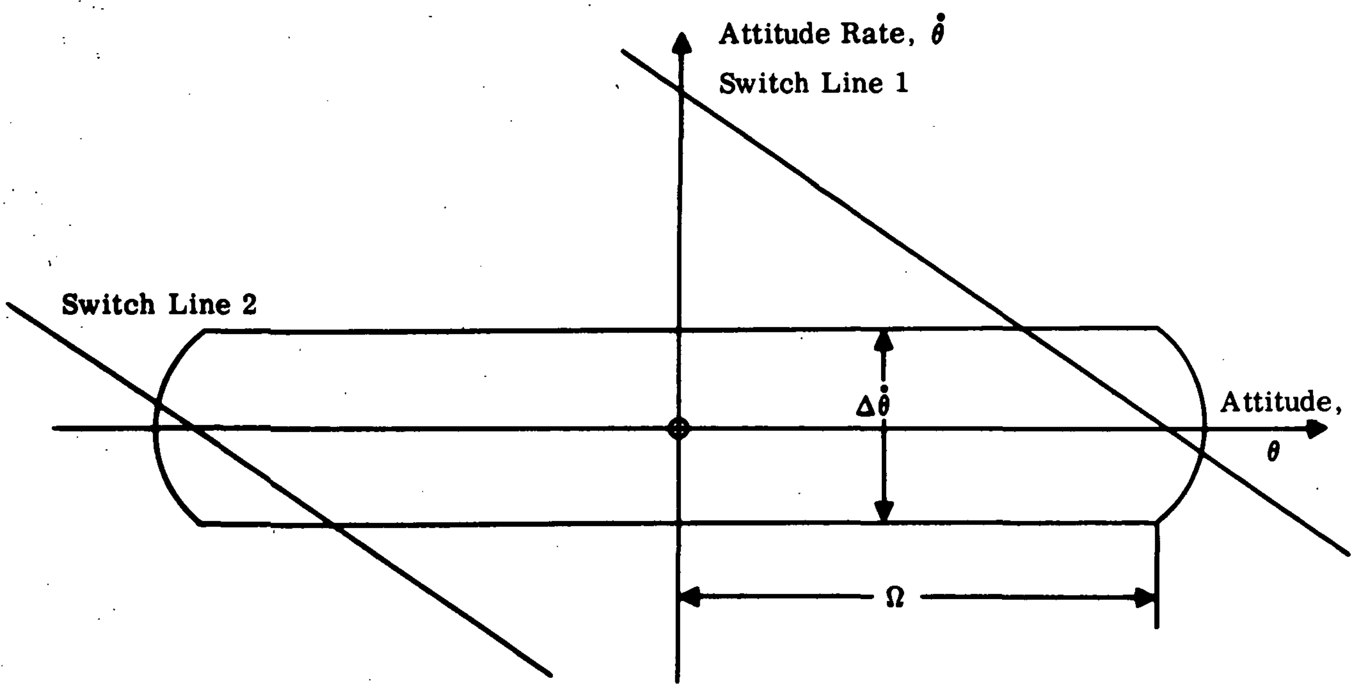
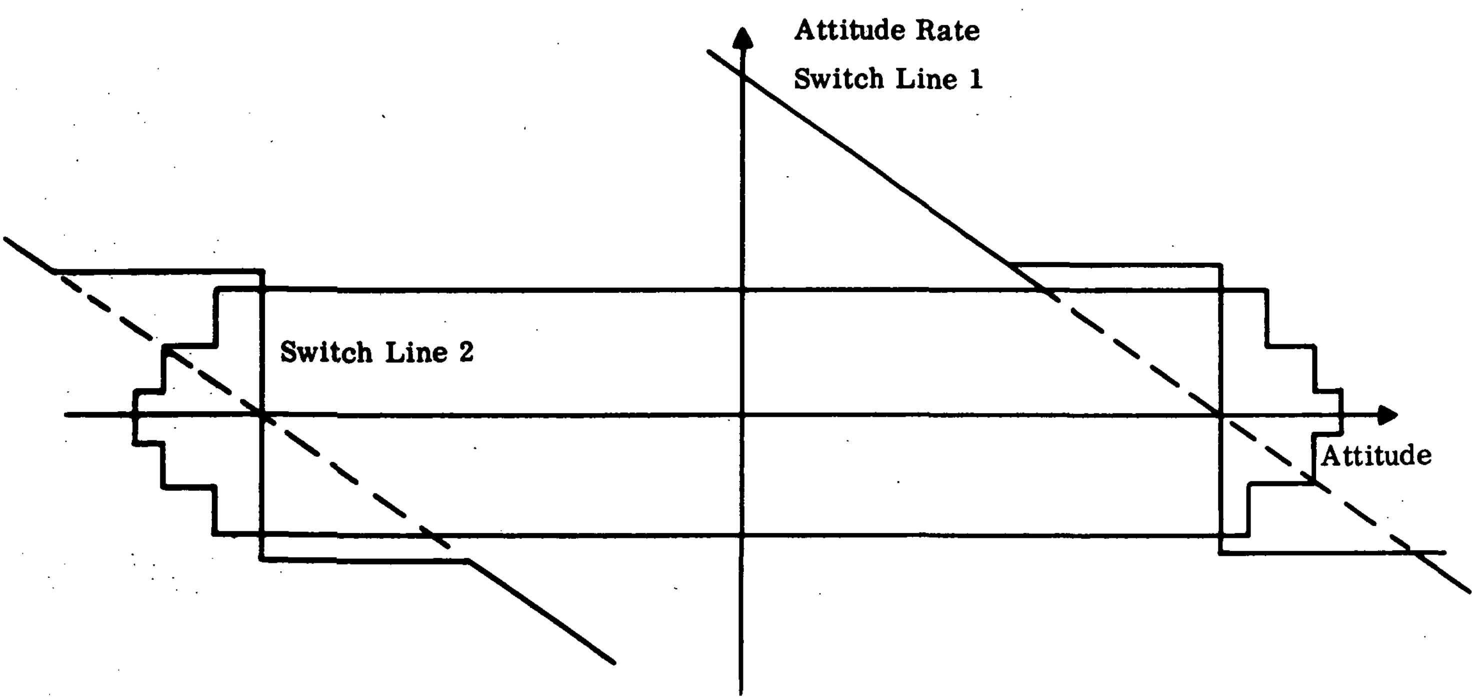


Fig. 4.2-13 Torque Disturbance vs Propellant Flow Rate



a) Normal Limit Cycle Operation



b) Normal Limit Cycle Operation Within Rate Gyro Deadzone (Threshold)

Fig. 4.2-14a/b Typical Limit Cycle for Normal and Disturbed Conditions

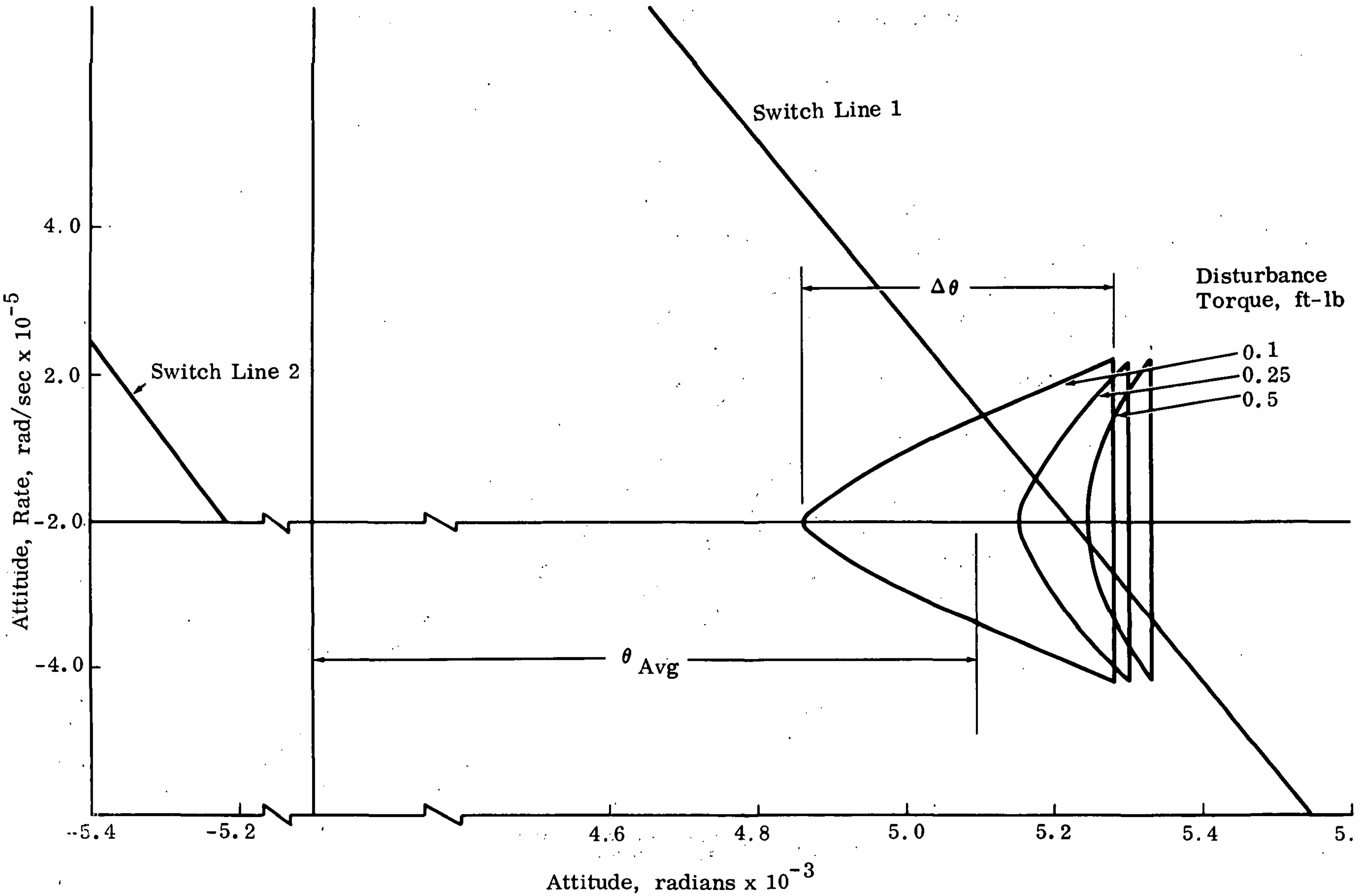


Fig. 4.2-14c Typical Limit Cycle for Normal and Disturbed Conditions

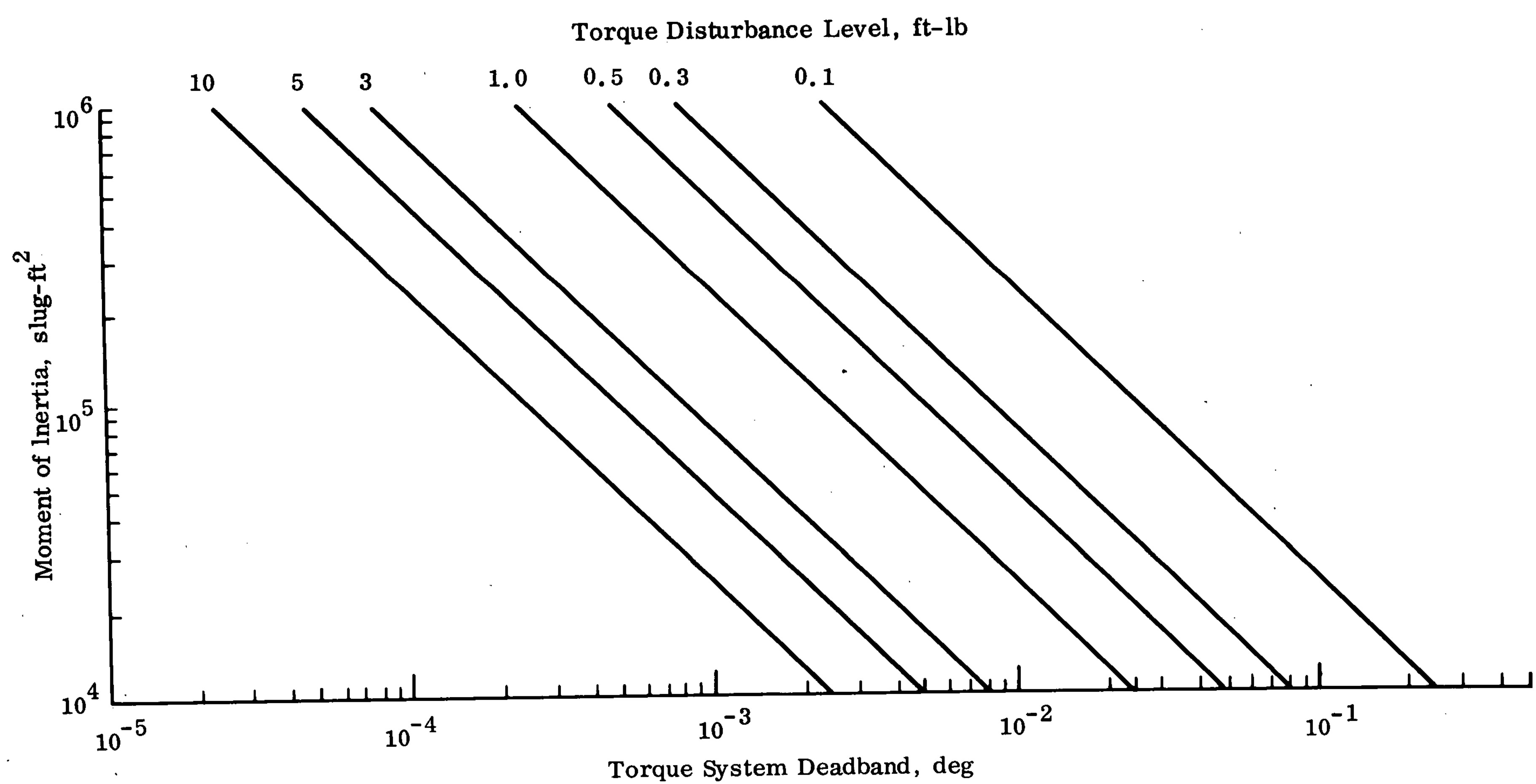


Fig. 4.2-15 Loci for Determining Switch Line 2 Intersection for Disturbed Limit Cycle Shown in Fig. 4.2-14C

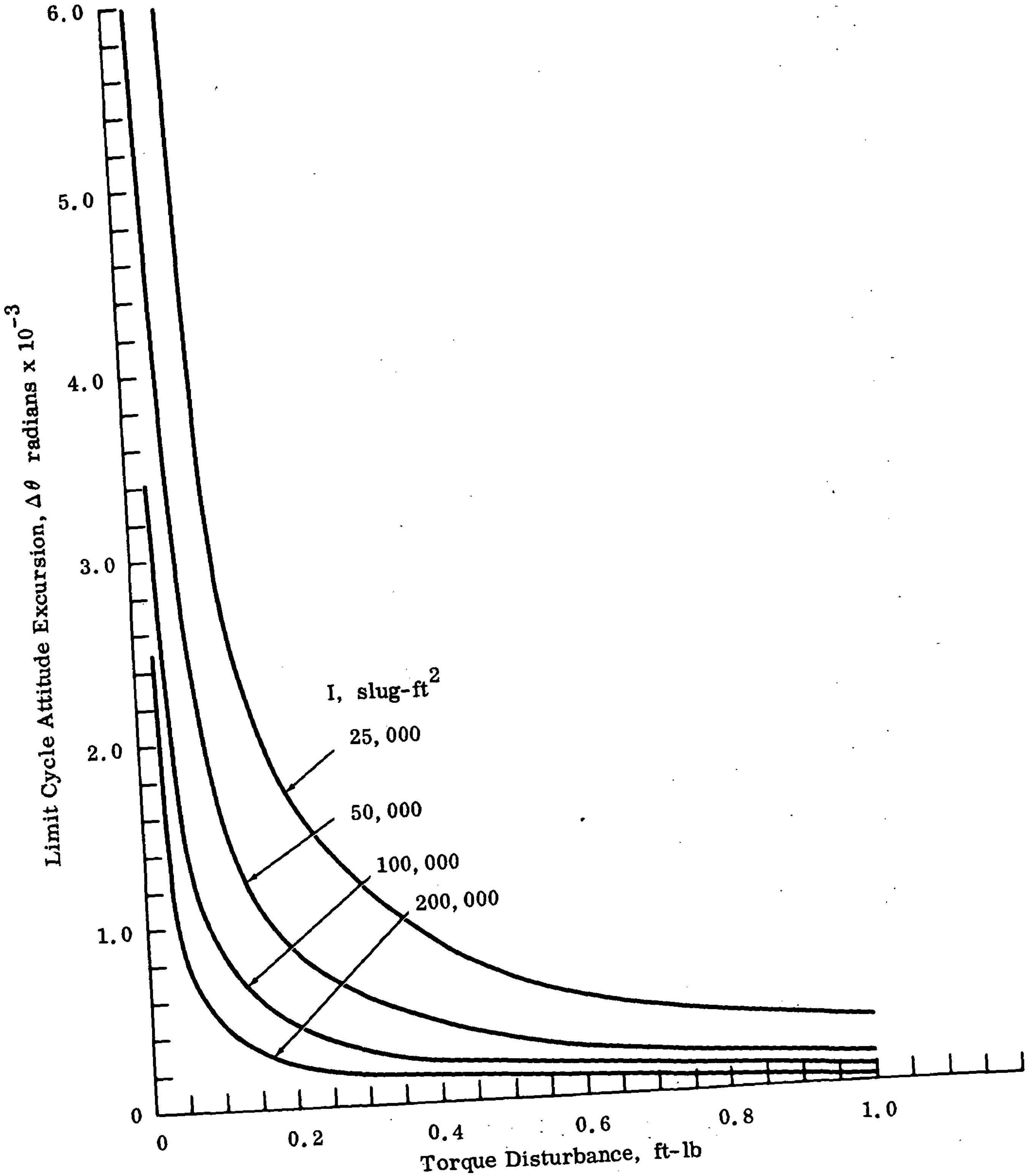


Fig. 4.2-16 Torque Dist vs Limit Cycle Attitude Excursion Two Jet Rotation

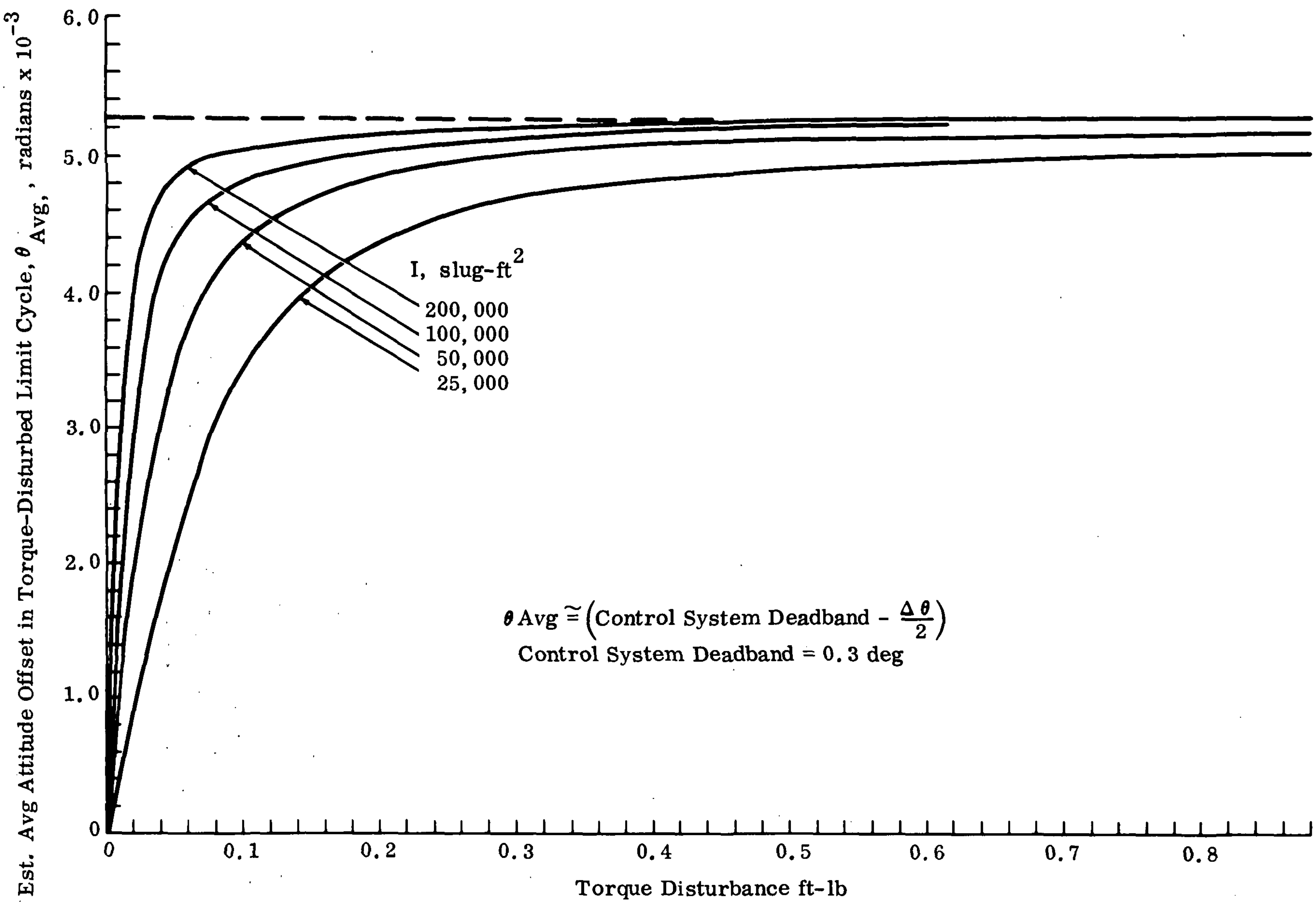


Fig. 4.2-17 Torque Disturbance vs Average Attitude Offset

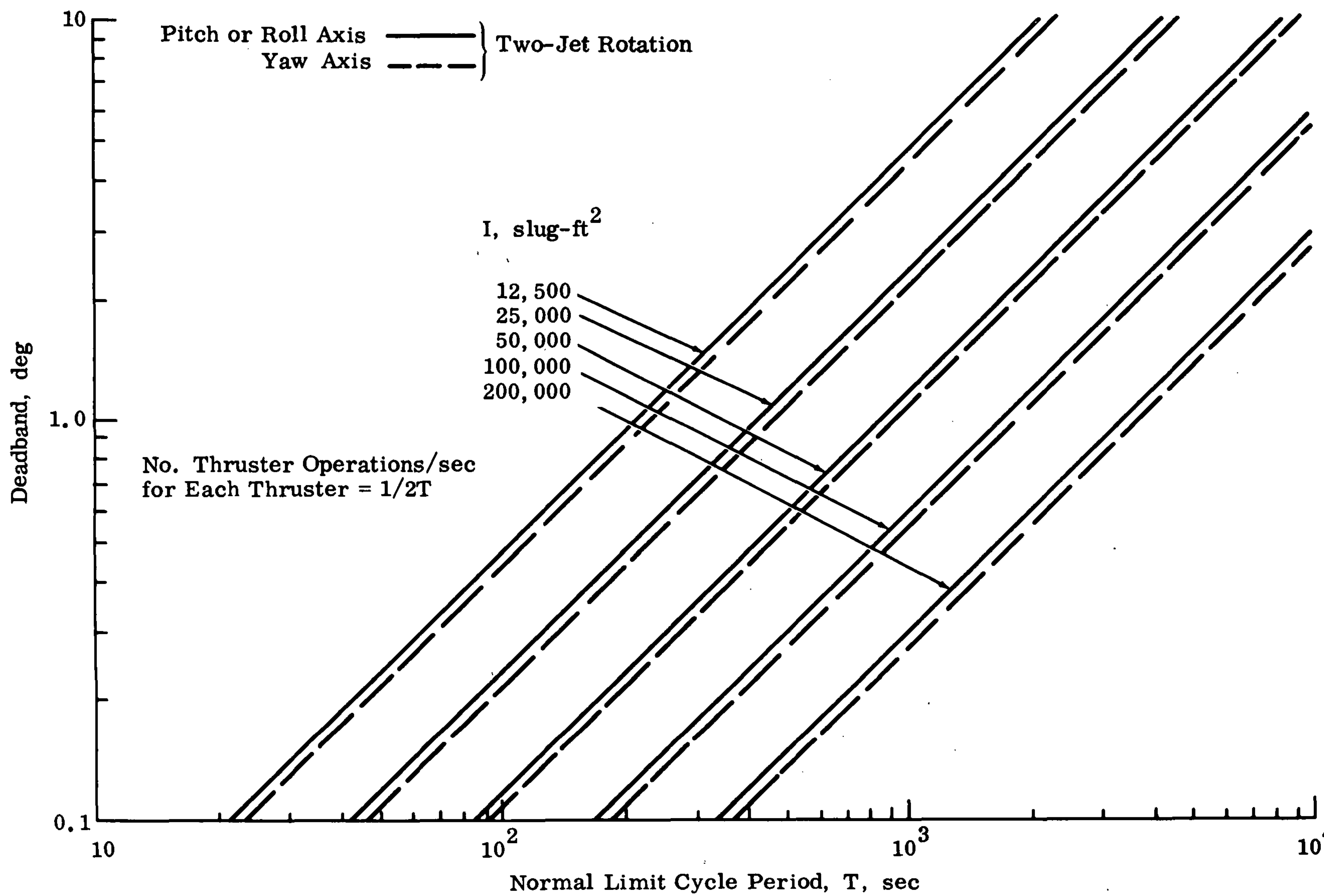


Fig. 4.2-18 Normal Limit Cycle Period vs Control System Deadband

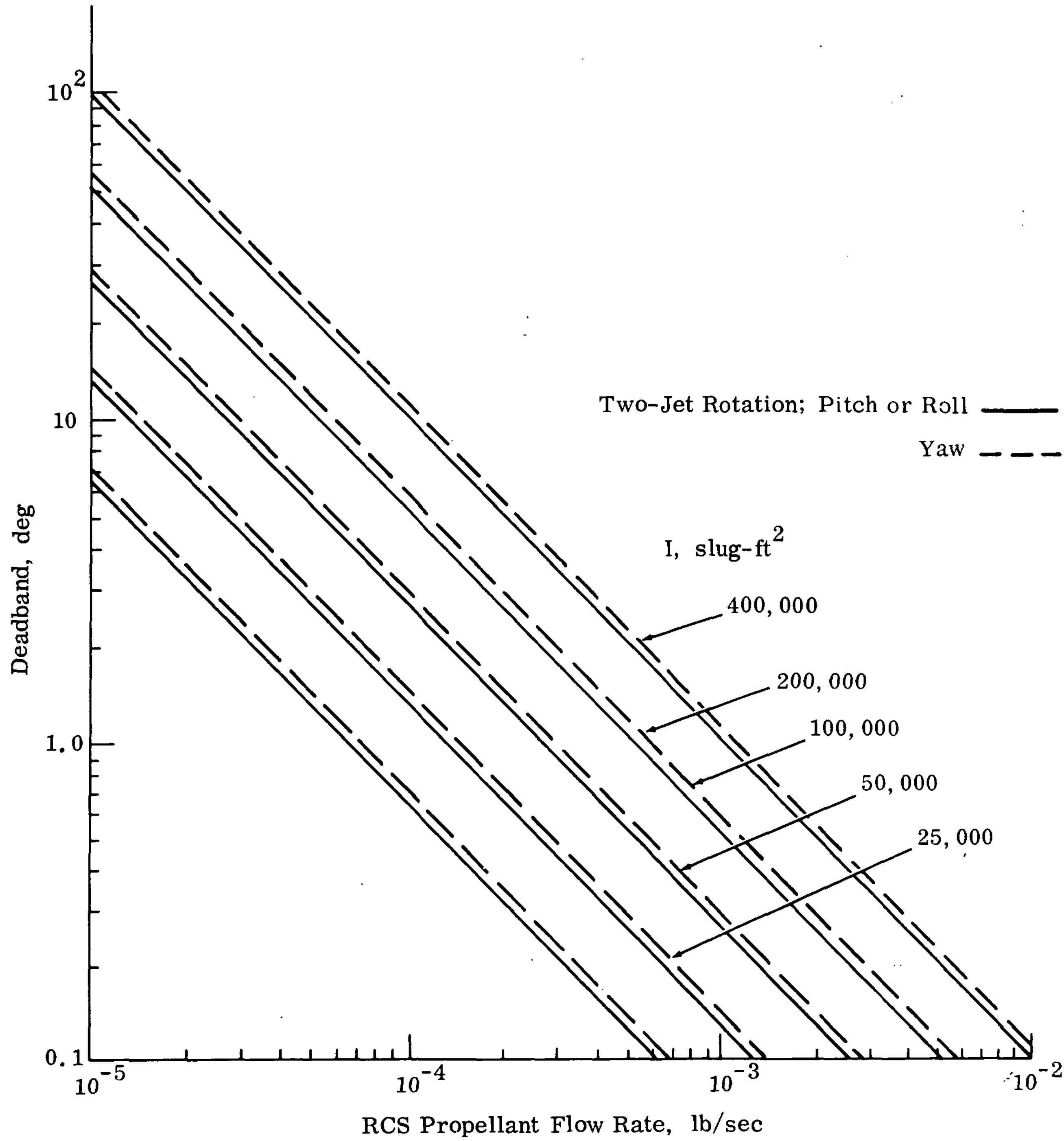


Fig. 4.2-19 Maximum Normal Limit Cycle Propellant Flow Rate vs Control System Deadband for I >25,000 Slug - Ft^2 and Rate Gyro Threshold of 0.01 Deg/Sec

4.3 REACTION CONTROL AND PROPULSION

4.3.1 Assumptions

- The Lab shall be used exclusively for attitude hold
- Two deadzone settings are available: ±0.3 deg and ±0.5 deg
- Gyro rate threshold sensitivity is compatible with the vehicle mass properties unless otherwise specified.
- The Marquardt 100 lb thruster performance is as follows:

  Minimum impulse (standard conditions) = 0.75 ± 0.15 lb. sec.

  Specific impulse (at minimum impulse) = 130 sec.

  O/F ratio (at minimum impulse) = 1.3
- Engine life time specifications:

  Burning time = 1000 sec total; 500 sec, Steady State; 500 sec Min Impulse Cycling

  Maximum Number of Cycles - 10,000
- Unmodified propellant tank capacity is 423 lb of usable propellant
- Modified (interchanged propellant tanks) tank capacity is 524 lb of usable propellant

4.3.2 Background Data

Propellant Tank Sizing For Phase II Labs - Estimated RCS propellant expenditure for undisturbed limit cycle operation is shown in Fig. 4.3-1 and 4.3-2. Two Rate Gyro thresholds are shown 0.001 deg/sec., and 0.01 deg/sec. The former threshold represents an order of magnitude increase in rate gyro sensitivity over that now available in the LEM Rate Gyro Assembly (RGA). The characteristics of the system which define the desirability of modifying the rate gyro threshold are defined in Paragraphs 4.2 and 5.3.

The RCS propellant consumption shown assumes attitude hold is required 100% of the mission time; part of the time at ±0.3 deg, and the remainder at ±5.0 deg. Figures 4.3-3 and 4.3-4 show RCS propellant consumption for attitude holds only at ±5.0 or ±0.3 deg for an 0.001 deg rate gyro threshold. Figure 4.3-5 gives the same information for a 0.01 deg. rate threshold. Note that all propellant consumption quoted assumes attitude hold about all three axes. Two sets of propellant tanks will provide a capability of 0.3 deg limit cycling for the entire mission with ideal rate sensing (0.001 deg/sec rate threshold) provided no disturbance torques are present. Retention of the current RGA, (0.01 deg/sec rate threshold) results in approximately a fifteen fold increase in RCS propellant consumption. Table 4.3-1 summarizes RCS attitude hold capability using either an unmodified RGA (0.01 deg/sec rate threshold) or a modified RGA with a rate threshold of 0.001 deg/sec. Further discussion on rate threshold effects is given in Paragraph 4.2.

4.3.3 Recommended Configuration

Based on the current LEM RCS propellant tank system, the maximum utilization of propellant in limit cycle mode (minimum impulse, O/F = 1.3) is 423 lb. If the oxidizer and fuel tanks are interchanged, the maximum propellant utilization increases to 524 lb (1048 lb for two sets of tanks). Estimated RCS propellant expenditure during disturbed inertial attitude hold operation is shown in Fig. 4.3-6. The minimum torque values at which these data are valid are given in Paragraph 4.2 (Fig. 4.2-15). The time average of external torque disturbances for Phase II Lab 200 n. mi missions is currently estimated to be between 0.2 and 0.3 ft-lb. The effect of internal disturbance torques, however, has not been analyzed. A precise knowledge of both CSM and Lab operations will be required for this analysis.

4.3.3.1 RCS Contingency Requirements

The above data, considered a good estimate of propellant requirements, are based on a limited amount of data on experiment payload, vehicle design, pointing requirements and disturbance torques. The normal limit cycling rate about a vehicle axis for moments of inertia above 23,500 slug ft^2 is a function of engine minimum impulse bit. Above this value " Gyro Rate Bias " exists wherein the propellant flow is determined by rate gyro sensitivity. The minimum impulse bit of the Marquardt RCS engine, although bracketed by an estimate, is undefined. Within tolerance limits the engine minimum impulse bit may vary between 0.35 and 1.45 lb sec. This variation includes engine to engine performance, power supply voltage, system pressure and environmental changes. The upper limit of minimum impulse bit is the most severe condition for limit cycle operation, possibly quadrupling the propellant flow rate (from rates shown in Fig. 4.3-1 through 4.3-5). An analysis of tolerance limit engine performance will be undertaken in Phase C.

As discussed in Paragraph 4.3.3 the addition of two sets of tanks to the present LEM system, and the reversing of the fuel and oxidizer lines, provides sufficient propellant (1048 lb) to maintain fine attitude control for the entire mission. This is true if no disturbance torques are present and if improved rate sensing (0.001 deg/sec) is provided. This is the recommended system.

4.3.3.2 Feed System Dynamics

The influence of feed system dynamics upon reaction control engine performance has been studied using the basic tools developed for the LEM RCS.* The reaction control system for the Labs will be used exclusively for attitude hold; therefore, the engines will be operated in a mode which requires one or more minimum impulse bits upon command. The results reported below use the computer mode for dynamic interaction developed for the LEM RCS. The duty cycle for all pulse modes was 10 ms "on-time" followed by 130 ms "off-time" (see Fig. 4.3-7). There are six possible operational modes for the RCS:

- Single Engine Firing a Single Pulse: The total impulse developed from the single pulse is reproducible from pulse to pulse as long as the time between pulses is greater than the time required for the feed system to return to equilibrium. The dynamic model of the RCS indicates that the time to return to equilibrium depends on the physical position of the engine in the system but is on the order of 0.500 seconds.
- Single Engine Firing Multiple Pulses: In the example analyzed, the total impulse of each pulse was not the same; the deviation being about 20% between the largest and smallest impulse bit. The total impulse produced by an RCS jet after the first pulse is in part a function of the time between pulses and the physical position of the engine in the system.

* Dynamic Interaction Analysis and Computer Model - LEM Reaction Control Propulsion System, Volume 1, R. Bowlin, R. Rose, Advanced Technology Laboratory Report, General Electric Company, Schenectady, New York

- Two Engines Firing a Single Pulse in Phase: Figure 4.3-8 shows, as a function of time, the chamber pressure, Pc, and the total impulse of two engines firing a pulse in phase. The engines are those in the "A System" which are used for a +Z rotation. The chamber pressure-time trace shows that neither the peak chamber pressure nor the total impulse from each engine is the same. A secondary peak, probably caused by "water hammer" effects appears in each trace at different times.
- Two Engines Firing Multiple Pulses in Phase: Figure 4.3-9 shows, as a function of time, the chamber pressure and the total impulse of two engines firing multiple pulses in phase. The engines are those in the "A system" which are used for a +Z rotation. It should be noted that none of the three pulses of either engine give the same total impulse; the deviation between largest and smallest pulse being 28.7% for engine 10 and 40.2% for engine 13. While the total impulse for each additional pulse diminishes, the cumulative difference in total impulse increases with each succeeding pulse.

  Figure 4.3-10 shows, as a function time, chamber pressure and total impulse for engine 5 and engine 10 in the "A System"; these jets are used for -Y rotation. Engine 5 has less total impulse than engine 10 for the first pulse but has more on the succeeding pulses. There is a 40% deviation in total impulse between the largest and smallest pulse by engine 10 but only a 12% deviation for engine 5.

The following comments apply to each of the operational modes mentioned below:

- Two Engines Firing a Single Pulse or Multiple Pulses Not in Phase: Conceptually, to get a pure couple, two engines on either side of the vehicle must fire with the same total impulse at the same time. However, due to control system electronics, this situation rarely occurs. One engine fires slightly sooner than the other. From a vehicle control point of view, this will cause no problems; however, from a feed system dynamics point of view, this could cause considerable difficulty. The total impulse and peak chamber pressure is a strong function of the static pressure of the propellants at the engine valve. If the propellant valves on the second engine open just as the rarefaction wave caused by the first engine's valve movement passes, the static pressure may be so low that cavitation will occur. The second engine will be fed only gaseous propellant, and no firing will occur. Conversely, if the valve on the second engine opens just as a reflected wave is passing, the static pressure may be considerably higher than nominal and the engine will use more propellant and develop a musch greater than nominal impulse bit. Either of these situations is obviously bad. Provisions have been made to analyze these cases when the magnitude of the delays is made known.

4.3.4 Baseline Configuration

The baseline configuration is the same as the recommended Configuration

4.3.5 Alternate Configuration - Low Level Thrusters

Table 4.3-2 shows a summary of reaction jet performance of several low level thruster during disturbed limit cycle operation, with ideal rate sensing, compared to the LEM RCS. Minimum impulse bit and specific impulse of these thrusters reflect nominal, single engine, single pulse, engine performance. Multiple pulse operation results in approximately a 10% increase in minimum impulse bit and specific impulse. It should also be pointed out that clustered engine performance could significantly change the results shown. However, except for the LEM RCS thrusters, clustered performance is not available for any of the engines shown. The following general conclusions can be drawn from Table 4.3-2

- In undisturbed limit cycle operation, Marquardt's 5 lb thruster yields the greatest reduction in RCS propellant requirements, 99.6%. However, the corresponding decrease in vehicle angular rate of 93.3% is somewhat of a disadvantage since rate sensing, already a critical item on the Labs, must be improved significantly to realize any propellant performance improvement. This would probably entail a major modification to LEM's RGA.
- For disturbed limit cycle operation, the Marquardt 22 lb thruster yields the best performance for the level of disturbance torques considered for Phase II Labs. In disturbed limit cycle operation, for disturbance torques much smaller than the control torque, propellant flow rate is inversely proportional to engine specific impulse. Since the Marquardt 22 lb thruster yields the highest specific impulse it has the lowest propellant consumption in this mode of operation. Of the engines considered, this engine yields the best overall performance for both undisturbed and disturbed limit cycle operation. As with the 5 lb thruster, the percentage reduction in vehicle angular rate with this thruster will make it necessary to obtain greater rate sensing sensitivity than is now available (0.01°/sec) using the current RGA on LEM.
- Using LEM thrusters for disturbed limit cycle operation results in the largest vehicle period (vehicle period is directly proportional to minimum impulse bit), and the least number of engine cycles. However, for normal undisturbed limit cycle operation the reverse is true; it has the greatest cycle requirement and the shortest vehicle period.
- The Gemini 25 lb thruster yields significant propellant savings over the LEM RCS, 85.8% in undisturbed and 60.0% in disturbed limit cycle operation, but is limited in spec life to 425 seconds. For Phase II Lab Flights where a large amount of limit cycling might be required, this could be a limiting factor.

Table 4.3-1

SUMMARY OF RCS ATTITUDE-HOLD CAPABILITY

		Max Attitude Hold Duration, days			
		Sets of RCS Tanks			
		2 Unmod		2 Mod	
	Deadzone, deg	±0.3	±5.0	±0.3	±5.0
RGA Threshold, deg/sec	0.01 (Unmod)	5.26	86.4	6.52	107.0
	0.001 (Mod)	49.6	830.0	61.6	1026.0

$I_{x-x} = 30{,}000$ slug-ft^2

$I_{y-y} = I_{z-z} = 200{,}000$ slug-ft^2

Table 4.3-2

Comparison of Low-Level Thruster Performance
To LEM RCS Thruster

Performance Characteristics	LEM RCS, 100 lb	Gemini Thruster, 25 lb	Advent Thruster, 22 lb	Syncom Thruster, 5 lb
Manufacturer	Marquardt	North American	Marquardt	Marquardt
Steady-State Thrust, lb	100	25	22	5
Pulse Width, ms	10	20	10	10
Minimum Impulse Bit, lb-sec	0.75	0.35(est.)	0.22	0.05
Specific Impulse at Min Impulse Bit, sec	130	180-200	210	150-195
% Reduction in Propellant, Undisturbed/Disturbed	Base	85.8/60.0	94.7/62.0	99.6/11.5
% Reduction In Vehicle Angular Rate, Undisturbed	Base	53.3	70.7	93.3
% Change in Vehicle Period Undisturbed/Disturbed	Base	Incr/Decr 114/53.3	Incr/Decr 241/70.7	Incr/Decr 1400/93.3
Peak Torque, (L=5.5 ft, 2 Engines) ft, lb	1100	275	242	55
Engine Status	Now building production config for qual test	In production, TCA failure life 578 sec; spec life, 425 sec.	42 Configs of 10 engines built & tested Total starts 1 engine, 13,111. Max time from 1 engine, 219 min.	25 Chambers built & tested. Total accumulated time, 37,000 sec. Total no. of tests, 1150.

*Ref. 1: Letter to D. Pierce from Marquardt Corporation dated 8 September 1965 "Liquid Bipropellant Pulse - Rocket Engine Data"

2: McDonnell Spec. dated 14 June 1965

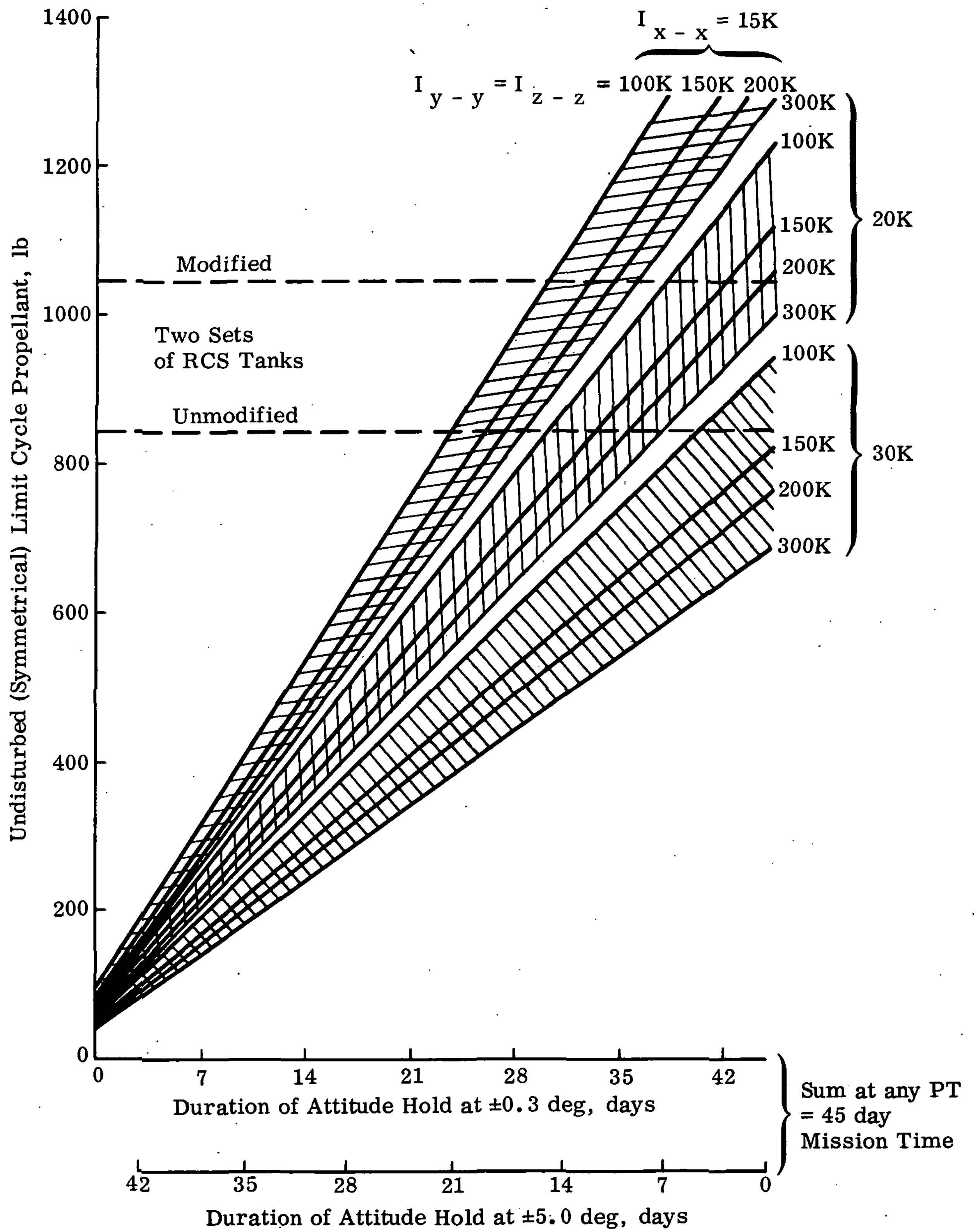


Fig. 4.3-1 Undisturbed Attitude Hold RCS Propellant Requirements .001 deg/sec Rate Threshold

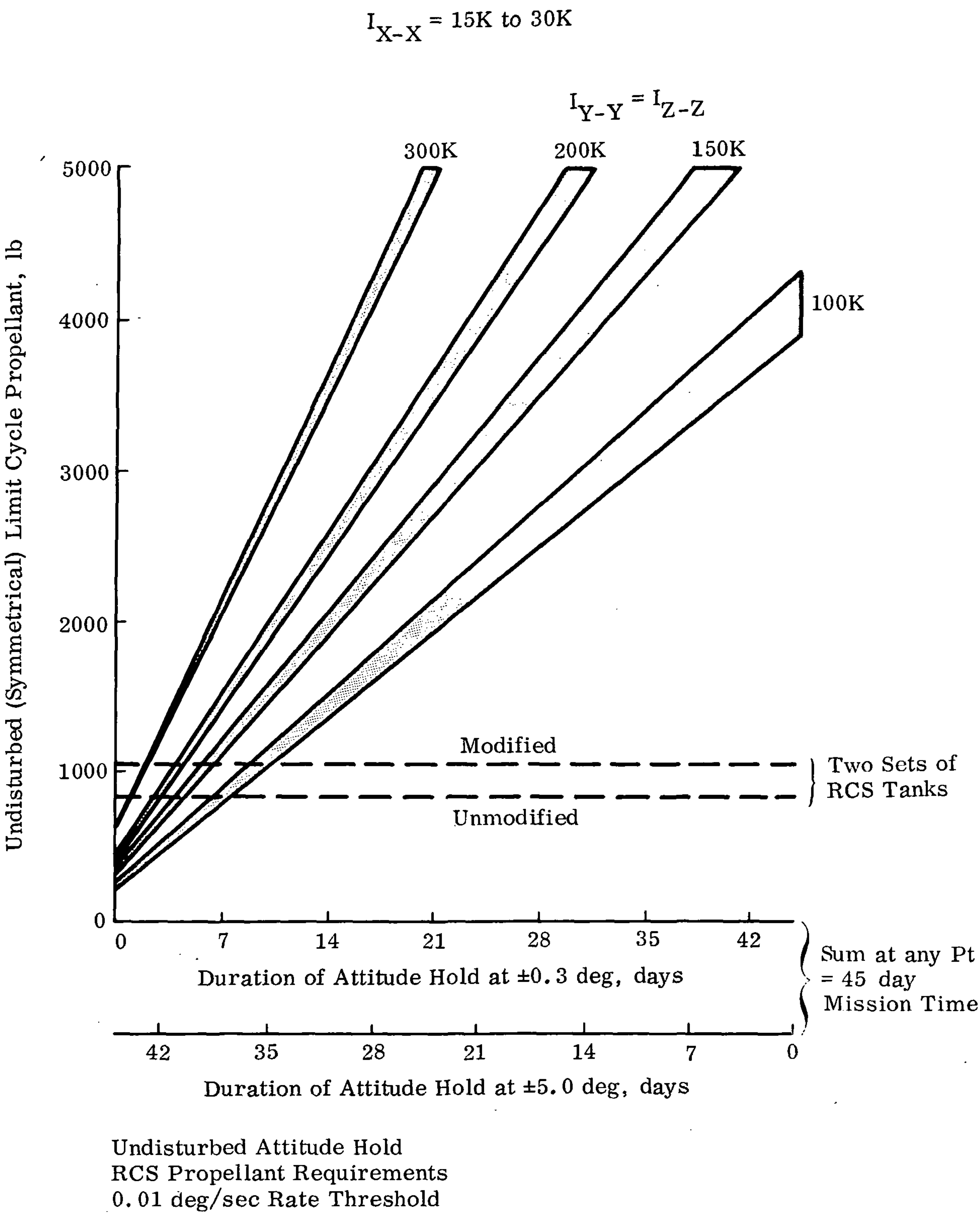


Fig. 4.3-2 Undisturbed Attitude Hold RCS Propellant Requirements 0.01 deg/sec Rate Threshold

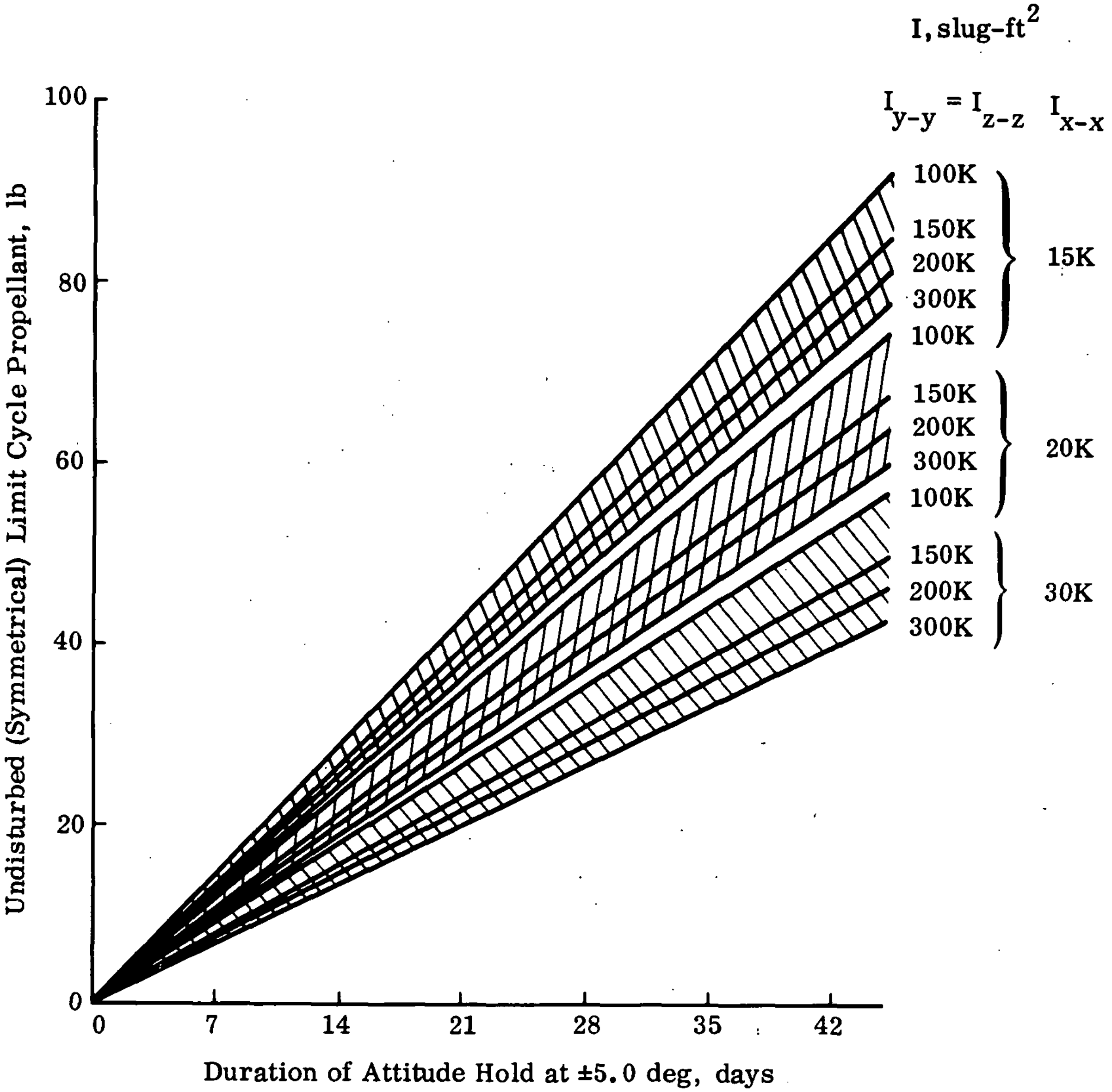


Fig. 4.3-3 Undisturbed Limit Cycle RCS Propellant Requirements .001 deg/sec Rate Threshold

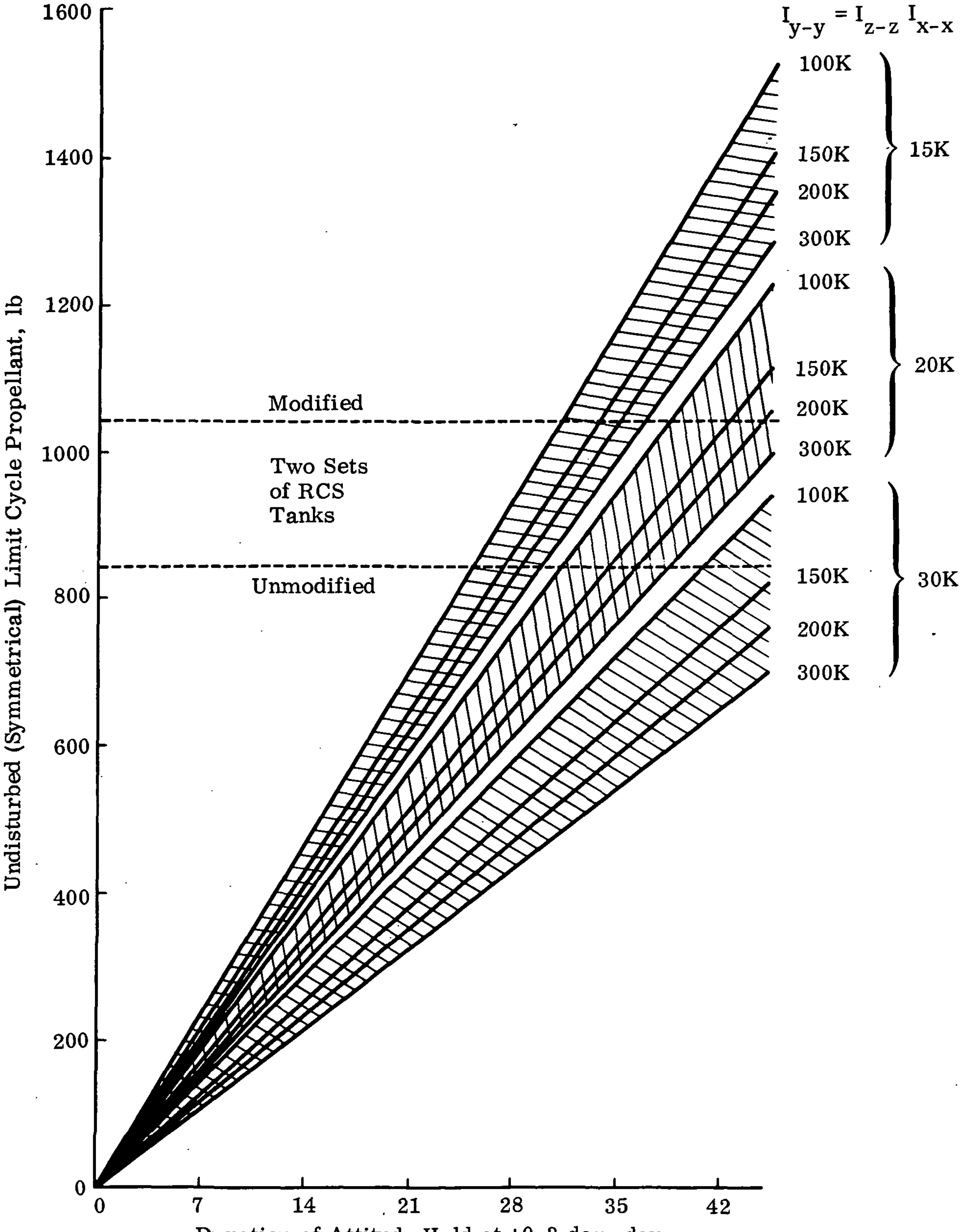


Fig. 4.3-4 Undisturbed Limit Cycle RCS Propellant Requirements .001 deg/sec Rate Threshold

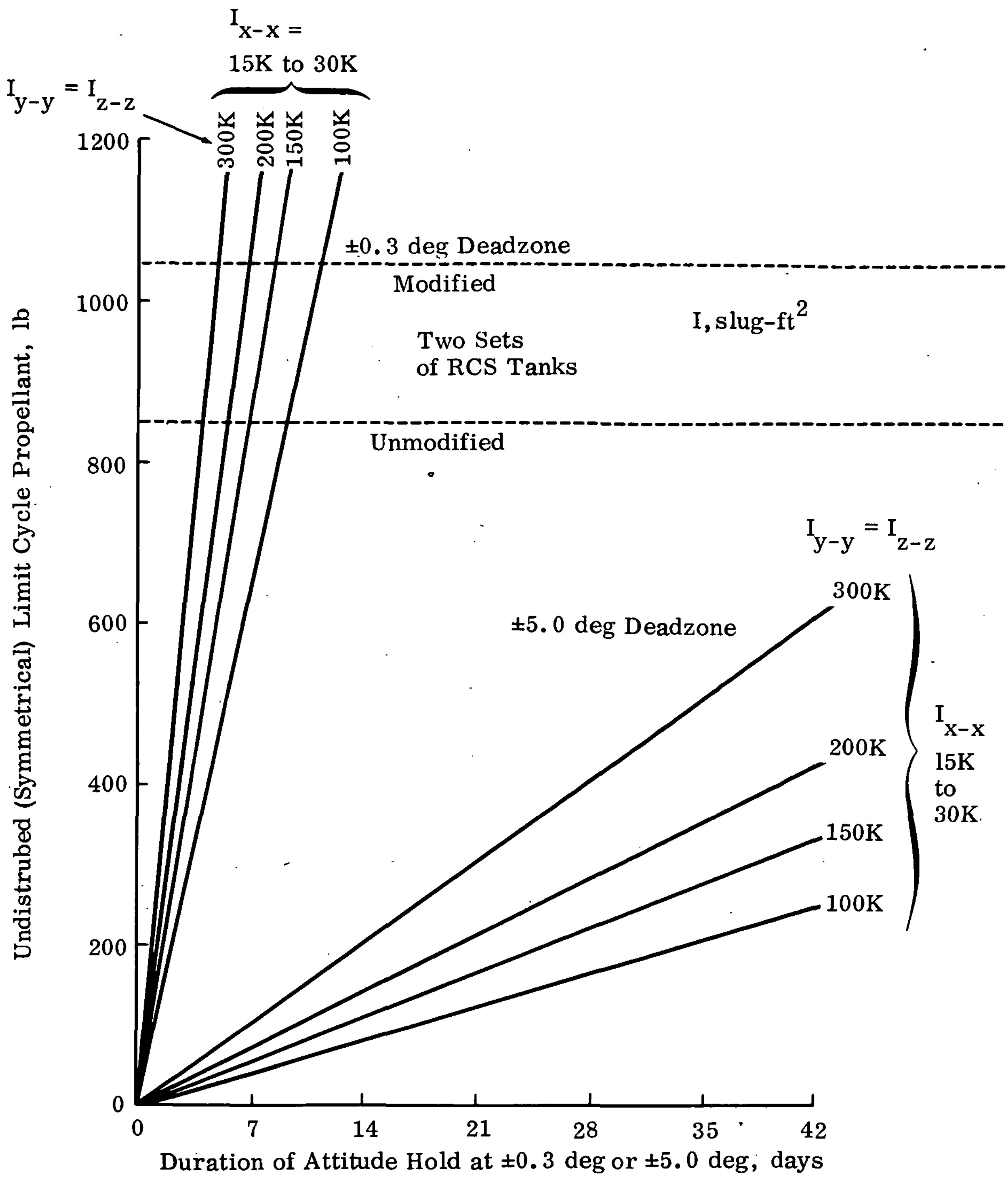


Fig. 4.3-5 Undisturbed Attitude Hold RCS Propellant Requirements
0.01 deg/sec Rate Threshold

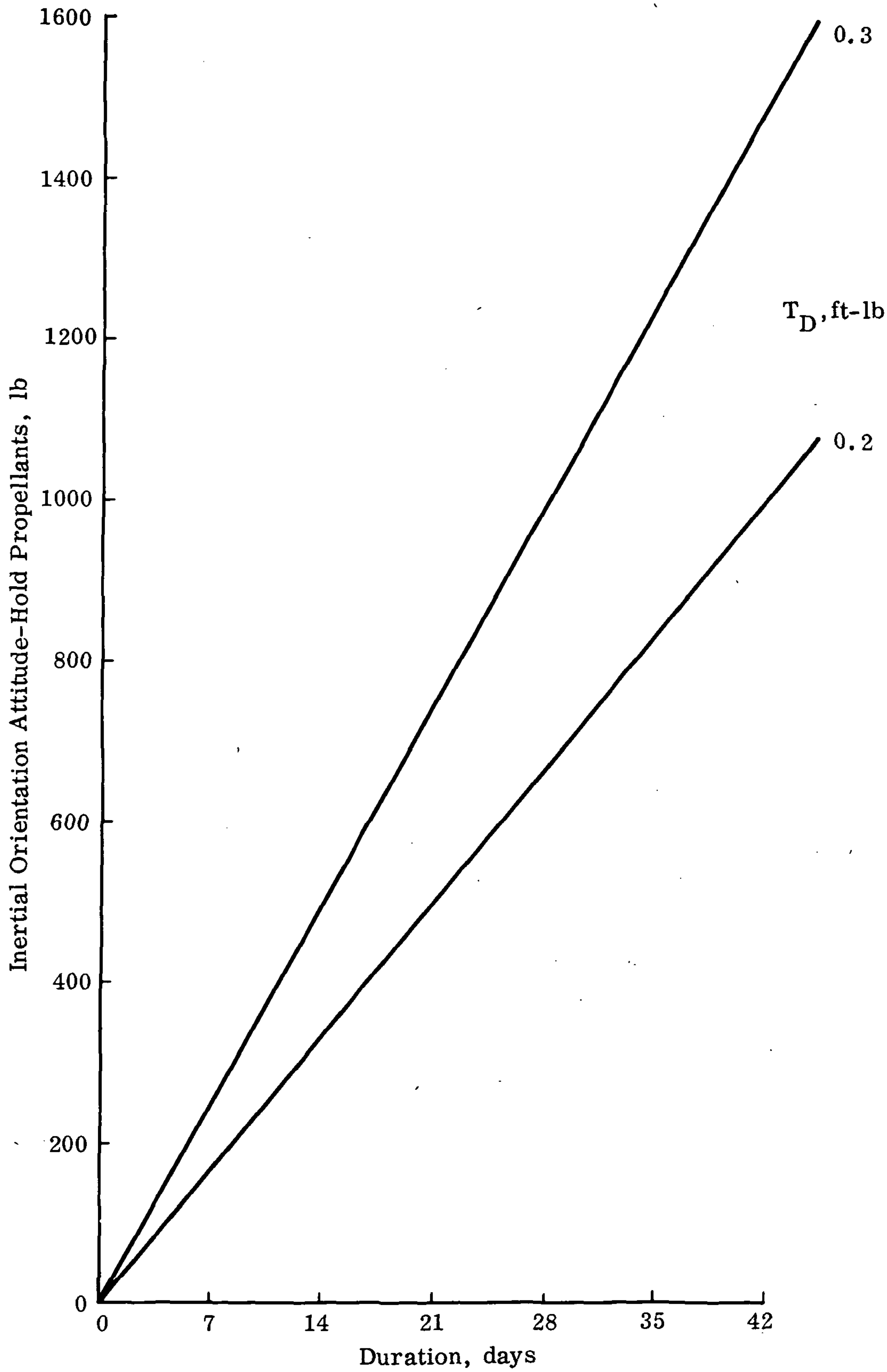


Fig. 4.3-6 Disturbed Attitude Hold RCS Propellant Requirements

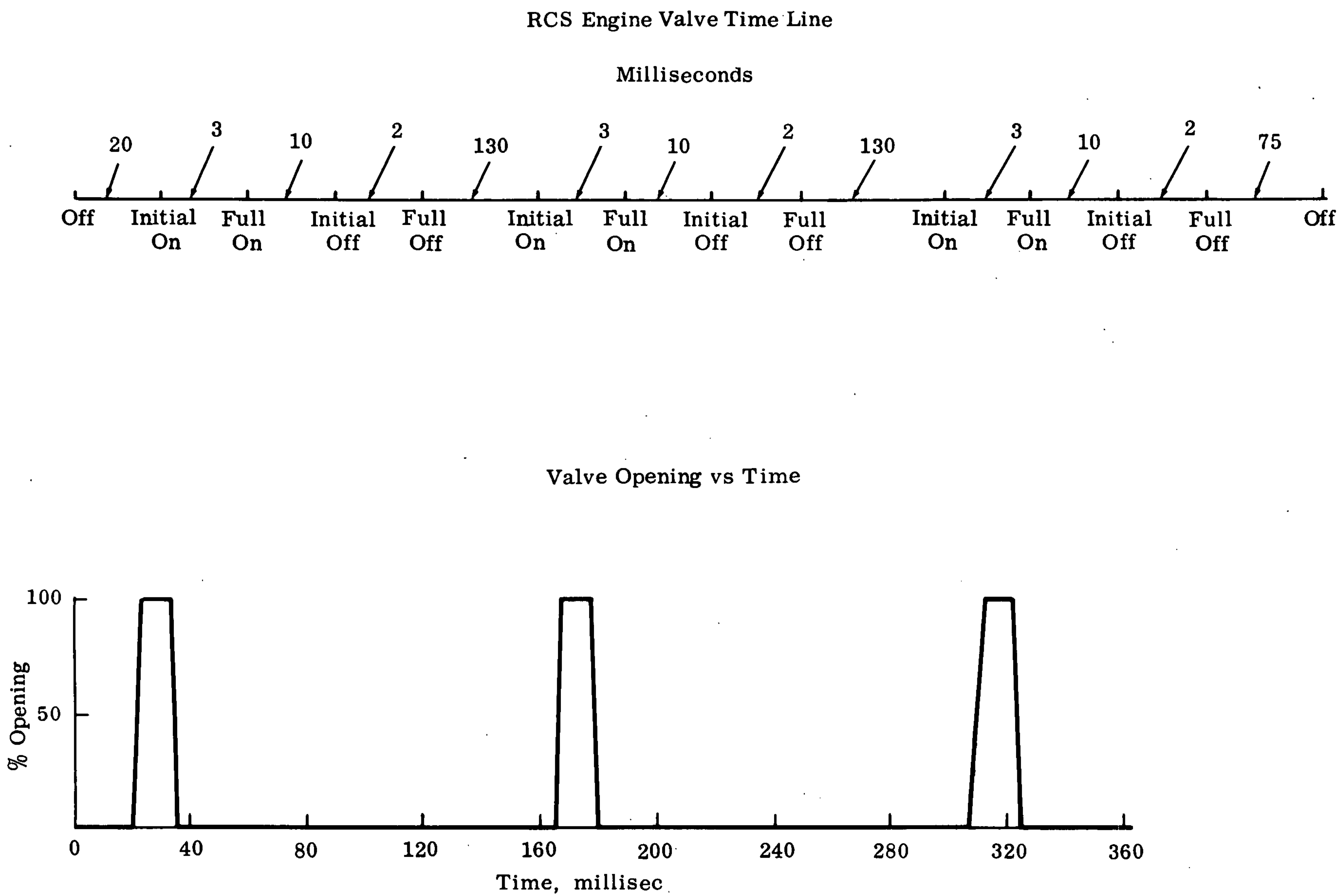
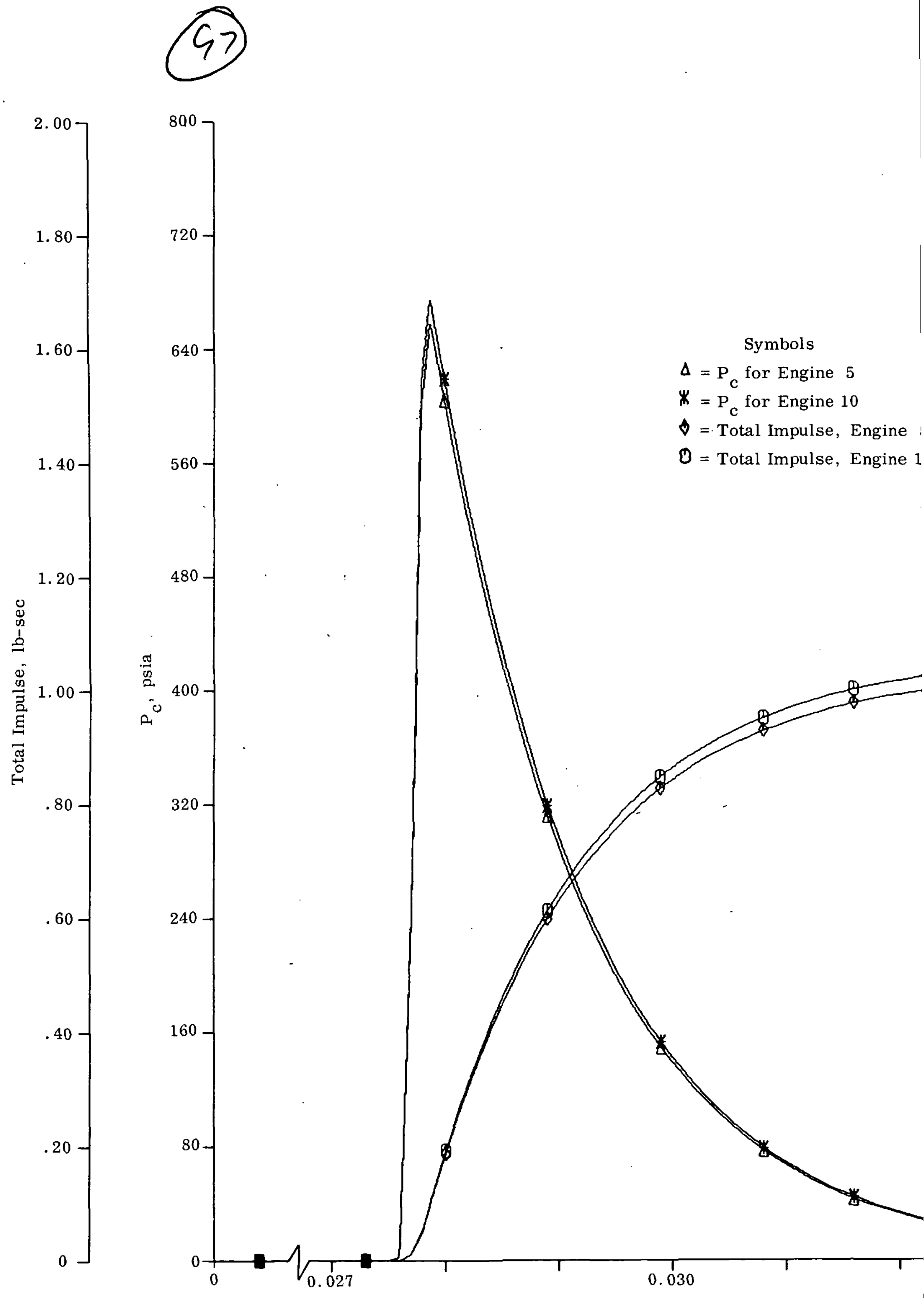


Fig. 4.3-7 RCS Engine Duty Cycle



97
Total Impulse, lb-sec
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0
P_c, psia
800
720
640
560
480
400
320
240
160
80
0
0
0.027
0.030
Symbols
Δ = P_c for Engine 5
✱ = P_c for Engine 10
◊ = Total Impulse, Engine
○ = Total Impulse, Engine 1

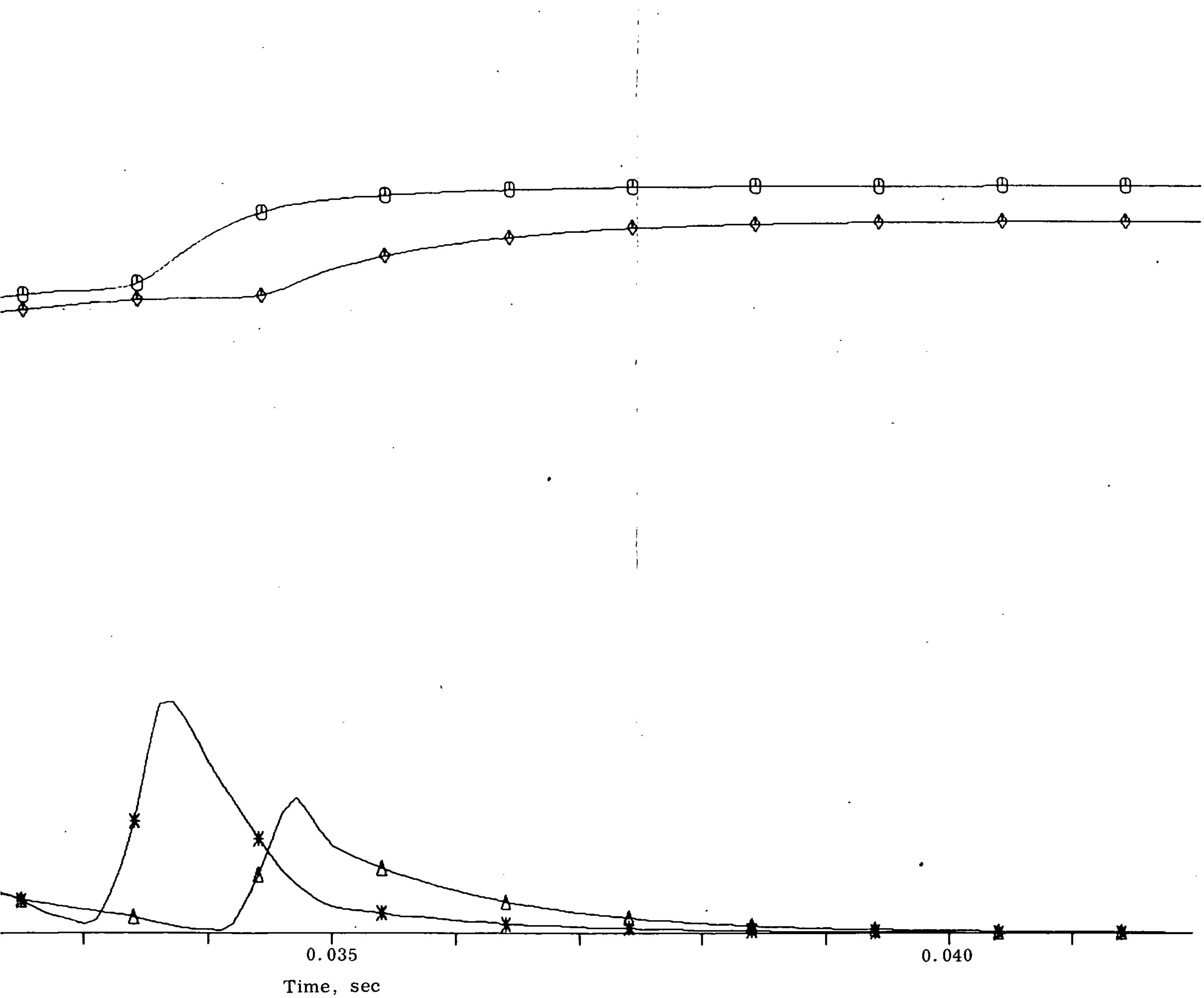
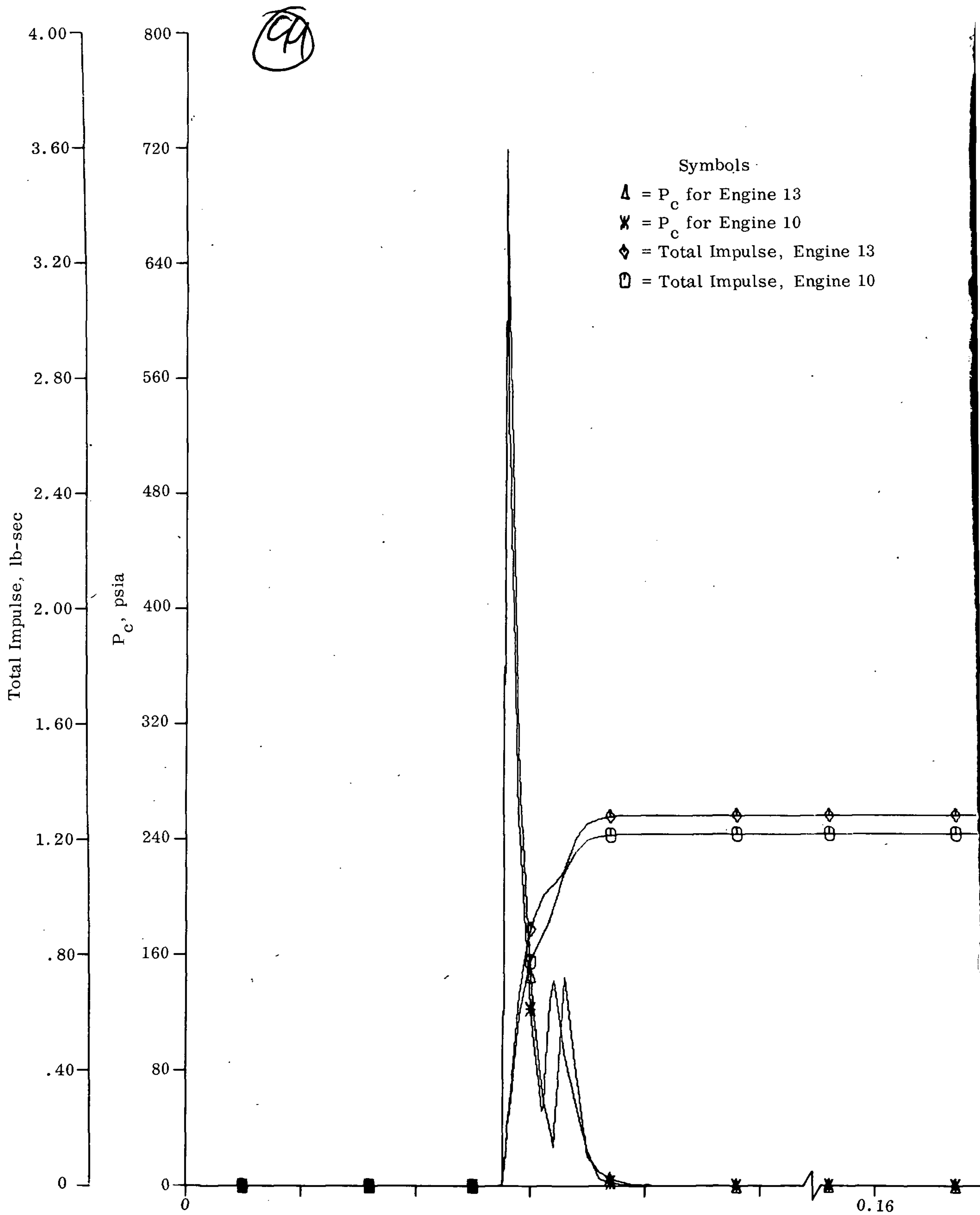


Fig. 4.3-8 Two RCS Engines Firing a Single Pulse in Phase + Z Rotation


(94)
Total Impulse, lb-sec
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
.80
.40
0
P_c, psia
800
720
640
560
480
400
320
240
160
80
0
Symbols
= P_c for Engine 13
= P_c for Engine 10
= Total Impulse, Engine 13
= Total Impulse, Engine 10
0
0.16

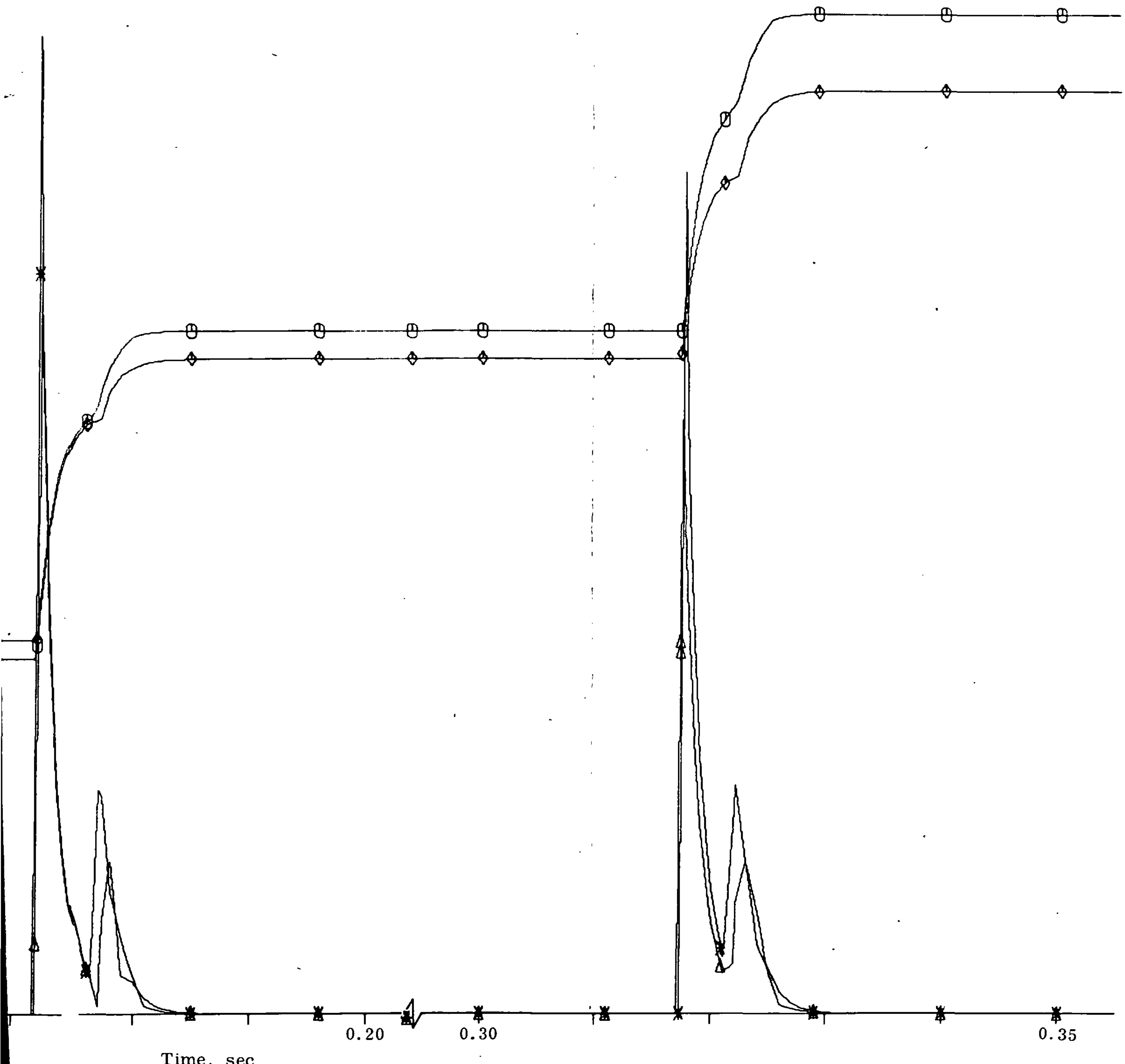
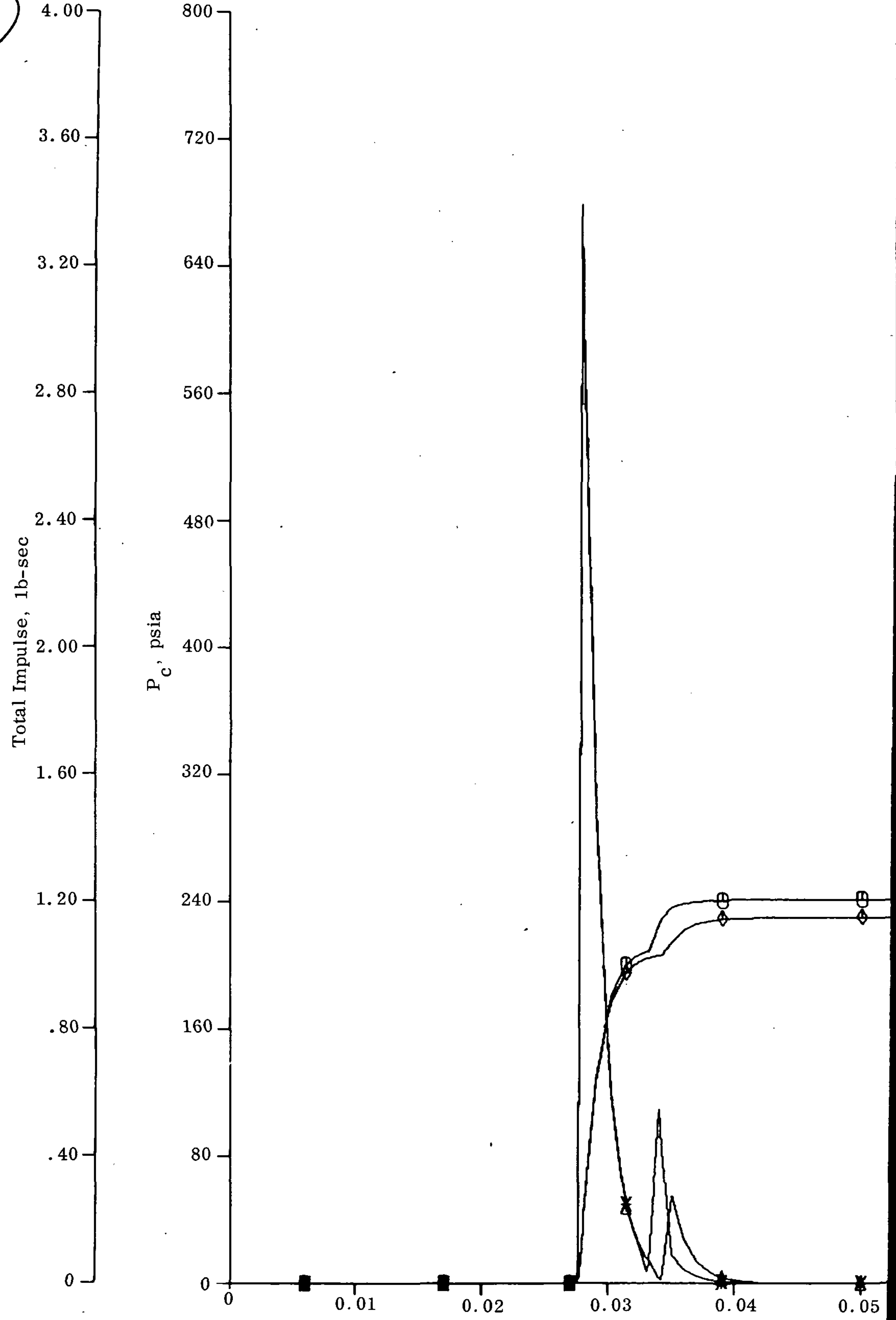
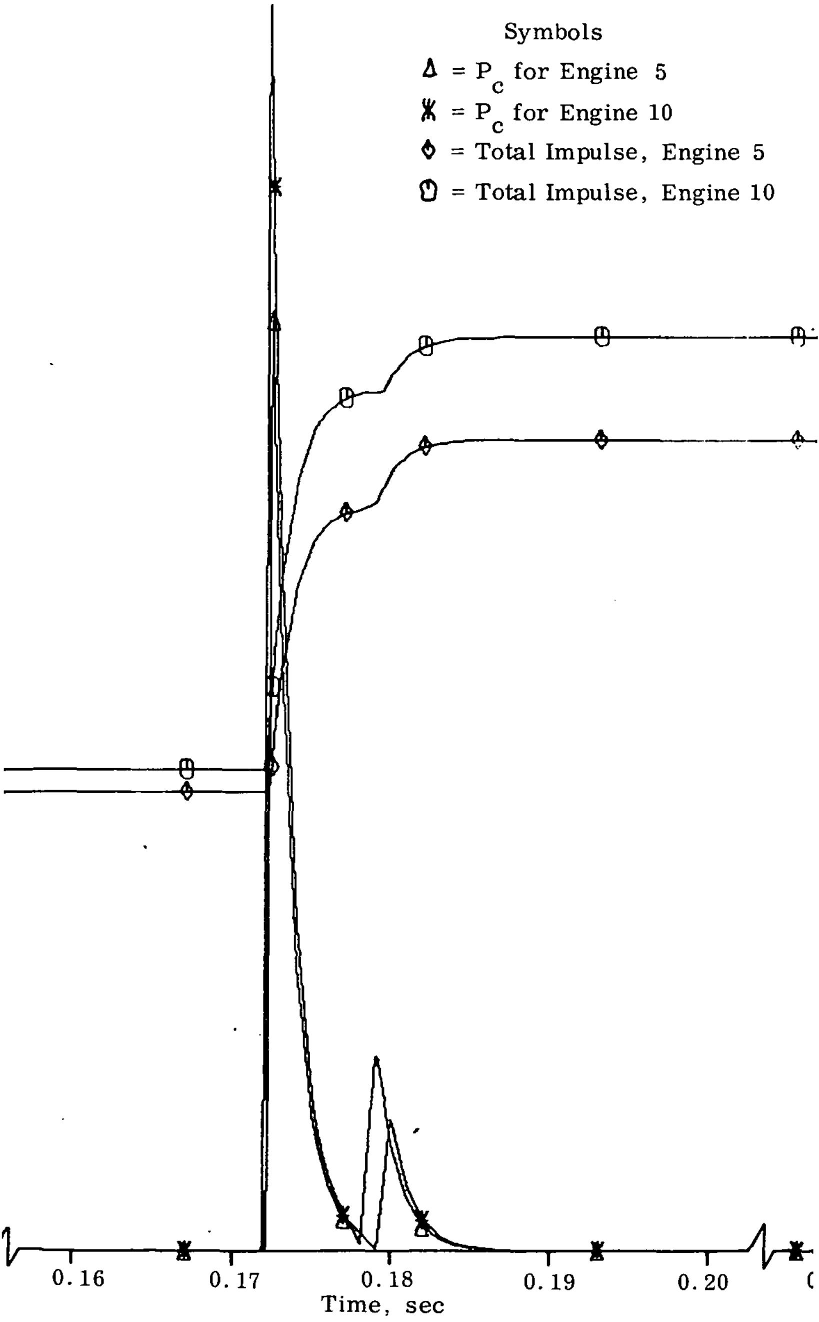


Fig. 4.3-9 Two Engines Firing Multiple Pulses in Phase + Z Rotation


Total Impulse, lb-sec
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
.80
.40
0
P_c, psia
800
720
640
560
480
400
320
240
160
80
0
0
0.01
0.02
0.03
0.04
0.05



Symbols
Δ = P_c for Engine 5
✱ = P_c for Engine 10
◊ = Total Impulse, Engine 5
⊖ = Total Impulse, Engine 10
0.16
0.17
0.18
0.19
0.20
Time, sec

2

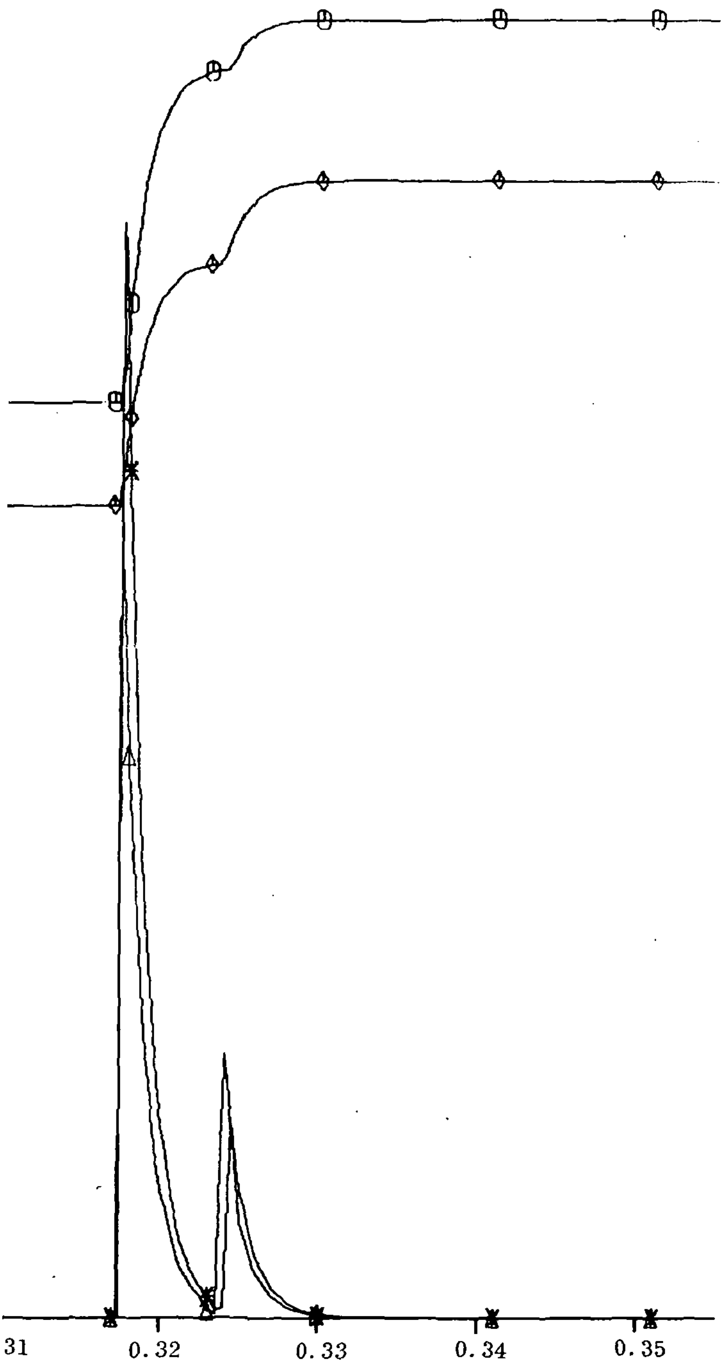


Fig. 4.3-10 Two Engines Firing Multiple Pulses in Phase - Y Rotation

4.4 CREW SYSTEMS

4.4.1 Introduction

The responsibility of Crew Systems is to insure that all hardware with which man must interface is designed to satisfy man's role within the context of the mission. This implies the analysis of:

- Mission(s)
- Man's role to satisfy the mission
- Hardware systems implications

The mission is first analyzed to determine its duration, type of on-board equipment carried, orbital inclination, orbital period, type of experiments to be carried, etc., to establish the frame of reference for evaluating man's role. Next, a work breakdown and apportionment among the crew establishes an activity schedule. Finally, the equipment required to accomplish these activities is determined.

4.4.1.1 Assumptions

- Waste management functions will be handled by the CM
- Crew safety package will be utilized in the Lab
- Suit loop will be utilized in the Lab
- Three men (two in the Lab, one in the CM during work activity in shirt-sleeves)
- Ten hours work/14 hours non-work per man per day
- Lab work activities will include housekeeping, and experiments
- Airlock is provided
- Two-gas atmosphere at 5 psia.

4.4.2 Background Data

Crew Systems requirements include such areas as:

- Life Support
- Radiation Monitoring
- Volume
- Crew Training

4.4.2.1.1 Environment: The environment is made up of a two gas system, (oxygen-nitrogen)

The total barometric pressure is equal to 259 mm Hg (5 psia), based on the following partial pressures:

		(mm Hg)
O_2	=	158
N_2	=	85
CO_2	=	5
H_2O	=	111

Control of oxygen and nitrogen in the atmosphere is accomplished by cryogenic storage ranging from 50 to 425 mm Hg in partial pressure.

In order to control the atmosphere, certain constituents such as carbon dioxide must be removed or rendered capable of utilization. Carbon dioxide will be removed by the CSM ECS.

Ventilation flow rates are important for environmental control of temperature and comfort. Flow-rate requirements depend on the level of activity in a given area commensurate with metabolic loads expressed in Btu. The following values are given as general requirements for ventilation flow rates.

		(cfm)
Living Area	=	240
Personal Hygiene and Toilet	=	240
Work Area	=	400
Sleeping Area	=	40

Trace contaminant removal by the CSM will be obtained with the filtering of gas flow used for other ambient control functions. Odors are absorbed by charcoal. Microbiological growth is controlled by ultraviolet radiation and the use of germicides. Aerosol (mist or fog) is removed by filtration.

4.4.2.1.2 Metabolism: A schedule of activities for the crew has been assumed and metabolic rates have been assigned to the duration of the activity in a 24 hr day.

Based upon a practical distribution time and activity for a given day, the energy expenditure ranges between 300 to 2400 Btu, with a total expenditure of approximately 12,000 Btu/man-day. This value requires a level of energy of approximately 3000 Calories/man-day.

4.4.2.1.3 Food and Water: Food quantity is estimated to be approximately 1.5 lb/man-day, where the amount of carbohydrates, protein fat and water totals approximately 1.32 lb/man-day and the remaining 0.28 lb/man-day consists of the calorifically valueless foods and unassimilated food. This is commensurate with the metabolic parameters defined in the schedule of events and the substrate required.

Water may be required in the preparation of certain foods. Total water requirements for input independent of sanitation is 2.6 lb/man-day. Five lb of wash water per man-day is estimated for personal hygiene; it may subsequently be used for laundry.

4.4.2.1.4 Waste Management (Table 4.4-1): Waste management will be a functional requirement of the CSM.

4.4.2.1.5 Clothing: The clothing required for the crew consists of extravehicular suits and undergarments, and flight garments and undergarments. The undergarments may be expendable.

Normal operation inside the Lab will be a shirt-sleeve environment. Space suits will be used to protect the occupants in the event a decompression is required to effect a minor repair. Pressure suit compatibility is therefore considered in the design of the interior.

4.4.2.1.6 Personal Hygiene: Personal Hygiene activities will include the use of:

- Treated, throwaway wash cloths that the astronaut will use to cleanse his entire body
- Toilet and urinal facilities to collect and store urine
- Means for collection of such stores of solids as nails, hair, and skin.

4.4.2.2 Personnel Radiation Safety Monitoring Package (Ref. 4.4-1)

Radiation exposure of astronauts in a parking earth orbit remains a potential rather than a definite hazard. The level of exposure of astronauts in the Mercury and the recent Gemini mission were within allowable limits. However, the following parameters still remain critical for any radiation analysis:

- Solar flares
- Duration of exposure
- Type and amount of vehicle and personnel shielding
- Quantitative chronological record of exposure of the individual crew member
- Age of the crew member
- Maximum permissible critical organ dosage

Tolerance limits which have been recommended for Apollo are listed in Table 4.4-2.

In view of the importance and complexity of the problem and the difficulty of getting adequate direct information on the effects of space radiation on the genetic makeup of the crew, the indirect evaluation is considered the best indicator of these biological effects of space radiation.

Table 4.4-3 lists techniques for personnel radiation monitoring.

4.4.2.3 Volume

4.4.2.3.1 Pressurized Volume: A pressurized volume of approximately 250 cu ft is available to accommodate the necessary hardware and two astronauts. This includes 183.5 cu ft in the front work area and 66.5 cu ft in the bulkhead area.

4.4.2.3.2 Usable Volume: A usable volume (free space) of approximately 154.0 cu ft is available to accommodate the astronauts. This insures 77 cu ft of free volume per man for the mission. According to Ref. 4.4-2 and 4.4-3 a free space volume of 75 cu ft/man is required for a 45 day confinement.

4.4.2.4 Crew Training

The AES flight crew training requirements and training equipment documents proposed by the Support Group have been reviewed and found to be generally acceptable at this time. A review of a sample of MSC training documents prepared for the Gemini Project has revealed certain guidelines which may be of importance in the AES training plans. These are:

- Crew members are normally scheduled as teams in designated positions
- Cross-seat and cross-team training is required on critical tasks
- Backup crew training should be equivalent to the primary crew
- Only one crew member participates in less critical tasks
- Gemini and Agena craft schedules are basic to other crew training schedules

- Thorough training in basic spacecraft systems is required.
- The crew commander is responsible for his crew-training activities.

4.4.3 Recommended Configuration

The recommended configuration shall include the following crew system inputs:

- Crew safety package
- Physiological consideration of one vs two gas atmosphere
- Suit loop
- Airlock
- Crew duty cycle
- Lighting
- Color scheme
- Furnishings

4.4.3.1 Crew Safety Package (Ref. 4.4-4)

The crew safety package will display respiration rate, and heart rate; the minimum requirement for crew safety. The astronaut and ground monitoring stations will be able to observe these rates whenever the biomedical umbilical is plugged into the jack provided in the control panel. This safety package is necessary for:

- Real time evaluation of astronaut's physical condition
- Simplicity of required instrumentation
- Medical significance
- Minimizing medical and physical hazard
- Minimizing time and crew training requirements

4.4.3.2 Some Physiological Considerations of a One Gas and Two Gas Systems (Table 4.4-2)

Atmosphere selection is based primarily upon physiological consideration. Since the physiological data is not available at this time, no attempt will be made to evaluate the percentages currently assumed. However, oxygen toxicity and hypoxia govern the upper and lower limits of the oxygen partial pressure 300 mm Hg and 110 mm Hg respectively.

The two-gas system recommended by NASA for the life support system of the Phase II Lab is essentially a composition of approximately 70% O_2 and approximately 30% of N_2 or helium at 5 psia. Concerning the critical physiological problem of the bends (dysbarism), recent studies have demonstrated that a helium/oxygen environment can produce "decompression sickness" as easily as does nitrogen/oxygen atmosphere.

Although the use of 100% oxygen at 5 psia may minimize the hazards of decompression, prolonged exposure may prove to be toxic. Moreover, an atmosphere free of an inert gas may itself be a physiological impediment because lung collapse (atelectasis) becomes a threat and the biophysical optimum of the respiratory systems requires it. In addition, a pure oxygen atmosphere presents a greater fire hazard than one to which an inert gas, preferably nitrogen, has been added.

4.4.3.3 Human Factors Requirements for A Suit Loop

The main function of the suit loop is to maintain both the physical and physiological continuity (e.g. the suit loop allows for medical monitoring and a closed ecological system which may operate independently of the prescribed shirtsleeve environment). It is assumed that normal work activity is accomplished with the astronauts in the shirtsleeve environment. However the suit loop is needed in the Lab to accomplish suit checkout and provide life support whenever the astronauts must "suit up".

When suit check must be performed, prior to entrance into the air lock, a suit loop is required. If this suit check can be accomplished with an umbilical from the command module, the physical mechanism of the suit loop connection in the Lab may not be required. However regardless of mechanization, the requirements for physiological continuity can not be changed.

At least two of the astronauts will be suiting up whenever an EVA is scheduled, one for EVA, and the other in the Lab, where he will be available in case of emergency. The second astronaut will operate suited and pressurized. The suit loop will keep him comfortable while he continues to observe the first crewman and perform other tasks.

An additional requirement of the suit loop is anticipated for purging of the suit (Paragraph 4.4.3.3).

Tables 4.4-5 and 4.4-6 indicate the activity in preparation for EVA and the specific procedures for the suit loop and PLSS.

4.4.3.4 Human Factors Requirements for an Airlock

With a proper sequence of preoxygenation/purging of the inert gas, the problem of decompression sickness can be minimized. The mode being considered to achieve the preoxygenation/purging sequence is to utilize an airlock where its total atmospheric volume of 70% (O_2) and 30% inert gas is purged and replaced by 100% O_2 or where it serves as an area to purge the man/suit/PLSS interface only.

Another problem that is minimized by the airlock is that of ensuring maximum crew time in shirtsleeves to complete prescribed tasks when an EVA is scheduled. Since cabin pressure does not have to be dumped, the door between the Lab and the CSM can remain open. This will permit the unsuited astronaut to move about more freely and perform the tasks required of him more easily while in shirtsleeves. The second astronaut will be suited and cooled by the suit loop, working with his helmet off. His performance in the unpressurized suit will be far less degraded than if he had to perform the same tasks with the suit pressurized.

The major human factors for an airlock are as follows:

- Preoxygenation/purging of the inert gas from the man/suit/suit accessories interface with the minimum utilization of gases.
- Maximum use of duty cycle work time in the pressurized shirtsleeve Lab.

4.4.3.5 Crew Duty Cycle

4.4.3.5.1 Guidelines:

- Each operator will be on a 10 hr work/14 non-work schedule
- The non-work schedule will include:
  - o Compatible recreation, socialization and eating periods for the operators (e.g., Crewmen 1 and 2 eat together twice a day for 0.5 hr each and socialize twice/day for 0.5 hr each; crewmen 2 and 3 schedule and crewmen 1 and 3 schedule are compatible).
  - o An extended period of 6 hr minimum, 8 hr maximum for each operator for eating, personal hygiene and undisturbed sleep. This is staggered for each operator.
- The work schedule will include:
  - o 4 hr of undisturbed work followed by a non-work period of 4 hr, (a 4:4:2, 4:2:4, or 2:4:4 work schedule is desired).
  - o At least one operator always awake
  - o All three operators awake during extra-vehicular activities (EVA)
  - o A 3.5 hr EVA period is maximum with PLSS (tethered operator)
- PLSS Usage
  - o The PLSS will use throwaway batteries.
  - o If using the same PLSS after an EVA, 1 hr is required for bringing PLSS up to requirements and checking out prior to going on next EVA.
  - o If switching PLSS after an EVA, 25 min is required prior to going on next EVA.

4.4.3.5.2 Work Routine: The normal work routine will include such activities as:

- Housekeeping
- Operational and experimental (not discussed here for basic Lab)

Housekeeping is an ongoing activity which follows a prescribed routine of monitoring system status, communicating with ground stations, checking out pressure suits, performing EVA's and replacing LiOH canisters (Table 4.4).

The data shown below is a daily breakdown of time required for housekeeping activities for the Lab and the CSM and the time available to run experiments and perform other necessary work. It is based upon a 10hr/day maximum work load per astronaut.

	Time, hr:min	
	Per Man	Total
Housekeeping activities for the Lab	0:23	1:09
Housekeeping activities for the CSM	0:47	2:20
(Ref. NAA Housekeeping Time Line for Phase I flights, CSM orbital phase.)		
Total Housekeeping AES	1:10	3:29
Experimental Time and Worktime Available	8:50	26:31
Total on Duty Time	10:00	30:00

4.4.3.5.3 Duty Cycle Description: The duty cycle is compatible with crew guidelines (Fig. 4.4-2):

- Maximum utilization made of the time where two astronauts can eat meals or rest together in the CM (example: hr 6-7 for crewmen 1 and 2, and hr 9:30-10:00 for crewmen 1 and 3, and hr 14-15 for crewmen 1 and 3, and hr 20-21 for crewmen 1 and 2).
- Two astronauts can also perform experiments and work together in the Lab (example: hr 11-14 for crewmen 1 and 3, and hr 16-19:30 for crewmen 1 and 2). In the case of the EVA during hours 7:20 to 9, all three crewmen are awake, and crewmen 1 and 2 are suited.

4.4.3.6 Lighting

The mission requirements of the Lab necessitate the placement of additional lighting both interior and exterior to supplement the existing sources provided for the LEM. The light package for the Lab will include:

- Interior
  - o Worktop
  - o Flood: panel and ceiling
  - o Dome: overall illumination of cabin interior mid-section
  - o EL: controls and displays

- Exterior
  - o Floods: two located at lower corners of descent stage 180 deg apart, illuminate underneath, away from, and along sides of vehicle. Can be controlled from exterior or interior switch.
  - o Docking Lights: same as the existing LEM

The present lighting array should supply the total light source needs. Power requirements are based on the worst possible case, i.e., no natural light source, direct or indirect.

4.4.3.7 Color Scheme

Optimum visual utilization is contingent on good light and a suitable colored surface that enhances light reflectivity. Colors provide for a psychological acceptance of the environment both aesthetically and physically. They possess properties that can stimulate or depress, irritate or relax, etc. subject to individual differences. Color schemes can be categorized as warm or cool to induce "color-moods." Warm colors are recommended for the interior to provide a cheerful habitat. A cool color should be employed to provide for a visual relief harmonious with the predominant ambient interior color schematic. Such colors, for example, would be specifically applicable in the immediate work areas whose trim would be painted with relatively bright colors.

For illustrative purposes, recommended color scheme (Ref. 4.4-5) is as follows:

- Floor - 30118 - Brown
- Walls and Ceiling - 30318 - Tan
- Control Panels - 30257 - Mustard Gold
- Furnishings - 35299 - Blue Green

4.4.3.8 Furnishings

Work space and layout

- Work top desk tables (2) -18 x 24 in, located on either side of the immediate front section of the forward cabin with suitable console lamps to uniformly light the entire perimeter of each desk. These desk tops serve as recreation tables, and are of the folddown type with appropriate wall recess and bracket for storage. This is an addition to the existing LEM
- Seat, swivel type (1) -14 in dia, located beneath desk tables. Adjustable swivel seats with vertical pin-break hinge to facilitate storage. This is an addition to the existing LEM
- Storage areas -6.63 cu ft of storage space is available in various locations (both in the forward cabin and in the mid-section of the Lab). This space is expected to be for the storage of experimental equipment.

Table 4.4-1

MAN'S WASTE PRODUCTION

Source	Quantity, lb/man-day
Urine	3.2
Feces	0.3
Water Vapor	5.3
Carbon Dioxide	2.3
Flatus	5×10^{-3}
Hair	7×10^{-4}
Nails	2×10^{-5}
Microorganisms	4×10^{-4}
Skin Cells	7×10^{-3}
Mucus	9×10^{-4}

Table 4.4-2

ANALYSIS OF ONE- VS. TWO-GAS SYSTEM

	One-Gas	Two-Gas
Component	O_2	O_2-N_2 O_2-He
Fire Hazard	Critical	Not so critical
Leak Rate	Not critical	He : Critical N_2 : Not so critical
Aeroembalism	Not critical	Critical
Storage	No problem	Problem
Equipt Reqmts	Not critical	Critical
O_2 Toxicity	Problem	No problem
Hypoxia	No Problem	Problem

Table 4.4-3

RADIATION EXPOSURE DOSE LIMITS

Critical organ	Maximum Permissible Intergrated Dosage, rem	Relative Biological Effectiveness, rem/rad	Average Yearly Dose, rad	Max. Permissible Single Acute Emergency Exposure, rad	Location of dose point
Skin of whole body	1600	1.4 (approx)	250	500	Depth of 0.70 mm from surface of cylinder 2 at highest dose-rate point.
Blood forming	270	1.0	55	200	5 cm Depth of cylinder 2.
Feet, ankles and hand	4000	1.4	550	700	Depth of 0.70 mm from surface of cylinder 3 at the highest dose point.
Eyes	270	2	27	100	Depth of 3 mm from surface on cylinder 1 along eyeline.

Table 4.4-4

PERSONNEL RADIATION MONITORING

PERSONNEL RADIATION MONITORING				
Equipment	Weight, lb	L x W x H, in. (Volume)	Frequency	Comments
Tissue Equivalent Ionization Chamber (Integrating)	1 each (3 total)	3 x 2 x 1/2	Up to 500 rad.	One chamber per man plus 1 charger shared by all. This unit is worn on the apparel and must be read. Requires recharging depending upon dose encountered.
Tissue Equivalent Ionization Chamber (Rate Meter)	2 each (4 total)	4 x 3 x 3	0.1 to 100 rad/hr	Two portable battery-operated units Recommend shelf mounting 1 unit near minimum shielding location in vehicle; 2nd unit should be moved to wherever astronauts are working. Gives off sound after danger level is reached; must be read.
Film Packs (21 packs total)	1.5	2 x 2 x 1/8	Up to 1000 rad	Seven film packs required for each astronaut.

Table 4.4.5

SET-UP FOR EVA, USING SUIT LOOP
FRONT HATCH AIRLOCK

Time min:sec	Crewman No. 1	Crewman No. 2	Time min:sec
06:00	• Don Suit (Less Helmet)		
00:15	• Hook up to Suit Loop (For cooling)		
01:00	• Don Emergency Oxygen Supply (EOS)		
02:00	• Erect PLSS Donning Station		
01:00	• Attach PLSS No. 1 to Donning Station and Prepare PLSS No. 1 for checkout	• Don Suit (Less Helmet) • Hook up to Suit Loop (for cooling)	06:00 00:15
01:30	• Checkout PLSS No. 1 Communication/Telemetry/Warning	• Don EOS	01:00
01:30	• Check PLSS No. 1 coolant		
00:15	• Don Helmet		
03:30	• Checkout PLSS No. 1 O_2 Supply and Suit Leakage - Connect PLSS Line - Disconnect ECS Umbilicals - Pressurize Suit thru PLSS		
01:30	• Prepare PLSS No. 1 for Standby		
02:30	• Don PLSS	• Assist Crewman No. 1	02:30
00:15	• Hook up to Suit Loop		
	• (Remain on Suit Loop until Cabin is Re-Pressurized at Completion of EVA)	• Attach PLSS No. 2 to Donning Station and Prepare for Checkout	02:00
		• Checkout PLSS No. 2 Communications/Telemetry/Warning	01:30
		• Checkout PLSS No. 2 Coolant	01:30
		• Don Helmet	00:15
		• Checkout PLSS No. 2 O_2 Supply and Suit Leakage -Connect PLSS Line -Disconnect ECS Umbilical -Pressurize Suit Thru PLSS • Enable PLSS No. 2 for Egress	03:30 02:00
02:30	• Assist Crewman No. 2 in Donning	• Don Plss No. 2	02:30
		• Open Hatch to Airlock	00:30
		• Enter Airlock	00:30
		• Secure Hatch	00:30
		• Dump Airlock Pressure	00:30
		• Open Hatch to Space	00:30
		• Egress Airlock	00:30
		• Secure Hatch	00:30

Suit Loop Time

Astronaut No. 1 = 13 min 0 sec (initially), then all EVA time

Astronaut No. 2 = 21 min 0 sec (Prior to EVA)

Total Suited Time

Astronaut No. 2 = 33 min 15 sec

Table 4.4.6

RETURN AFTER EVA

FRONT HATCH AIRLOCK

Time Min sec	Crewman No.1	Crewman No.2	Time Min:Sec
		• Open Airlock Hatch	00:30
		• Ingress Airlock	00:30
		• Secure Hatch	00:30
		• Pressurize Airlock	00:30
		• Open Interior Hatch	00:30
		• Ingress Lab	00:30
		• Connect to Lab Systems - Hookup to Suit Loop - Disconnect & Shutdown PLSS No. 2	02:00
00:30	• Secure Hatch		
03:00	• Assist Crewman No. 2	• Doff PLSS No.2	03:00
		• Stow PLSS No.2	01:00
		• Remove & Stow PLSS Donning Station	01:00
03:00	• Remove PLSS No.1	• Assist Crewman No.1	03:00
01:00	• Stow PLSS No.1	• Disconnect Suit Loop	00:15
10:00	• Assist Crewman No.1	• Doff Suit & Accessories & Hang to air dry prior to stowing	10:00
00:15	• Disconnect Suit Loop		
10:00	• Doff Suit & Accessories & Hang to air dry prior to stowing	• Assist Crewman No. 1	10:00

Suit Loop Time

Astronaut No.1 = 19 min 5 sec
Astronaut No.2 = 13 min 15 sec

Total Suited Time
Astronaut No.2 = 21 min 15 sec

Table 4.4-7

HOUSEKEEPING ACTIVITIES PHASE II LAB

Subsystem	Frequency, Every:	Time min: sec	Work Activity Description
EPS	6 hr	02:00	Purge fuel cells
Communication	45 min (Approx.)	00:10	Turn on and off. Talk while in range of station (0-40 min)
RCS	2 hr	00:30	Check pressure and temperature
GN & C	90 min	01:00	Visual check and adjust if necessary
Instrumentation	1 hr	01:00	Visual check of displays
ECS	2 hr	01:00	Visual check of gauges and lights.
Suit & PLSS	EVA	20:00	Test of sealing, maneuverability, pressure, etc.
LiOH	5 days	05:00	Unloading used canisters; loading and setup of fresh canister.

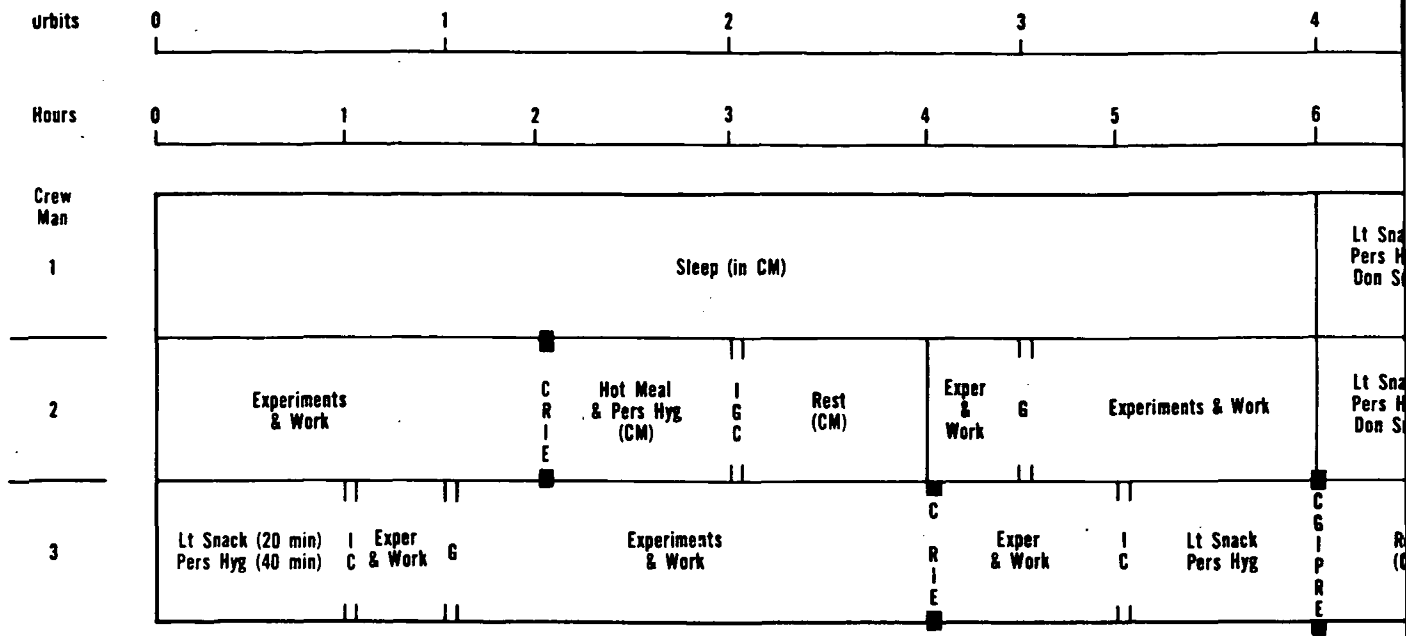
Atmosphere	Atmosphere Control
61% O_2	Cryogenic Storage, 158 mm Hg
33% N_2	Cryogenic Storage 85 mm Hg
CO_2 (30 mm Hg Max.)	Vent Overboard
H_2O vapor (13 mm Hg Max.)	Absorption
Barometric pressure, 5 psi	Partial Pressures of Constituents
Ventilation	
- Living Area	240 cu ft/min Flow Rate
- Pers Hyg & Toilet	240 cu ft/min Flow Rate
- Work Area	400 cu ft/min Flow Rate
- Sleep Area	40 cu ft/min Flow Rate
Contamination	
- Odor	Charcoal Absorption
- Low mol wt contaminants	Catalyst Bed
- Microbiological	UV Radiation
- Germacides & Aerosol	Filtration

Wastes, lb/man-day		Waste Control
H_2O vapor,	5.3	Absorption
Urine,	3.2	Decontamination/Store
Feces,	0.3	Store
CO_2,	2.3	LiOH or Molecular Sieve
H_2O,	5.0	Store

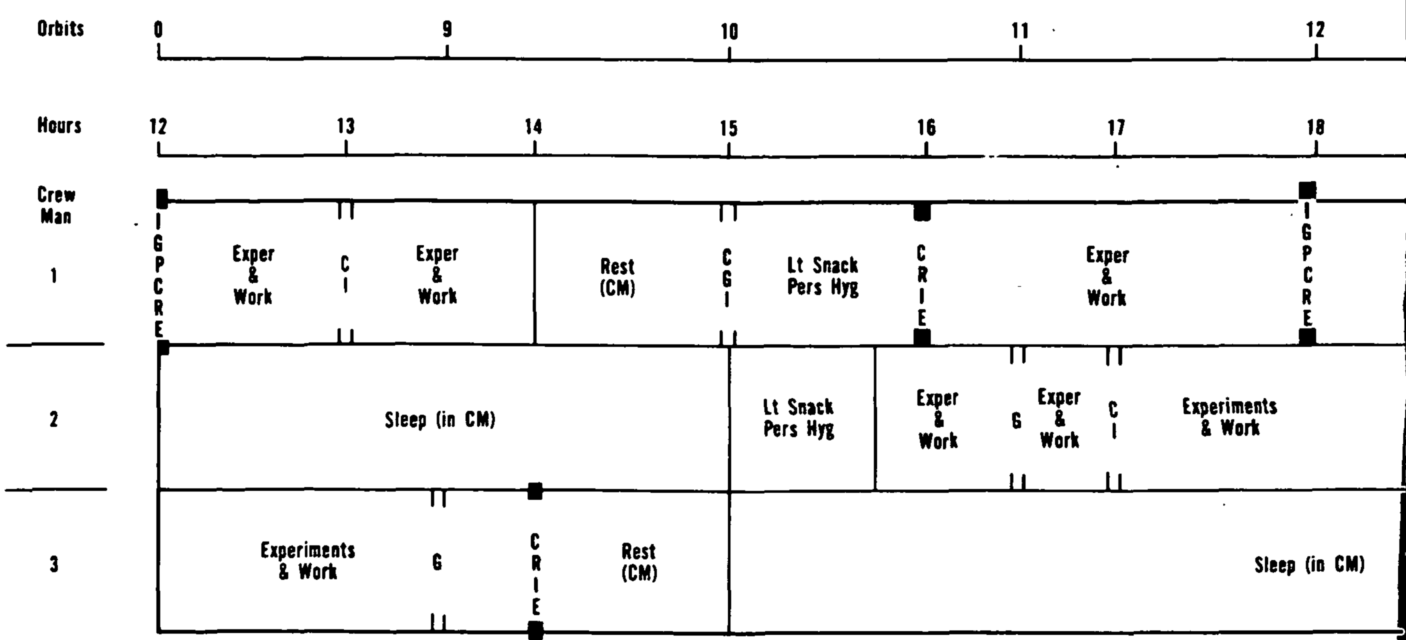
- Metabolism: 300 to 2400 Btu depending on level of activity (sleeping, eating, exercise, recreation, housekeeping, personal maintenance, system monitoring, and experimental work). Total energy expenditure = 12,000 Btu/man-day.
- Food: 3000 calories/man-day, 1.5 lb/man-day (GFE Diet).
- Water: 2.6 lb/man-day, drinking and food preparation.
  5.0 lb/man-day, sanitation and hygiene.
- Clothing: EVA suits, undergarments, and flight garments.
- Interfaces: Pressure suit accessories, life support pack, shelter, and EVA clothing.
- Requirements: storage, donning space, O_2 and H_2O tank filling, air-lock operation, ECS checkouts, bacteriological decontamination, communications system mobility, waste handling, and biomedical instrumentation.
- Work-Rest Activities
  - Duty: console monitoring, experimentation, EVA
  - Unscheduled: experiment reporting.
  - Rest: relaxation and sleeping.
  - Exercise: body conditioning.
- Personal: toilet and general grooming.

Fig. 4.4-1 Life Support Requirements - Phase II Lab

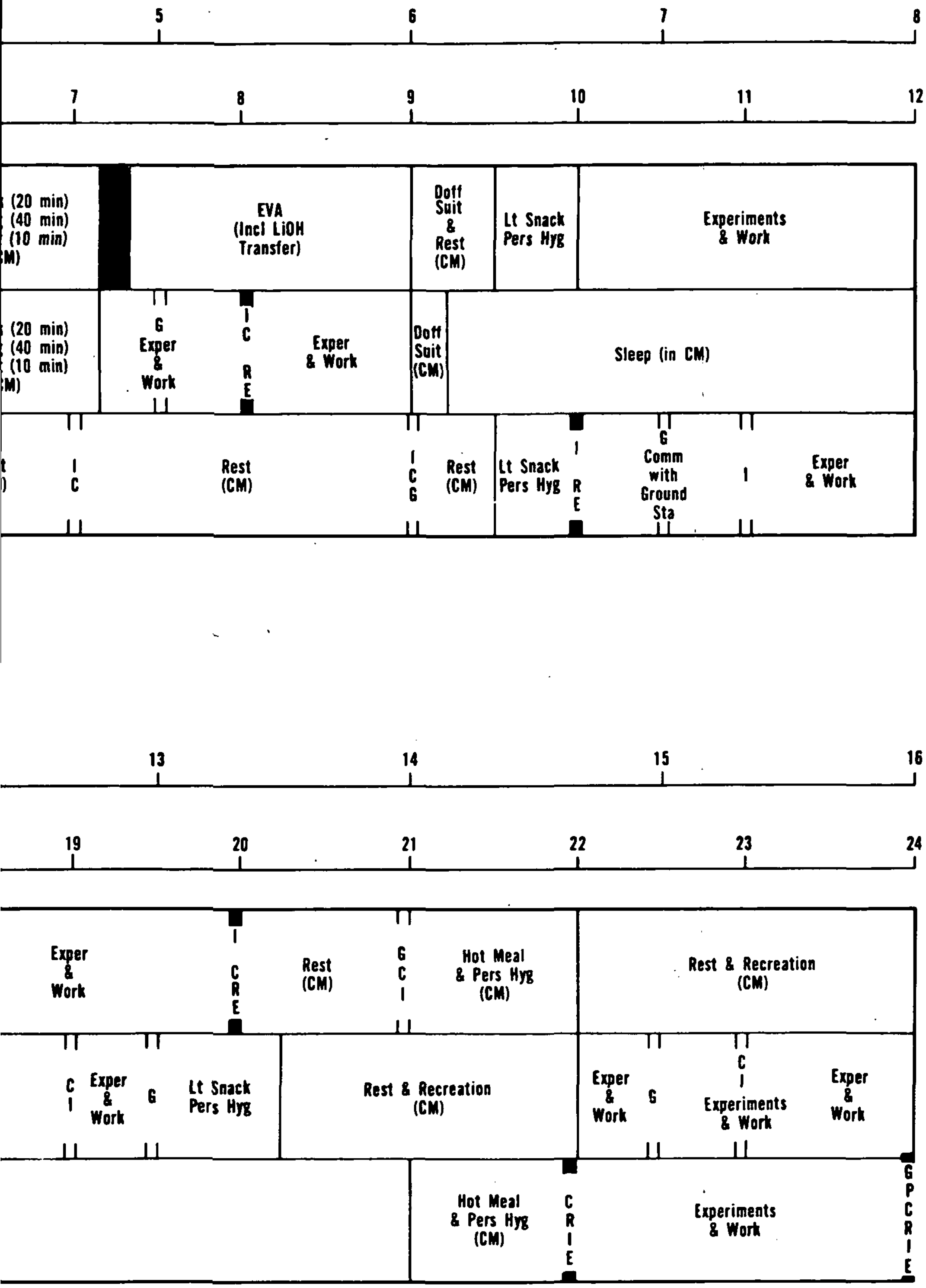
119



Orbits
0
1
2
3
4
Hours
0
1
2
3
4
5
6
Crew Man
1
2
3
Sleep (in CM)
Lt Sna
Pers H
Don S
Experiments & Work
C R I E
Hot Meal & Pers Hyg (CM)
I G C
Rest (CM)
Exper & Work
G
Experiments & Work
Lt Sna
Pers H
Don S
Lt Snack (20 min)
Pers Hyg (40 min)
I C
Exper & Work
G
Experiments & Work
C R I E
Exper & Work
I C
Lt Snack Pers Hyg
C G I P R E



Orbits
0
9
10
11
12
Hours
12
13
14
15
16
17
18
Crew Man
1
2
3
I G P C R E
Exper & Work
C I
Exper & Work
Rest (CM)
C G I
Lt Snack Pers Hyg
C R I E
Exper & Work
I G P C R E
Sleep (in CM)
Lt Snack Pers Hyg
Exper & Work
G
Exper & Work
C I
Experiments & Work
Experiments & Work
G
C R I E
Rest (CM)
Sleep (in CM)



Housekeeping Work Activity in Lab

- EPS (P)
- Comm (C)
- RCS (R)
- GN&C (G)
- Instr (I)

- ECS (E)
- Suit, PLSS
- LiOH

Notes:

- Wash-up before meals; personal hygiene & toilet duties (if reqd) after meals.
- Tasks designated with bars top & bottom relate to housekeeping tasks.
- Astronauts on a 10-hr work, 14-hr non-work schedule
- All tasks in Lab except when specified CM (Command Module).
- Except for EVAs, all work done with astronauts in shirtsleeves.

Fig. 4.4-2 Typical Day Activity - Phase II Lab

4.5 RELIABILITY AND MAINTAINABILITY

4.5.1 Assumptions

4.5.1.1 Mission Profile

A time-line summary for a Phase II Lab design reference mission (DRM) is presented in Table 4.5-1. This profile is not intended to represent any particular flight. It has been selected to provide a basis for reliability estimation, configuration analysis, trade-off studies, and mission success predictions.

The mission times are divided into boost and non-boost periods. Applicable environmental stress factors (K Factors) are shown for each period depending on operation or non-operation of the equipment during boost and non-boost periods. These factors are used to modify equipment inherent failure rates. In accordance with the mission time lines and K factors, as well as the subsystem equipment failure rates, math models, and operating usage times shown in this report, the probability of mission success can be calculated on a subsystem basis.

4.5.1.2 Vehicle Configuration Definition

Mission success probability calculations are based on the recommended vehicle configuration defined in Table 2.3-1.

4.5.1.3 Mission Success Definition

Mission success is defined as the probability of not aborting the DRM because of a failure of the defined configuration. Although failures of the booster, CSM, or experimental packages would cancel the scientific and engineering experiments, they could not be judged failures against the Phase II Lab. A mission shall be aborted if either the future occurrence of a single functional failure would endanger the general well-being of any crew member, or if the projected probability of catastrophe is greater than a maximum acceptable level.

4.5.1.4 Failure Rate Data

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 elsewhere in this report.

4.5.2 Background Data - Comparison of Stabilization & Control Subsystems

The S&CS of the Phase II Lab plays a major role in the determination of overall vehicle reliability. Because of this, and since there is more than one possible S&CS, a special study was undertaken to define the reliability of the S&CS choice. The S&CS function of the recommended Lab configuration consists of equipment required for rate stabilization, and equipment required for attitude hold. The equipment considered to be the minimum requirement for the recommended configuration is:

- Rate Stabilization Equipment: Rate Gyro Assembly (RGA), Attitude and Translation Control Assembly (ATCA), and Attitude Controller Assembly (ACA).
- Attitude Hold Equipment: Abort Sensor Assembly (ASA), and Abort Electronics Assembly (AEA).

4.5.2.1 Abort Guidance System

4.5.2.1.1 Rate Stabilization Section. This section consists of three assemblies:

- ATCA: This may be divided into two parts:
  - o Input section, consisting of the limiters, gradient amplifiers, summing amplifiers, demodulators, and deadband.
  - o Output section, consisting of jet select logic, vertical and horizontal summing amplifiers, pulse ratio modulators, preamps, and jet drivers.

Based on a grouping of the pulse ratio modulators in two sets of four each, one set for the horizontal thrusters and one set for the vertical thrusters, the circuits of the output section may be divided in the same manner. In the group of vertical circuits there is full capability if three out of four operate. In the group of horizontal circuits, if three out of four operate full X-rotation capability is retained. For Y and Z translation, one thruster is used in one-half of the cases, and a pulsed couple balances out the torque caused by one thruster operating. Thus automatic control remains intact, but with a fuel and time penalty for Y and Z translation only. If we do not include this penalty in the reliability calculation, we have the reliability model shown in Fig. 4.5-1

- RGA: This assembly is included with a failure rate of 99.1×10^{-6} failures/hr.
- ACA: This assembly is included with a failure rate of 33.4×10^{-6} failures/hr.

The reliability of the Rate Stabilization Section is

$$R_S = R_A\,(R_1R_2R_3R_4 + Q_1R_2R_3R_4 + R_1Q_2R_3R_4 + R_1R_2Q_3R_4 + R_1R_2R_3Q_4)$$

$$(R_5R_6R_7R_8 + Q_5R_6R_7R_8 + R_5Q_6R_7R_8 + R_5R_6Q_7R_8 + R_5R_6R_7Q_8)$$

$$R_{RGA}R_{ACA}$$

4.5 2.1.2 Attitude Hold Section. It has been assumed that two alternatives are possible for the Lab: one which does not require accelerometers, and one which does require them for small translational changes. If accelerometers are not required, a considerable reduction in failure rate can be realized. If accelerometers are required, the configuration will be the same as for LEM. The reduction in failure rate is not anticipated as due to physical removal of subassemblies, a removal which would have undesirable thermal side-effects, but simply due to a mathematical reduction.

The failure rates, based on actual parts count, are as follows:

Assembly	LEM Failure Rates Failures per Million Hrs.		AES Failure Rates. Failures per Million Hrs.	
ASA	370.29		265.35	
AEA	1016.00		802.80	
		1386.29		1068.15
ATCA	132.00		51.34	
ACA	33.40		33.40	
RGA	99.10		99.10	
		264.50		183.84
	Total:	1650.79		1251.99

If the Rate Stabilization Section operates at 100% duty cycle and the Attitude Hold Section operates at 50% duty cycle, the following values indicate the reliability of both sections of the S&CS for 5, 10, 30, 65, 100, 300, and 1100 hrs, for a configuration which does not require accelerometers.

Equivalent Time (Hrs)	$\Sigma K \lambda t$	Reliability
5 hr	0.003587	0.99647
10	0.007174	0.99285
30	0.021523	0.97871
65	0.046633	0.95444
100	0.071743	0.93077
300	0.215230	0.80635
1100	0.789173	0.45422

The operating time of the basic S&CS is not fixed because the experiments may require various other types of stabilization, guidance, and control, each with its own operating time.

4.5.2.2 Primary Guidance System

If the guidance system consists of the Primary Guidance and Navigation subsystem (PGNS), and if accelerometers are not required, mathematical reduction in failure rates may be realized, as with the Abort Guidance System.

Regarding the IMU, if accelerometers are not required, three PIPA's and three Power Amplifiers can be deleted from reliability calculations.

Regarding the PTA circuitry associated with accelerometers can be deleted from reliability calculations.

Regarding the LGC, circuits not required for acceleration can be put to other uses. Failure rates based on those given in the specification for the PGNS, are as follows:

Subassembly	LEM Failure Rates Failures per Million Hrs.	AES Failure Rates Failures per Million Hrs.
IMU	137	69
PSA	126	126
PTA	62	12
CDU (181 ea)	905 (5)	543 (3)
LGC	352	352
	1582	1102
ATCA	132	1
ACA	33.4	34.4
Total:	1747.4	1136.4

Note, the DSKY is considered as part of Displays and Controls. If other types of sensors are used during some experiments, thus allowing the PGNS to be shut down, the RGA and ATCA would be used. The following failure rates are for the configuation used under these conditions:

Subassembly	LEM Failure Rates Failures per Million Hrs.	AES Failure Rates Failures per Million Hrs.
IMU*	7.8	7.8
Electronics*	6.3	6.3
ATCA	132.0	51.34
RGA	99.1	99.1
ACA	33.4	33.4
TCA	31.0	----
Total:	309.6	197.94

If the PGNS is assumed to operate at a 50% duty cycle, the following values indicate the reliability of the system when using the PGNS:

Equivalent Time Hrs.	$\Sigma K\lambda t$	Reliability
5	0.003335	0.996669
10	0.006671	0.993350
30	0.020015	0.980184
65	0.043366	0.957561

*Standby Failure Rate

Equivalent Time Hrs.	$\Sigma K\lambda t$	Reliability
100	0.066717	0.935476
300	0.200151	0.819025
1100	0.673887	0.509761

Figure 4.5-2 shows reliability vs time for the stabilization and attitude hold function using the AGS. The reliability of stabilization only, of attitude hold only, and of both, but with duty cycles for attitude hold of 50% and 100% is shown. Similar information is shown in Fig. 4.5-3 for the PGNS.

The choice of system reliability and duty cycle depends on what other systems are available for guidance, navigation and control during the various experiments, and the reliability desired. Thus, if a lower reliability can be tolerated, the operating time can be extended, whereas if overall planning requires a high reliability, operating time would be curtailed and other types of systems would be used for other portions of the mission.

It is assumed that the minimum time between shut-down and turn-on for the PGNS or the AGS is 1/2 hr, due to the time required for thermal stabilization. Another factor limiting the number of on-off cycles is the failure rate associated with this cycling. It is desirable to arrange the experiments of the Lab according to the type of guidance system required, so that the operating times can be grouped, thus avoiding excessive on-off cycling.

4.5.2.3 Comparison of Systems

The reliability estimates of the AGS and PGNS have been made by independent sources and are therefore not subject to comparison. Consideration of the equipment, as to its design and adaptability to mission requirements, is more meaningful under the circumstances than a consideration of the reliability numbers available.

It should be noted that the PGNS in the LEM configuration has a higher failure rate than the AGS. However, if acceleration measurements are not required, the PGNS will have a lower failure rate than the AGS. This is because when the accelerometers and associated circuits are deleted from reliability calculations, the reduction for the PGNS is greater than for the AGS.

The specified operating life for the AGS is 5000 hrs., whereas the specified operating life of the PGNS is only 2000 hrs. The respective specification for each equipment require 1000-hr periods free of scheduled maintenance for the AGS, whereas the maintenance-free mission of the PGNS is limited to 30 days or 720 hr. Thus the PGNS would be available for a maximum mission of 720 hrs., from the erection of the spacecraft onto the assembled launch vehicle through mission accomplishment. The AGS would be available for a maximum mission of 1000 hr. These times apply if no maintenance is allowed on either system.

4.5.3 Recommended Configuration - Reliability Estimates

Subsystem reliability math models, functional block diagrams (Fig.4.5-4), and equipment utilization times (Table 4.5-2) were developed to determine subsystem and recommended configuration reliability estimates.

4.5.3.1 Subsystem Reliability Estimates

4.5.3.1.1 Stability and Control. The S&CS recommended configuration for the Lab is considered to be a minimum configuration capable of rate stabilization and attitude hold. In the absence of definitive information as to the time of required use for this equipment, it is assumed that the rate stabilization is required for 100% of the mission, and attitude hold for 50% of the mission. This yields a 0.461006 subsystem reliability. The subsystem housekeeping reliability, assuming 100% rate stabilization without attitude hold capability, is 0.820252. A detailed analysis including the ATCA failure rate derivation is described in Paragraph 4.5.2.

4.5.3.1.2 Reaction Control Subsystem. Reliability analysis of the RCS involves the attitude and fine translation capabilities of the vehicle, including: helium, oxidizer, and propellant storage; as well as regulation and thrust capability. The reliability math model is:

$$
\begin{aligned}
R_{RCS} = \{ & R_1^2 R_2^4 R_3^2 R_4^5 R_5 (2 - R_5) R_6 \left[R_7 R_8 (2 - R_8) R_9^2\right] \left[2 - R_7 R_8 (2 - R_8) R_9^2\right] \\
& \left[R_{10}^4 + 4R_{10}^3 (1 - R_{10}) + 2R_{10}^2 (1 - R_{10})^2\right] \left[R_{11}^4 + R_{11}^3 (1 - R_{11}) + 2R_{11}^2 (1 - R_{11})^2\right] \\
& \left[R_{12}^4 + 4R_{12}^3 (1 - R_{12}) + 4R_{12}^2 (1 - R_{12})^2\right] \left[R_{13}^4 + 4R_{13}^3 (1 - R_{13}) + 4R_{13}^2\right] (1 - R_{13})^2] \\
& R_{14}^2 (R_{15} R_{16} + R_{17} - R_{15} R_{16} R_{17})^2 R_{18}^2 R_{19}^2 R_{20} \}^2 \{ (R_{21} + R_{22} - R_{21} R_{22})^2 \\
& \left[2 - (R_{21} + R_{22} - R_{21} R_{22})^2\right] \}^2 (R_{23} + R_{24} - R_{23} R_{24})^{30} R_{25}^4 R_{26}^4 R_{27}^{16} \\
& R_{28}^{16} R_{29}^{80} R_{30}^{32} R_{31}^{32} R_2^4
\end{aligned}
$$

Insertion of the element reliability values into the math model, yields a 0.834995 RCS reliability.

The propellant tank bladders are the major contributing factor to unreliability because of their high failure rate. No additional problem areas are pointed out, RCS reliability improvement can be achieved only if the inherent reliability of each component in the subsystem is upgraded.

4.5.3.1.3 Electrical Power Subsystem (EPS). The Lab II EPS configuration consists of two Allis-Chalmers fuel cells with an associated cryogenic supply system. In addition to the fuel cell system, one 7-kw-hr peaking battery and associated control assembly is utilized to supplement the fuel cell power system for peak demand intervals (12 min. every 14 hrs.). For the purpose of reliability calculations, the peaking battery is considered operational when it is activated and charged and the ECA operational duty cycle is considered only during battery discharge time. The cryogenic hydrogen and oxygen supply system shown is a single tank (one O_2, one H_2) non-redundant feed system. Mission success was based on the requirement that all systems be operational throughout the 45-day Earth orbital mission. Based on the above ground rules the reliability of the EPS configuration is 0.89940.

4.5.3.1.4 Environmental Control Subsystem (ECS). The analytical model was developed using the following guidelines and assumptions which were incorporated into the ECS reliability model.

- Water tank undergoes one operating cycle for the extent of the mission.
- Heat transport system is considered in an operative state for the extent of the mission.
- Oxygen supply system for the atmosphere revitalization section was considered integrated with the EPS fuel cell configuration (cryogenic supply) and is therefore not included in this analysis.
- Atmosphere revitalization section is considered pressurized only during EVA time
- LED 550-58, dated 18 June 1965, and failure rate data supplied by Hamilton Standard were used as the basis for the reliability assessment.

The mission success probability based on the above assumptions is 0.96120.

4.5.3.1.5 Communications Subsystem. The reliability analysis of the Phase II Lab Communications Subsystem consists of an investigation into the S-band transmission and receiving capabilities between the crew and earth, including status data, and the VHF communications mode during EVA and experimentation. This analysis has assumed that the ranging requirement capability necessary for mission success is fulfilled by the CSM ranging network. The ranging function is an inherent capability of the Phase II Lab, using S-band equipments (PM modulating functional capability is backup to CSM ranging potentials) which operate for large portions of the mission time, with insignificant degradation of subsystem reliability.

Several additional assumptions have been made to expedite the reliability modeling analysis. The first involves the failure-rate apportionment to the signal processor assembly. Since this part of the system has multiple operational modes, sometimes acting independently of one another and at other times operating in a completely dependent arrangement, it was assumed that for the majority of the mission time the entire failure rate of the unit ($\lambda = 64.549 \times 10^{-6}$) shall be applied to the mathematical model during any period of mission time where any one section of the signal processor is used. This is in fact assuming complete interdependency of internal components. This assumption is justified because the signal processor assembly is of paramount importance to the successful operation of the communications subsystem in every mode of operation. The analysis based on the above assumption depicts a "worst case" reliability estimate. Configuration analysis reflecting interdependency of operational functions within the Signal Processor Assembly is beyond the present scope of work, since a parts count of the assembly (including filters) is approximately 1700 items.

Another assumption is that the VHF channel B transmitter has the capability to be used as a backup mode for voice communications with the CM (assuming CM capability to receive voice communications on this channel). Consequently, the VHF transmitters A and B are considered as active redundancies in the reliability analysis (as are VHF receivers A and B). Also configured as redundant items in the modeling analysis are the astronaut's headset receiver and microphone assemblies - under the assumption that headset receiver 1 and microphone 1 operate together in series.

The mathematical expression for the communications subsystem is:

$$R_c = \left[1-(1-R_1)^2\,(1-R_{13})\right] R_2R_3(2-R_3)\left[1-(1-R_4)\,(1-R_5)^2\right] R_6R_7R_8\,(2-R_7R_8)$$
$$R_9(2-R_9)R_{10}(R_{11A}+R_{11B}-R_{11A}R_{11B})(R_{12A}+R_{12B}-R_{12A}R_{12B})$$

When the combined factors are introduced for each reliability block established above, the product run through the equation yields a reliability of the Communications Subsystem equal to 0.903965. As mentioned before, the prime degrading component for this analysis is the Signal Processor Assembly. Aside from the SPA, no additional problem areas are pointed out and improvement in the reliability of the Communications Subsystem can be achieved only if the inherent reliability of each component in the system is upgraded.

4.5.3.1.6 Instrumentation. It is assumed that the two PCMTEA's are operated one-fourth of the time during the mission. Other portions of instrumentation are assumed to operate all of the time. The first PCM is considered to be a backup for the caution and warning. The tape recorders are not considered to be redundant, because one is being filled while the other is emptying its information through the communications system. It is to be noted that the two PCM/TEA are used for different purposes: one for housekeeping, the other for experiment data, and are therefore not redundant. The subsystem reliability estimate equals 0.685671.

4.5.3.1.7 Controls and Displays Subsystem. The reliability analysis of the C&D Subsystem consisted of an examination of all of the individual controls and displays required by the other subsystems in the AES Phase II Lab. The overall C&D Subsystem reliability was obtained from the following mathematical model:

$$R_{C\&D} = R_1R_2R_3R_4R_5R_6\,(2-R_6)R_7(2-R_7)R_8R_9R_{10}(R_{11}+R_{12}-R_{11}R_{12})$$
$$R_{13}\left[1-(1-R_{14})^2(1-R_{15})^2\right] R_{16}(2-R_{16})R_{17}(2-R_{17})$$
$$R_{18}(2-R_{18})R_{19}(2-R_{19})R_{20}(2-R_{20})R_{21}(2-R_{21})$$
$$R_{22}(R_{23}+R_{24}R_{25}-R_{23}R_{24}R_{25})\,(R_{26}+R_{27}-R_{26}R_{27})$$
$$R_{28}R_{29}R_{30}.$$

Applying time (t), environmental factor (K), and failure rates (λ), to this equation and solving yields a reliability equal to 0.735841.

4.5.3.2 System Reliability Analysis

A summary of subsystem reliability estimates for the Phase II Lab is shown in Table 4.5-3, together with pertinent LEM data. Approximation of Structure and Explosive 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 $K\lambda t$, $Q \approx K\lambda t$, and $K\lambda \approx \frac{Q}{t}$

then

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

$$Q_2 \approx \frac{Q_1}{115.567} \times 1079 \approx 9.3366\, Q_1$$

were subscript 1 represents LEM and subscript 2 represents AES.

Subsystem	Q_1	Q_2	R_2
Controls & Displays and Instrumentation	0.000622	0.005870	0.994193
Structure	0.000022	0.000205	0.999795
Explosives	0.000076	0.000709	0.999291

The values above for Controls & Displays and Instrumentation show the effect of not including sensor reliabilities.

Figure 4.5-5 represents vehicle reliabilities for mission durations up to 45 days. The curves shown are based on an exponential degradation of reliability with mission duration, and therefore represent close approximations to the actual estimates. Also included in Fig. 4.5-5 are curves representing experiment package reliabilities plotted against a scale which indicates the product of vehicle and experiment package reliabilities.

Although the Lab reliability curve indicates values in excess of the LEM estimate curve, both fall below the LEM specification goal. Further study is required to determine reliability improvement potential by applying maintainability and/or configuration modification concepts.

4.5.3.3 Identification of Wearout Items

Although the LEM equipments have not been designed to optimize in-flight maintenance characteristics, approximately 80 out of 250 items investigated would permit in-flight and/or lunar surface maintenance. Further effort is required to investigate each of these applicable items for the Lab configuration to determine the degree of maintenance significance.

As a minimum, before any of these items become actual candidates, each will be analyzed with respect to:

- Availability requirements
- Failure rates and failure modes

- Constraints of the maintenance task on the time line
- Complexity of the maintenance task (skill, training, and tool requirements)
- Accessibility (for removal, replacement, calibration, adjustment and/or servicing)
- Alternate modes of operation
- Fault diagnostic aids requirement.

For each maintenance candidate, a figure of merit or maintainability index (MI) will be apportioned. The MI will be a quantitative expression of the desired or optimized goal for performing the maintenance task in a prescribed time. As each candidate is analyzed, its inherent maintainability will be determined. If the measure of maintainability is less than the index, means for maintainability improvement will be recommended and the impact will be traded off with reliability, weight, cost, schedule, etc., such that overall system effectiveness and/or mission success may be enhanced.

Table 4.5-4 presents a potential wearout list which indicates that a number of items are potential AES problems. Items identified by an "X" indicate a high probability of wear out while those identified by an "*" indicate that wear out problems are suspected but further study and information is required to be more conclusive.

Concern has been expressed over the life characteristics of kynar seals and teflon seats in the RCS to meet mission requirements when exposed to propellants or propellant vapors. The LEM project has initiated a change request (number 94 dated 10/26/65) to extend qualification tests to 44 days, such that the LEM mission requirements can be met. These test results will be monitored for AES applications.

The maximum estimated time that the RCS will be exposed to propellant or propellant vapors for the AES mission is as follows:

	Time (days)
Load propellant (prior to launch)	5
Allowable launch window	3
Time for prelaunch recycle	30
Orbital time	45
Total:	83

Another potential problem under study is the ability of the electroluminescent displays to meet AES mission requirements. The AES/LEM window panel assembly has been identified as another AES life-limited item.

4.5.4 EPS Reliability Configuration Analysis

A study was conducted to assess the GE, P&W, and A-C fuel cell assemblies for the Lab baseline, alternate, and recommended configurations. The following tabulation presents the evaluation based on a continuous operating cycle for the full mission (45 days) for the housekeeping and experiment portions combined, with and without the mapping radar experiment.

Lab Fuel Cell Evaluation

Configuration Requirement	Fuel Cell Type*	Qty. Provided	Qty. Required	Reliability
• Continuous Operation for 45 days without mapping radar experiment	P&W	2	1	0.999139
	GE	4	7 for 115.7 hrs 6 for 964.3 hrs	0.999501
	$\bar{A}$C	2	1	0.998787
• Continuous Operation for 45 days with mapping radar experiment	P&W	2	2	0.942310
	GE	4** (12 stacks)	10	0.705480
	$\bar{A}$C	2	2	0.931260

- - - - - - -

* Cell Failure Rates:

AC: 1 f/10^6 hrs per cell section (33 sections)

P&W: 0.86 f/10^6 hrs per cell

GE: 5 f/10^6 hrs per cell

** With one additional section added the reliability will increase to 0.978123.

Table 4.5-1

DESIGN REFERENCE MISSION

Nom 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	Launch	.1656	.0011	.1667
2	Earth Parking Orbit	.0082	.02083	.02903
3	Hohmann Transfer	.00316	.99683	.99999
4	Orbital	.00306	1077.8012	1077.8043
	TOTAL	.180	1078.82	1079.0

Table 4.5-2

RECOMMENDED PHASE II LAB RELIABILITY SUMMARY

Ident No.	Name (& Quantity if More Than One)	Fail Rate $f/10^6$ hr	Equipment Usage Time, hr			
			Operate		Non-Operate	
			Boost	Non-Boost	Boost	Non-Boost
	A. Stabilization & Control Subsystem (R = 0.4610064 for 100% Rate Stab, 50% Attitude Hold) (R = 0.820252 for 100% Rate Stab, No Attitude Hold)					
1	ATCA - Attitude & Translation Control Ass'y	51.34		1077.8	.18	1.02
2	ACA - Attitude Controller Ass'y	33.40		1077.8	.18	1.02
3	RGA - Rate Gyro Ass'y	99.10		1077.8	.18	1.02
4	ASA - Abort Sensor Ass'y	265.35		538.9	.18	539.92
5	AEA - Abort Electronics Ass'y	802.80		538.9	.18	539.92
	B. Reaction Control Subsystem (R = .834995)					
1	Helium Pressure Vessel (2)	.04	.321	1078.679	0	0
2	Pressure Transducer (4)	.05	.321	1078.679	0	0
3	Manifold (2)	.04*	.321	1078.679	0	0
4	Temperature Transducer (5)	.05	.321	1078.679	0	0
5	Helium Initiate Squib Valve	.06	.321	1078.679	0	0
6	Helium Filter	.31	.321	1078.679	0	0
7	Shut Off Valve-Solenoid	14.20	.321	1078.679	0	0
8	Pressure Regulator - Foil Open	13.67	.141	0	0	0
9	Pressure Regulator - Foil Closed	13.67	.141	0	0	0
10	Quad Check Valve-Oxidizer - Foil Closed	8.7*	.141	0	0	0
11	Quad Check Valve-fuel - Foil Closed	8.7*	.141	0	0	0
12	Quad Check Valve-Oxidizer - Foil Open	8.7*	.18	1078.679	0	0
13	Quad Check Valve-Fuel - Foil Open	8.7*	.18	1078.679	0	0
14	Burst Disc (2)	.11	.321	1078.679	0	0
15	Pressure Relief Valve	5.7	.321	1078.679	0	0
16	Test Point	12.5	.321	1078.679	0	0
17	Burst Disc	.11	.321	1078.679	0	0
18	Oxidizer Tank (bladder)-(2) failure rate	8400.0	0	1	0	0
19	Fuel Tank (bladder)-(2) 10^6 cycles	8400.0	0	1	0	0
20	Main Shutoff Valve	3.09	.321	1078.679	0	0
21	Fill Valve	3.66	.321	1078.679	0	0
22	Cap	80.0	.321	1078.679	0	0
23	Fill Valve 30ˉ Redundancies in Series	3.66	.321	1078.679	0	0
24	Cap	80.0	.321	1078.679	0	0
25	Thrust Chamber Assembly-Fire (4)	1057.9	.141	0	0	0
26	Thrust Chamber Assembly-Nofire (4)	1057.9	0	0	.18	1078.679
27	Isolation Valve (16)	3.09	.321	1078.679	0	0
28	Propellant Inlet Filter (16)	.31	.321	1078.679	.321	1078.679
29	Lines, Joints, Fittings (80)	.05	.321	1078.679	0	0
30	Thrust Chamber Assembly Injector Valve-Fire (32)	34.4	.141	0	0	0
31	Thrust Chamber Assembly Injector Valve-No Fire (32)	34.4	0	0	.18	1078.679
	* Assumed vendor estimate					
	C. Electrical Power Subsystem (R =)					
1	Fuel Cell Assembly (2)	1.0/Sect*	.180	1078.82		
2	Peaking Battery	2.0**	.180	1078.82		
3	Battery ECA	20		15.40		1063.6
C	Cryogenic Feed System	***	.180	1078.82		
4	Tank	.50	.180	1078.82		
5	Fill Valve	.171	.180	1078.82		
6	Vent Valve	.171	.180	1078.82		
7	Cap (2)	.80.0	.180	1078.82		
8	Heater (2)	.05	.180	1078.82		
9	Thermostat (2)	.03	.180	1078.82		
10	Motor Fan (2)	3.59	.180	1078.82		
11	Manual Override SW.	.015	.180	1078.82		
12	Pressure Xducer	13.0	.180	1078.82		

CONFIDENTIAL

Table 4.5-2 (Cont)

Ident No.	Name (& Quantity if More Than One)	Fail Rate f/10^6 hr	Equipment Usage Time, hr: Operate, Boost	Operate, Non-Boost	Non-Operate, Boost	Non-Operate, Non-Boost
37	Regen. Heat exchanger (2)	2.0	.180	1078.82		
38	Cabin Fan (2)	8.58	.180	1078.82		
39	Temperature Control Valve (2)	.39	.180	1078.82		
40	Regulator Control Valve (2)	.81	.180	1078.82		
41	Radiator (2)	.50	.180	1078.82		
42	Cabin Dump Valve	3.01	.180	1078.82		
43	H_2O Hose	.10	.180	1078.82		
44	H_2O Disconnect	1.33	.180	1078.82		
45	H_2O Hose Assy	.02	.180	1078.82		
46	O_2 Relief Valve	3.37	.180	1078.82		
47	O_2 Manual Shutoff Valve	2.43	.180	1078.82		
48	O_2 Filler	.05	.180	1078.82		
49	O_2 Hose	.05	.180	1078.82		
50	O_2 Disconnect	.24	.180	1078.82		
51	O_2 Hose Assy	.05	.180	1078.82		
	E. Communications (R = .90396)					
1	S-Band Omnidirectional Antenna	.025	0	354.982	.18	723.84
2	S-Band Diplexer	1.7	0	354.982	.18	723.84
3	S-Band Transmit-Receive Electronic Replaceable Assembly	52.9	0	354.982	.18	723.84
4	FM Modulator	.162*	0	354.982	.18	723.84
5	PM Modulator	.757*	0	354.982	.18	723.84
6	Signal Processor Assembly	64.549	0	1078.82	.18	0
7	Headset Audio Receiver	.30	0	1078.82	.18	0
8	Headset Microphone	.120	0	1078.82	.18	0
9	VHF Omnidirectional Antenna	.025	0	132.0	.18	946.82
10	VHF Diplexer	1.7	0	132.0	.18	946.82
11A	VHF Transmitter A	12.067*	0	132.0	.18	946.82
11B	VHF Transmitter B	12.067*	0	132.0	.18	946.82
12A	VHF Receiver A	13.252*	0	132.0	.18	946.82
12B	VHF Receiver B	13.252*	0	132.0	.18	946.82
13	S-Band Steerable Antenna	41.0	0	354.982	.18	723.84
	*Assumed Vendor Estimate.					
	F. Instrumentation (R = .685671)					
1	Transducers	49.06		1077.8	.18	--
2	Signal Conditioning Electronics Ass'y	122.69		1077.8	.18	--
3	Pulse Code Modulator #1	20.00		269.4	.18	808.4
4	Caution & Warning Elec. Ass'y	59.55		1077.8	.18	808.4
5	Displays	121.00		1077.8	.18	808.4
6	Timing Electronics Ass'y #1	8.20		269.4	.18	808.4
7	Pulse Code Modulator #2	20.00		269.4	.18	808.4
8	Tape Recorder #1	80.40		1077.8	.18	--
9	Tape Recorder #2	80.40		1077.8	.18	--
10	Timing Electronics Ass'y #2	8.20		269.4	.18	808.4
11	Voice Recorder	12.90		1077.8	.18	--
	G. Controls & Displays (R = .73584068)					
1	Explosive Devices	5.20			.180	1.019
2	Electrical Power System	56A0		1077.801	.180	1.019
3	Caution & Warning *					
4	Environmental Control System	27.70		1077.801	.180	1.019
5	Reaction Control System	44.10	.141	1077.660	.180	1.019
6	R.C.S. - System A Regulators	1.00	.141	1077.660	.180	1.019
7	R.C.S. - System B Regulators	1.00	.141	1077.660	.180	1.019
8	Flight Controls	53.60		949.240	.180	13.711
9	Stabilization & Control	5.70		1077.801	.180	1.019
10	Communications	19.85		1077.801	.180	1.019
11	Comm - VHF A	1.11		1077.801	.180	1.019
12	Comm - VHF B	1.21		1077.801	.180	1.019
13	Communication Antennas	13.10		1077.801	.180	1.019
14	Audio - VHF A	0.91		1077.801	.180	1.019
15	Audio - VHF B	0.91		1077.801	.180	1.019

[redacted]FIDEN[redacted]

Table 4.5-2 (Cont)

Ident No.	Name (& Quantity if More Than One)	Fail Rate $f/10^6$ hr	Equipment Usage Time, hr: Operate, Boost	Operate, Non-Boost	Non-Operate, Boost	Non-Operate, Non-Boost
13	Pressure Switch	9.09	.180	1078.82		
14	Motor Switch	1.28	.180	1078.82		
15	Temperature Sensor	.37	.180	1078.82		
16	Quantity gauge	7.71	.180	1078.82		
17	Signal Conditioner	15.0	.180	1078.82		
18	Shutoff Valve (2)	2.43	.180	1078.82		
19	Heat Exchanger	.05	.180	1078.82		
20	Pressure Relief Valve	3.30	.180	1078.82		
21	Lines	.05				

*Assumed f of one $f/10^6$ hr/section.
**Assumed f = to LEM modified descent battery (10 kw-hr)
***Cryogenic supply system consists of signal O_2 & H_2 tanks and feed. One system shown; other system (H_2 or O_2) identical. (See Fig.). Fail rates on cryogenic tank systems obtained from vendor sources.

**Assumed failure rate equal to LEM modifies descent 6 Hr (10 kcoh)

***Cryogenic supply system consist of single Oxygen and Hydrogen tanks and feed. One system is shown, the other system (H_2 or O_2) is identical (refer to figure) Failure rates on cryogenic tank system were based on estimates obtained from vendor sources.

D. Environmental Control Subsystem (R = .96120)

Ident No.	Name (& Quantity if More Than One)	Fail Rate $f/10^6$ hr	Operate, Boost	Operate, Non-Boost	Non-Operate, Boost	Non-Operate, Non-Boost
1	Select Valve	.81	.180	1078.82		
2	Pressure Regulator	1.46	.180	1078.82		
3	H_2O Tank	296/c	1 cycle	1078.82		
4	Fill Valve	3.66	1 cycle	1078.82		
5	Cap	80	1 cycle	1078.82		
6	Check Valve (3)	.67	1 cycle	1078.82		
7	Pressure Regulator (2 in Serves)	1.46	1 cycle	1078.82		
8	Shutoff Valve (2)	2.43	1 cycle	1078.82		
9	Descent nitrogen Tank	.04	1 cycle	1078.82		
10	Vent Valve	3.66	1 cycle	1078.82		
11	Cap	80	1 cycle	1078.82		
12	Pressure Regulator	1.46	1 cycle	1078.82		
13	Pressure Refief Valve	3.30	1 cycle	1078.82		
14	N_2 Shutoff Valve	2.43		132.0	.180	946.82
15	O_2 Shutoff Valve	2.43		132.0	.180	946.82
16	Select Valve	.09		132.0	.180	946.82
17	H_2O Separate	1.01		132.0	.180	946.82
18	Check Valve	.67		132.0	.180	946.82
19	Suit CKT Regen. Heat Exchanger	2.0		132.0	.180	946.82
20	Suit CKT Assy	2.95		132.0	.180	946.82
21	Suit CKT Relief Valve	2.54		132.0	.180	946.82
22	Suit CKT Fan	15.50		132.0	.180	946.82
23	Fan Check Valve	.44		132.0	.180	946.82
24	Pressure Control	22.17		132.0	.180	946.82
25	Pressure Sensor	2.0		132.0	.180	946.82
26	Selector Valve	.09		132.0	.180	946.82
27	LIOH Cannister	.14				
28	H_2O Evaporator	2.0		132.0	.180	946.82
29	Suit CKT Heat Exchanger	2.0		132.0	.180	946.82
30	Primary H_2O Boiler	2.0	.180	1078.82		
31	Glycol Accumulator	1.34	.180	1078.82		
32	Glycol Filter	0.0	.180	1078.82		
33	Glycol Pump	16.1	.180	1078.82		
34	Check Valve	.67	.180	1078.82		
35	Bypass Relief Valve	1.12	.180	1078.82		
36	Cabin Heat Exchanger	2.0	.180	1078.82		

Table 4.5-2 (Cont)

Ident No.	Name (& Quantity if More Than One)	Fail Rate f/10^6 hr	Equipment Usage Time, hr			
			Operate		Non-Operate	
			Boost	Non-Boost	Boost	Non-Boost
16	Audio - S-Band	0.91		1077.801	.180	1.019
17	Audio - I C S	0.91		1077.801	.180	1.019
18	Audio - V O X	0.91		1077.801	.180	1.019
19	Audio - Master Control	0.51		1077.801	.180	1.019
20	Audio - Audio Control	0.30		1077.801	.180	1.019
21	Audio - Relay Select	0.30		1077.801	.180	1.019
22	Lighting Controls	28.00		1077.801	.180	1.019
23	Lighting - Anun/Num Control	0.20		1077.801	.180	1.019
24	Lighting - Anun Override Switch	0.30		1077.801	.180	1.019
25	Lighting - Num Override Switch	0.30		1077.801	.180	1.019
26	Lighting - Integral Control	0.20		1077.801	.180	1.019
27	Lighting - Integral Override Switch	0.30		1077.801	.180	1.019
28	Heaters	12.60		1077.801	.180	1.019
29	Bio Med	8.80		1077.801	.180	1.019
30	Instrumentation	21.10		812.182	.180	1.019
	*Calculations included with Instrumentation.					

Table 4.5-3

SUBSYSTEMS SUMMARY, VEHICLE & EXPERIMENT RELIABILITY

	LEM (See Note 1)			AES Ph II Lab DRM
Subsystem	Crew Safety	Apportion	Estimate	
Nav/Guidance	.999651	.990700	.988205	.820252 (Note 2)
Descent Propul.	.999899	.999075	.998764	Not Reqd
Ascent Propul.		.999961	.998300	Not Reqd
RCS	.997807	.999804	.919600	.834995
EPS	.999993	.998600	.963896	.899400
ECS	.999994	.999446	.994760	.961200
Communications		.999910	.997680	.903962
Instrumentation Controls & Displays		.999500	.999378*	.994193**
Structure	.999999	.999950	.999978	.999795**
Explosives	.999954	.999980	.999924	.999291**
Crew Provisions		.999990	Not Avail.	Not Avail.
System	.987	.987	.866	.531645

*Does Not Include Sensors.
**Utilizes LEM Estimate With Exponential Degradation For Extended Duration

Notes: 1. Values Obtained From LPR-550-9, QUARTERLY RELIABILITY STATUS REPORT, 1 Aug 1965

2. Does Not Include Attitude Hold.

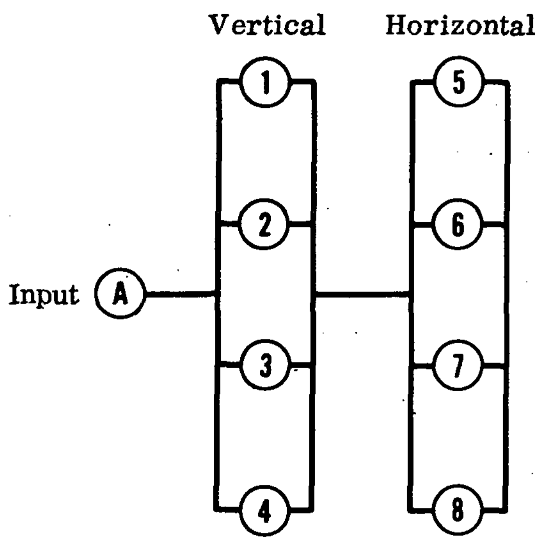
Table 4.5-4

POTENTIAL WEAR-OUT ITEMS

Equip Comm.		Dwg Ref No.	Spec Life hr	days	Cycles
Pwr Divider	X	LSC 380-00143	2000		
Pwr Divider	X	LSC 380-00151	2000		
Crew Provisions					
Waste Mgmt Equip	*	LSC 340-201	2000		
EL Lamps	*	LSC 340-201	2000		
Floodlight Interior	X	LSC 340-403-1 thru 5 & 71	1000		
Displays & Controls					
Attitude Ind	X	LSC 350-301		Unknown	
Digital Event Timer	X	LSC 350-307	1200		
RCS Quant. Gage	X	LSC 350-401	1200		
D'Arsonval Meter	*	LSC 350-801	Unknown		
Flag Ind.	*	LSC 350-804	2000		
Helium Temp & Pres Ind.	X	LSC 350-201	1200		
Environmental Control					
Cabin Fan	X	LSC 330-102	1250		
Cartridge (LiOH)	X	LSC 330-122	20		
PLSS Refill	X	LSC 330-125	5		
Suit Circuit Assy	*	LSC 330-190	2500		
Cabin ARS	*	LSC 330-191	2500		
Coolant Pump	*	LSC 330-201	Unknown		
Cabin Temp Cont Valve	*	LSC 330-203	2500		5000
Suit Temp Cont Valve	*	LSC 330-208	2500		3000
Coolant Accum.	*	LSC 330-210	2500		500
Water Control Module	*	LSC 330-490	2500		
Electrical Power					
Inverter, Gen. Purpose	X	LSC 390-6	1000		
Relay Box-ECS	*	LSC 390-21051	Unknown		
Relay Box EED	*	LSC 390-2 1052	Unknown		
Instrumentation					
SCEA requires investigation-	*				
Design presently in development					
Sensors: additional info req	*				
Reaction Controls					
Ox Sensing Unit A	X	LSC 310-5-11	144		100
Fuel Sensing Unit B	X	LSC 310-5-12	144		100
Control Unit Assy	X	LSC 310-5-21	144		100
Ox Inlet Filter	X	CSC 310-125-3		30	
Fuel Inlet Filter	X	LSC 310-125-4		30	
He, Quad Check Valve	X	LSC 310-306-1 thru 4	720		8000
He, Coupling Disconnect	X	LSC 310-308			400

Table 4.5-4 (Con't)

Equip		Dwg Ref No.	Spec Life hr	days	Cycles
He, Coupling, Test Port	X	LSC 310-308			400
Ox, Coupling Fill	X	LSC 310-401-101		30	400
Fuel, Coupling Fill	X	LSC 310-401-202		30	400
Ox Coupling, Bleed	X	LSC 310-401-402		30	400
Fuel Coupling, Bleed	X	LSC 310-401-402		30	400
Ox Coupling, Disconnect	X	LSC 310-401-501		30	400
Fuel Coupling Disconnect	X	LSC 310-401-602		30	400
Ox Tank Vent Disconnect	X	LSC 310-401-701		30	400
Fuel Tank Vent Disconnect	X	LSC 310-410-802		30	400
Ox Isolation Valve	X	LSC 310-403-101		30	165
Fuel, Main S/O Valve	X	LSC 310-403-202		30	165
Fuel, Crossfeed Valve	X	LSC 310-403-202		30	165
Ascent Inlet Feed Valve	X	LSC 310-403-202		30	165
Ox, Main S/O Valve	X	LSC 310-403-301		30	165
Ox Isolation Valve	X	LSC 310-403-301		30	165
Ox Crossfeed Valve	X	LSC 310-403-301		30	165
Ox Ascent Intconnect	X	LSC 310-403-301		30	165
Fuel Isolation Valve	X	LSC 310-403-402		30	165
Tank, Oxidizer	X	LSC 310-405-1	1500		
Tank Fuel	X	LSC 310-405-2	1500		
Ox, Filter, Asc. I Intconnect	X	LSC 310-406-1		30	
Fuel, Filter Asc. Intconnect	X	LSC 310-406-2		30	
Stabilization & Control					
Gimbal Drive Act	X	LSC 300-170-1	1000		
Structures					
Panel Assy	X	LDW 280P101-24-3	600		
Panel Assy	X	LDW 280P101 24-4	600		
Panel Assy	X	LDW 280-10141-3	600		



	$\lambda \times 10^{-6}$
(A)	51.34
(1)	8.98
(2)	8.98
(3)	8.98
(4)	10.68
(5)	7.39
(6)	7.39
(7)	10.68
(8)	10.68

Fig. 4.5-1 ATCA Block Diagram

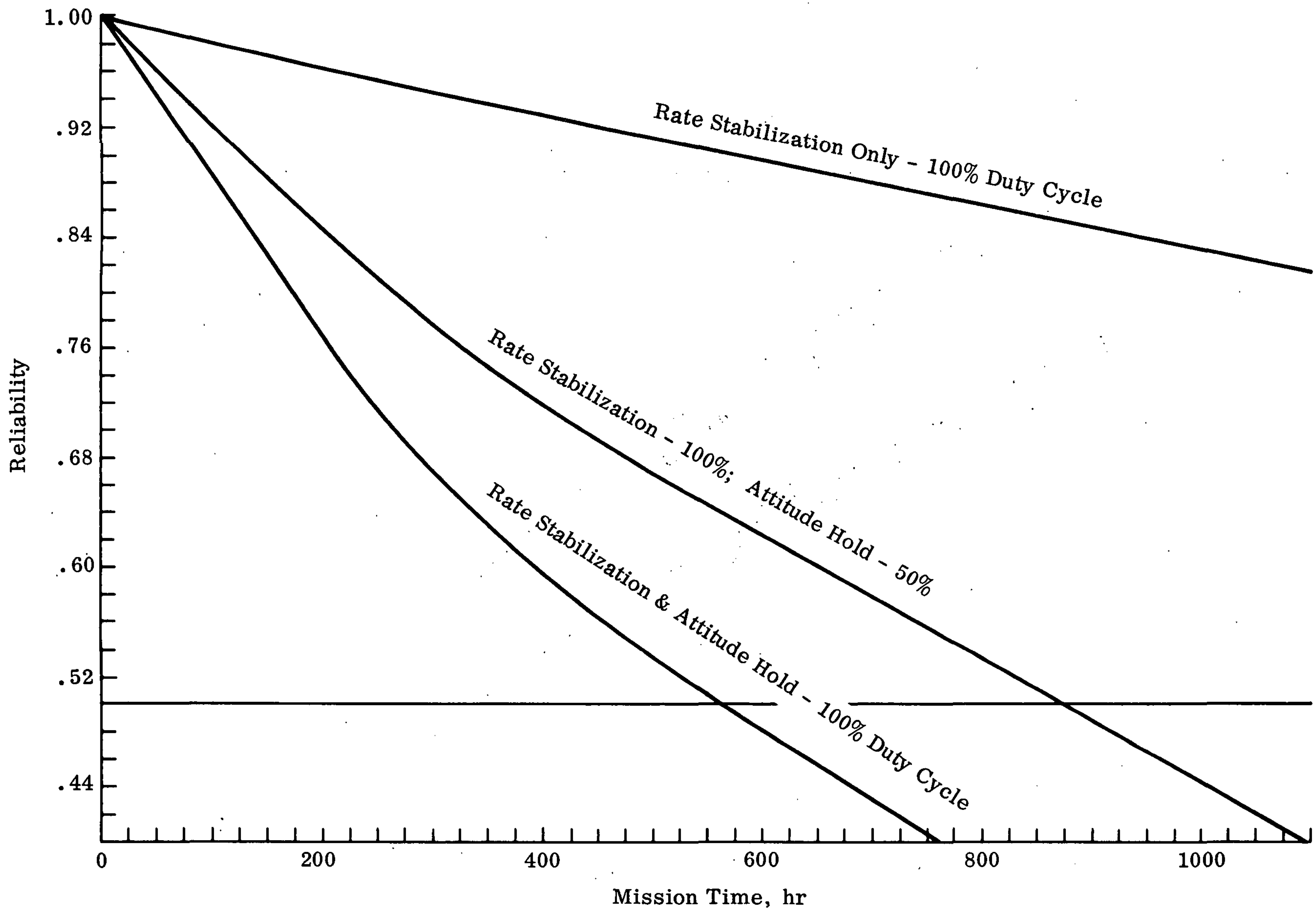


Fig. 4.5-2 Abort Guidance Section Used for Stability & Control

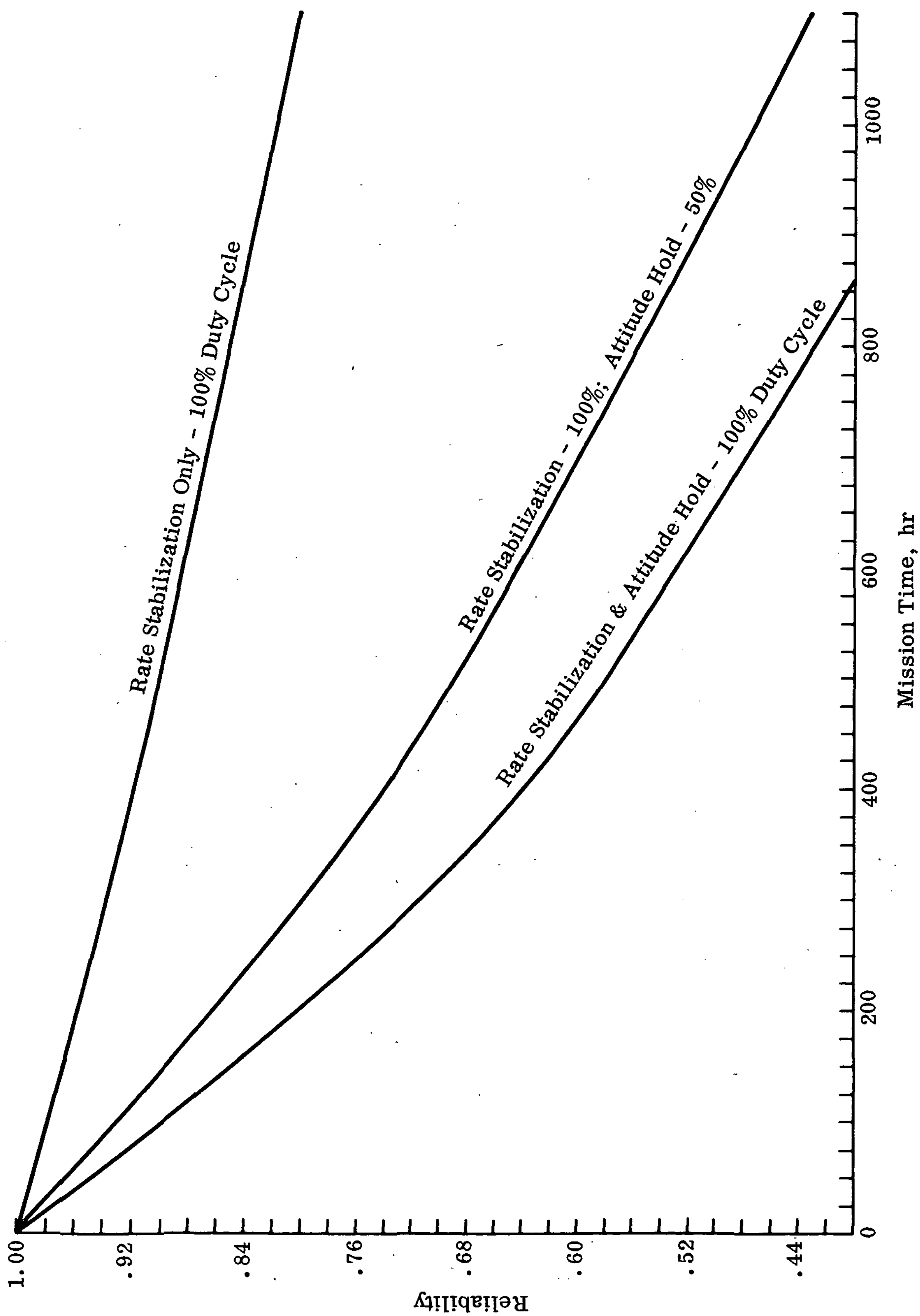
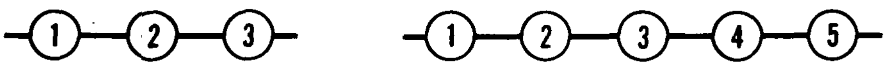


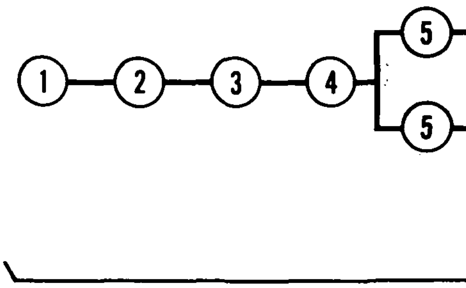
Fig. 4.5-3 Primary Guidance Section Used for Stability & Control

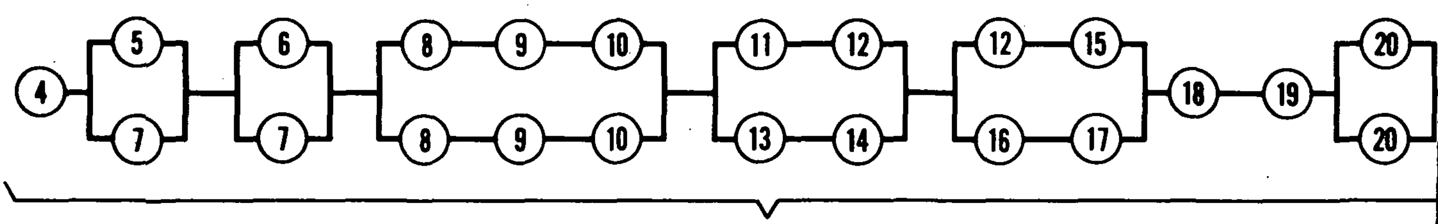
Rate Stab Only

Rate Stab & 50% Attitude Hold



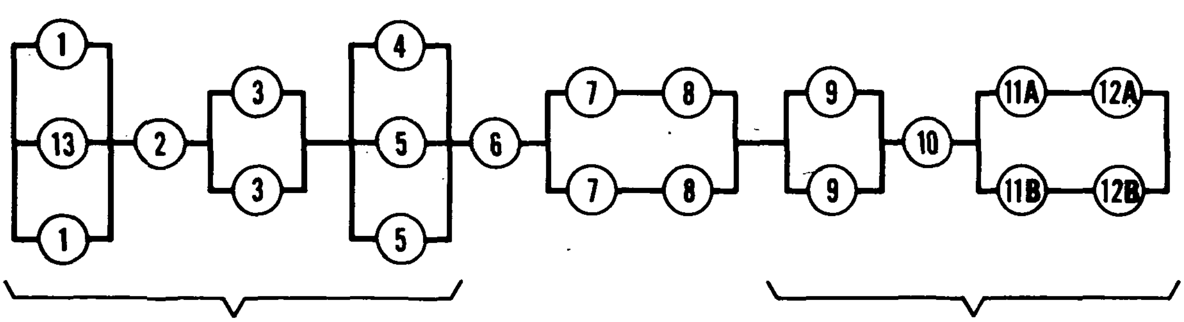
A. Stability & Control





Cryogenic (c) O_2 Supply System

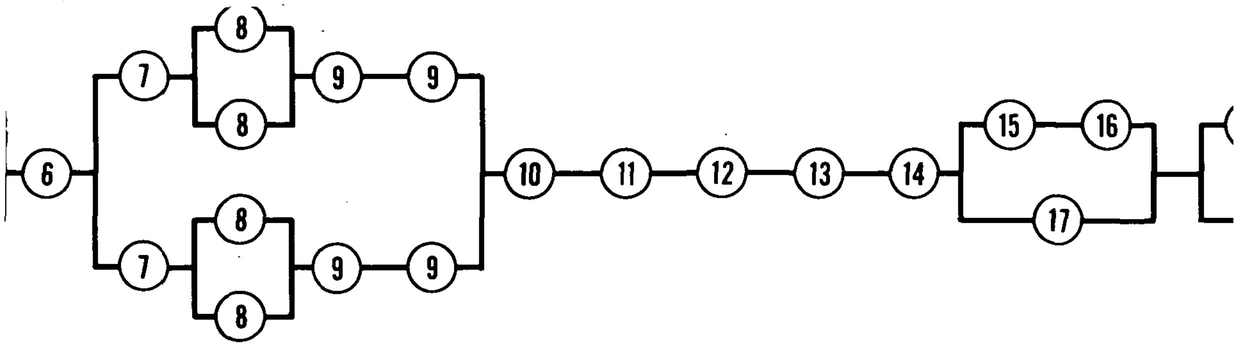
C. Electrical Power



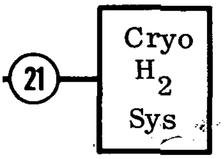
S - Band

E. Communications

VHF

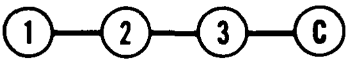


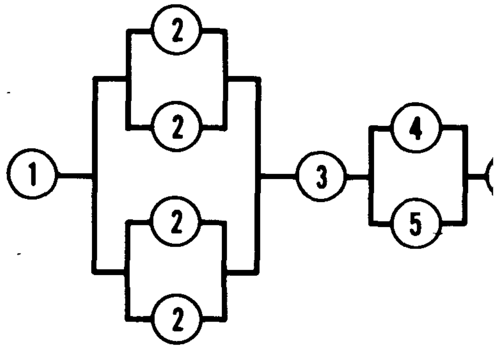
System A

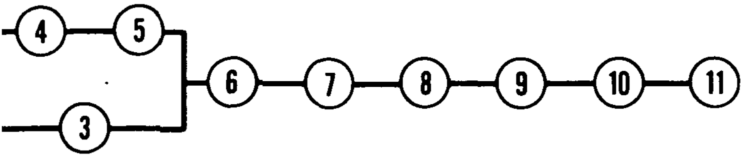


Same as O_2

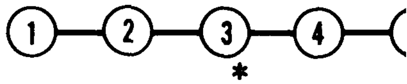
Integrated System
(Cryogenics, FCAs,
Peaking Battery & ECA)







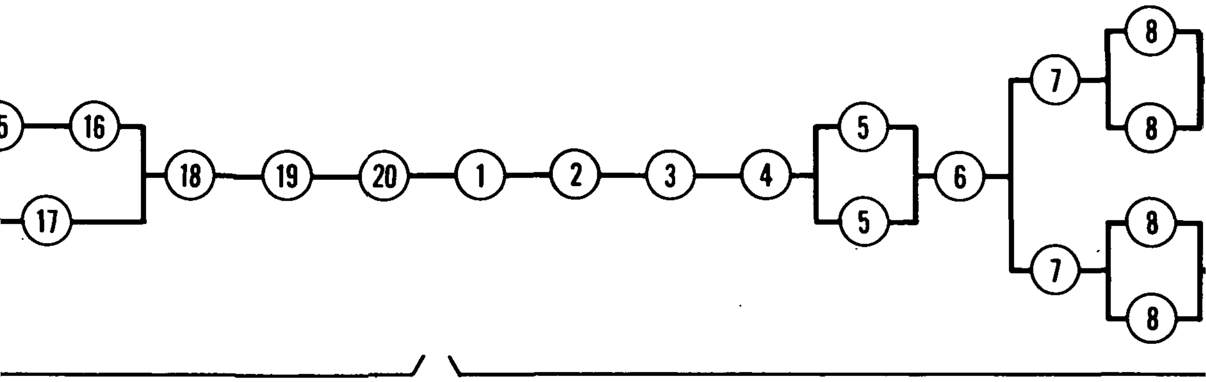
F. Instrumentation



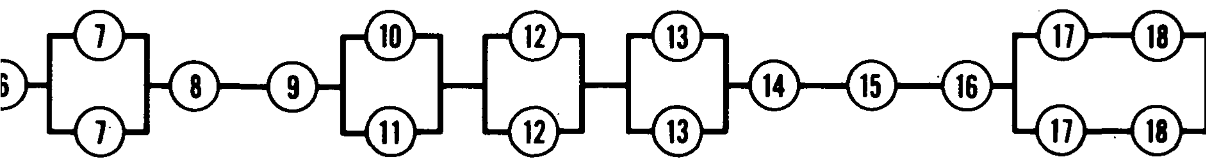
* Calculations included in

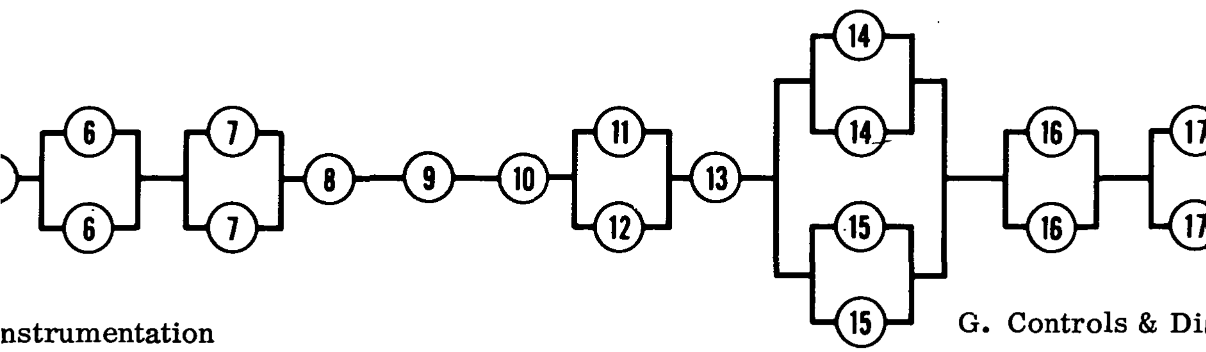
4.5-4

(2)



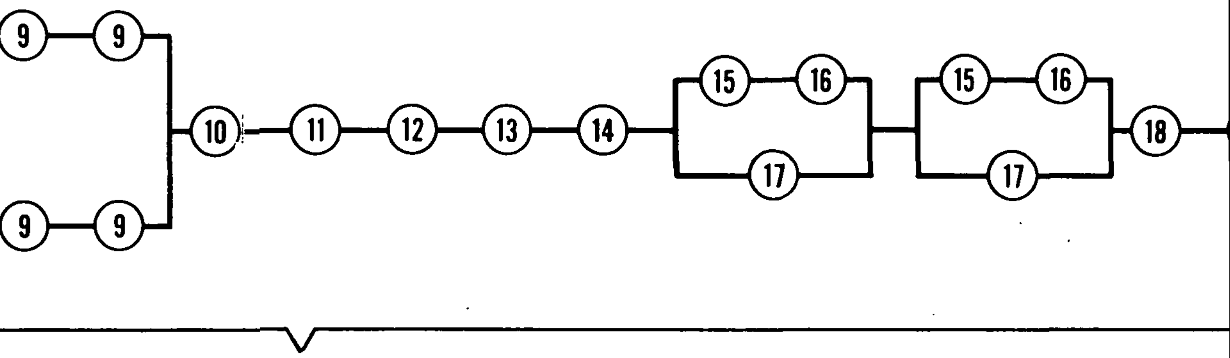
B. Reaction Control



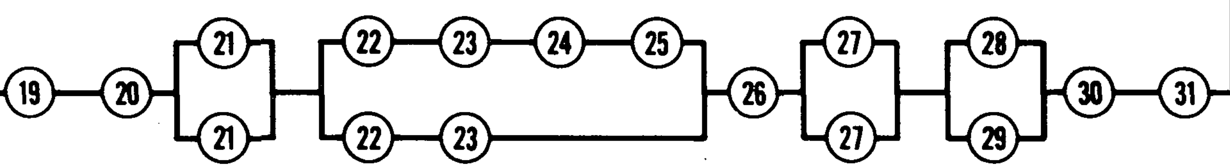


nstrumentation

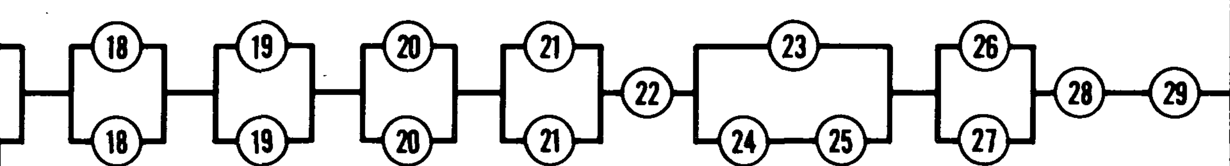
G. Controls & Di



System B



D. Environmental Control



plays

4.5-4

(4)

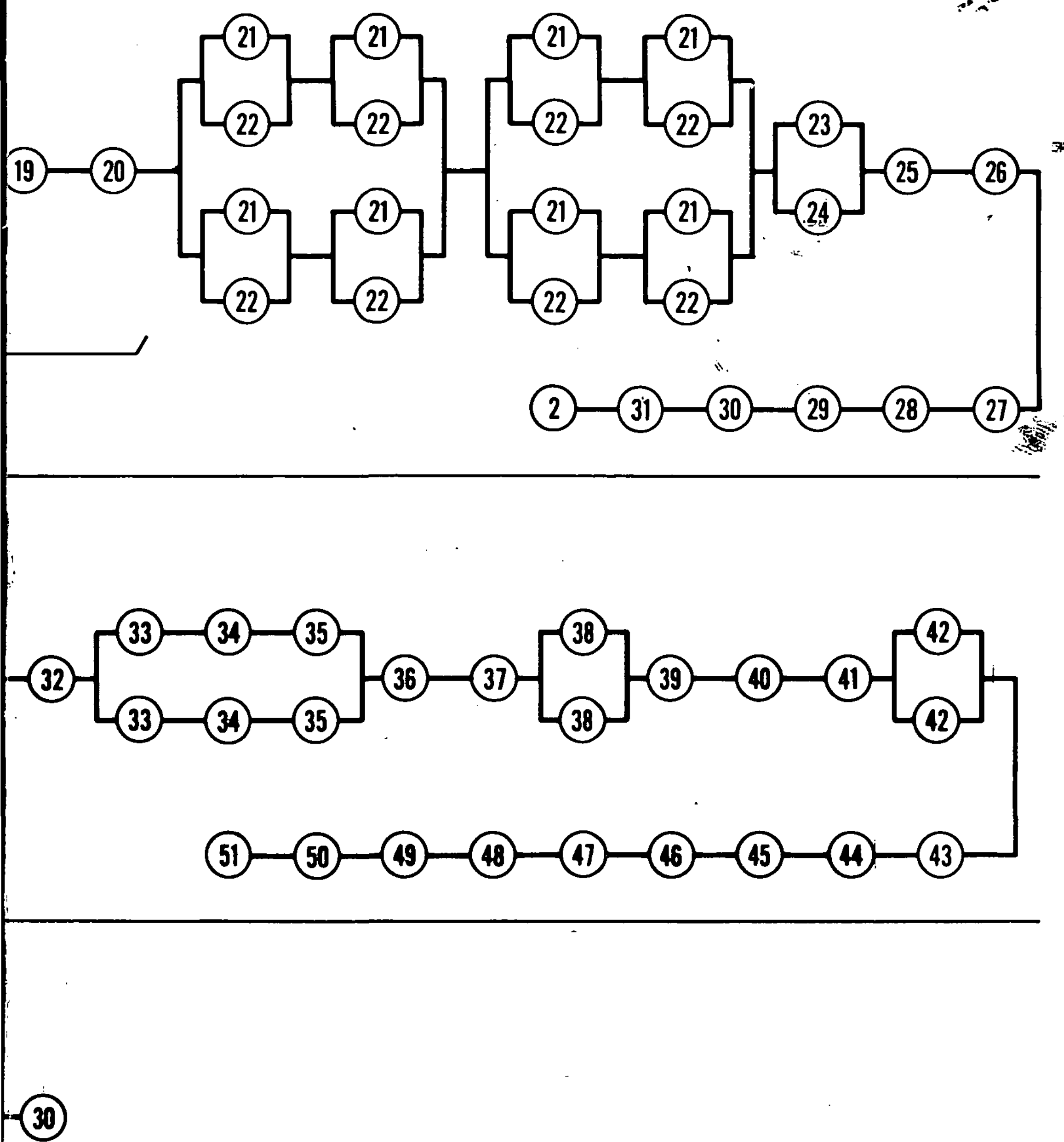


Fig. 4.5-4 Reliability Block Diagram

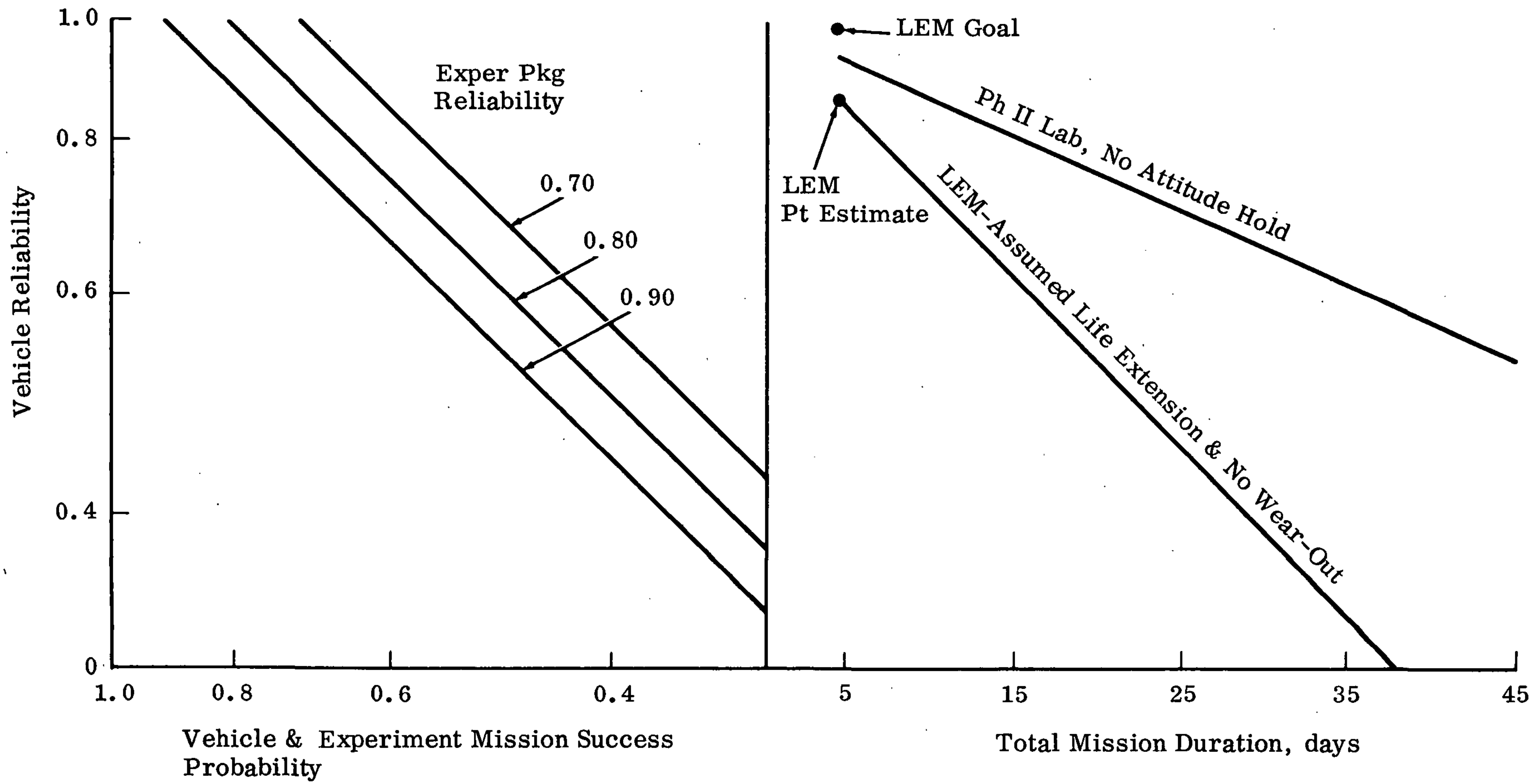


Fig. 4.5-5 Mission Success Probability

4.6 MASS PROPERTIES

4.6.1 Ground Rules

The major ground rules affecting the mass properties analyses are tabulated in the configuration summary section of this report. The weight limitations for various Phase II flights as listed in Table V of the Blue Book are:

FLIGHT NO.	ALLOWABLE LAB & EXPERIMENT WEIGHT (LB.)
513	72,900
218	TBD
516	19,900
221	TBD
517	TBD
518	TBD
224	TBD
521	72,900
522	TBD
523	TBD
229	TBD

The August 11, 1965, coordination meeting generated the following ground rules:

- There are no restrictions on the cg positions or inertias for the Lab missions.

4.6.2 Assumptions and Background Data

The basis for all reported mass properties remains the 1 August LEM weight statement changed by the addition of 77 lb of descent propulsion and 18 lb of ascent stage structure to attain the LEM design separation weight.

Specific assumptions affecting the mass properties of the Phase II Lab are:

- Experiment weight is not included in the baseline or recommended laboratory weights
- AES (CSM) maximum volume cryogenic tanks (1 hydrogen and 1 oxygen) plus Allis-Chalmers fuel cells utilized in the recommended configuration result in 675 kw-hrs of available experiment energy; AES (CSM) housekeeping cryogenic tanks (2 hydrogen and 2 oxygen) plus Pratt & Whitney Aircraft fuel cells utilized in the baseline configuration result in 654 kw-hrs of available experiment energy.
- Water, oxygen, LiOH and PLSS batteries for 16 and 44 EVA's are provided by the baseline and recommended labs respectively
- Food and CSM LiOH for 44 days are carried in the baseline Lab
- Food for 44 days is carried in the recommended Lab
- Experiment weight must include the following dependent items in addition to the experiment itself.
    - o supports and mounts
    - o micrometeoroid and thermal shielding
    - o signal conditioning and sensors

- o electrical wiring
- o controls and displays
- o GN&C for special requirements
- o electrical power, propellant, oxygen and water (and associated hardware) for requirements in excess of above.

4.6.3 Recommended Configuration

Tabulations of the recommended configuration mass properties summary by mission phase (Table 4.6-1) and mass properties summary by subsystem (Table 4.6-2) are presented herein. These tables describe the weight, cg and moments of inertia for each of the mission phases or subsystems listed. Table 4.6-4 presents a mass property summary, by module of an orbiting spacecraft including CSM, lab and the experiments of Flight 518 as shown in the Phase A addendum study.

A detailed weight statement for the recommended configuration is presented in Table 4.6-5. This weight statement is a listing of the applicable information from the IBM cards used in determining the mass properties of the Phase II Lab. In most cases, the initial weight in each subsystem is a one line entry taken directly from LEM; the subsequent weights indicate additions or deletions from the basic LEM subsystem. Where only one or two items from the LEM are used, these are listed as separate cards and the subsystem weight is built up.

The weight changes to the baseline configuration resulting in the recommended configuration, are detailed in Table 4.6.7. In addition, a brief description of these changes is presented.

Although no specific airlock design has been chosen for the recommended Phase II Lab, the descent stage airlock and docking tunnel has been used for mass property analyses.

4.6.4 Baseline Configuration

The following tables define the baseline configuration:

4.6-1	Mass properties Summary by Mission Phase
4.6-3	Mass properties Summary by Subsystem
4.6-6	Detailed Weight Statement
4.6-8	Changes to the Baseline Configuration

The changes shown in Table 4.6-8 represent an updating to the mid-term report resulting from corrections and/or omissions.

4.6.5 Alternate Configurations

Weight estimates have been made of the various alternates being offered. The delta effects of these alternates on the recommended configuration orbiting mass properties are presented in Table 4.6-9. A detailed tabulation of the various alternates appears in Table 4.6-10. This table shows the details of items removed and added and their weight impact, as a delta, on the orbiting configuration weight.

Table 4.6-1

PHASE II LAB MASS PROPERTIES SUMMARY BY MISSION PHASE

Mass Property		Dry		Burn Out		Earth Launch	
		Base*	Rec*	Base	Rec	Base	Rec
Weight, lb		6,325	6,223	7,033	6,728	10,055	9,607
cg, in.	x	232	223	230	224	236	220
from	y	1	0	1	-2	1	-6
Ref. Datum	z	-7	-4	-7	-4	-16	-5
Moments	I_{x-x}	4,332	4,248	4,459	4,436	6,182	5,916
of Inertia (cg)	I_{y-y}	4,920	5,857	5,252	6,045	7,397	8,259
slug-ft^2	I_{z-z}	4,561	5,287	4,865	5,365	6,302	8,647

*Base: Baseline
Rec : Recommended

Notes:
- cg Given in inches from reference 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 4.6-2

PHASE II RECOMMENDED LABORATORY
MASS PROPERTIES SUMMARY BY SUBSYSTEM

Code	Subsystem	Wt, lb	cg, in. from Ref. Datum			Moments of Inertia, slug-ft^2		
			x	y	z	I_{xx}(roll)	I_{yy}(pitch)	I_{zz}(yaw)
1.0	Structure- Asc	1497	250	-1	10	601	909	660
	-Desc	1123	163	-1	-1	1211	768	771
2.0	Stab & Cont	96	275	15	-26	69	76	11
3.0	Nav & Guid	32	297	0	58	6	1	1
4.0	Crew Provisions	111	245	2	47	17	11	22
5.0	Environ Cont	463	226	12	-7	276	365	353
7.0	Instrumentation	291	250	-13	-52	43	42	13
8.0	Elect Power	1857	212	-2	-15	1017	1334	1557
10.0	Reaction Control	475	264	0	-15	344	177	199
11.0	Communications	105	265	29	-35	51	51	52
12.0	Cout & Displ	173	266	1	53	55	38	26
	TOTAL DRY WT	6223	223	0	-4	4248	5857	5287
	TRAPPED & RESIDUAL							
4.0	Crew Provisions	315	243	-24	0	59	1	59
5.0	Environ Cont	38	253	11	-11	5	10	13
8.0	Elect Power	70	140	-44	0	17	0	17
10.0	Reaction Control	82	259	0	-19	37	9	30
	TOTAL WT AT BURN-OUT	6728	224	-2	-4	4436	6045	5365
	ORBITING EXPENDABLES							
4.0	Crew Provisions	345	243	38	0	1	1	1
5.0	Environ Cont	30	182	40	-59	1	2	3
8.0	Elect Power	1412	157	-44	0	387	51	389
10.0	Reaction Control	1092	274	0	-19	381	119	286
	TOT WT AT EARTH LCH & ORBITAL INSERT'N	9607	220	-6	-5	5916	8259	8647

[redacted]IDENTIAL

Table 4.6-3
PHASE II BASELINE LAB 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-Asc	1,363	258	-1	11	620	699	432
	-Desc	1,079	164	0	-1	1,177	759	735
2.0	Stab & Cont	92	275	15	-26	67	74	11
3.0	Nav & Guid	32	297	0	58	0	1	1
4.0	Crew Provisions	119	235	3	31	24	18	19
5.0	Environ Cont	424	252	8	-2	199	111	201
7.0	Instrumentation	283	249	-13	-52	42	41	12
8.0	Elect Power	2,139	227	1	-24	1,128	632	1,047
9.0	Propulsion	45	180	0	0	6	9	14
10.0	Reaction Control	475	279	0	-2	333	179	245
11.0	Communications	119	263	29	-28	62	62	54
12.0	Cont & Displ	155	267	1	53	55	38	25
	TOTAL DRY WT	6,325	232	1	-7	4,332	4,920	4,561
	TRAPPED & RESIDUAL							
4.0	Crew Provisions	92	190	0	0	0	0	0
5.0	Environ Cont	456	199	1	-1	7	64	66
8.0	Elect Power	78	222	0	-70	9	1	10
10.0	Reaction Control	82	283	0	0	38	10	43
	TOT WT AT BURN-OUT	7,033	230	1	-7	4,459	5,252	4,865
	ORBITING EXPENDABLES							
4.0	Crew Provisions	345	260	0	0	1	1	1
8.0	Elect Power	1,585	222	0	-70	184	18	196
10.0	Reaction Control	1,092	292	0	-1	355	62	359
	TOT WT AT EARTH LCH & ORBITAL INSERTION	10,055	236	1	-16	6,182	7,397	6,302

* From Ref. Datum.

CONFIDENTIAL

Table 4.6-4

MASS PROPERTIES SUMMARY OF FLIGHT 518
SPACECRAFT IN ORBITING CONFIGURATION

Module	Wt. lb.	cg, in. From Ref. Datum			Moments of Inertia, slug-ft^2		
		x	y	z	I_{xx} (roll)	I_{yy} (pitch)	I_{zz} (yaw)
Command Module	10,300	374	0	6	4,800	4,100	3,800
Service Module	13,400	508	-3	2	9,300	14,800	14,700
Retro Propellant	1,400	577	12	2	700	100	700
Total CSM & Prop	25,100	457	-1	4	14,892	46,219	46,431
Recommended Phase II Lab	9,607	220	-6	-5	5,916	8,259	8,647
Flight 518 Experiments	5,476	192	21	30	6,661	5,780	6,169
Total Lab & Experiments	15,083	210	4	8	14,048	15,552	15,955
Total Spacecraft, Orbiting Configuration	40,183	364	1	5	29,019	185,895	186,524

CONFIDENTIAL

AES RECOMMENDED PHASE 2 LAB DRY WT

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.0001	AST STRUCT	1326	259-	1	9
1.313	ENGINE COV-	13	245	0	2
1.3821	FUEL TK ST-	3	228-	45-	27
1.3822	FUEL TK ST-	2	239-	59-	27
1.3823	OX TNK SPT-	1	238	45-	27
1.3824	OX TNK SPT-	2	228	34-	27
1.3825	FUEL TK BR-	14	222	50	47
1.3812	H20 TK SPT-	4	302	0	0
1.0010	CNT WT INC	18	259-	1	9
1.323	PROP SHIEL-	11	252	0	0
1.4	AFT EQ BAY-	192	254	0-	56
1.426	ATTACHMNTS	26	254	0-	55
1.44	COLD PLATE	50	254	0-	63
1.4831	HE TANK ST	-2	245	25	-49
1.4832	HE TANK ST	-2	245	-25	-49
1.489	RCS SUPTS	4	238	53-	53
1.489	RCS SUPTS	5	238-	53-	53
1.4104	EQ BAY SHL	15	270	0	0
1.5	INC MM SHL	60	240	0	0
1.37	PLSS BATSP	5	243	-38	0
1.37	FOOD SUPTS	5	243	38	0
1.384	RCS TNK MT	30	265	0	-37
1.385	HE TNK MTS	8	248	0	-37
1.39	AIRLOCK	87	190	0	0
1.39	AL HATCH	25	237	0	0
1.39	AL HATCH	25	130	0	0
1.39	DOCKING ST	39	141	0	0
1.4	H20 TK SPT	2	265	0	-55
1.410	F/C SUPTS	10	260	0	-53
1.411	ECA MOUNT	3	260	0	-53
1.0	ASCT STRUCT	1497	250	-1	10
1.0002	DST STRUCT	1499	156	2	0
1.16	BS HT SHLD-	262	124	0	0
1.16	LWR DK INS	30	124	0	0
1.1111	OXID TK ST-	34	141	0	54
1.1111	BATT SUPT -	50	164	57	36
1.1211	FUEL TK ST-	29	141-	54	0
1.12	SH2 TK SPT	12	141	54	0
1.1411	FUEL TK ST-	29	141	54	0
1.14	SO2 TK SPT	31	141	-54	0
1.1511	OXID TK ST-	34	141	0-	54
1.1511	H20 TK SPT-	13	169-	36-	36
1.1511	HE TK SUPT-	18	149	50-	37
1.17	INC MM SHL	20	160	0	0
1.0	DSCT STRUCT	1123	163	-1	-1
2.0001	S+C WO DEC	87	273	16-	31
2.2	MODFY ATCA	3	263	18	-63
2.3	MODIFY RGA	1	302	9	54
2.621	MODIFY AEA	5	307	0	63
2.0	STAB + CONT	96	275	15	-26
3.12	AOT TELES	26	295	0	59
3.17	NAV BASE	6	307	0	55
3.0	NAV + GUID	32	297	0	58
4.19	ST REPR KT	10	238	37	49
4.31	RESTRAINTS	18	255	22	40
4.32	RESTRAINTS	17	255-	22	40
4.42	INT LIGHTG	3	252	0	46
4.61	WAST MANAG	7	215	40	46
4.62	WAST MANAG	8	215-	40	46
4.7	EXT LIGHTG	5	200	0	90
4.71	FLOOD LITE	5	280	0	60
4.811	WORK LIGHT	2	260	0	45
4.81	WORK TOP	8	252	22	45
4.82	WORK TOP	8	252	-22	45
4.83	SEAT	5	245	-22	45
4.85	MISC	15	250	0	45
4.0	CREW PROVS	111	245	2	47
5.0001	AST ECS	347	269	12	0
5.7	GLYCOL -	37	255	10-	10
5.8	EXPENDABLS-	61	293	2-	3
5.0002	DST ECS	302	156-	19-	46
5.8	EXPENDABLS-	213	148-	30-	47
5.311	GOX TK ASC	- 3	266	-14	-53
5.312	GOX TK ASC	-3	266	14	-52
5.313	GOX ACCUM	3	245	0	-55
5.401	FC H20 TNK	15	265	0	-55
5.401	MOD H20 TK	1	265	0	-55
5.41	AS H20 TNK-	11	302	0	0
5.4	DST H20 TK-	24	145-	49-	49
5.21	MFY GYPUMP	1	247	16-	13
5.222	RED GLY+WB-	3	280	25-	27
5.65	CP PCM	2	249-	18-	64
5.66	CP RECORD	2	250-	20-	60
5.9	MOD 2 GAS	15	245	0	0
5.91	RADIATOR	30	165	-70	-40
5.91	RADIATOR	30	165	-44	-65
5.91	RADIATOR	30	165	70	40
5.91	RADIATOR	30	165	44	65
5.91	ASA BYPASS	1	260	0	0
5.92	RECIPC DUC	4	280	0	0
5.10	AL SUIT LP	5	210	0	0
5.0	ENV CONTROL	463	226	12	-7
7.0001	INSTRUMNTN	202	249-	11-	48
7.12	PCMTEA	39	249-	18-	64
7.13	VOICE RCDR	3	285	0	-35
7.15	TAPE RECDR	18	250-	20-	60
7.15	TAPE RECDR	18	250-	20-	60
7.15	MOD RECRDS	5	250	-20	-60
7.16	SLCTR SWT	6	250-	20-	60
7.0	INSTRUMNTN	291	250	-13	-52
8.0001	AST EPS	767	255	1-	28
8.0002	DST EPS	656	162	58	33
8.11	AS BATTS -	261	253	0-	66
8.12	BATT CONTR-	20	276	0-	66

CONFIDENTIAL

CONFIDENTIAL

DS BATTS -	556	159	63	36
! BATT CONTR-	38	171	44	36
)1 PEAK BATT	65	230	0	-40
)2 RADIATOR	30	165	83	0
)2 RADIATOR	30	165	-83	0
)2 RADIATOR	30	165	0	83
)2 RADIATOR	30	165	0	-83
)4 SH2 TANK	290	165	55	0
)4 TK ACCESSS	4	165	55	0
)5 SO2 TANK	395	156	-55	0
)5 TK ACCESSS	4	156	-55	0
)6 AC F/C	164	260	-17	-53
)6 AC F/C	164	260	17	-53
)7 CRYO PLUMB	12	260	0	-50
)8 F/C ECA	14	260	10	-53
)8 F/C ECA	14	260	-10	-53
! F/C COOL	10	260	0	-40
! FC GLY PMP	10	260	0	-40
} CABLES	14	260	0	-40
EXPT SWBD	20	250	0-	60
! PLSS BATCH	3	260	0	0
} CRYO HT EX	3	270	0	-40
} FC H20 BLR	3	260	0	-40
ELECT POWER	1857	212	-2	-15
)01RCS	386	265	0-	2
PROPELLANT-	81	264	0	0
32 HELIUM -	2	263-	2	0
21 FUEL TANK	10	268	8	-37
21 FUEL TANK	9	268	-8	-37
22 OXID TANK	11	268	-30	-37
22 OXID TANK	11	268	30	-37
23 PLUMBING	73	268	0	-37
31 HE TANK	11	247	30	-37
31 HE TANK	11	247	-30	-37
33 HE PLUMBNG	36	247	0	-37
) REACTN CONT	475	264	0	-15
001AST COMM	100	267	37-	35
002DST COMM	16	138-	44	44
25 SB ERT ANT-	12	138-	34	49
INTRCOM HL	10	270	0	0
3 TV + ACCES-	9	240	40	35
) COMMUNICTNS	105	265	29	-35
001DISP + CON	213	267-	1	58
217S+C CONTS -	1	279-	2	71
218S+C CONTS -	1	279-	9	72
219S+C CONTS -	1	279	13	70
211S+C FDIA -	8	273-	10	72
211S+C CONTS -	2	279-	9	72
211S+C CONTS - -	5	294-	4	71
211S+C GASTA -	7	273	0	72
21 S+C CONTS -	1	270	0	72
221MDIFY DEDA	2	256-	43-	47
231S+C ACA -	3	250-	10	58
232S+C ATCA -	4	250-	34	58
N+G CONTS -	22	256-	3	65
3 EPS CONTS	4	262	1	56
) PROP CONTS-	10	276-	4	68

12.11 COMM CONTS	1
12.30 MISC CONTS	18
12.0 DISPS+CONTS	173
PH2 REC LAB DRY	6223

****** ****** ***

AES RECOMMENDED PHASE 2

CODE TITLE	WEIGHT POUNDS
PH2 REC LAB DRY	6223
4.444 CLOTHES 66	57
4.445 PLSS BATTS	60
4.444 PLSS LIOH	198
4.0 T+R PROVS	315
5.4446GLYCOL	37
5.444 T+R N2	1
5.0 T+R ECS	38
8.444 T+R SH2	7
8.445 T+R SO2	63
8.0 T+R EPS	70
10.444TRPD PROP	39
10.445HELIUM	2
10.444TRPD PROP	39
10.445HELIUM	2
10.0 T+R RCS	82
PH2 REC LAB B/O	6728

****** ****** ***

AES RECOMMENDED PHASE 2

CODE TITLE	WEIGHT POUNDS
PH2 REC LAB B/O	6728
4.444 FOOD	345
4.0 EXPEND PROVS	345

Table 4.6-5

DETAILED WEIGHT STATEMENT
RECOMMENDED PHASE 2 LAB

257	23	53
266	0	53
266	1	53
223	0	-4
**		******
LAB BURNOUT		
	C.G.	
X	Y	Z
223	0	-4
243	38	0
243	-38	0
243	-38	0
243	-24	0
255	10-	10
177	43	-59
253	11	-11
140	55	0
140	-55	0
140	-44	0
264	0	0
263-	2	0
255	0	-37
247	0	-37
259	0	-19
224	-2	-4
**		******
LAB ORBITNG		
	C.G.	
X	Y	Z
224	-2	-4
243	38	0
243	38	0

5.444 N2 EXPEND	28	177	43	-59
5.444 GOX EXPEND	2	245	0	-55
5.0 EXPEND ECS	30	182	40	-59
8.444 EXPEND SH2	144	165	55	0
8.445 EXPEND SO2	1268	156	-55	0
8.0 EXPEND EPS	1412	157	-44	0
10.4460XIDIZER	155	280-	40-	15
10.4460XIDIZER	154	280	40	15
10.446FUEL	118	280	45	15
10.446FUEL	119	280-	45-	15
10.446FUEL	118	268	8	-37
10.446FUEL	119	268	-8	-37
10.4460XIDIZER	154	268	30	-37
10.4460XIDIZER	155	268	-30	-37
10.0 EXPEND RCS	1092	274	0	-19
P2 REC LAB ORBIT	9607	220	-6	-5

155

Table 4.6-4a Phase 2 Bas

CONFIDENTIAL

AES BASELINE PHASE 2 LAB DRY WEIGHT

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.0001	AST STRUCT	1326	259-	1	9
1.313	ENGINE COV-	13	245	0	2
1.315	CANISTER	13	215	0	2
1.3821	FUEL TK ST-	3	228-	45-	27
1.3822	FUEL TK ST-	2	239-	59-	27
1.3823	OX TNK SPT-	1	238	45-	27
1.3824	OX TNK SPT-	2	228	34-	27
1.3825	FUEL TK BR-	14	222	50	47
1.3812	H2O TK SPT-	4	302	0	0
1.0010	CNT WT INC	18	259-	1	9
1.323	PROP SHIEL-	11	252	0	0
1.4	AFT EQ BAY-	192	254	0-	56
1.426	ATTACHMNTS	26	254	0-	55
1.44	COLD PLATE	50	254	0-	63
1.489	RCS SUPTS	4	238	53-	53
1.489	RCS SUPTS	5	238-	53-	53
1.4101	FC SUPTS	25	205	0-	50
1.4102	O2 TK SUPT	15	230	0-	70
1.4103	H2 TK SUPT	8	230	0-	70
1.4104	EQ BAY SHL	15	270	0	0
1.4	H2O TK SPT	2	250	0	0
1.5	INC MM SHL	60	240	0	0
1.384	RCS TNK MT	30	303	0	0
1.385	HE TNK MTS	8	303	0	0
1.0	STRUCTURE AS	1363	258	- 1	11
1.0002	DST STRUCT	1499	156	2	0
1.16	BS HT SHLD-	262	124	0	0
1.16	LWR DK INS	30	124	0	0
1.1111	OXID TK ST-	34	141	0	54
1.1211	FUEL TK ST-	29	141-	54	0
1.1411	FUEL TK ST-	29	141	54	0
1.1511	OXID TK ST-	34	141	0-	54
1.1511	H2O TK SPT-	13	169-	36-	36
1.1511	GOX TK SPT-	1	187	33-	50
1.1511	HE TK SUPT-	18	149	50-	37
1.17	INC MM SHL	20	160	0	0
1.1111	BATT SUPT -	50	164	57	36
1.0	STRUCTURE DS	1079	164	0	- 1
2.0001	S+C WO DEC	87	273	16-	31
2.621	MODIFY AEA	5	307	0	63

CODE	TITLE	WEIGHT	X	Y	Z
2.0	STAB CONTROL	92	275	15	-26
3.12	AOT TELES	26	295	0	59
3.17	NAV BASE	6	307	0	55
3.0	NAV GUIDANCE	32	297	0	58
4.19	ST REPR KT	10	238	37	49
4.31	RESTRAINTS	18	255	22	40
4.32	RESTRAINTS	17	255-	22	40
4.42	INT LIGHTG	3	252	0	46
4.51	H2O PROBE	1	238	37	49
4.61	WAST MANAG	7	215	40	46
4.62	WAST MANAG	8	215-	40	46
4.7	EXT LIGHTG	5	200	0	90
4.8	FURNISHNGS	50	230	0	10
4.0	CREW PROVS	119	235	3	31
5.0001	AST ECS	347	269	12	0
5.7	GLYCOL -	37	255	10-	10
5.8	EXPENDABLS-	61	293	2-	3
5.0002	DST ECS	302	156-	19-	46
5.8	EXPENDABLS-	213	148-	30-	47
5.41	AS H2O TNK-	11	302	0	0
5.4	DST H2O TK-	24	145-	49-	49
5.3	DST GOX TK-	46	184	40-	40
5.401	FC H2O TNK	15	260	20	0
5.402	FC H2O TNK	15	260-	20	0
5.3	GOX ACCUM	10	260	0-	30
5.21	MFY GYPUMP	1	247	16-	13
5.222	RED GLY+WB-	3	280	25-	27
5.65	CP PCM	2	249-	18-	64
5.66	CP RECORD	2	250-	20-	60
5.91	ECS RADIAT	60	235	65	0
5.92	ECS RADIAT	60	235-	65	0
5.91	ASA BYPASS	1	260	0	0
5.92	RECIRC DUC	4	280	0	0
5.0	ENV CONTROL	424	252	8	- 2
7.0001	INSTRUMNTN	202	249-	11-	48
7.12	PCMTEA	39	249-	18-	64
7.15	TAPE RECDR	18	250-	20-	60
7.15	TAPE RECDR	18	250-	20-	60
7.16	SLCTR SWT	6	250-	20-	60
7.0	INSTRUMENTN	283	249	-13	-52

CODE	TITLE
8.0001	AST EPS
8.0002	DST EPS
8.11	AS BATTS
8.12	BATT CONTR
8.11	DS BATTS
8.12	BATT CONTR
8.001	PEAK BATT
8.002	FC RADIATR
8.003	FC RADIATR
8.004	SH2 TANK
8.004	SH2 TANK
8.005	SO2 TANK
8.005	SO2 TANK
8.006	P+W FC
8.006	P+W FC
8.007	CRYO PLUMB
8.48	CABLES
8.5	EXPT SWBD
8.0	ELECT POWER
9.0001	AST SCARWT
9.002	DST SCARWT
9.0	PROPULSION
10.001	RCS
10.1	PROPELLANT-
10.32	HELIUM
10.21	FUEL TANK
10.22	OXID TANK
10.23	PLUMBING
10.31	HE TANK
10.33	HE PLUMB
10.0	REACT CONT
11.001	AST COMM
11.002	DST COMM
11.25	SB ERT ANT-
11.	SIG PR MOD
11.	INTRCOM HL
11.0	COMMUNICTNS
12.001	DISP + CON
12.217	S+C CONTS -
12.218	S+C CONTS -

CONFIDENTIAL

ːline Lab Detail Weight Statement

767	255	1-	28
656	162	58	33
261	253	0-	66
20	276	0-	66
556	159	63	36
38	171	44	36
85	230	0-	40
50	165	85	0
50	165-	85	0
195	230	40	0
195	230-	40	0
210	220	27-	55
210	220-	27-	55
266	222	55-	38
266	222-	55-	38
30	230	0-	60
14	164	0	0
20	250	0-	60
2139	227	1	-24
15	220	0	0
30	160	0	0
45	180	0	0
386	265	0-	2
81	264	0	0
2	263-	2	0
19	303	0	0
22	303	0	0
73	303	0-	5
22	303	0	0
36	303	0	0
475	279	0	- 2
100	267	37-	35
16	138-	44	44
12	138-	34	49
5	267	0	0
10	270	0	0
119	263	29	-28
213	267-	1	58
1	279-	2	71
1	279-	9	72

12.219S+C CONTS -	1	279	13	70
12.211S+C FD1A -	8	273-	10	72
12.211S+C CONTS -	2	279-	9	72
12.211S+C CONTS -	5	294-	4	71
12.211S+C GASTA -	7	273	0	72
12.21 S+C CONTS -	1	270	0	72
12.221MDIFY DEDA	2	256-	43-	47
12.231S+C ACA -	3	250-	10	58
12.232S+C ATCA -	4	250-	34	58
12.3 N+G CONTS -	22	256-	3	65
12.8 EPS CONTS	4	262	1	56
12.9 PROP CONTS-	10	276-	4	68
12.11 COMM CONTS	1	257	23	53
12.0 DISPS CONTS	155	266	1	53
PH2 LAB DRY WT	6325	232	1	- 7

AES BASELINE PHASE 2 LAB BURN OUT

CODE TITLE	WEIGHT POUNDS	C.G. X	Y	Z
PH2 LAB DRY WT	6325	232	1	- 7
4.444 PLSS LIOH	72	190	0	0
4.445 PLSS BATT	20	190	0	0
4.0 T+R CR PROV	92	190	0	0
5.4444ECS LIOH L.	23	265	0	0
5.4446GLYCOL	37	255	10-	10
5.444 ECS LIOH A	396	190	0	0
5.0 T+R ENV CONT	456	199	1	-1
8.445 TRPD OX	35	220	20-	70
8.445 TRPD OX	35	220-	20-	70
8.446 TRPD H2	4	240	40-	70
8.446 TRPD H2	4	240-	40-	70
8.0 T+R ELEC POW	78	222	0	-70
10.444TRPD PROP	39	264	0	0
10.444TRPD PROP	39	303	0	0
10.445HELIUM	2	263-	2	0
10.445HELIUM	2	303	0	0

10.0 T+R RCS	82	283	0	0
PH2 LAB AT B/O	7033	230	1	- 7

AES BASELINE PHASE 2 LAB ORBITING

CODE TITLE	WEIGHT POUNDS	C.G. X	Y	Z
PH2 LAB AT B/O	7033	230	1	- 7
4.444 FOOD	345	260	0	0
4.0 EXPEND PROV	345	260	0	0
8.445 EXP OX	713	220	20-	70
8.445 EXP OX	712	220-	20-	70
8.446 EXP H2	80	240	40-	70
8.446 EXP H2	80	240-	40-	70
8.0 EXPEND EPS	1585	222	0	-70
10.4460XIDIZER	154	303	25-	5
10.4460XIDIZER	155	303-	25-	5
10.4460XIDIZER	154	280	40	15
10.4460XIDIZER	155	280-	40-	15
10.446FUEL	118	280	45	15
10.446FUEL	119	280-	45-	15
10.446FUEL	118	303	38	0
10.446FUEL	119	303-	38	0
10.0 EXPEND RCS	1092	292	0	- 1
PH2 LAB ORBIT	10055	236	1	-16

Table 4.6-7
RECOMMENDED PHASE II LAB MASS DATA CHANGES; BASELINE TO RECOMMENDED

CODE	SUBSYSTEM	ITEM	Δ WT.	DESCRIPTION OF CHANGE
1.315	Structure-Ascent	Canister	-13	Canister replaced by airlock
1.483	Structure-Ascent	Helium tank supports	-4	Removed ascent propulsion He tanks.
1.37	Structure-Ascent	Equipment supports	+10	Added supports for PLSS L_iOH, batteries & food.
1.410	Structure-Ascent	Fuel Cell supports	-15	Reduced F/C supports due to lighter, smaller fuel cells.
1.411	Structure-Ascent	ECA mount	+3	Added separate entry for ECA mount.
1.39	Structure-Ascent	Center Airlock	+176	Added center airlock.
1.4102	Structure-Ascent	Oxygen tank support	-15	} moved to descent stage
1.4103	Structure-Ascent	Hydrogen tank support	-8	
1.151	Structure-Descent	GOX tank support	+1	Added 1 GOX tank and support
1.12	Structure-Descent	Hydrogen tank support	+12	} weight increased and moved to descent stage
1.14	Structure-Descent	Oxygen tank support	+31	
2.2	Stabilization & Control	Attitude Control Assembly	+3	Change ATCA rate gain to insure one pulse limit cycle
2.3	Stabilization & Control	Rate Gyro Assembly	+1	Modify RGA to provide lower rate threshold
4.51	Crew Provisions	Water probe	-1	Remove water probe and holster
4.8	Crew Provisions	Furnishings	-7	Better definition of furnishing items
5.311	Environ Control	Ascent GOX tank	-3	} Remove both ascent GOX tanks-modify and use a GOX tank as an accumulator
5.312	Environ Control	Ascent GOX tank	-3	
5.313	Environ Control	GOX accumulator	+3	
5.402	Environ Control	Fuel Cell water management tank	-14	Removed 1 water management tank, modified remaining tank
5.9	Environ Control	Two gas system	+15	Estimate of weight required to modify existing system to two gas
5.4	Environ Control	Descent GOX tank	+46	Retain descent GOX tank as N_2 tank.
5.3	Environ Control	GOX accumulator	-10	Use modified ascent GOX tank as accumulator
5.10	Environ Control	Airlock suit loop	+5	Added suit loop lines and connections in the airlock.

Table 4.6-7 (continued)

CODE	SUBSYSTEM	ITEM	ΔWT.	DESCRIPTION OF CHANGE
7.13	Instrumentation	Voice recorder	+3	Added one voice recorder
7.15	Instrumentation	Tape Recorders	+5	Modified recorders for single phase AC operation
8.005	Electric Power Supply	Oxygen & Hydrogen tanks	-117	Replaced CSM 'housekeeping' tanks with AES tanks
8.002	Electric Power Supply	EPS radiators	+20	Increased radiator area due to Fuel Cell change
8.001	Electric Power Supply	Peaking Battery	-20	Reduced peaking battery size as required for recommended configuration.
8.006	Electric Power Supply	Fuel Cells	-204	Replaced PSW fuel cells with AC fuel cells
8.008	Electric Power Supply	Electric Control Assy.	+28	Added ECA's required for AC fuel cells
8.007	Electric Power Supply	Cryo plumbing	+8	Added details for cryogenic plumbing and battery cooling
8.51	Electric Power Supply	PLSS battery charger	+3	Added battery charger for back pack batteries
9.0	Propulsion	Scar weight	-45	Capability for retaining propulsion no longer required
11.0	Communications	Signal Processor	-5	Removed modification to SPA
11.3	Communications	Television & Accessories	-9	Removed television
12.	Displays & Controls	Misc. Controls & Displays	+18	Added contingency for modification and additions to controls & displays
		DRY WEIGHT CHANGES	-102	
4.444	Crew Provisions	PLSS L_iOH	+126	Increased number of EVA's to 44
4.444	Crew Provisions	Constant wear garments	+57	Provide constant wear garments for 44 days
4.445	Crew Provisions	PLSS batteries	+40	Carry sufficient batteries for 44 EVA's rechargeable
5.444	Environ Control	LEM ECS L_iOH canisters	-23	CSM provides atmosphere revitalization
5.447	Environ Control	Apollo ECS L_iOH canisters	-117	CSM now using a molecular sieve
5.444	Environ Control	Trapped Nitrogen	+1	Two gas system requires Nitrogen
8.444	Electrical Power Supply	Trapped reactants	-8	AES tanks have less residual reactants
		TRAPPED AND RESIDUAL WEIGHT CHANGES	+76	

Table 4.6-7 (continued)

CODE	SUBSYSTEM	ITEM	Δ WT.	DESCRIPTION OF CHANGE
4.444	Crew Provisions	Food	+243	Carry food for 44 days (omitted by error from baseline)
5.444	Environ Control	Nitrogen	+28	Carry nitrogen for two gas system
5.444	Environ Control	Gaseous Oxygen	+2	Carry gaseous oxygen in accumulator
8.446	Electrical Power Supply	Power Supply Reactants and ECS oxygen	-163	Hydrogen tank filled to capacity; Oxygen tank filled to EPS and ECS requirements
		EXPENDABLE WEIGHT CHANGES	+110	
		TOTAL CHANGES	+76	

Table 4.6-8

BASELINE PHASE II LAB MASS DATA CHANGE; MID-TERM TO PRESENT

Code	Subsystem	Item	ΔWt	Reason for Change
2.621	Stab & Control	Abort Elect Assy (AEA)	+5	Mod. to AEA omitted by error from Mid-Term Report.
3.17	Nav & Guid	Navigation Base	+6	Base must be retained.
5.21	Environmental Control	Glycol Pump Mod	+1	These changes from the basic LEM were omitted by error from Mid-Term Report.
5.222		Redundant Glycol Loop	-3	
5.6		Cold Plates	+4	
5.91		ASA Bypass	+1	
5.92		Recirculating Duct	+4	
8.004	Electrical Power Supply	SH_2 Tanks	+90	Better information on tank & fuel cell weights.
8.005		SO_2 Tanks	+120	
8.006		P & W Fuel Cells	+40	
12.221	Displ's & Cont	Modify DEDA	+2	Omitted; Mid-Term Rept error.
		Dry Wt Δs	+270	
4.444	Crew Provisions	PLSS LiOH	-68	Reduced no. of back-pack recharges to 16.
4.445		PLSS Batteries	-20	
5.444	Environ Control	ECS LiOH (Apollo)	+279	LiOH increased for 44 days.
		Trapped & Residual Δs	+191	
4.444	Crew Provisions	Food	+243	Food increased for 44 days.
10.446	Reaction Control	Propellant	-58	Reduced max. usable propell't based on reversing tanks & reducing O/F.
		Expendable Δs	+185	
		TOTAL WT CHANGES	+646	

Table 4.6-9

MASS PROPERTIES SUMMARY OF DELTA CHANGES DUE TO ALTERNATES TO THE RECOMMENDED CONFIGURATION

Alternates	Wt, lb	cg, in. from Ref. Datum			Moments of Inertia, slug-ft^2		
		x	y	z	I_{xx}(roll)	I_{yy}(pitch)	I_{zz}(yaw)
Front hatch airlock and center compartment, remove center airlock	134	230	0	140	-90	-120	-4
Add voltage regulator, remove peaking battery	-36	230	0	-40	0	0	0
Replace AC fuel cells with GE fuel cells	171	215	0	-39	79	89	50
Two gas system without airlock	123	142	32	-61	136	-72	116
Use control moment gyros or inertia wheels	-	-	-	-	-	-	-
Remove suit circuit package	-47	260	23	13	-1	-4	-3
Replace center airlock with front airlock	-5	-1435	0	-3565	14174	17018	2855
Increase cabin pressure to 7 psi	-	-	-	-	-	-	-
Modify ASA & AEA for lower threshold rate	7	280	14	-9	6	7	1
Retain primary Navigation and Guidance, remove Abort Guidance System	124	276	-7	21	-9	15	13
Provide new RGA for lower rate	0	0	0	0	0	0	0

NOTE: All inertias are about the alternate delta change cg.

ALTERNATES TO RECOMENDED PH2 LAB

FRONT HATCH AIRLOCK, CENTER COMPART
REMOVE CENTER AIRLOCK

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.39	AIRLOCK	- 87	190	0	0
1.39	AL HATCH	- 25	237	0	0
1.39	AL HATCH	- 25	130	0	0
1.39	DOCKING ST	- 39	141	0	0
1.39	AIRLOCK	78	228	0	114
1.39	HATCH	25	208	0	141
1.39	RING+CLAMP	10	235	0	86
1.39	AL BLKHEAD	17	235	0	86
1.39	MISC HDWE	8	228	0	114
1.39	AL BLKHEAD	10	208	0	141
1.39	ADAPTER	10	235	0	74
1.49	PRES SHELL	75	172	0	0
1.49	FLOOR	10	140	0	0
1.49	HATCH ETC	9	238	0	0
1.49	FLEX JOINT	5	225	0	0
1.49	CONSOLE	25	170	0	20
1.49	SEAT	8	160	0	0
1.49	CONT MODS	10	170	0	20
1.49	WIRING MOD	10	170	0	20
	DELTA WEIGHT	134	230	0	140

****** ****** ****** ******

ADD VOLT REG, REMOVE PEAK BATTERY

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
8.001	PEAK BATT	-65	230	0	-40
8.001	VOLT REG	24	230	0	-40
8.001	WIRNG MOD	5	230	0	-40
	DELTA WEIGHT	-36	230	0	-40

****** ****** ****** ******

USE GE FUEL CELLS, REMOVE AC F/C'S

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.410	F/C SUPTS	- 10	260	0	-53
1.411	ECA MOUNT	- 3	260	0	-53
8.002	RADIATOR	- 30	165	83	0
8.002	RADIATOR	- 30	165	-83	0
8.002	RADIATOR	- 30	165	0	83
8.002	RADIATOR	- 30	165	0	-83
8.006	AC F/C	-164	260	-17	-53
8.006	AC F/C	-164	260	17	-53
8.007	CRYO PLUMB	- 12	260	0	-50
8.008	F/C ECA	- 14	260	10	-53
8.008	F/C ECA	- 14	260	-10	-53
8.22	F/C COOL	- 10	260	0	-40
8.22	FC GLY PMP	- 10	260	0	-40
1.410	FCA MT STR	16	254	0	-58
1.411	ECA MT STR	7	250	0	-55
8.002	RADIATOR	42	165	83	0
8.002	RADIATOR	43	165	-83	0
8.002	RADIATOR	42	165	0	83
8.002	RADIATOR	43	165	0	-83
8.006	FUEL CELLS	380	254	0	-53
8.007	CRYO PLMBG	16	265	0	-47
8.008	ECA	56	254	0	-53
8.009	VOLT REG	24	250	0	-58
8.22	GLYCOL PMP	20	260	0	-40
8.22	H2O BOILER	3	255	0	-40
	DELTA WEIGHT	171	215	0	-39

****** ****** ****** ******

TWO GAS SYSTEM W/O AIRLOCK

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.39	AIRLOCK	- 87	190	0	0
1.39	AL HATCH	- 25	237	0	0
1.39	AL HATCH	- 25	130	0	0
1.39	DOCKING ST	- 39	141	0	0
1.315	CANISTER	13	215	0	2
5.3	GOX TK N2	46	178	50	-50
5.3	GOX TK O2	46	149	60	-38
1.151	TNK SPT N2	1	178	50	-50
1.151	TNK SPT O2	1	149	60	-38
5.444	NITROGEN	29	178	50	-50
5.444	OXYGEN	46	149	60	-38
8.445	ECS SO2	107	156	-55	0
5.3	PLMBG CHGS	10	180	40	-20
	DELTA WEIGHT	123	142	32	-61

****** ****** ******

CONTROL MOMENT GYROS / INERTIA WHLS

NO WEIGHT ESTIMATE HAS BEEN MADE

****** ****** ******

REMOVE SUIT CIRCUIT PACKAGE

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
5.1117	PKG SC	-50	267	22	12
5.10	AL SUIT LP	- 5	210	0	0
5.10	CSM SL UMB	8	270	0	0

Table 4.6-10

DETAILED WEIGHT STATEMENT
PHASE II LAB ALTERNATES

DELTA WEIGHT	-47	260	23	13

****** ****** ******

REPLACE CENT AIRLOCK WITH FRONT A/L

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.39	AIRLOCK	- 87	190	0	0
1.39	AL HATCH	- 25	237	0	0
1.39	AL HATCH	- 25	130	0	0
1.39	DOCKING ST	- 39	141	0	0
1.39	AIRLOCK	78	228	0	114
1.39	HATCH	25	208	0	141
1.39	RING+CLAMP	10	235	0	86
1.39	AL BLKHEAD	17	235	0	86
1.39	MISC HDWE	8	228	0	114
1.39	AL BLKHEAD	10	208	0	141
1.39	ADAPTER	10	235	0	74
1.315	CANISTER	13	215	0	2
	DELTA WEIGHT	- 5	-1435	0	-3565

****** ****** ******

INCREASE CABIN PRESSURE TO 7PSI

NO WEIGHT CHANGE, RESULTS IN REDUCTION OF COMBINED LOADING SAFETY FACTOR FROM 1.5 TO 1.1

****** ****** ******

MODIFY ASA + AEA FOR LOWER RATE

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
2.61	MODIFY ASA	3	307	0	63
2.62	MODIFY AEA	4	260	25	-63
	DELTA WEIGHT	7	280	14	- 9

****** ****** ******

RETAIN PRIMARY N+G REMOVE AGS

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
3.11	IMU PLATFRM	42	307	0	50
3.12	AOT TELSCPE	26	295	0	59
3.13	LGC CMPUTER	58	248	0	-24
3.16	LGC-PSA CBL	10	261	0	-26
3.18	PTA TORQUER	12	305	0	30
3.110	CDU CONVTR	33	265	0	-24
2.61	ABORT SNSER	-20	307	0	63
2.62	ABORT ELECT	-37	260	25	-63
	DELTA WEIGHT	124	276	- 7	21

****** ****** ******

PROVIDE NEW PGA FOR LOWER RATE

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
2.3	USE NEW PGA	0	0	0	0
	DELTA WEIGHT	0	0	0	0

5. SUBSYSTEMS ENGINEERING

5.1 ELECTRICAL POWER SUBSYSTEM (EPS)

5.1.1 Ground Rules

The Phase II Lab EPS shall be designed in accordance with the following ground rules:

- No interchange of electrical power between the CSM and the Lab
- Use existing cryogenic tank designs

5.1.2 Assumptions and Background Data

5.1.2.1 Assumptions

5.1.2.1.1 Housekeeping Design Profile. The EPS Electrical Power Profile for the Lab is shown in Fig. 5.1.1. This profile is composed of all those loads that are required to maintain the vehicle in an operable condition. Loads directly associated with the performance of experiment and experiment type loads have been included in the integrated profile in the following section. Where difficulty was encountered in clearly associating a load with the housekeeping or experiment requirements, the duty cycle of the load was divided between the two categories in relationship to their supporting functions. Table 5.1-1 details the load and duty cycles assumed for the housekeeping requirements. The housekeeping load analysis and profile have been generated using the following assumptions:

- 7.5% distribution losses for all loads
- 20% growth allowance for the total of all loads
- load values based on LEM current status or latest vendor test data when available
- Housekeeping provides power for rate stabilization only
- 19,350 n. mi synchronous earth orbit with a 1080 hr in-orbit mission time

Except for the launch through transposition phase, there is no similarity between the LEM and Lab missions; thus, the power, energy and profiles bear no similarity. Housekeeping power levels including fuel cell parasitics and cryogenic heaters average 930 w and use 1004 kw-hr of energy over the 1080 hr mission. Actual housekeeping power levels vary from 790 to 1100 w.

For the earth orbit mission, all fuel cells will be started prior to launch and operated for the remainder of the mission. Table 5.1-2 details the parasitic requirements of the contending fuel-cells. After transposition has been accomplished, the Lab will be entered and checked out to verify its functional capabilities. Among the housekeeping requirements are the Environmental Control Subsystem (ECS) with its glycol pump, cabin fan, radiator controller, and CO_2 sensor (on continuously) and the ECS relay box for switching functions with a 10% assumed cycle. The power for the average of two cluster heaters on continuously has been included to maintain the shadowed RCS clusters within their miminum temperature range. For the synchronous orbit the S-band transceiver and its heater and instrumentation equipment were assumed to be operating continuously for status and experiment data transmission. The S-band power amplifier only operates when "high bit" rates of status data are required and is assumed on 50% of the mission time. Voice storage recorder power requirements accrue from the use of two recorders to their maximum capacity of 10 hr each. They are used to record proprietary information, coverage and support of EVAs, and vehicle status when off-station. Flood and dome lights have been given 50% and 12 1/2% duty cycles, respectively. The dome lights were added to this vehicle to provide illuminations required for the midsection area.

To conserve energy, in the standby operation, the Abort Sensor Assembly has been by-passed by the coolant loop. In this configuration, only 5 w of heater power (average) is required to maintain it within required temperature limits. Without this by-pass, 73 w of heater power would be required. The S-band steerable antenna for full communication operational mode is assumed operating at a 65% duty cycle. The omni antenna (which does not require power) will be used the rest of the time. The individual ac load requirements are noted under their own subsystems. The inverter supplying these loads has been assumed to operate with a 65% efficiency and its losses have been included under EPS.

5.1.2.1.2 Integrated Design Profile. The EPS Electrical Integrated Design Profile for the Phase II Lab is the combination of housekeeping and experimental loading requirements and is shown in Fig. 5.1-2. At the time of this report, the experimental power requirements have not as yet been finalized. Therefore, to illustrate a typical mission, a portion of one of the Lab flights was assumed. The profile shown in Fig. 5.1-2 is a critical combination of power levels (from Phase "A" Flight 518) and total energy within the capabilities of the 1300 lb reactant storage capability of the AES tanks. The fuel-cell integrated design power level for the mission averages 1555 w and uses 1680 kw-hr of energy over the 1080 hr mission. Table 5.1-3 shows the breakdown in energy between FCA gross output and housekeeping/experiment loading requirements. Power levels vary from 790 w to 3910 w. A peaking battery is required to supplement the fuel cell power output (estimated at 3.5 kw) during the peak power levels. The peak power levels occur during the two 45 minute periods where 2.25 kw of radar mapping loading is assumed. Energy requirements above the fuel cells' power capability was estimated at 5 kw-hr. Other peaks (within FCA capability) occur due to the assumed combination of housekeeping and experiment duty cycle type of loads. The 14 hr integrated profile has been assumed as typical; and repeated 77 times for the mission of 1080 hr and equals the design energy requirements.

5.1.2.1.3 Vehicle and Related Subsystem Constraints.

- Radiators - 60 sq ft available for EPS fuel cell cooling
- Voltage at Fuel Cell terminals - 28 to 32.5 v
- Environmental Temperature - Cryogenic tanks +130°F max.
Fuel Cells + 40 to +130°F
- ECS Requirements - Total O_2 = 116.8 lb
0.91 lb O_2 per PLSS recharge

5.1.2.2 Background Data

5.1.2.2.1 <u>Fuel Cells.</u> In response to Grumman's fuel cell technical information request, the vendors have submitted the following documents:

Allis-Chalmers - Response to T.I.R. and Supplement (31 August 1965)
General Electric - Preliminary Technical Information (1 September 1965)
Pratt & Whitney - Powercel Technical Information PWA-2676 (27 August 1965)

The fuel cells and their respective operating characteristics are described below:

- Allis-Chalmers - The Allis-Chalmers fuel cell is a moderate temperature (200°F) and pressure (55 psi) fuel cell that uses 37 - 40% KOH electrolyte imbibed in an asbestos matrix.

  A basic cell is composed of two electrodes separated by a KOH saturated asbestos matrix, oxygen and hydrogen distribution plates, a water transport matrix (also a KOH saturated asbestos matrix) supported by porous plaques, and a water removal plate. Two such basic cells joined in parallel electrically form a section and 33 sections comprise the fuel cell stack.

  Heat is removed from the cells by conduction through the metal electrode support plates to the surface of the stack. The ends of the plates extend beyond the surface of the stack to form cooling fins over which helium is circulated to remove the heat. The helium is then drawn through a heat exchanger where a glycol water loop removes heat from the helium which is then recirculated by means of a set of fans back through the stack.

  A magnesium canister houses the fuel cell stack, the helium-glycol heat exchanger, and the helium recirculating fans.

  Moisture is removed from the stack by creating a pressure differential across the water transport matrix which is located between the hydrogen electrode and the water removal plate. This is accomplished by the use of a temperature, vacuum, concentration controller which senses the operating conditions and maintains a proper balance. The moisture is then drawn outside the main fuel cell canister to the water recovery unit. In this unit the moisture is condensed by a glycol-water loop and water removed through a porous plate and drawn through a de-ionizer by means of a diaphragm pump. The diaphragm pump is discharged by using 40 psi helium or oxygen gas and the water is sent through a p^H sensor to a storage tank.

  A schematic of the AC fuel cell is shown in Fig. 5.1-3. A curve of voltages and reactant flow vs gross power is shown in Fig. 5.1-4. Heat rejection vs. gross power is shown in Fig. 5.1-5. A curve of step load change versus initial power is shown in Fig. 5.1-6. A fuel cell data sheet is shown in Table 5.1-4.

- General Electric - The General Electric fuel cell is a low temperature (120°F), low pressure (20 psi) fuel cell that utilizes a solid ion exchange electrolyte and a static water system.

The basic cell unit is comprised of the solid electrolyte, two platinum film electrodes, a dacron water removal wick, and integral cooling tubes between the cells. Thirty two cell units form a stack (or module) and three stacks form a fuel cell section.

A titanium container, whose void is filled with a unicellular foam, houses the three stacks. Accessory equipment, such as purge valves, fluid control components, etc., are mounted on the exterior of the container between the vehicle mounting brackets.

To cool the fuel cell a glycol water mixture is pumped in two parallel loops that flow in series through the three modules. The dacron wicks that are adjacent to the coolant tubes condenses and absorb by capillary action the product water that is formed by the hydrogen-oxygen reaction. This product water is then carried to a main separator plate from which the water is removed and sent to storage.

Hydrogen fuel is fed to each module from a manifold and each module is capable of independent operation. The container housing the modules is filled with oxygen and the cells draw on this environment for the oxidant.

A schematic of the fuel cell is shown in Fig. 5.1-7. A curve of fuel cell voltage and reactant flow vs gross power is shown in Fig. 5.1-8.

A curve of heat rejection vs gross power is shown in Fig. 5.1-9. A curve of step load change capability vs initial gross power is shown in Fig. 5.1-10.

Fuel cell performance information is shown in Table 5.1-4.

- Pratt & Whitney Aircraft (P&WA) - The P&WA fuel cell is a Bacon type fuel cell that utilizes dual porosity sintered nickel electrodes and high concentration (75 - 85%) KOH electrolyte. Operation of the cell is carried out at 382 to 427°F and 55 psi.

Hydrogen and oxygen are manifolded to each of the 31 cells that comprise the fuel cell. Excess hydrogen is used to carry product water from the anode, through a glycol-water cooled condenser, to a hydrogen pump separator. The centrifugal action of the pump separates the heavier water particles from the gaseous hydrogen, sending the by-product water to storage and recirculating the hydrogen.

The recirculating hydrogen is actually a dual purpose stream. Besides serving as a carrier for the water, it also acts as a heat transport medium that allows the cell to be maintained at the desired operating temperature.

Temperature regulation of the P&WA cell is necessary due to the dependence of the polarization characteristics on operating temperature. By using a by-pass valve, regenerator, and in-line heater on the hydrogen stream, and a regenerator by-pass valve combination on the glycol-water loop, a fairly wide range of operating temperatures may be obtained.

A schematic of the fuel cell is shown in Fig. 5.1-11. A curve of fuel cell voltage and reactant flow vs gross power is shown in Fig. 5.1-12. A curve of heat rejection vs gross power is shown in Fig. 5.1-13. A curve of step load change capability vs initial power is shown in Fig. 5.1-14. Additional fuel cell performance information is shown in Table 5.1-4, and a curve of secondary cooling loop characteristics is shown in Fig. 5.1-15.

5.1.2.2.2 Cryogenic Tanks. The cryogenic tank characteristics used during the study were supplied by NASA and shown in Table 4.1-4, AES Cryo Tank Characteristics. In addition, the following was assumed:

- Maximum standby limited to 20 hr
- Vapor cooled shield design
- Minimum flow design insulation heat leak (vapor-cooled heat leak)
- 12 lb per tank for mounted components

Three manufacturers of cryogenic storage tanks were contacted during Phase B for tank designs applicable to AES missions. The manufacturers contacted and the programs for which they are currently supplying tanks as well as the tank sizes are listed below:

Manufacturer	Program		O_2 Tank Storage Capacity, lb	H_2 Tank Storage Capacity, lb
AiResearch	Gemini		104 177	22
Beech	Apollo (Block II)		320	28
Bendix	NAS 9-2978	Phase A	175	
		Phase B		29

The Bendix Phase A and B tanks for the NAS 9-2978 program were developed in sizes to duplicate current Apollo and Gemini tanks. Since none of the existing tank designs listed above is capable of supplying the large amounts of usable reactants for the Lab missions without venting and multiple tank systems, each manufacturer was asked to submit design data for specific usable quantities for the Phase II Lab missions. The usable quantities and pertinent design constraints given to the vendors were:

Usable O_2	1174 lb
Usable H_2	136 lb
Min flow rates	
O_2	0.259 lb/hr
H_2	0.033 lb/hr
Standby time	30 hr
Delivery time	45 days
Max environmental temp.	130°F

These requirements were established early in the Phase B study and were used as being most representative of the mission profiles being considered. The information presented by each manufacturer has been normalized to reflect consistent environmental and design safety factors. Table 5.1-5 is a comparison of the pertinent information received for each design. The design approach used by each manufacturer is discussed below.

- AiResearch - The AES tanks proposed by AiResearch reflect the design concepts developed for the Gemini cryogenic storage tanks, with one important exception: the use of a vapor cooled shield within the insulation. The inner pressure vessel is supported by local composite support pads and the vacuum space is filled with aluminized mylar super-insulation and the vapor cooled shield. The tank materials proposed are as follows:

	O_2	H_2
Inner Shell	Inconel 718	Ti-5 Al-2.5 Sn
Outer Shell	Ti-5 Al-2.5 Sn	Ti-5 Al-2.5 Sn

Both inner and outer shells are presently planned to be manufactured by the hydro-forming process. The heater is a cal-rod element brazed to one or more concentric spherical copper shells which are used to distribute the heat input into the tank so as to minimize temperature stratification in a zero-g environment. The external tank components are mounted on a girth ring which is used to mount the tank in the vehicle as well as transmit induced loads. AiResearch is currently fabricating tanks using a vapor-cooled shield for the BIOS program. Development and fabrication is 90% complete.

Past Gemini heat leak test data have indicated that a high degree of quality control is required in applying the mylar super-insulation for this design in order to minimize the "artisan" factor during tank manufacture and thus achieve consistent heat leak values from tank to tank. It is estimated that 50% of the heat leak into the tanks is by conduction through the support pads.

- Beech - The AES tanks proposed by Beech reflect the design concepts developed for the Apollo CSM H_2 cryogenic storage tanks for the Block II vehicle. This design features a discrete vapor cooled shield in the evacuated annulus. The inner pressure vessel is supported by a network of beams or straps which distribute the induced loading evenly throughout the system. Beech has not demonstrated the feasibility of this support system for tanks in the size range being considered for AES missions and it appears to require some development work. The tank materials are as follows:

	O_2	H_2
Inner Shell	Inconel 718	Inconel 718
Outer Shell	Al-6061	Al-6061

The Apollo CSM Block II tanks use titanium for the hydrogen inner pressure vessels, however, indications of fabrication problems with the Apollo tanks have led Beech to propose the materials mentioned above. Both inner and outer tank shells can be forged and machined or formed, depending on the size, cost and schedule effects. Beech makes use of a cal-rod heater element brazed to a support tube and two fans and motors to distribute the incoming heat evenly throughout the stored fluid. The fluid delivery line which carries the vapor to cool the shield is not brazed to the shield in the proposed design. This concept simplifies manufacture of the tank; however, the effect of the vapor cooling may be lessened if heat transfer from the shield to the fluid is not complete. The discrete shield design presents a great possibility of eliminating the "artisan" factor from cryogenic tank manufacture. Beech has indicated that they are investigating a composite insulation system which utilizes superinsulation and the discrete vapor cooled shield. Preliminary thermodynamic investigation has shown that it may be desirable to insert superinsulation between a discrete vapor-cooled shield and the outer shell in some cases. The Beech tanks may be mounted in the vehicle in a skirt type mount or with trusses using a flange that is integral with the outer shell.

- Bendix - The AES tanks proposed by Bendix reflect the design of their Phase B tank for the NAS 9-2978 program. The purpose of that program was to determine the feasibility of the discrete shield - radial bumper design for tanks in the size ranges of the Gemini and Apollo C/SM tanks. The proposed AES tanks follow the design of the Phase B tank, using discrete shields with vapor cooling, radial bumpers for pressure vessel support and motor fans with an electrical heater to mix fluid. The materials proposed by Bendix are as follows:

	O_2	H_2
Inner Shell	Cryo-formed SS-301	Cryo-formed SS-301
Outer Shell	Al-6061	Al-6061

The use of cryo-formed SS-301 for the inner pressure vessels is very attractive from a weight standpoint due to its high strength; however, further investigation into its use for these critical items are required.

The radial bumper support scheme transmits very small amounts of heat when loaded, and negligible amounts of heat when unloaded during zero-g operation. This type of design yields essentially radiative thermal coupling through the insulation space resulting in a low heat leak design.

The radial bumper concept requires further analysis and testing to verify the structural integrity of the inner pressure vessel and outer shell under the induced loadings of the Lab missions. The tank mounting scheme used by Bendix is adaptable for skirt mounting or truss mounting, utilizing flanges which are intergral with the tank outer shell. As mentioned before, discrete shield design should yield a more repeatable heat leak from tank to tank, because of the elimination of the "artisan" effect in manufacture. However, quality control on shields and plated surfaces must be very thorough to insure this repeatability.

5.1.3 Recommended Configuration

5.1.3.1 General

The EPS supplies all the energy required for the Phase II Lab mission. The total energy available is that which can be generated from 1300 lb of usable reactant.

The recommended configuration consists of:

- Two Allis Chalmers 2000 w nominal 33 sections fuel cells
- One AES hydrogen tank containing 144.2 lb of usable fluid
- One AES oxygen tank containing 1375 lb of usable fluid
- One 5 kw-hr Peaking battery
- One LEM water glycol pump and circulation assembly

- 60 sq ft of radiator area
- One water storage tank
- One gaseous oxygen (GOX) accumulator
- Two reactant pre-heaters, one for hydrogen, one for oxygen
- Two fuel cell Electrical Control Assemblies (ECA) and one battery ECA
- Two LEM inverters
- Plumbing, feed components and electrical wiring

A schematic diagram of the fluid and electrical distribution sections is shown in Fig. 5.1-16.

5.1.3.2 Performance

The EPS performance capability is as follows:

• Voltage Output	28 to 32.5 vdc
• Fuel-Cell Peak Power Available to Vehicle (Net)	
- At start of mission	4400 watts
- At end of mission	3570 watts
• Fuel Cell Energy Available from 1300 lb of reactants, kw-hr	

	Radar Mapping Mission	Nominal Mission
Total Energy Generated	1680	1708
Total Experiment Energy (at bus)	676	704
Total Housekeeping plus FCA Parasitic loads	1004	1004

• Peak Fuel Cell Heat Rejection Rate	10500 Btu/hr @ 3570 w
• Total Water Generated	1300 lb
• Peak Power Available from Battery	0.4 kw
• Battery Energy Available from Battery	5 kw-hr
• Transient Load Capability (Fig. 5.1-17)	

The system performance in terms of voltage and specific reactant consumption as a function of net power for one and two fuel cells is shown in Fig. 5.1-18.

5.1.3.3 Expendables

The reactant supply for the Lab shall consist of the following:

Fluids	Stored Quantity (lb)	Residuals (lb)	Usable Fluid (lb)
Cryo H_2	151.4	7.2	144.2
Cryo O_2	1326.0	63.1	1268.2
Gaseous O_2	2.4	0.2	2.2

The total quantity of usable oxygen contains 116.8 lb of oxygen for ECS use. Of this 2.2 lb is initially stored in the gaseous oxygen accumulator.

5.1.3.4. Operation

Prior to Earth Launch, the fuel cells, cryogenic tanks, cooling loop and associated components will be checked out, filled, and started. The fuel cells will be supplying power to the Lab prior to and during launch and during the entire mission. Throughout the mission, the two fuel cells will be on the line supplying power to the vehicle loads in parallel for maximum reactant economy. At peak power conditions when the voltage falls below 28 volts, the peaking battery will be put on the line to maintain system voltage.

The fuel cell coolant loop will reject cell waste heat during normal and peak power conditions through a space radiator. By-product water will be utilized by the ECS. A LEM three-pump package and associated valving will be used to circulate the water glycol through the system at 220 lb/hr, 110 lb/hr per fuel cell. In the fuel cell cooling loop the water is directed through the water condenser initially, since the condenser water outlet temperature is limited to 150°F to properly condense the water. The coolant is then put through the fuel cell helium-to-glycol heat exchanger to absorb the waste heat and then through the radiator as required. The fuel cell maximum coolant outlet temperature is 185°F.

Cryogenic tankage will be filled on the ground with liquid cryogens and brought to the supercritical state prior to launch. Reactant preheaters in the fuel cell coolant loop add heat to the cryogens to raise the temperature to the minimum required by the fuel cell and, in addition, absorb heat from the coolant loop. The allowable minimum flow rate for the O_2 tank is 0.47 lb/hr and 0.047 lb/hr for the H_2 tank. The minimum flow rate required at an average power of 1300 w is 0.79 lb/hr of O_2 and 0.098 lb/hr for H_2.

5.1.3.5 Interface Requirements

- Electrical
  - o Main feed lines
  - o Telemetered instrumentation data
  - o Instrumentation and displays
- Fluid
  - o Oxygen line to ECS
  - o Oxygen to PLSS recharge
  - o By-product water line to water tank
- Structural Mounting Provisions
- Launch Pad interface
  - o Instrument lines
  - o Control lines
  - o O_2 and H_2 fill and vent lines

5.1.3.6. Component Description

The fuel cell unit proposed in the recommended configuration is an Allis Chalmers 33 section Hydrogen-Oxygen unit having the following nominal characteristics:

• Power Output	2,000 w nominal
• Voltage limits	28 to 32.5 volts
• Reactant Consumption	0.774 lb/kw-hr gross
• Thermal Efficiency	65.5% @ 50% power

- Parasitic power 115 w
- Total weight 164 lb

Detailed performance of the AC fuel cell is presented in Paragraph 5.1.2.2.1.

The coolant circulation assembly is identical to that used in the LEM-ECS and consists of three DC motor pumps, any one capable of pumping 220 lb per hour at 30 psi. There is only one coolant circulation assembly feeding the two fuel cells in parallel. It consumes 30 w of power, including distribution losses.

The EPS radiator area required is 60 sq ft to meet the peak power requirement of the fuel cells. It has a heat rejection rate of 150 Btu/sq ft at rated operating inlet temperatures of 185°F, and outlet temperature of 136°F. See Paragraph 4.1 for sizing criteria.

The 5 kw-hr, 167 a-hr, 70 lb primary peaking battery is capable of meeting the peak loads due to experiment usage.

The AES cryogenic reactant storage tank performance is presented in Paragraph 5.1.2.2.2.

The inverters used on the vehicle are the LEM inverters. The characteristics are as follows:

- 115 volt
- Single Phase
- 400 Cycle
- 350 va
- 15 lb weight
- Cold Rail Mounting Configuration

5.1.3.7 Modification to basic LEM (EPS only)

- Remove ascent batteries
- Remove descent batteries
- Install EPS as described in Paragraph 5.1.3.1
- Rewire vehicle structure consistent with new requirements
- Add Displays and Controls
- Add Instrumentation
- Add GSE servicing and checkout points

5.1.3.8 Total Weight

The total weight of the EPS and other subsystems components related to EPS operation is 2720 lb. Detailed breakdown is given in Table 5.1-6.

5.1.3.9 Total Volume

The total volume of the EPS is 85 cu ft.

5.1.4 <u>Baseline Configuration</u>

The baseline configuration differs from the recommended as follows:

- Two Pratt and Whitney fuel cells were used. Differences between these and Allis Chalmers units are described in Paragraph 5.1.2.2.1.
- Two CSM AES housekeeping O_2 tanks and two CSM AES housekeeping H_2 tanks were used for the baseline configuration compared with one AES max. volume O_2 tank and one AES max. volume H_2 tank for the recommended configuration. The CSM tanks considered for the baseline configuration are described in Table 5.1-7.
- Two 25 sq. ft. radiators were used on the baseline compared with 60 sq ft on the recommended configuration.
- One 7 kw-hr peaking battery was used for the baseline, whereas a 5 kw-hr battery is required for the recommended configuration.

5.1.5 Alternate Configuration - General Electric Fuel Cells

An alternate configuration for the EPS is the use of four General Electric fuel cells in place of the two AC fuel cells. The GE fuel cells are described in Paragraph 5.1.2.2.1. This configuration would differ from the recommended configuration as follows:

	Alternate	Recommended
Fuel Cells	General Electric	Allis-Chalmers
Number of fuel cells	4	2
Maximum net power available, watts	3940	3770
Reactant Quantity, lb	1300	1300
Radiator area, sq. ft.	60 + 300 lb of by-product water	60
Radiator area, sq. ft. (850 lb of by-product water used for supplemental cooling)	23	16
EPS weight, lb	2942	2720
Experiment Energy Available, kw-hr		
No-radar mission	671	704
Radar mission	625	676

The GE fuel cell is considered an alternate configuration because it represents a further development of an existing NASA utilized fuel cell design. The fuel cell evaluation of Paragraph 5.1.6.1 shows it to be applicable for use on the Lab missions. It should be pointed out that this configuration produces 51 kw-hr less experiment energy than the recommended configuration for the mission where radar is used and 33 kw-hr less for the mission without radar.

The proposed fuel cells for this alternate configuration would consist of the 92 lb, 3 stack Gemini fuel cell configuration modified to the "S" membrane configuration and qualified to a 1200 hr life. The performance of this fuel cell would be boosted from 560 w to 1 kw at 28 volts minimum by utilizing a voltage regulator. Since the average Lab power is 1555 w, the voltage regulator would only be utilized when high powers are required such as radar mapping or other high power experiments. Normal operation would require 4 fuel cells to supply both the average and peak power requirements.

5.1.6 Configuration Choices

The recommended EPS configuration evolved from the following fuel cell evaluation.

5.1.6.1 Fuel Cell Configuration Evaluation

The use of fuel cells to supply electrical power to the Phase II Lab was recommended based on the results of the Phase A study. This recommended power source was utilized in the Phase B studies to determine the optimum configuration of the EPS.

The following study assumptions were used:

- Consideration should be given, but not limited, to utilization of existing Gemini, Apollo and proposed AES hardware.
- Fuel cell power should be considered redundant for simultaneous housekeeping and EVA power, but not redundant for simultaneous housekeeping and radar mapping.
- FCAs considered must be the same for Phase II Lab and Shelter.
- 1200 hr life
- FCA can exist under hot-standby condition, i.e., hot but not generating.
- Paralleling capability: 100%
- Fuel cells must be capable of being checked-out prior to earth launch.
- LEM Glycol pump package should be used in cooling loop.
- Ethylene Glycol/water mixture (62.5/37.5) should be used as coolant.

The three fuel cell configurations (described in Paragraph 5.1.2.2.2) considered in the evaluation were as follows:

- Two (2) Allis-Chalmers 2000 watt nominal fuel cells
- Four (4) General Electric 1000 watt fuel cells with voltage regulators
- Two (2) Pratt & Whitney 2000 watt nominal fuel cells.

The technical evaluation considered:

Category	Relative Importance
Design and Performance:	46%
Weight:	27%
Reliability:	27%
Total	100%

The specific criteria evaluated under the above categories and the rating given each criteria are presented in Table 5.1-8.

5.1.6.1.1 Design and Performance.

- Optimum Fuel Cell Operation - The specific reactant consumption (SRC) trade off is summarized in Fig. 5.1-19, which presents the net SRC as a function of the net power available at the bus connection, i.e., after the parasitic powers of the fuel cells on and off the line have been deducted from the gross power generated. The SRC includes the purge rates as well as the flow required to keep fuel cells in a self-sustained hot-standby condition. The net SRC is obtained by dividing the total reactant flow of the system by the net power delivered. Energy available for experiments (radar mission): AC--676 kw-hr, GE--625 kw-hr, P&W--691 kw-hr.
- Total System Polarization and Degradation - The effect of degradation on the total EPS fuel cell output for the three fuel cells based on 1200 hr of operation is shown in Fig. 5.1-20. This is based on test data performed on experimental units. All fuel cell manufacturers indicate that the production units will have reduced degradation. This indicates that all fuel cells have a considerable amount of development work to be performed on them to reduce degradation. The GE unit is less sensitive to degradation when a voltage regulator with sufficient capacity is used.
- Comparison of Step Load Performance - The step load capabilities of the three systems are compared in Fig. 5.1-17. Both the AC and GE systems are capable of delivering peak power immediately. This is because both systems perform at constant temperature. The P&W fuel cell transient performance occurs at constant temperature although the steady state polarization curve is at variable temperature. The steep constant temperature polarization curve severely limits step load performance.

The results of the design and performance evaluation are:

Max. Possible Points	AC	GE	P&W
46	29.80	28.98	22.75

5.1.6.1.2 Weight. The itemized weights for each complete configuration, including radiator and all expendable, are given in Table 5.1-6. The total weights are:

	AC	GE	P&W
Weight, lb	2720	2850 (2942)*	2927

* Configuration weight with 5 fuel cells

The overall weight evaluation ratings based on the criteria of Table 5.1-10 are:

Max. Possible Points	AC	GE	P&W
27	17.25	11.25	13.50

5.1.6.1.3 Reliability. The reliability evaluation was performed in accordance with the following assumptions:

- The reliability predictions were estimated using the following individual fuel cell failure rates:

Vendor	Failure Rate Per Individual Cell/10^6Hrs	Source
AC	1.0	No data supplied by vendor, assumed similar to P&W
GE	5.0*	GE
P&W	0.86	P&W

* The failure rate of $5/10^6$ hours is based on Gemini "D" membrane units. GE had estimated a rate of $1/10^6$ hours for their "S" membrane unit. Since there was no substantiating data or any long history of test runs with the "S" membrane, the $5/10^6$ hrs failure rate was used for all GE reliability estimates.

- The fuel cell reliability model used for all fuel cells consisted of the series connection of only the individual cells. No other peripheral components or equipment in the fuel cell package were considered.
- Individual stacks of the GE fuel cell section can be isolated from the section in the event of a failure and stacks of other sections could be individually put on the lines as a replacement.
- For reliability purposes, two specific missions were chosen as the basis for calculation. They are as follows:

  - Mission A - When the flight includes radar mapping, two fuel cells are required for mission success for the AC and PWA configurations and 10 of 12 stacks for the GE configuration for 1080 hr.
  - Mission B - When the flight does not include radar mapping, one of two fuel cells are required for mission success for the AC and PWA configuration and 6 of 12 stacks required for the GE configuration for 1080 hr.

The computed mission success reliability of the three fuel cell candidates for the stated mission conditions are as follows:

Mission	AC	GE	P&W
A	0.93126	0.70548 (0.978123)*	0.94231
B	0.998787	0.999501	0.999139

* Reliability that would be obtained by adding one more GE fuel cell, weight would be increased by 92 lb.

Owing to the low reliability value with the 4 GE fuel cells, consideration was given to adding an additional fuel cell. This brought the reliability number to an acceptable level as shown in the above tabulation. Further investigation into failure rates for these operating conditions are required to ascertain the number of fuel cells needed.

The results of the reliability evaluation are as follows:

Max. Possible Points	AC	GE	P&W
27	11.25	12.50	16.2

5.1.6.1.4 Technical Evaulation Summary. The results of the fuel cell technical evaluation are:

	AC	GE	P&W
Design and Performance	29.80	28.98	22.75
Weight	17.25	11.25	13.50
Reliability	11.25	12.50	16.2
TOTAL	58.30	52.73	52.45

After further qualitative analysis of each system, in particular, back-up endurance test data of the contending fuel-cells which would effect confidence in the fuel cell being able to meet the endurance requirements with acceptable degradation, the Allis Chalmers fuel cell is recommended as the one showing the best prospect of insuring mission success. Test units have accumulated 4078 hr of testing during which 2000 kw-hr were generated with electrodes and electrolyte identical in materials and size to those included in the fuel cell under development for NASA. The operating temperature (205°F) is sufficiently high to provide adequate heat removal potential while not posing any particular vehicle integration problem even during prelaunch checkout. It is recognized that the mechanical design needs further refinements but these are not of a fundamental nature and can be worked out in time to satisfy the AES schedule.

The General Electric fuel cell is a well integrated, flight tested unit with innovations such as the solid electrolyte Ion Exchange Membrane and the water removal wicks. The very nature of the Ion Exchange Membrane causes a loss of thermal efficiency (high resistance) and requires a low operating temperature. General Electric has met this requirement with a very efficient liquid cooling loop requiring very little parasitic power. This results in good net fuel cell performance particularly at low power. The low cooling loop temperature on the other hand introduces a high radiator and water boiler penalty, but this would not make the GE fuel cell inapplicable. The major unknown at this time is the lack of test data with the "S" membrane which is to replace the "D" membrane of the Gemini flight cells which was found to degrade after initial activation even during storage.

The Pratt & Whitney fuel cell from an electrochemical viewpoint is fundamentally sound and obtains excellent cell efficiency. However, the high operating temperature (400°F) required by the high KOH concentration leads to a heavy and complex mechanical design. Except for the small radiator which is feasible with a high temperature coolant loop, the P&W fuel cell does not lend itself to easy integration in the vehicle. In addition, the amount of heat radiated to the vehicle is large and requires cooling on the launch pad, the heating period during starting is long and costly in energy, the parasitic power inherent to the hydrogen coolant loop and water separator is high, and the step load capability is limited by the thermal time constant. Furthermore, the electrolyte (which freezes at 280°F) requires a high heat input during hot-standby. The overall result shows that the Pratt & Whitney fuel cell has a smaller operational range than the Allis-Chalmers and General Electric fuel cells.

In conclusion, the Allis-Chalmers fuel cell powered EPS is recommended for the Phase II Lab.

5.1.6.2 Fuel Cell Peaking Requirements

Initial analysis has indicated that for short periods of time, power requirements will exceed the capability of the fuel cells in the recommended configuration. A 65 lb primary peaking battery has been included to augment the fuel cells during these high peak loads to keep the voltage within required limits. The estimated peaking requirements are detailed on the Electrical Power Integrated Design Profile, Fig. 5.1-2. A total of 5 kw-hr of energy at levels up to 400 w was estimated for the entire mission on the assumption that the fuel cell could supply loads up to 3520 watts (degraded) within required voltage regulation. The peak loads were generated during the periods of radar mapping that have been assumed to occur for two 45 minute periods every 14 hr.

A fuel cell voltage regulator and peaking secondary battery charger combination have also been considered to handle the peak loading requirements. Although these approaches offer advantages, the primary battery was selected on the basis that it provides fuel cell topping at the lowest cost, complexity and development time. However, it is felt that further analyses as to the possible use of a voltage regulators or secondary battery/charger combination should be conducted when the topping requirements, fuel cell characteristics and Lab system parameters are better known.

5.1.7 Additional Studies

5.1.7.1 Cryogenic Tankage Evaluation

A technical evaluation was made of the cryogenic tank designs submitted by AiResearch, Beech and Bendix. The technical evaluation considered:

Category	Relative Importance
Design and Performance:	46%
Weight:	27%
Reliability:	27%

5.1.7.2 Technical Evaluation Summary

The scores achieved by the three tank designs are as follows:

	AiResearch	Beech	Bendix
Design and Performance	29.23	28.24	32.02
Weight	14.75	18.00	21.75
Reliability	17.75	15.00	14.25
	61.73	61.24	68.02

Table 5.1-9 is a detailed breakdown of the items considered in each major category, the relative weight of each item and the ratings of each individual design.

5.1.7.3 Conclusions

The recommended configuration for the Phase II Lab is the AES cryogenic tanks for EPS and ECS expendables. If cryogenic tanks other than the AES tanks were required, this evaluation indicates a technical preference for the Bendix design. Further evaluation of vendor capability, cost, and schedule effects must be carried out before a final choice can be made.

5.1.7.4 Comparison of AES Tanks and Vendor Optimized Tanks

Table 5.1-10 compares the weights of the AES hydrogen and oxygen cryogenic storage tanks for the Phase II Lab with the weights submitted by the tank manufacturers. The tanks designed for the Phase II Lab are optimized for the standby time and delivery requirements of the mission. The AES tanks are not very different in weight from the vendor proposed tanks, although they are slightly over-sized and cylindrical in configuration.

Table 5.1-1

ELECTRICAL POWER HOUSEKEEPING ASSUMPTIONS

(For 45 Day Manned Mission; 19,350 n. mi Synch Earth Orbit)

Subsystems	Power, watts	Duty Cycle, %	Avg Power, watts
ECS			
Glycol Pump	40.0	Cont.	40.0
Cabin Fan	39.0	Cont.	39.0
Radiator Controller	3.0	Cont.	3.0
CO_2 Sensor	1.0	Cont.	1.0
ECS Relay Box	7.4	10	0.7
RCS			
Cluster Heater (2)	15.0 eac.	Cont.	30.0
Displays			
Meters and Indicators	34.3	Cont.	34.3
Indicators	14.2	Cont.	14.2
Instrumentation			
Transducers	11.1	Cont.	11.1
Sig. Cond. Elec. Ass'y	37.0	Cont.	37.0
Caution & Warning	22.0	Cont.	22.0
Timing Equip.	5.5	Cont.	5.5
Pulse Code Mod.	7.4	Cont.	7.4
Voice Storage Recorder	2.3 (AC)	6	0.1
Crew Provisions			
EL Lighting	6.2 (AC)	Cont.	6.2
Flood Lights	75.0	50	37.5
Dome Light	37.5	12.5	4.7
GN & C			
ATCA	126 pk/25 min. -70 avg.	Operating Mode	70.0
ASA	288 pk/5 min. -5 avg.	Standby	5.0
Communications			
S-Band Heater	6.0	Cont.	6.0
S-Band Transceiver	36.0	Cont.	36.0
S-Band Steer Ant Elect	1.7	65	1.1
S-Band Steer Ant Elect	3.2 (AC)	65	2.1
S-Band Power Amplifier	62.0	50	31.0
Sig Proc Assy	15.5	Cont.	15.5
EPS			
Lighting Cont Assy	5.0	Cont.	5.0
Lighting Cont Assy	9.0 (AC)	Cont.	9.0
FCA - ECAs	15.0	Cont.	15.0
Battery ECA	5.0	Cont.	5.0
Cryo Tank Heaters	(O_2 57W) (H_2 10W)	43	29.0
Inverter Losses (assume 65% eff)	18.9	Cont.	18.9
Fuel Cell Parasitics		See Table 5.1-2	
		Subtotal	542.3
		Distrb. Losses (7.5%)	40.6
		Current Status Avg Pwr	582.9
		Growth Allow (20%)	116.6
		Design Avg Power w/o FCA Parasitics	699.5

Design Energy Without FCA Parasitics = (1080 hr x 699.5w) = 755 kw-hr

Design Avg Pwr. without FCA Parasitics = 699.5 w
*FCA Parasitics - Avg. Power = 230.1 w
Total Design Avg. Power With FCA Parasitic 929.6W

Total Design Energy with FCA Parasitics = (1080 hr x 929.6 w) = 1,004 kw-hr

*Based on the use of (2) Allis Chalmers fuel cells

Table 5.1-2

FUEL CELL PARASITICS

Fuel Cell System	Power, watts	Duty Cycle	Avg. power, watts
* 1. Allis Chalmers			
(Standby)	57.0	------	------
(Operate) (2)	115.0 ea.	Cont.	230.0
		Sub-Total	230.0
		Distrib Losses (7.5%)**	
		FCA Parasitics Avg Power	230.00

FCA Parasitics - Energy = (1080 Hrs. x 230.0W) = 248 Kw-Hrs.

Fuel Cell System	Power, watts	Duty Cycle	Avg. power, watts
2. Pratt & Whitney			
(Standby)	105.0	------	--------
(Operate) (2)	118.0 ea.	Cont.	236.0
		Sub-Total	236.0
		Distrib Losses (7.5%)	17.7
		FCA Parasitics Avg Power	253.7

FCA Parasitics - Energy - = (1080 hrs. x 253.7w) =274.0 Kw-Hrs.

Fuel Cell System	Power, watts	Duty Cycle	Avg. power, watts
3. General Electric			
(Standby)	0.0	------	-----
(Operate) (4)	14.0 ea.	Cont.	56.0
		Sub-Total	56.0
		Distrib Losses (7.5%)	4.2
		FCA Parasitics Avg Power	60.2

FCA Parasitics - Energy = (1080 Hrs. x 60.2w) = 65.0 kw-hr

* Recommended configuration

xx Assumed fuel cells supply
Their own electrical parasitics

Table 5.1-3

ENERGY SUMMARY FOR RADAR MAPPING MISSION

	P&W	A-C	GE
• FCA Output Gross Energy from 1300 lb of Reactants, Kw-hr	1721	1680	1445
• Housekeeping with 20% Growth, 7.5% Distrib Losses & Parasitic Losses, kw-hr	1030	1004	820
• Experiments + 7.5% Distrib Losses, kw-hr	691	676	625
• Experiments Net Energy, kw-hr	640	625	578
• Avg Experiment Load, watts	593	579	535

Table 5.1-4

FUEL CELL DATA

	Allis-Chalmers	GE	P & W
Power Capability at 28V, watts			
• Initial	2350	500**	2000
• Degraded	1750	1000**	1800
Operating Temperature, °F	200	120	382 to 427
Operating Pressure, psia	40	20	55
Weight, lb	164	95***	265.4
Volume, cu ft	6.5	5.59	9.3
Product Water			
• Outlet Temperature, °F	150	100	155-170
• Outlet Pressure, psia	40	20	63
Purge Rate, %			
• H_2	0.2	3.0	0.5
• O_2	0.2	3.0	0.5
Environment	He	O_2 (Unicellular)	N_2
Start-up Energy Reqd, kw-hr	1.0	Zero (40° F +)	4.0
Start-up Time, hr	1.0	Zero (Instant)	1.0
Parasitic Power, watts			
• Full power	115*	15	127
• Hot standby/open circuit	57	Zero	113
Storage Environment Limits			
• Temperature, °F	-50 to +185	+40 to +120	-20 to +130
• Pressure		Space Vacuum	

*100 per Internal Cooling Loop + 15 for Glycol Pump.
**With Voltage Regulator
***Plus 6 for Voltage Regulator.

Table 5.1-5

VENDOR CRYOGENIC TANK COMPARISON

	AiResearch		Beech		Bendix	
	H_2	O_2	H_2	O_2	H_2	O_2
Max Operating Pressure, psia	300	1000	250	875	400	1000
Standby Time, hr	30	30	30	30	30	30
Usable Fluid, lb	136	1174	136	1174	136	1174
Inner Pressure vessel						
Material	Ti-5Al-2.5Sn		Inco 718		Cryoformed 301-SS	
Weight, lb	141.76	193.8	92.5	187.4	93	129.5
Outer Shell						
Material	Ti-5Al-2.5Sn		6061 Al		6061 Al	
Weight, lb	77.1	46.2	75.0	45.0	75.0	45.0
Insulation Wt, lb	17.1	9.3	29.2	38.8	48.7	6.4
Press. Vessel Supt Wt, lb	13.5	64.6	Included		3.5	1.9
Mount Wt, lb	27.5	40.1	16.2	19.2	15.6	13.2
Components Wt, lb	24.5	18.0	12.0	12.0	8.9	8.1
Residual Fluid, lb	7.8	68.8	5.7	49.0	4.2	82.0
Vented Fluid	0	0	0	0	0	0
Tank Outer Dia, in.	53.4	48.8	52.8	44.5	51.8	42.5
Total Dry Wt, lb	235.7	372.0	224.9	302.4	244.6	204.1
Total Fluid Wt, lb	143.8	1242.8	141.7	1223.0	140.2	1256.0
Total Loaded Wt, lb	379.0	1614.8	366.6	1525.4	384.8	1460.1

Table 5.1-6

CONFIGURATION WEIGHTS

	2 A-C	4 GE	2 PGW
Fuel cells	328.0	404.0	532.0
FC mount structure	10.0	16.0	15.0
FC ECAs	28.0	56.0	28.0
ECA mount structure	3.3	6.6	3.3
Peaking battery	65.0	65.0	65.0
FC pad cooling hardware	10.0	-----	10.0
FC cooling (radiator)	32.0	46.0	24.0
ECS Hdwe for FCA cooling & Q mod	-----	-----	19.0
Glycol pump assy	10.0	20.0	-----
H_2O boiler for FCA cooling	3.0	3.0	3.0
H_2 reactant	144.2	144.2	144.2
O_2 reactant & ECS	1268.2	1268.2	1268.2
Residual H_2	7.2	7.2	7.2
Residual O_2	63.1	63.1	63.1
Cryogenic H_2 tank	290.0	290.0	290.0
Cryogenic O_2 tank	395.0	395.0	395.0
GOX in accumulator	2.2	2.2	2.2
Residual GOX in accumulator	0.2	0.2	0.2
GOX accumulator	3.0	3.0	3.0
Cryo H_2 tank mount structure	8.8	8.8	8.8
Cryo O_2 tank mount structure	34.5	34.5	34.5
GOX tank mount structure	0.1	0.1	0.1
Cryo heat exchangers	2.6	2.6	----
Cryo plumbing & feed section	11.5	14.3	11.5
Total	2719.9	2850.0	2927.3

Notes:

1. FC Mount Structure (each): GE, 4 lb; A-C, 5 lb; & P & W, 7.5 lb.
2. Radiator weights assume use of 850 lb of water for cooling. Water available as fuel cell by-product as required. (See Section 4.1 for radiator sizing.)
3. ECS O_2 = 116.8 lb, 2.2 of which is carried in GOX accumulator.
4. Cryogenic O_2 + H_2 tanks are AES tanks. Weights are assumed to include 12 lb each for internally and externally mounted components.
5. GOX accumulator is LEM ascent stage GOX tank.
6. Tank mount weights are 2% of loaded tank weights.
7. P&W has cryogenic heat exchangers (reactant preheaters).
8. G.E. fuel cell includes voltage regulator (6 lb/kw).

Table 5.1-7

CSM AES HOUSEKEEPING TANK CHARACTERISTICS

	H_2	O_2
Usable Capacity, lb	80	712.5
Vessel Shape	Cyl with Heads	Sphere
Dimensions, in	41.5 OD x 45.25	36.2 Dia.
Min. Steady-State Flow Rate, lb/hr	0.05	0.4

	Wt	Max Possible
I. Design and Performance (46%)		
A. Design concept of cell (8%)		
1) Originality	1	
2) Adaptability to space		
(a) gravitational effects	1	
(b) operational temp. as affects ability to reject heat	2	
3) Growth potential	1	
4) Complexity		
(a) fuel-cell itself	1	
(b) water removal concept	1	
(c) cooling concept	1	
5) Size (amperes per square ft capability)	1	
6) Weight (effect of cell conceptual design on power plant weight)	1	
7) Development of cell concept	1	
I.A Total out of 44 mass Weighted rating based on 8	11	44
B. Mechanical realization (8)		
1) Electrodes	1	
2) Electrolyte	1	
3) Reactant passages incell	1	
4) Cell stacking method	1	
5) Cell wiring	1	
6) Operating temperatures (mechanical effects)	1	
7) Operating pressure		
8) Cooling loop mechanical design	1	
9) Reactant feed to stack	1	
10) Housing design	1	
11) Water removal	1	
12) Package in controls and accessories	1	
13) Fuel cell mounting	1	
14) FCA specific volume, watts/ft3 in/ft	1	
15) FCA Specific Weight in watt per lb	1	
I.B Total out of 56 max possible Weighted rating (8)	14	56

A.C.	G.E.	P & W	
			C. Performance (15
			1) Voltage rang
F-2	G-3	P-1	2) Performance
			at end of LA
G-3	E-4	F-2	(1080 hours)
G-6	P-2	E-8	3) Gross therma
			4) Parasitic pc
			5) Open circuit
G-3	F-2	G-3	by capabilit
			6) Cold start (
F-1	G-3	P-1	7) Stopping prc
F-2	G-3	F-2	temporary
F-2	G-3	F-2	permanent
F-2	P-1	G-3	8) Storage capa
			9) Step load
F-2	G-3	P-1	
			Weighted rat
			D. Vehicle Integra
F-2	P-1	P-1	1) Thermal inte
26	25	24	2) Coolant loop
4.72	4.55	4.32	penalty
			3) Electrical i
G-3	G-3	F-2	4) Pre-launch c
G-3	F-2	P-1	5) Mechanical i
F-2	F-2	F-2	6) By product w
F-2	G-3	F-2	on vehicle i
G-3	G-3	F-2	7) Total volume
F-2	G-3	P-1	
			Weighted rat
G-3	G-3	G-3	II. Weights (27)
F-2	G-3	F-2	A. Mission Weight
			1) Shelter
F-2	F-2	F-2	2) Lab II
F-2	F-2	F-2	B. Weight Dated Va
P-1	E-4	F-2	C. Weight Control
P-1	G-3	G-3	cedure organiza
			D. Potential weigh
F-2	G-3	P-1	development
F-2	G-3	P-1	
			Weighted rat
E-4	G-3	P-1	
34	42	27	
4.86	6.0	3.85	

5.1-8

(2)

Table 5.1-8
FUEL CELL TECHNICAL EVALUATION

	Wt	Max Possible	A.C.	G.
	1		F-2	P-
egradations II missions	1		G-3	P-
efficiency	2		G-6	P-2
er	2		P-2	G-
and/or stand-	2		G-6	G-
rom 40°F)	1		G-3	E-
edure:				
	1		G-3	E-
	2		F-2	F-2
ility (at 40°F)	1		G-3	F-2
	1		E-4	E-
	13	52	34	32
ng (15)			9.82	9.
ion (15)				
face	2		G-6	E-8
and radiation	2		E-8	P-2
terface	1		F-2	F-2
eckout	1		F-2	G-
terface	1		F-2	G-
ter (effect tegration)	1		F-2	P-
	1		G-3	G-
	9	36	25	22
ng (15)			10.4	9.
	9		G-27	P-9
	6		G-18	P-6
idation	5		F-10	G-
method, pro- ion)	4		F-8	G-
saving during	3		F-6	P-
	27	108	64	45
ng			17.25	11.

P & W

	III. Reliability
F-2	A. Fuel cell reliability
F-2	1) Shelter with peak (DRILL)
	2) Shelter WITHOUT PEAK
	3) LAB II with peak (RADAR)
G-6	4) LAB II WITHOUT PEAK
P-2	B. Reliability method procedure
P-2	and organization
	C. Back-up Data
P-1	D. Possible Improvement
	E. Maintainability (pre-launch
F-2	period)
F-2	III. Totals
G-3	Weighted rating
P-1	
23	Summary & Totals
6.64	
	I. Design and Performance:
P-2	A. Design Concept
E-8	B. Mechanical Realization
	C. Performance
F-2	D. Vehicle Integration
P-1	
P-1	II. Weights
G-3	III. Reliability
F-2	GRAND TOTALS
19	
7.90	
F-18	
P-16	
G-15	
G-12	
P-3	
54	
13.5	

Wt	Max Possible	A.C.	G.E.	P & W
6	24	P-6	M-0	F-12
3	12	G-9	E-12	G-9
2	8	P-2	M-0	P-2
4	16	F-8	G-12	G-12
4	16	P-4	G-12	G-12
4	16	F-8	P-4	G-12
2	8	F-4	F-4	F-4
2	8	F-4	G-6	P-2
27	108	45	50	65
		11.25	12.5	16.20
8		4.72	4.55	4.36
8		4.86	6.00	3.85
15		9.82	9.23	6.64
15		10.40	9.2	7.90
46		29.80	28.98	22.75
27		17.25	11.25	13.5
27		11.25	12.50	16.20
100		58.30	52.73	52.45

5,1.8

(5)

Grumman

	Wt	Max Possible
I. Design & Performance 46%		
A. Overall Design concept 15%		
1) Size and shape	1	
2) Simplicity or complexity	2	
3) Pressure vessel & outer shell design	2	
4) Pressure vessel support	2	
5) Tank mounting scheme	1	
6) Component mounting scheme	1	
7) Interface requirements	1	
	10	40
I.A Total out of 40 max Weighted rating based on 15°		
B. Thermal Design & Performance 20%		
1) Insulation technique	2	
2) Thermal effectiveness	2	
3) Growth potential - lowering heat leak w/o redesign	1	
4) Thermal optimization with respect to AES mission	1	
5) Solution to stratification	1	
6) Analytical methods	2	
	9	36
I.B Total out of 36 maximum Weighted rating based on 20		
C. Mechanical Design - 5		
1) Materials selection	2	
2) Materials compatibility	1	
3) Design approach & analysis of:		
(a) o Pressure vessel	1	
(b) o Outer Shell	1	
(c) o Insulation	1	
(d) Pressure vessel support	1	
(e) Outer shell support	1	
(f) Components & supports	1	
4) Confidence in stress properties	1	
5) Manufacturing methods	1	
	11	44
I.C Total out of 44 maximum Weighted rating based on 5		
D. Instrumentation - 2	1	
I.D Total out of 4 maximum Weighted rating based on 2	1	4

5.1.9 (I)

AiResearch	Beech	Bendix
G-3	G-3	F-2
G-6	F-4	F-4
F-4	F-4	F-4
G-6	F-4	G-6
G-3	G-3	G-3
G-3	G-3	G-3
G-3	F-2	F-2
28	23	24
10.50	8.62	9.00
F-3	(G-)-5	(E-)-7
F-4	G-6	(E-)-7
P-1	G-3	E-4
F-2	F-2	F-2
G-3	E-4	E-4
E-8	P-2	F-4
21	22	28
11.66	12.21	15.56
G-6	G-6	F-4
F-2	G-3	G-3
P-1	F-2	F-2
F-2	G-3	F-2
G-3	F-2	G-3
G-3	F-2	F-2
G-3	G-3	G-3
G-3	G-3	G-3
F-2	G-3	F-2
F-2	G-3	F-2
27	30	26
3.07	3.41	2.96
G-3	G-3	G-3
3	3	3
1.50	1.50	1.50

E. Power - 2
1) Heater powe
2) Heater ener
I.E Total out of 8
Weighted ratin
F. GSE Requiremen
1) Handling re
2) Filling
I.F Total out of 8
Weighted ratin
II. Weights 27
A. Comparative to
1) Shelter
2) Lab
B. Weight data va
C. Weight control procedures, or
D. Possible wt. s development
II. Total out of 1
Weighted ratin
III. Reliability
A. Comparative ov reliability
1) Reliability of overall
2) Failure Rat
3) Failure mod analysis
B. Reliability Me & organization
C. Data in suppor analysis
1) Stress to f
2) Actual flig
D. Possible futur improvement
E. Maintainabilit
III. Total out of
Weighted rati

Table 5.1-9
CRYOGENIC TANK EVALUATION

	Wt	Max Possible	AiResearch	Be
	1		G-3	F
	1		G-3	G
	2	8		
aximum			6	
based on 2			1.50	1
- 2				
iirements	1		G-3	G
	1		F-2	F
	2	8		
aximum			5	
based on 2			1.25	1
l weights				
	9		F-18	G
	6		F-12	G
.dation	5		G-15	F
methods	4		F-8	F
nization)				
rings during	3		F-6	G
	27	108		
3 maximum			59	7
based on 27			14.75	18
7				
rall				
on basis	10	40	G-30	F
ystem				
s.	3	12	G-9	F
s & effects	2	8	F-4	G
ods procedures	4	16	F-8	G
of Reliability				
lure tests	2	8	F-4	G
data	2	8	E-8	P
reliability	2	8	F-4	F
	2	8	F-4	F
	27	108		
8 maximum			71	6
based on 27			17.75	15

:h	Bendix
2	F-2
3	F-2
	4
25	1.00
3	G-3
2	G-3
	6
25	1.50
27	E-36
18	E-24
10	F-10
3	F-8
9	G-9
	87
00	21.75
20	F-20
6	G-9
6	F-4
12	G-12
6	P-2
2	P-2
4	F-4
4	F-4
	57
00	14.25

Summary & Totals

I. Design & Performance
  A. Overall design concept
  B. Thermal Design & Performance
  C. Mechanical Design
  D. Instrumentation
  E. Power
  F. GSE Requirement

II. Weights
III. Reliability

GRAND TOTAL

Wt	Max Possible	AiResearch	Beech	Bendix
15		10.50	8.62	9.00
20		11.66	12.21	15.56
5		3.07	3.41	2.96
2		1.50	1.50	1.50
2		1.25	1.25	1.50
2		1.25	1.25	1.50
46		29.23	28.24	32.02
27		14.75	18.00	21.75
27		17.75	15.00	14.25
100		61.73	61.24	68.02

5.1.9

(5)

Grumman

Table 5.1-10

COMPARISON OF AES TANKS & VENDOR PROPOSED TANKS

	Weight, lb	AES	AiResearch	Beech	Bendix
H_2	Usable	144.2	136.0	136.0	136.0
	Dry	290.0	235.7	224.9	244.6
	Loaded	441.4	379.5	366.6	384.8
O_2	Usable	1268.2	1174.0	1174.0	1174.0
	Dry	395.0	372.4	302.4	204.1
	Loaded	1726.3	1614.8	1525.4	1460.1

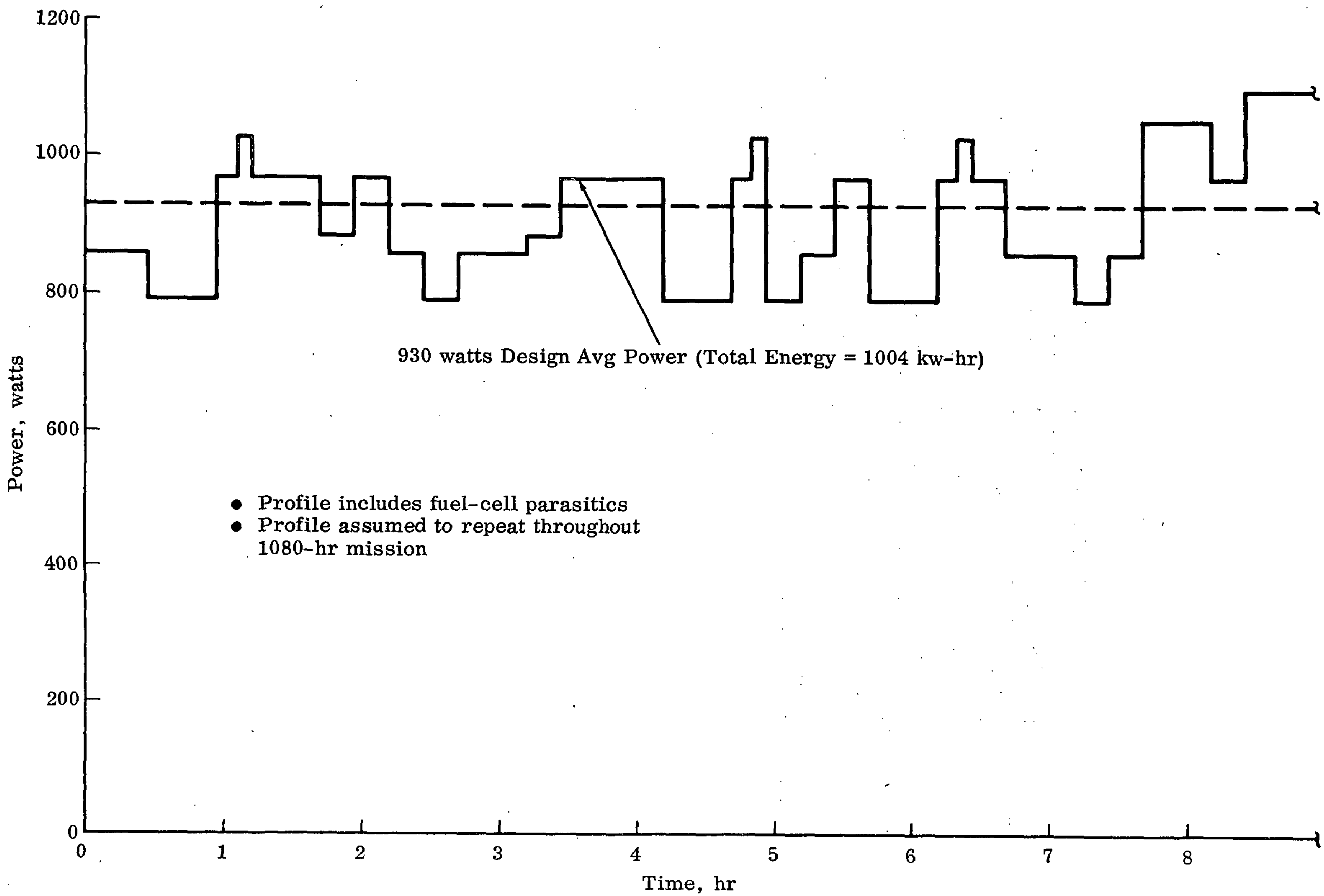


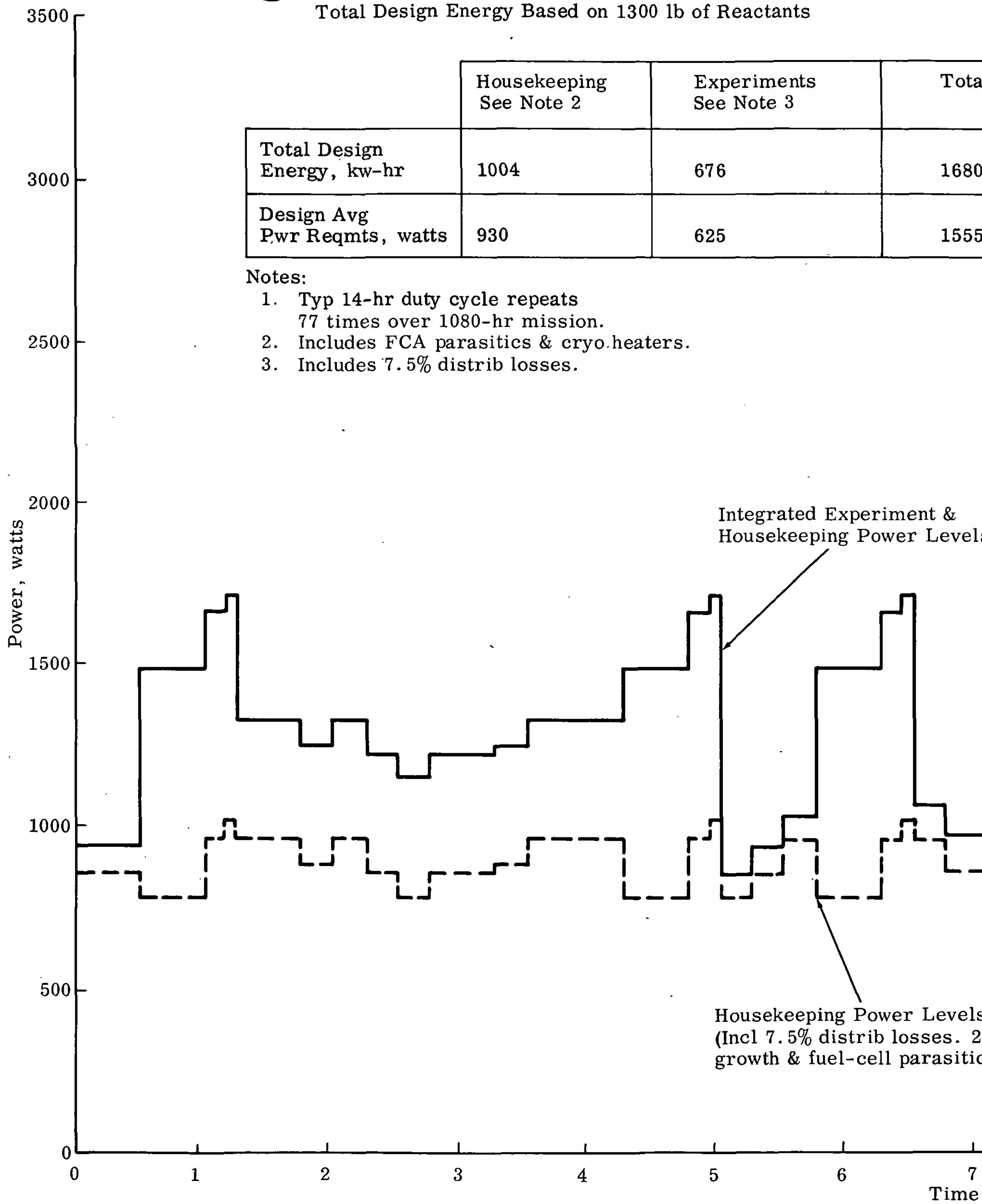
Fig. 5.1-1 Housekeeping Power Profile

Total Design Energy Based on 1300 lb of Reactants

	Housekeeping See Note 2	Experiments See Note 3	Total
Total Design Energy, kw-hr	1004	676	1680
Design Avg Pwr Reqmts, watts	930	625	1555(

Notes:

1. Typ 14-hr duty cycle repeats 77 times over 1080-hr mission.
2. Includes FCA parasitics & cryo heaters.
3. Includes 7.5% distrib losses.



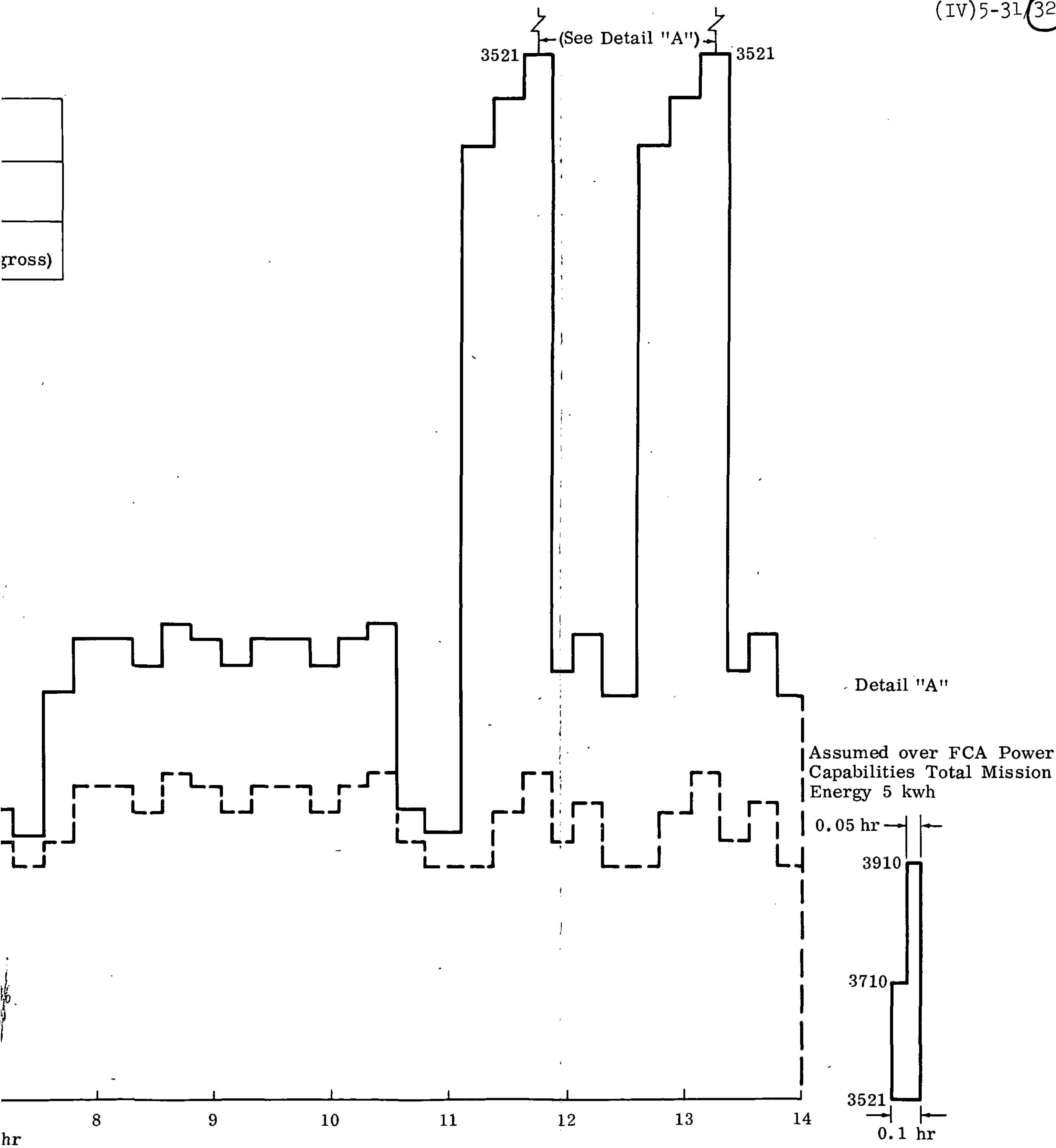
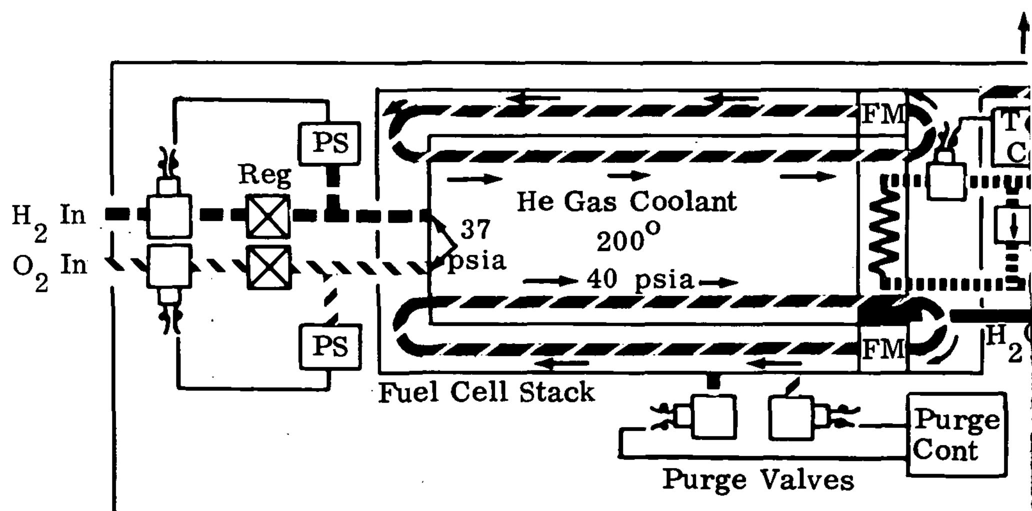


Fig. 5.1-2 Electrical Power Integrated Design Profile - Integrated Housekeeping & Experiment Power Levels (Based on EPS Recommended Configuration)

33



PS
Reg
H_2 In
O_2 In
PS
37
psia
He Gas Coolant
200°
40 psia
FM
FM
Fuel Cell Stack
Purge Cont
Purge Valves

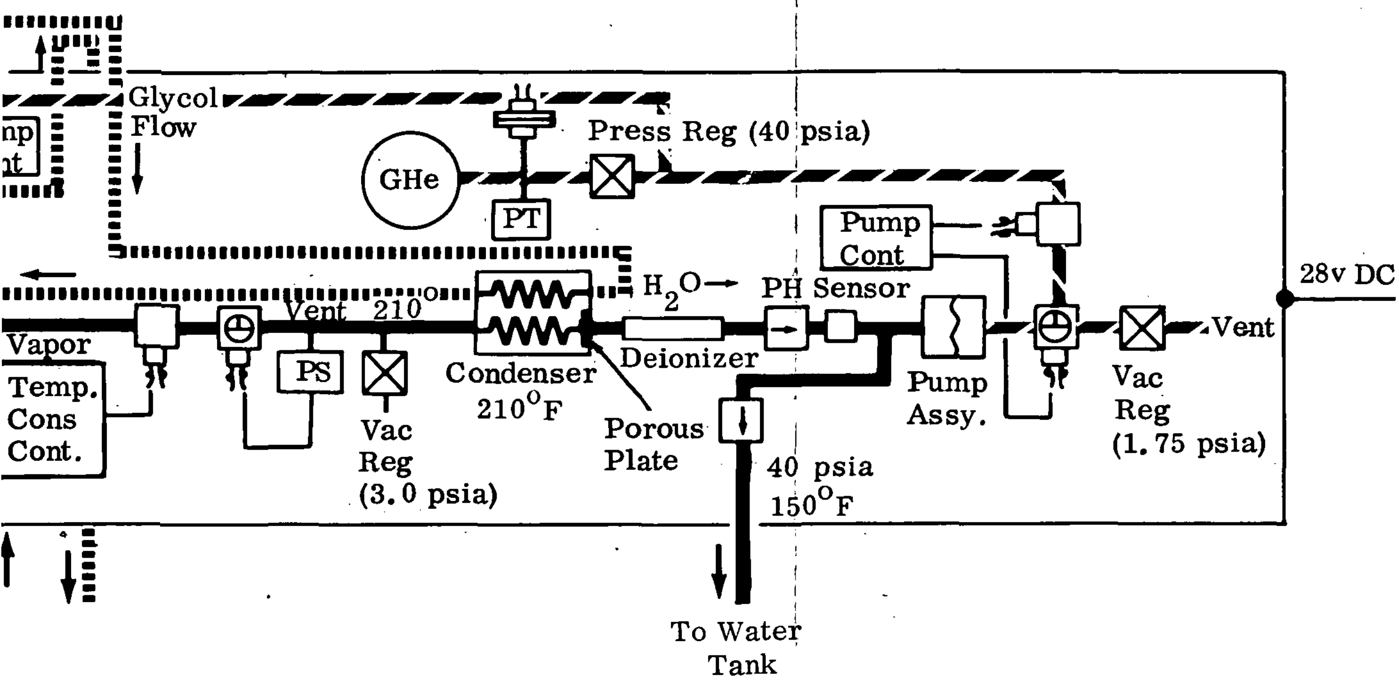


Fig. 5.1-3 Allis Chalmers Fuel Cell Schematic

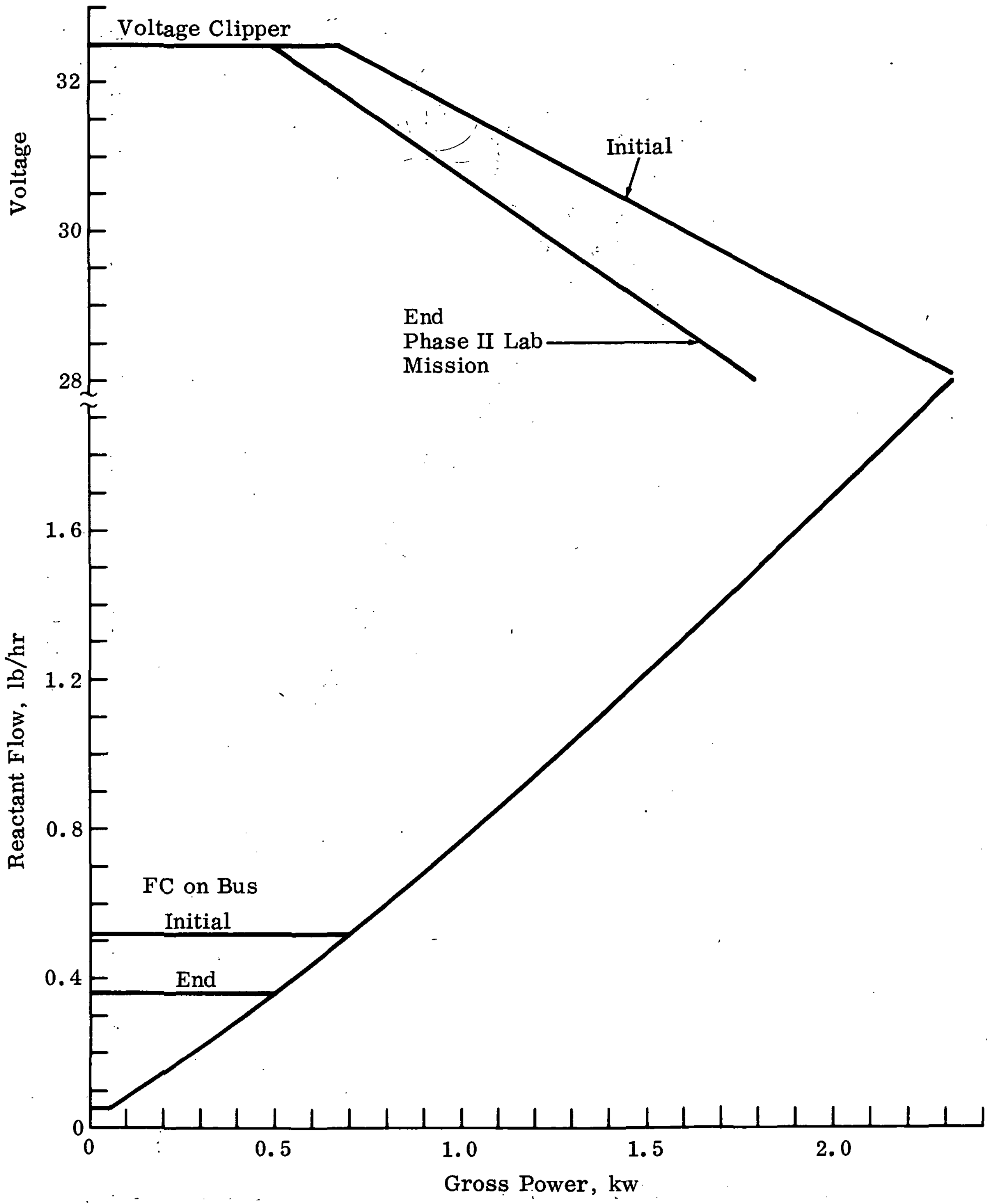


Fig. 5.1-4 Allis Chalmers Fuel Cell Voltage & Reactant Flow vs Gross Power

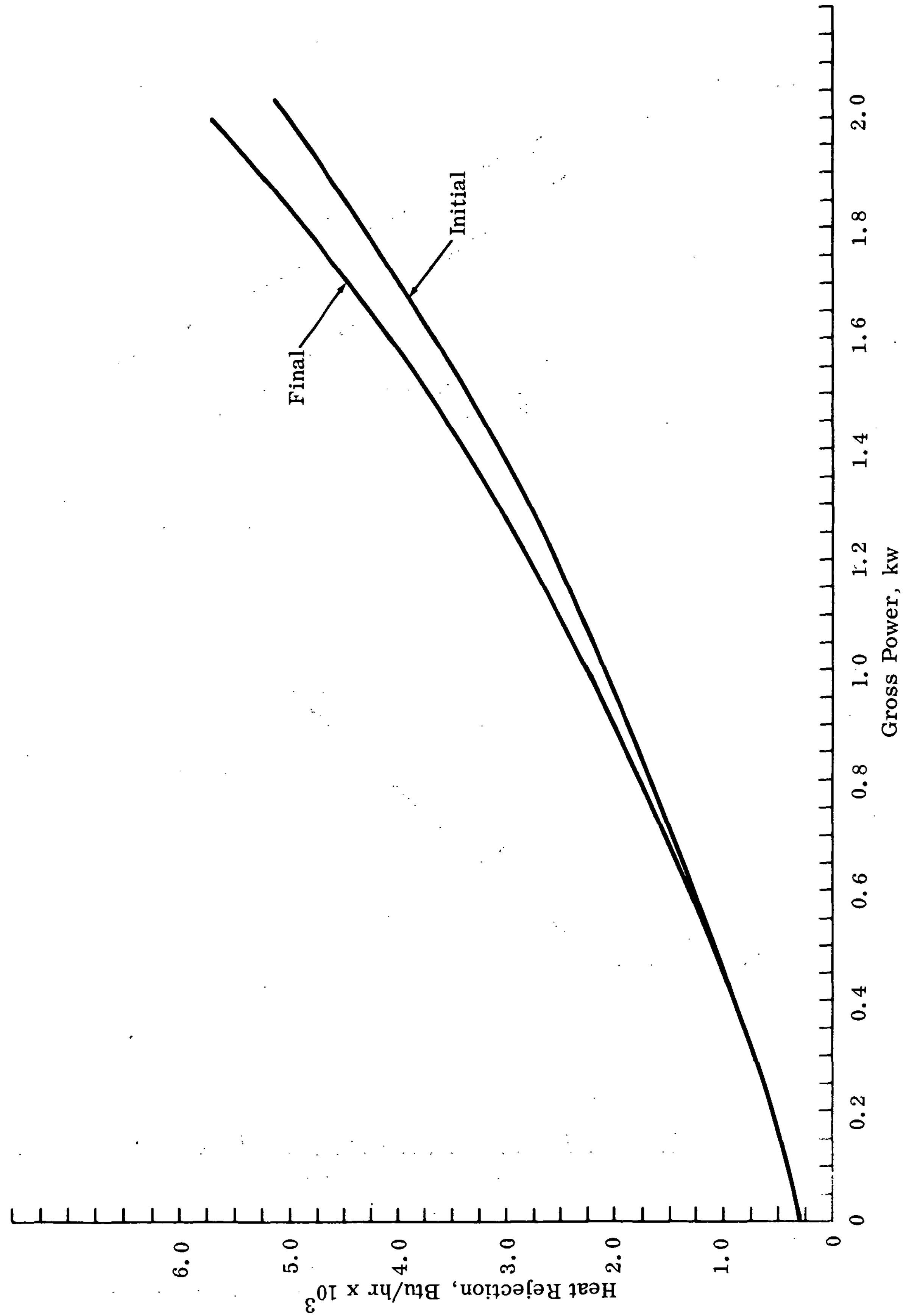


Fig. 5.1-5 Allis Chalmers Fuel Cell Heat Rejection

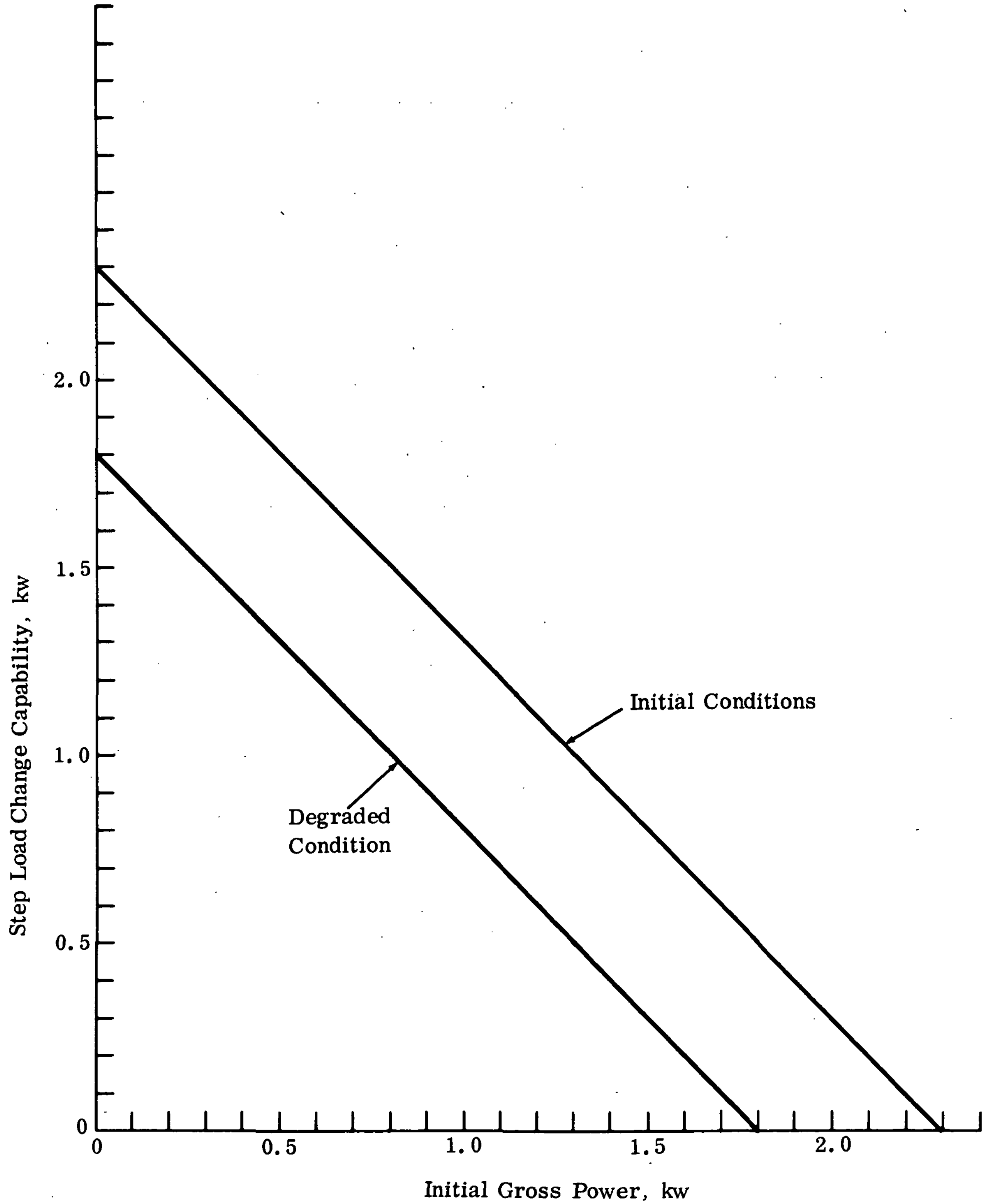
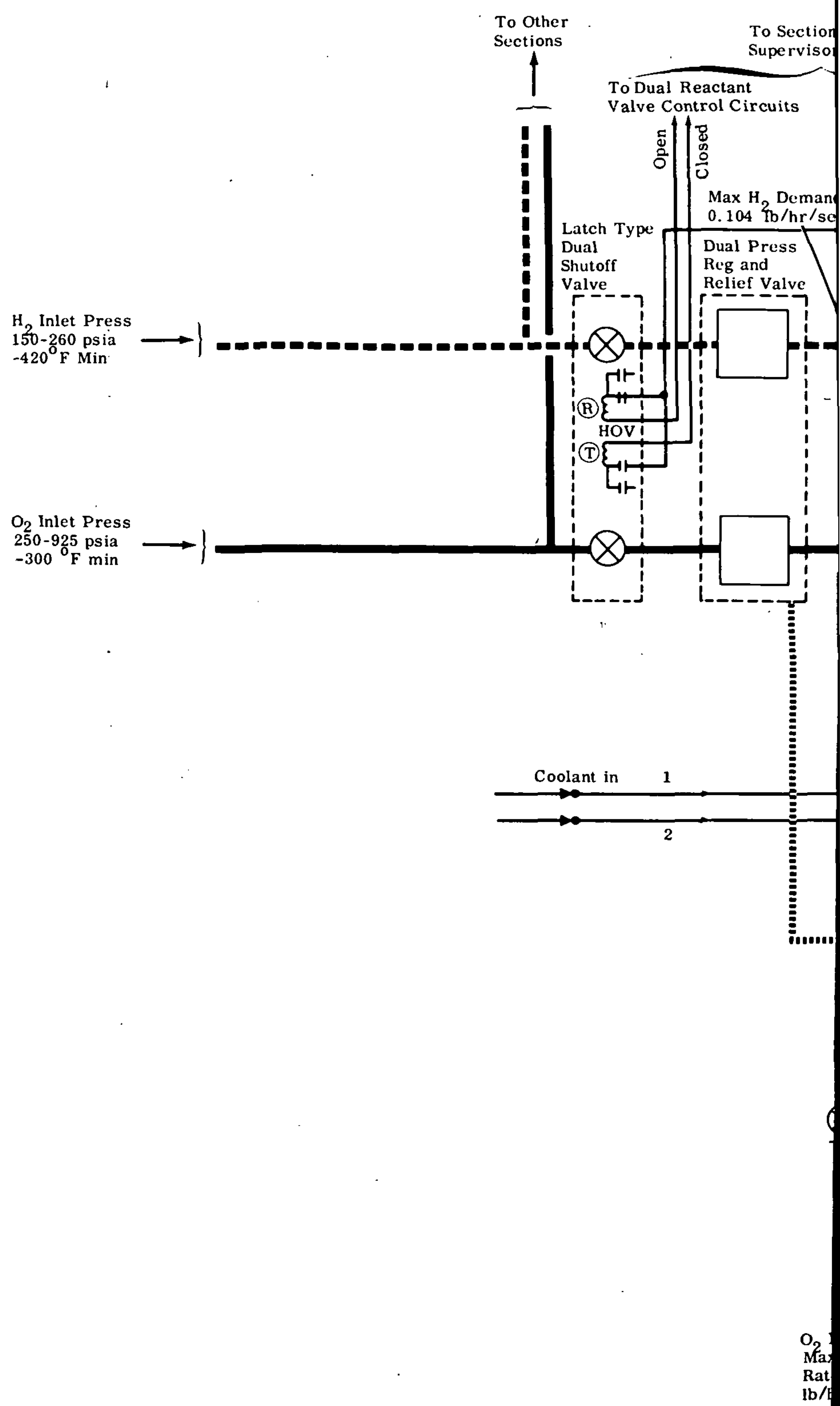
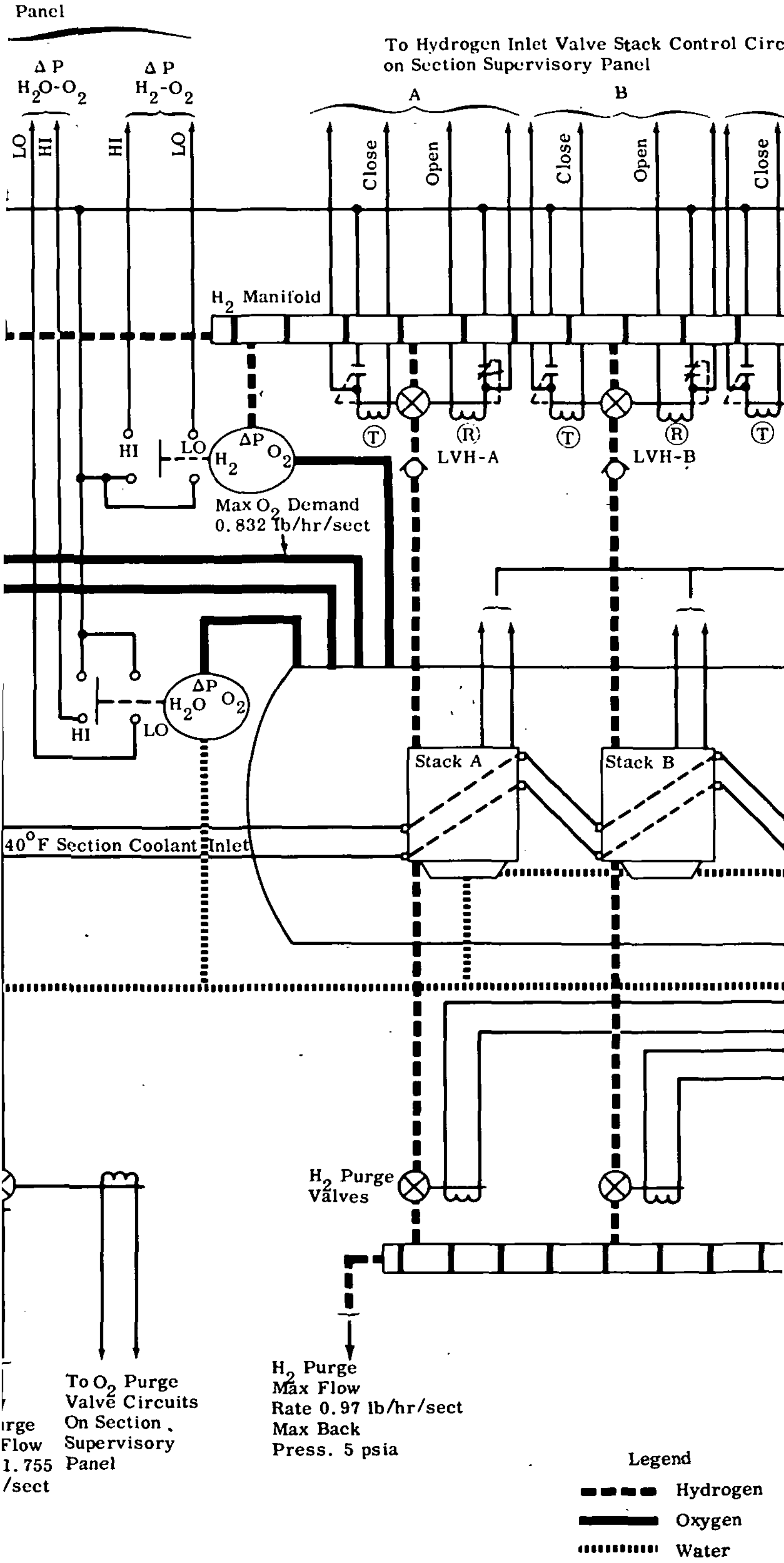


Fig. 5.1-6 Allis Chalmers Fuel Cell Step Load Capability



To Other Sections
To Dual Reactant Valve Control Circuits
Open
Closed
Latch Type Dual Shutoff Valve
Dual Press Reg and Relief Valve
H2 Inlet Press 150-260 psia -420°F Min
HOV
O2 Inlet Press 250-925 psia -300 °F min
Coolant in
1
2


Panel
ΔP H_2O-O_2
ΔP H_2-O_2
LO
HI
HI
LO
To Hydrogen Inlet Valve Stack Control Circ
on Section Supervisory Panel
A
B
Close
Open
Close
Open
Close
H_2 Manifold
LVH-A
LVH-B
ΔP H_2 O_2
HI
LO
Max O_2 Demand
0.832 lb/hr/sect
ΔP H_2O O_2
HI
LO
Stack A
Stack B
40°F Section Coolant Inlet
H_2 Purge Valves
To O_2 Purge Valve Circuits On Section Supervisory Panel
irge
Flow
1.755
/sect
H_2 Purge
Max Flow
Rate 0.97 lb/hr/sect
Max Back
Press. 5 psia
Legend
Hydrogen
Oxygen
Water

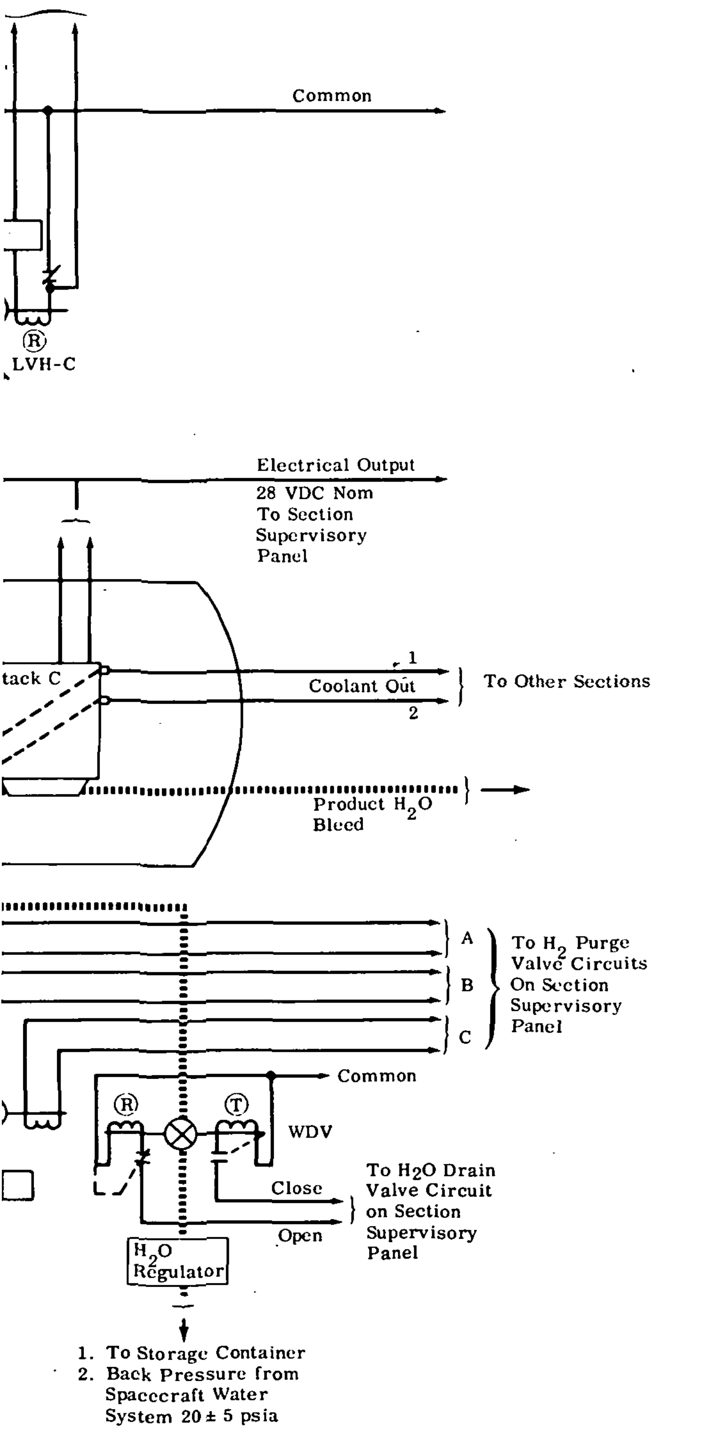


Diagram Courtesy General Electric Co.

Fig. 5.1-7 GE Fuel Cell Schematic

This Page Intentionally
Left Blank

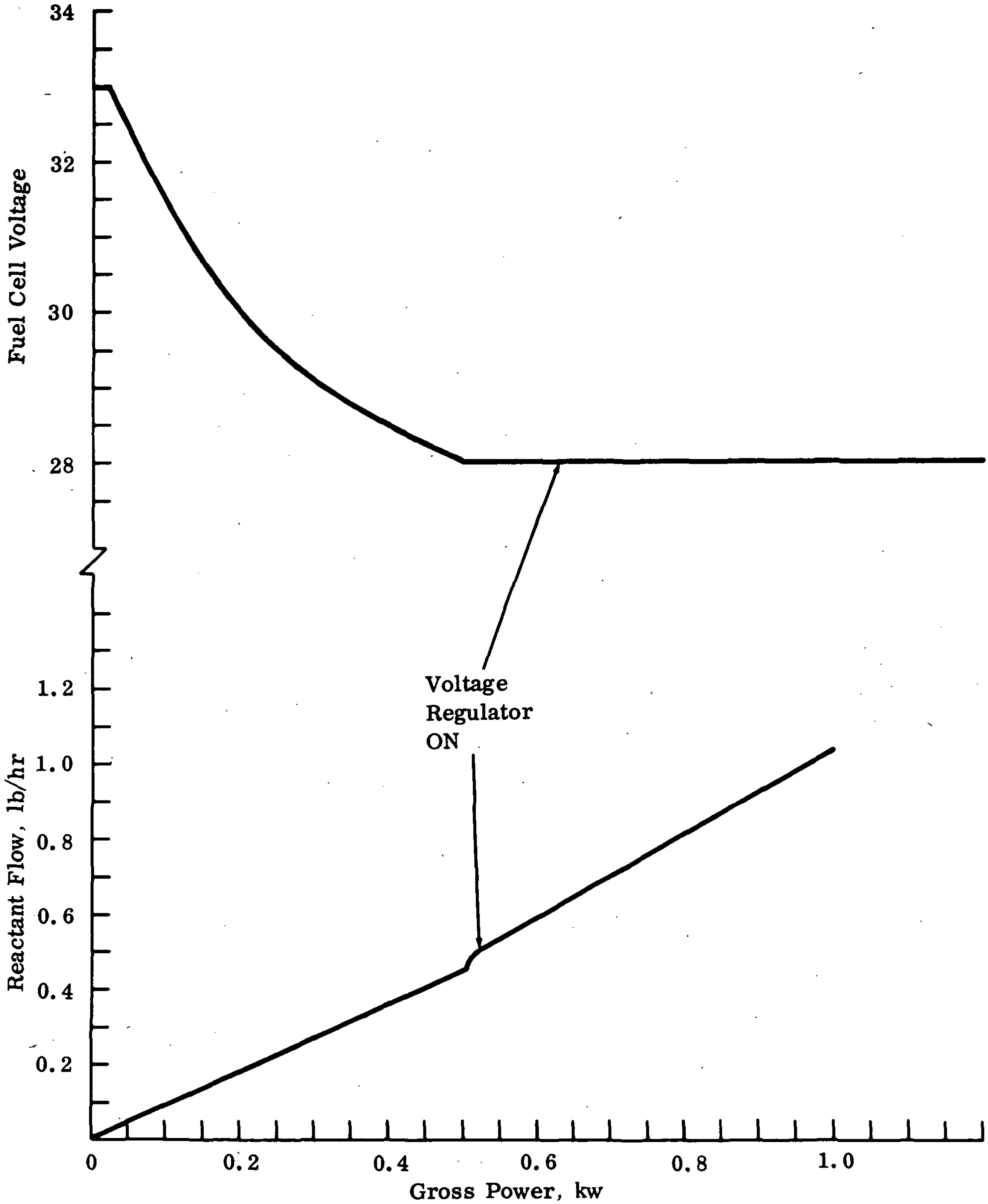


Fig. 5.1-8 GE Fuel Cell Voltage & Reactant Flow vs Gross Power

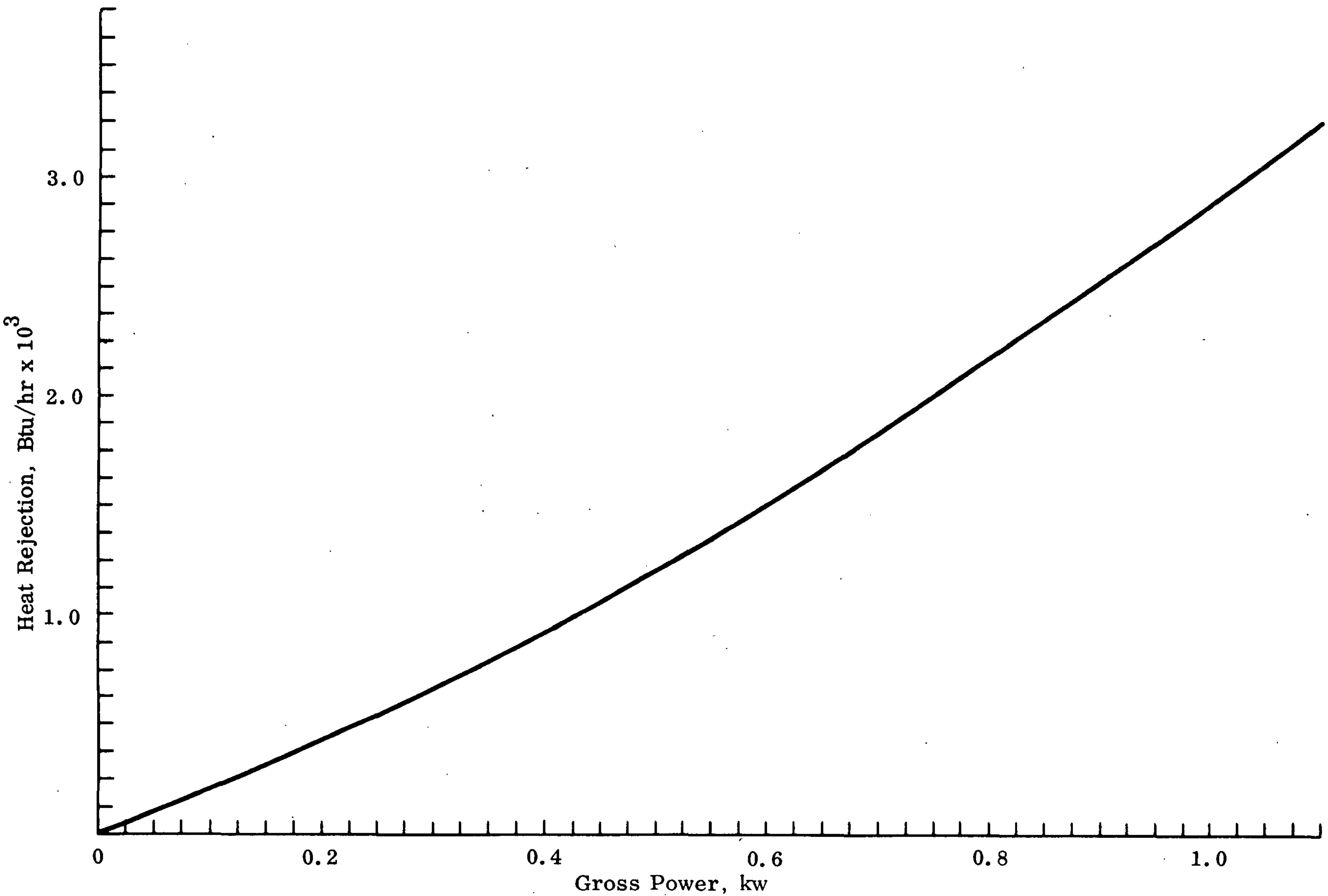


Fig. 5.1-9 GE Fuel Cell Heat Rejection

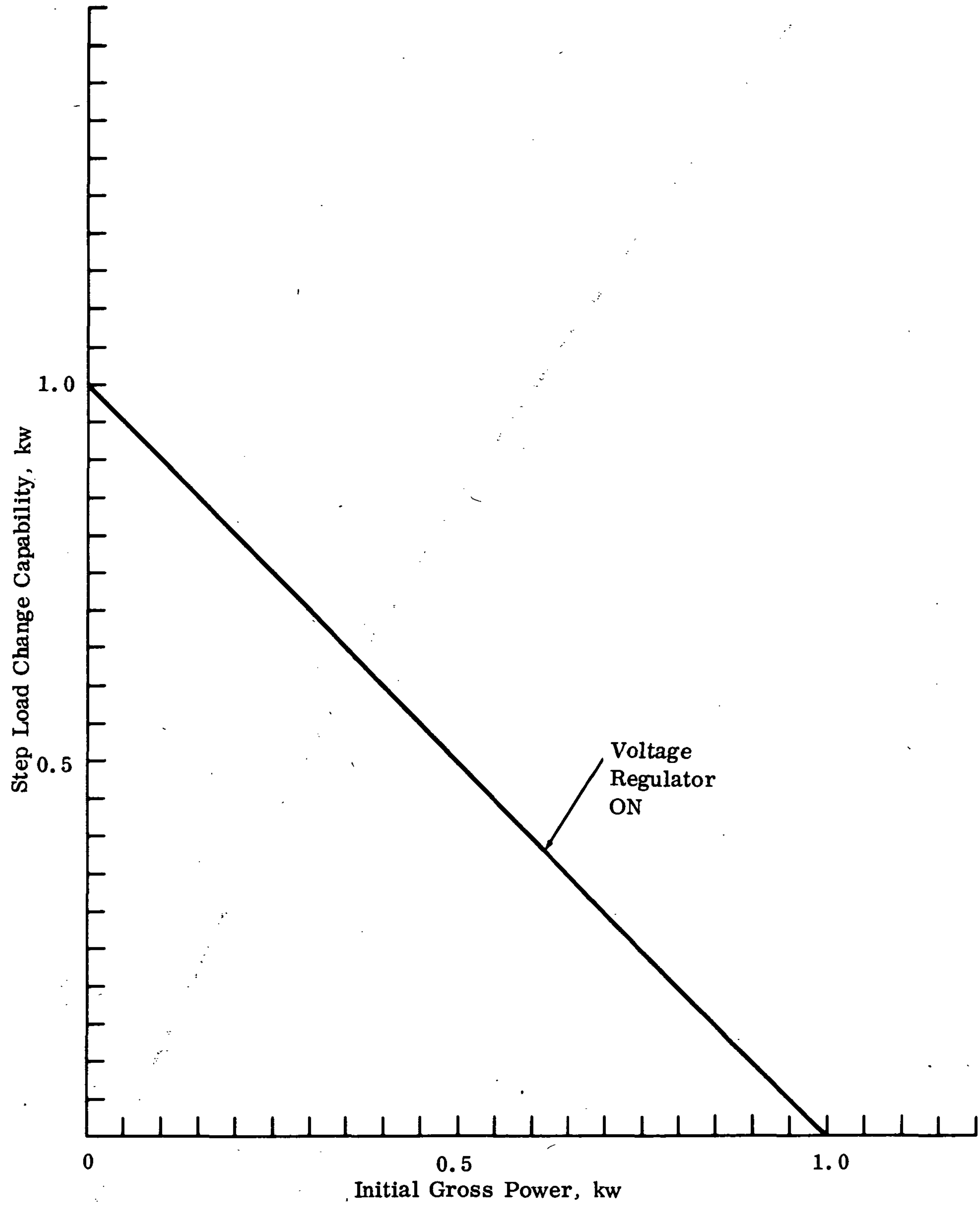
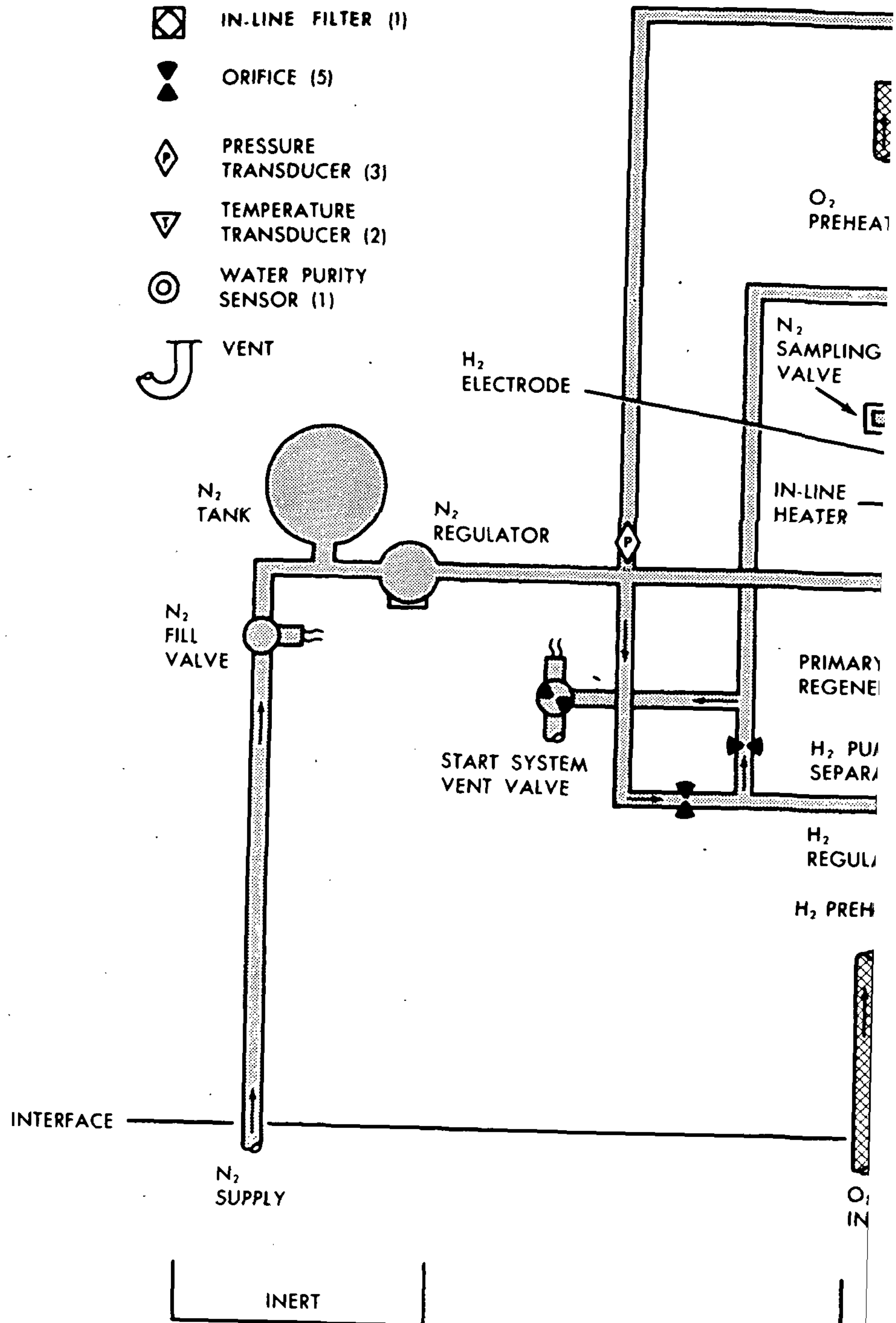


Fig. 5.1-10 GE Step Load Capability


IN-LINE FILTER (1)
ORIFICE (5)
PRESSURE TRANSDUCER (3)
TEMPERATURE TRANSDUCER (2)
WATER PURITY SENSOR (1)
VENT
H_2 ELECTRODE
N_2 SAMPLING VALVE
IN-LINE HEATER
N_2 TANK
N_2 REGULATOR
N_2 FILL VALVE
START SYSTEM VENT VALVE
INTERFACE
N_2 SUPPLY
INERT

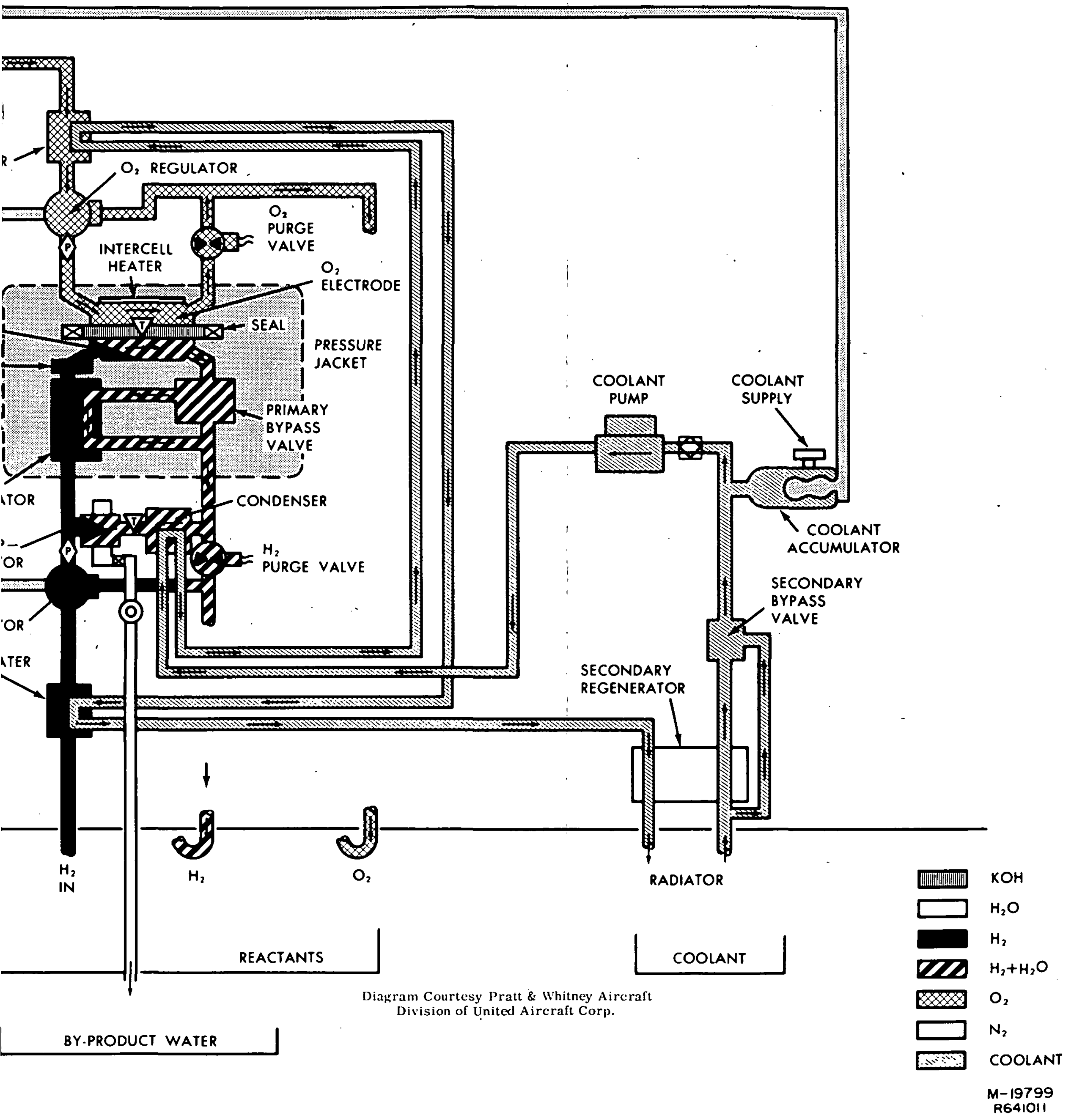


Diagram Courtesy Pratt & Whitney Aircraft
Division of United Aircraft Corp.

Fig. 5.1-11 P&WA Fuel Cell Powerplant Model PC3A-2 Flow Schematic

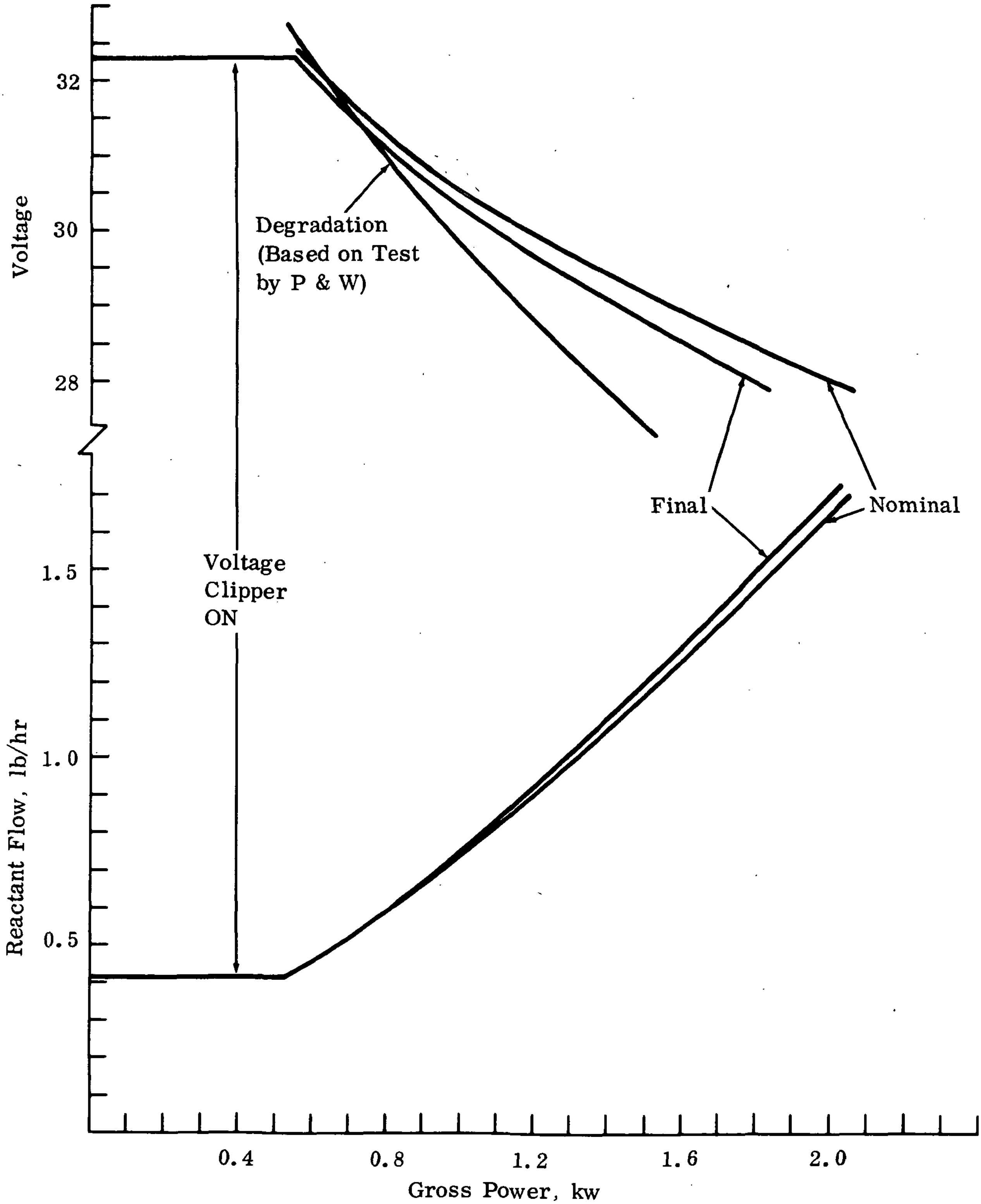


Fig. 5.1-12 P&WA Fuel Cell Voltage & Reactant Flow vs Gross Power

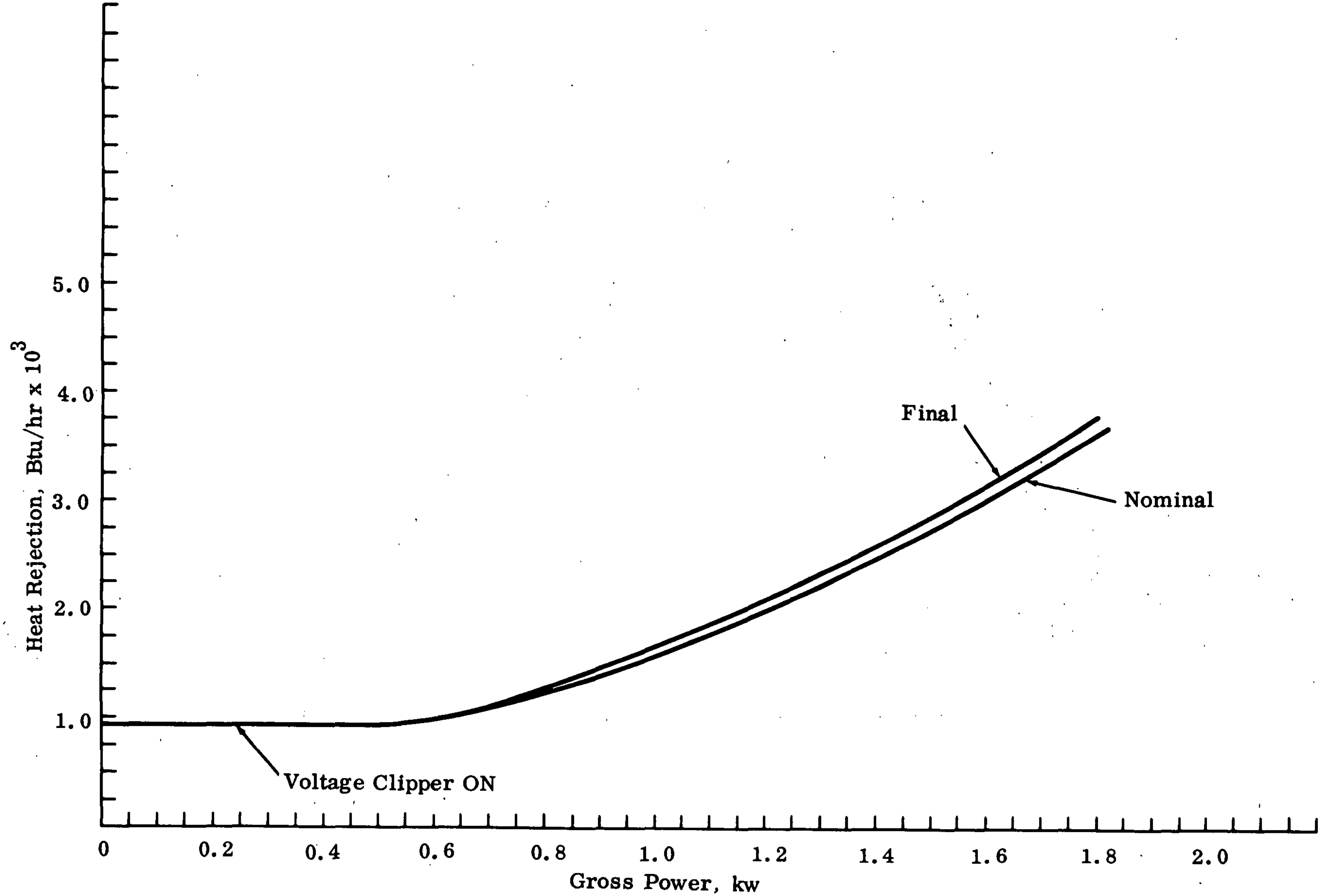


Fig. 5.1-13 P&WA Fuel Cell Heat Rejection

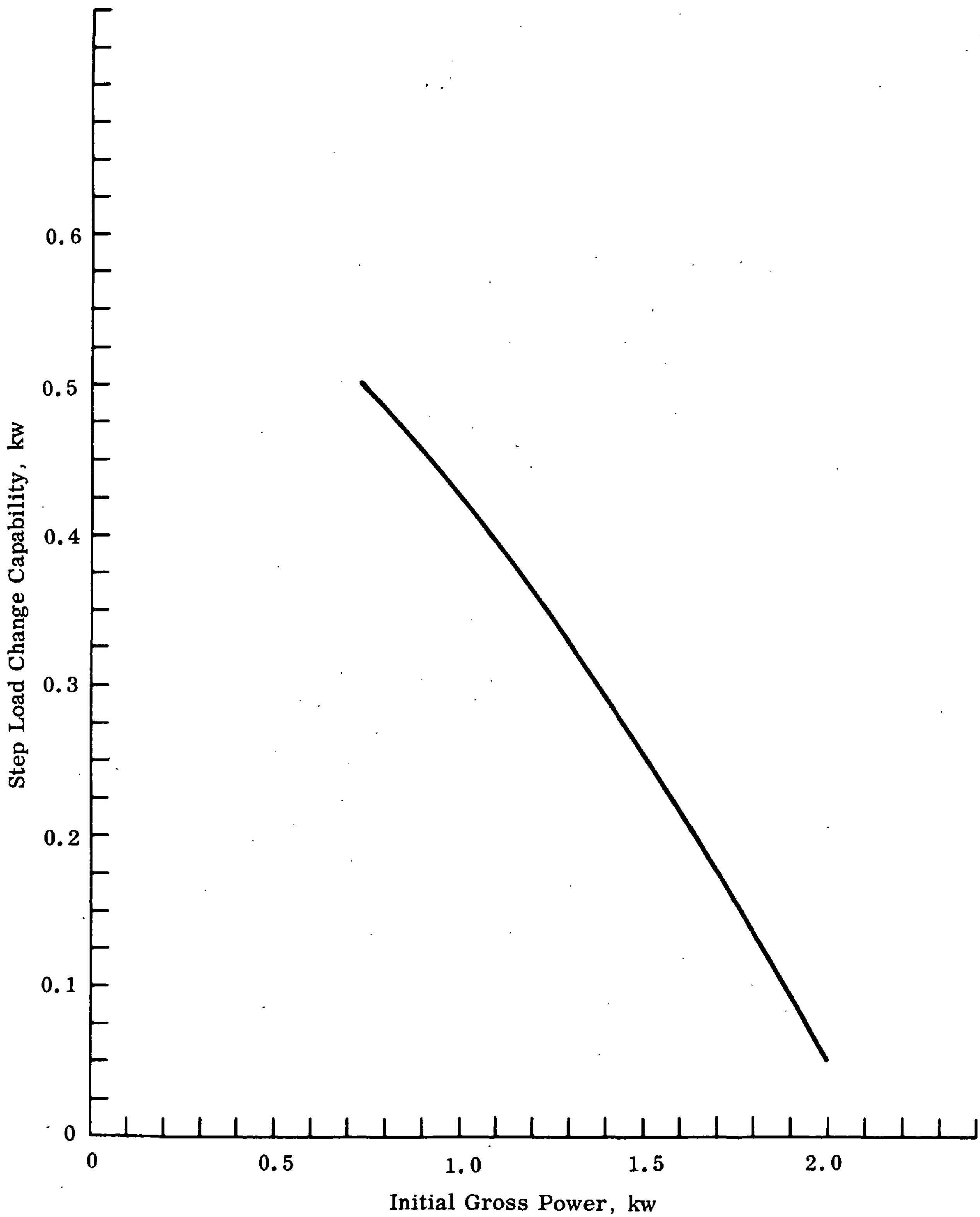


Fig. 5.1-14 P&WA Fuel Cell Step Load Capability

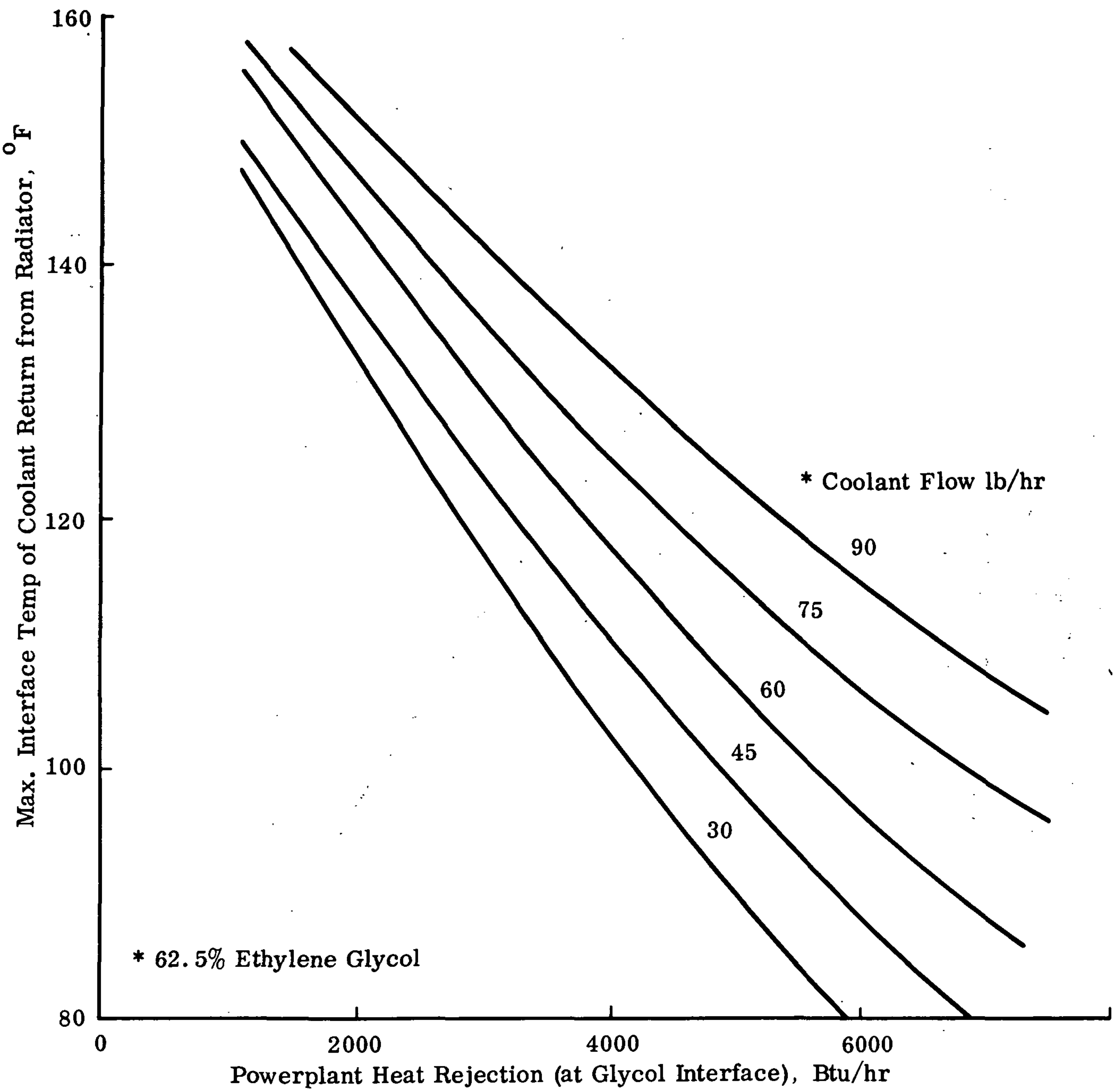
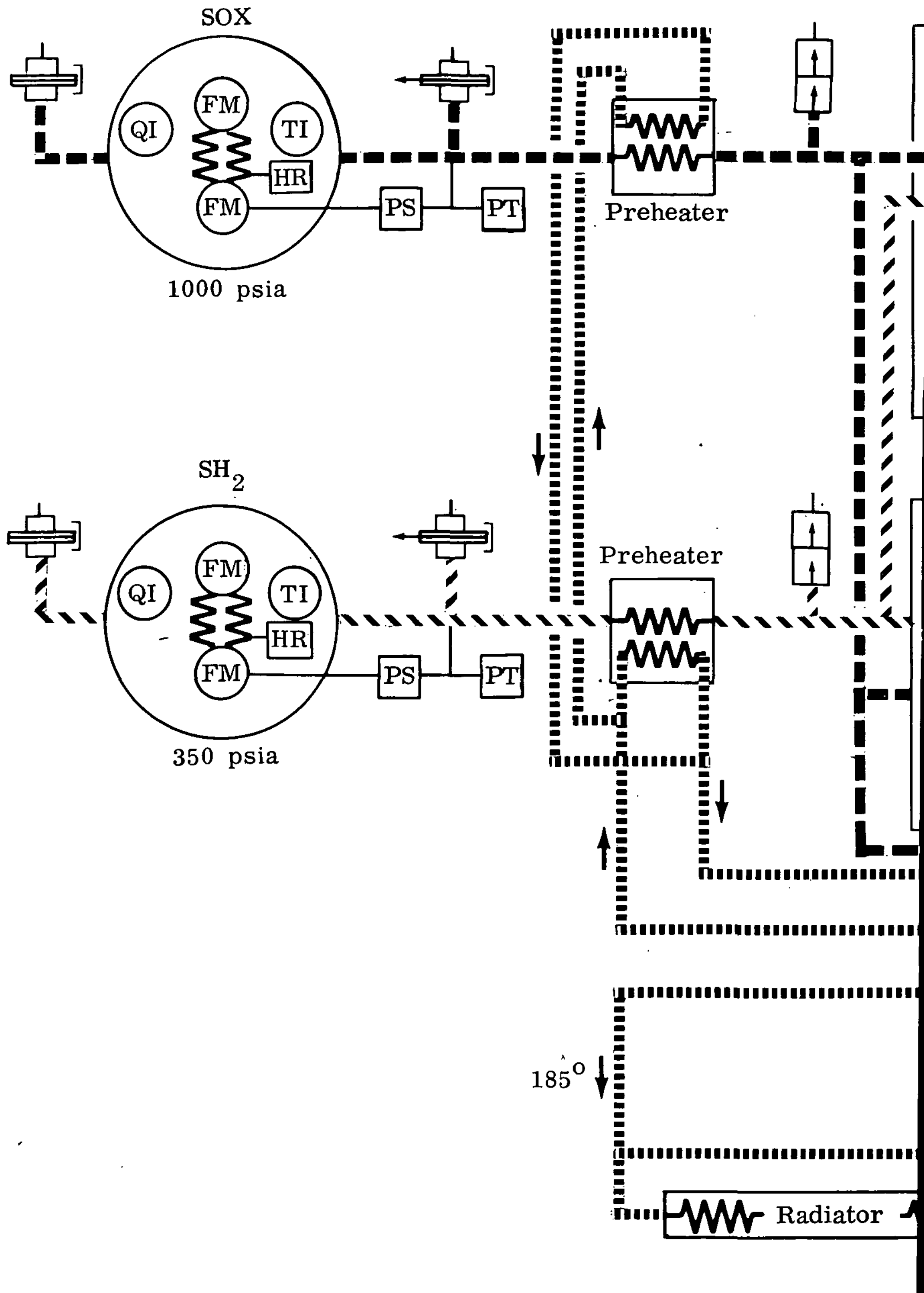
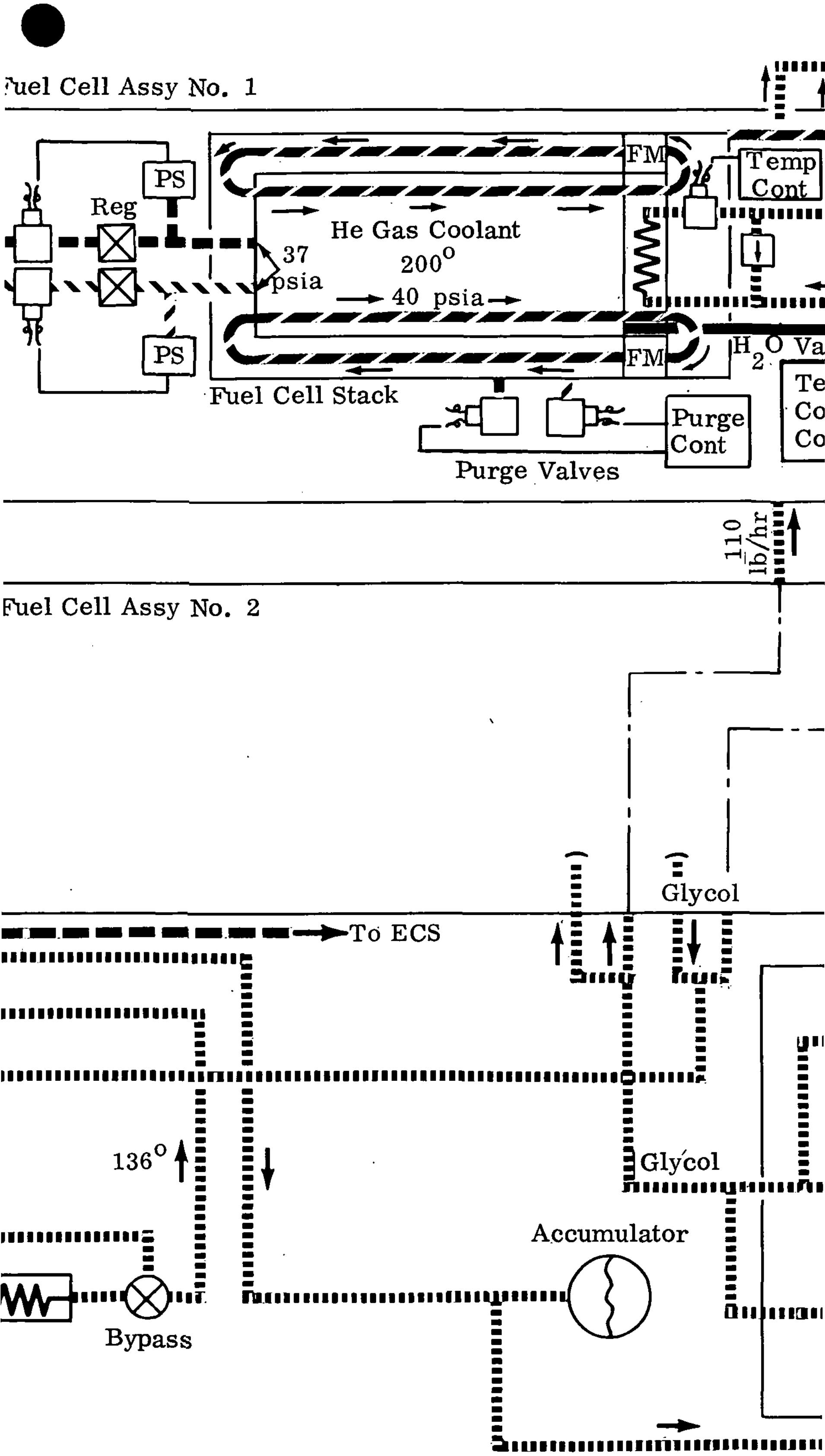


Fig. 5.1-15 P&WA Fuel Cell Secondary Cooling Loop Characteristics

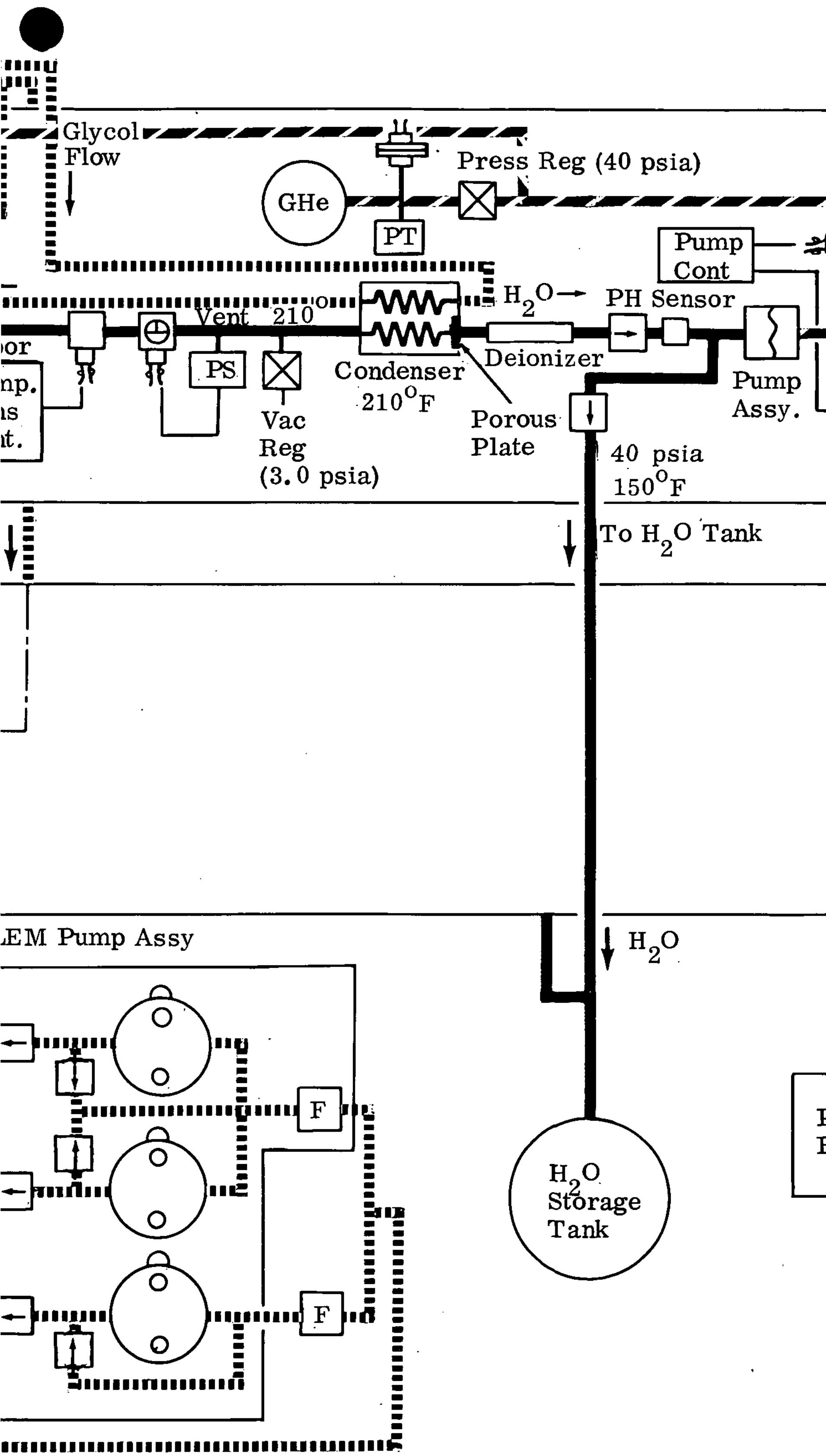

SOX
FM
QI
TI
HR
FM
PS
PT
Preheater
1000 psia
SH2
FM
QI
TI
HR
FM
PS
PT
Preheater
350 psia
185°
Radiator

5.1.16
(1)



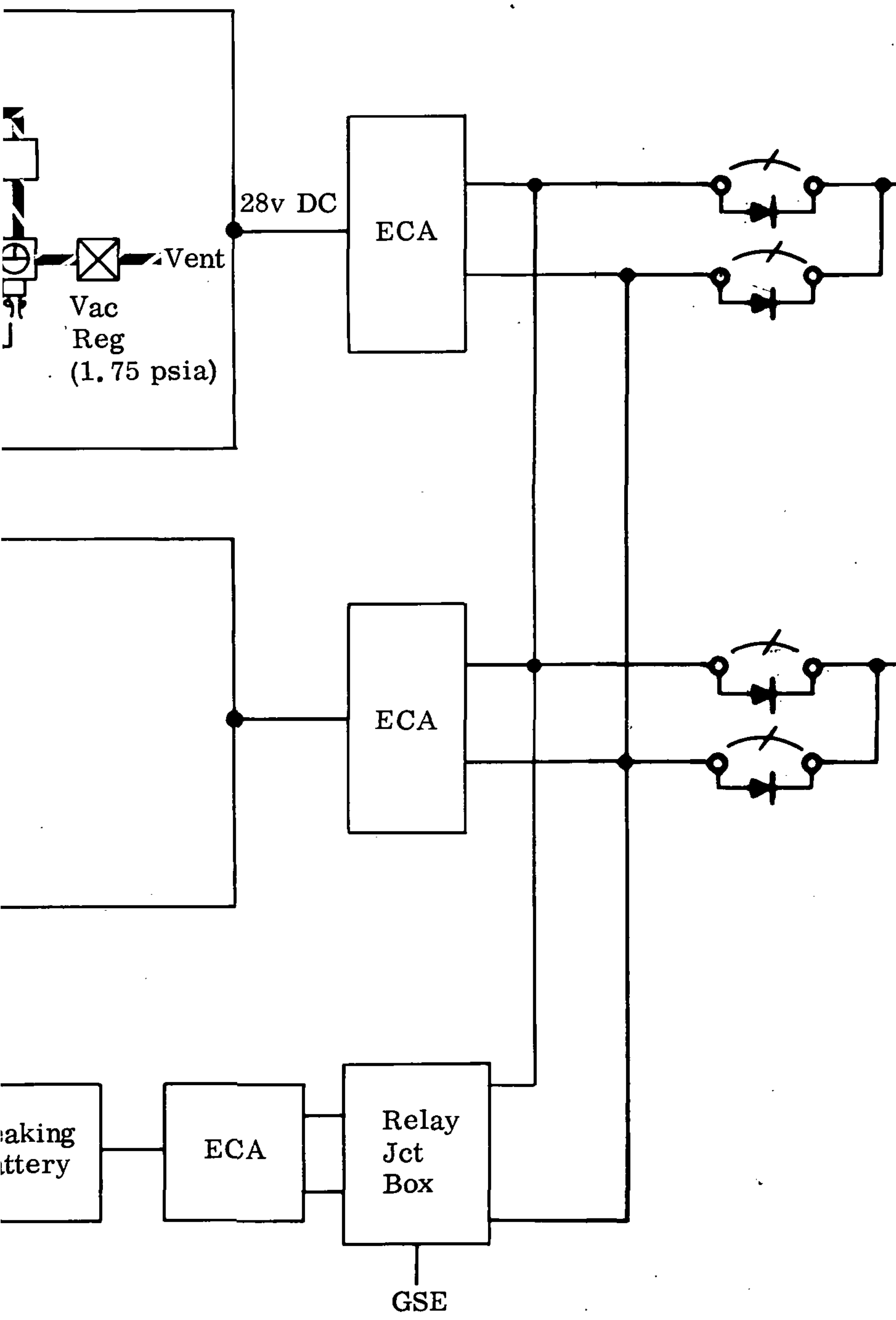
Fuel Cell Assy No. 1
PS
Reg
PS
37
psia
He Gas Coolant
200°
40 psia
FM
FM
Temp
Cont
H_2O Va
Fuel Cell Stack
Purge
Cont
Purge Valves
110
lb/hr
Fuel Cell Assy No. 2
Glycol
To ECS
136°
Glycol
Accumulator
Bypass

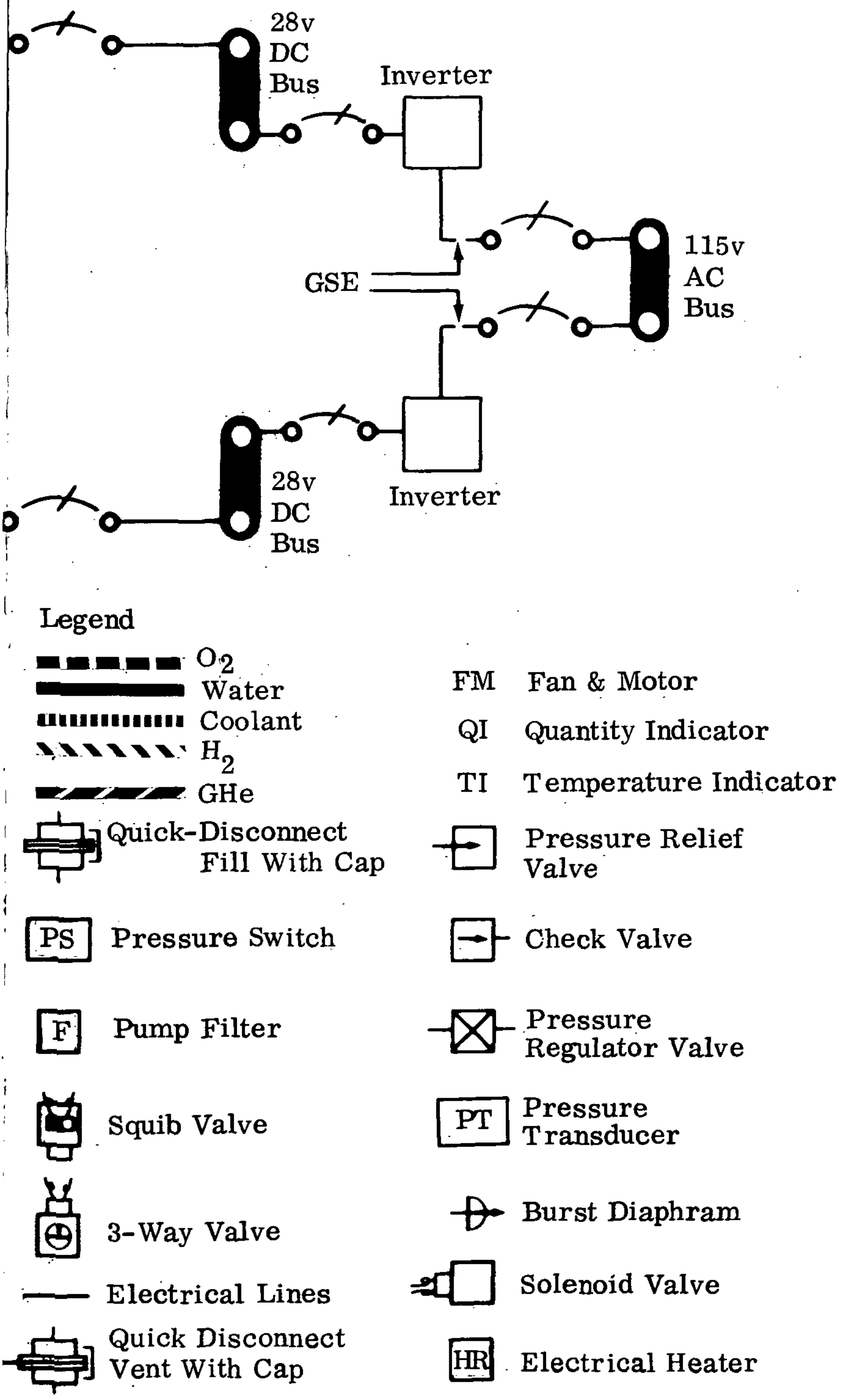
5.1.16 (2)


Glycol
Flow
GHe
PT
Press Reg (40 psia)
Pump
Cont
H2O
PH Sensor
Vent
210
PS
Vac
Reg
(3.0 psia)
Condenser
210°F
Deionizer
Porous
Plate
Pump
Assy.
40 psia
150°F
To H2O Tank
EM Pump Assy
H2O
F
F
H2O
Storage
Tank

5.1.16

(3)


28v DC
ECA
Vent
Vac
Reg
(1.75 psia)
ECA
aking
ttery
ECA
Relay
Jct
Box
GSE



g. 5.1-16 Phase II Lab Recommended EPS Schematic

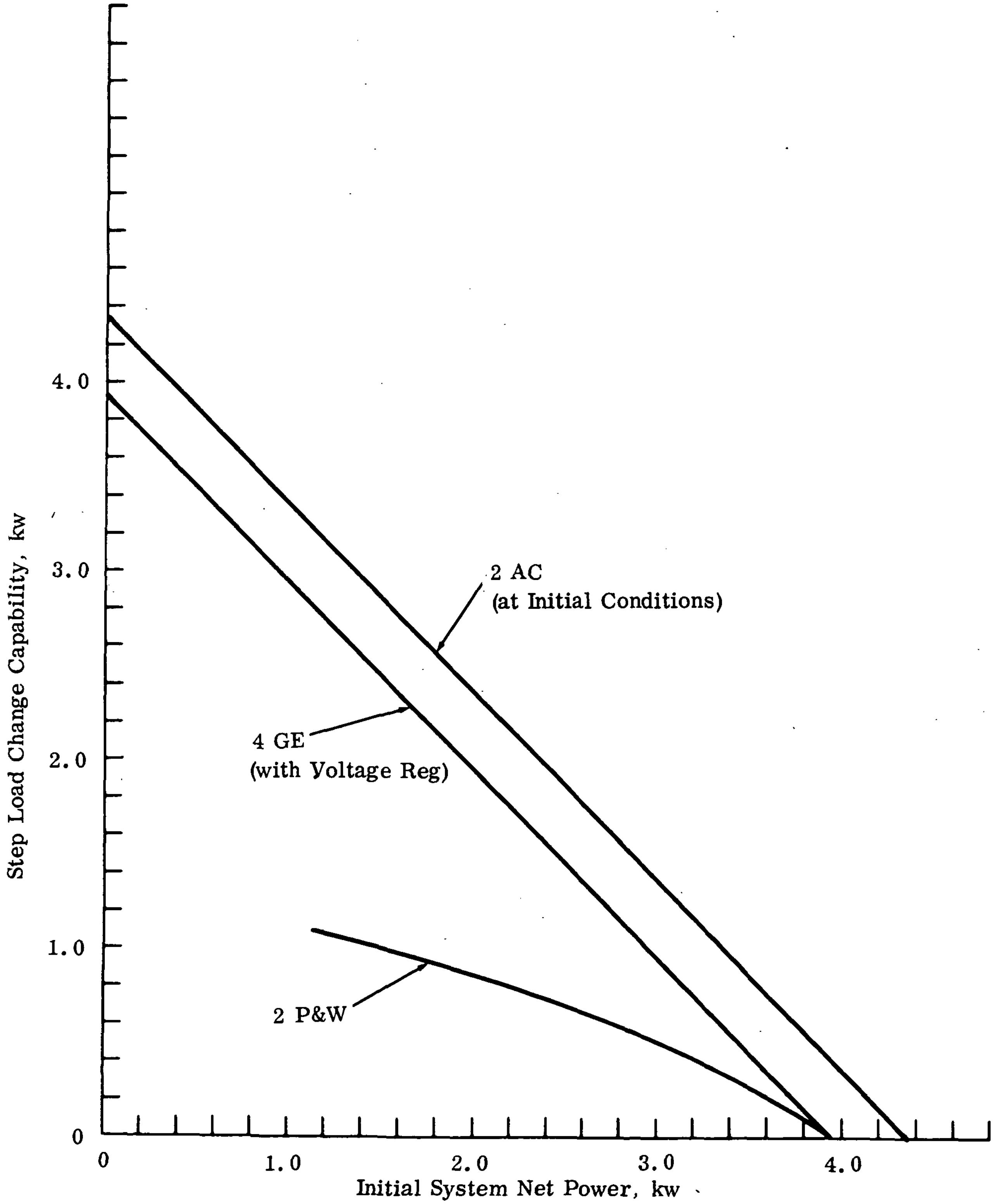


Fig. 5.1-17 System Step Load Capability

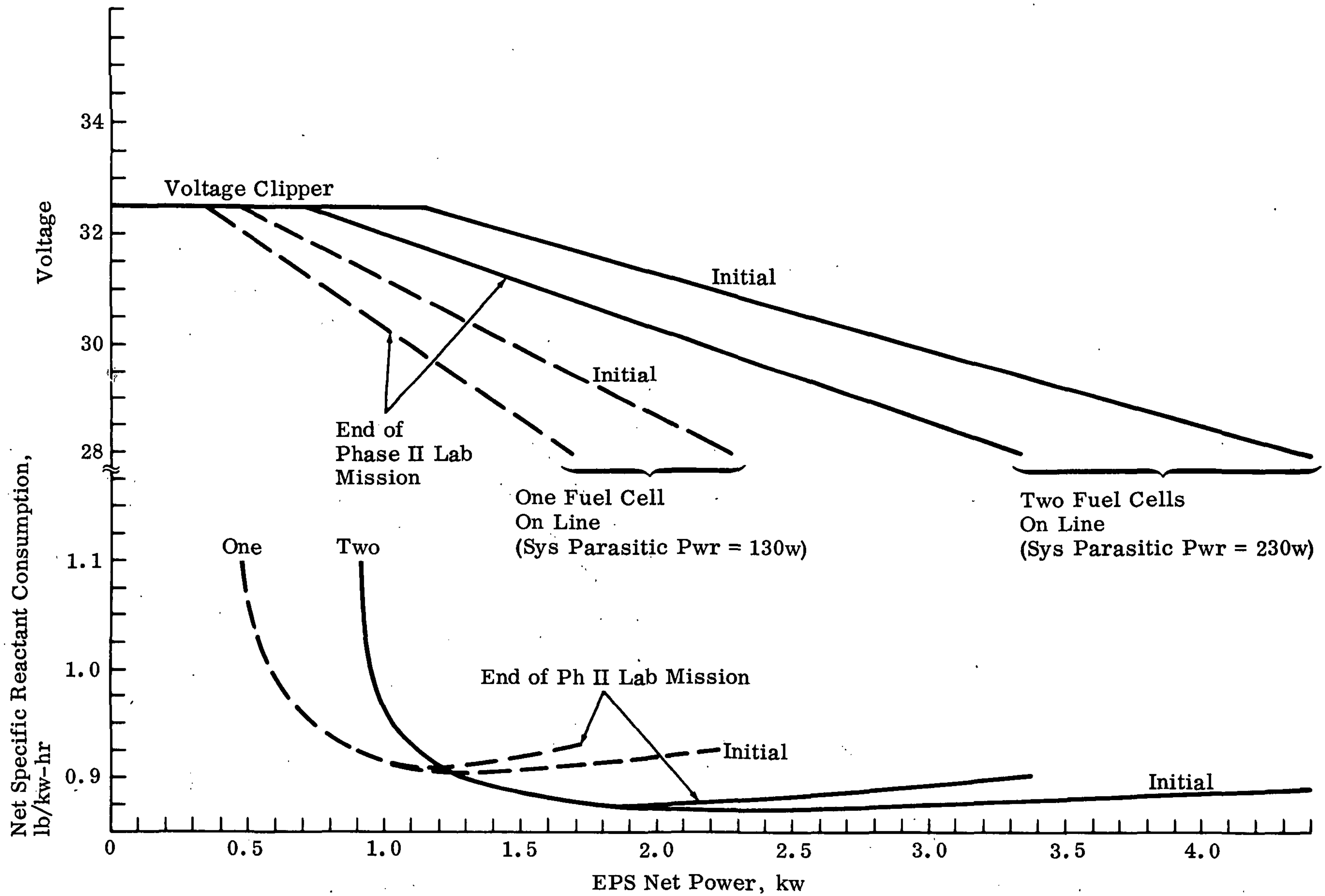


Fig. 5.1-18 System Performance with 2 Allis-Chalmers Fuel Cells

Curve No.	No. Cells	Cell Type	Parasitic Pwr/Cell, watts		
			Operation	Hot Standby	Source
1	4	GE, 32VR	15	0	Bus
2	4	GE 34 Cells	15	0	Bus
3	2	A-C 33	115	57	100 from cell, 15 Bus
4	2	P & W-D	127	113	Bus

A Half the number of fuel cells on Bus, the others on Hot Standby.
- GE: Two operating cells use same coolant pump requiring 30 watts; the other two are completely shut down.
- P&W: Cell on Standby requires 113 watts from Bus into cell heaters; otherwise, cell is off Bus.
- A-C: Hot Standby is off Bus entirely & cycles its own fans to maintain 200°F cell temp. This requires an average of 57 watts from cell itself. Glycol pump common to both cells is kept running using 30 watts.

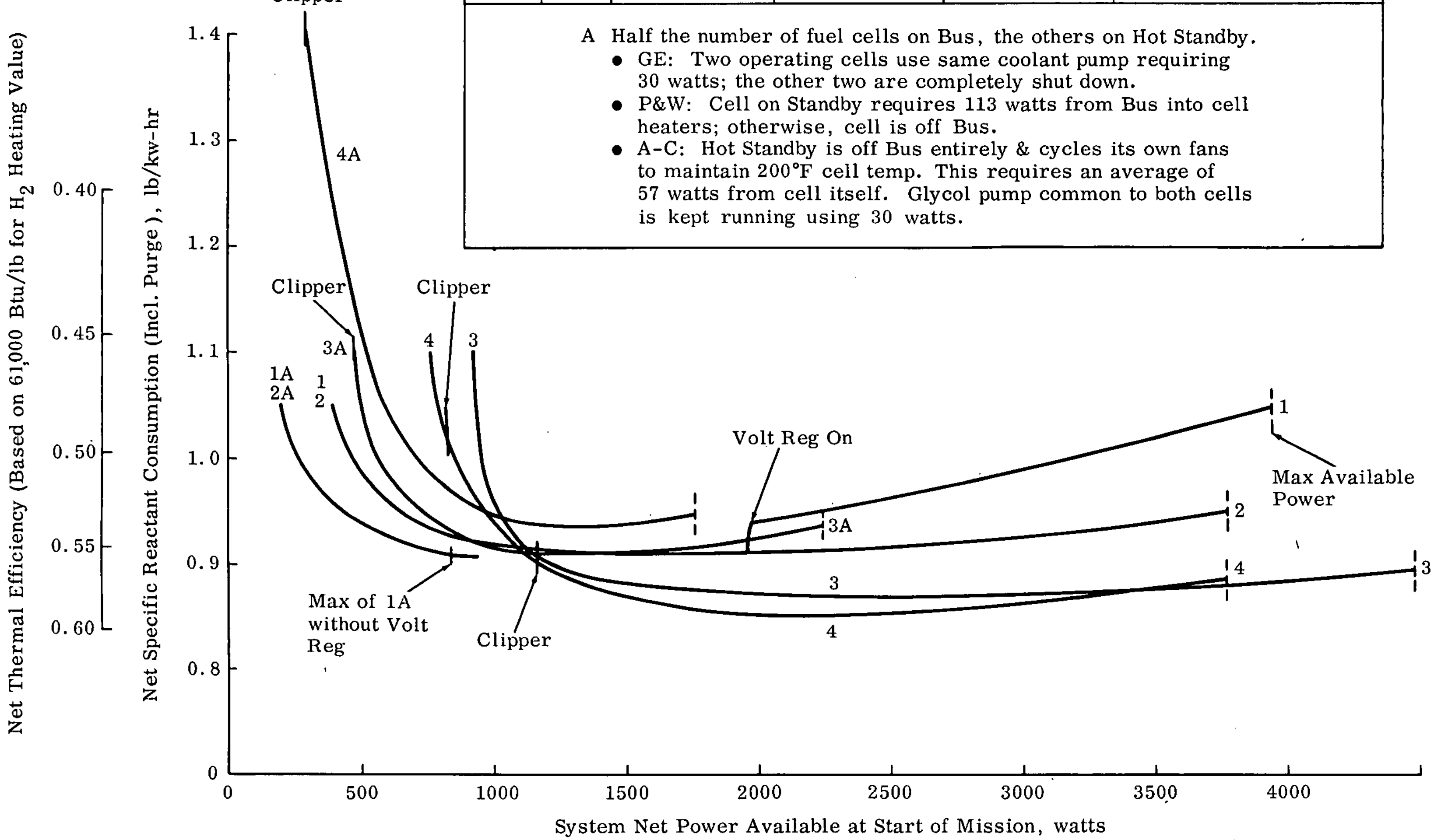


Fig. 5.1-19 Specific Reactant Consumption vs Net Power

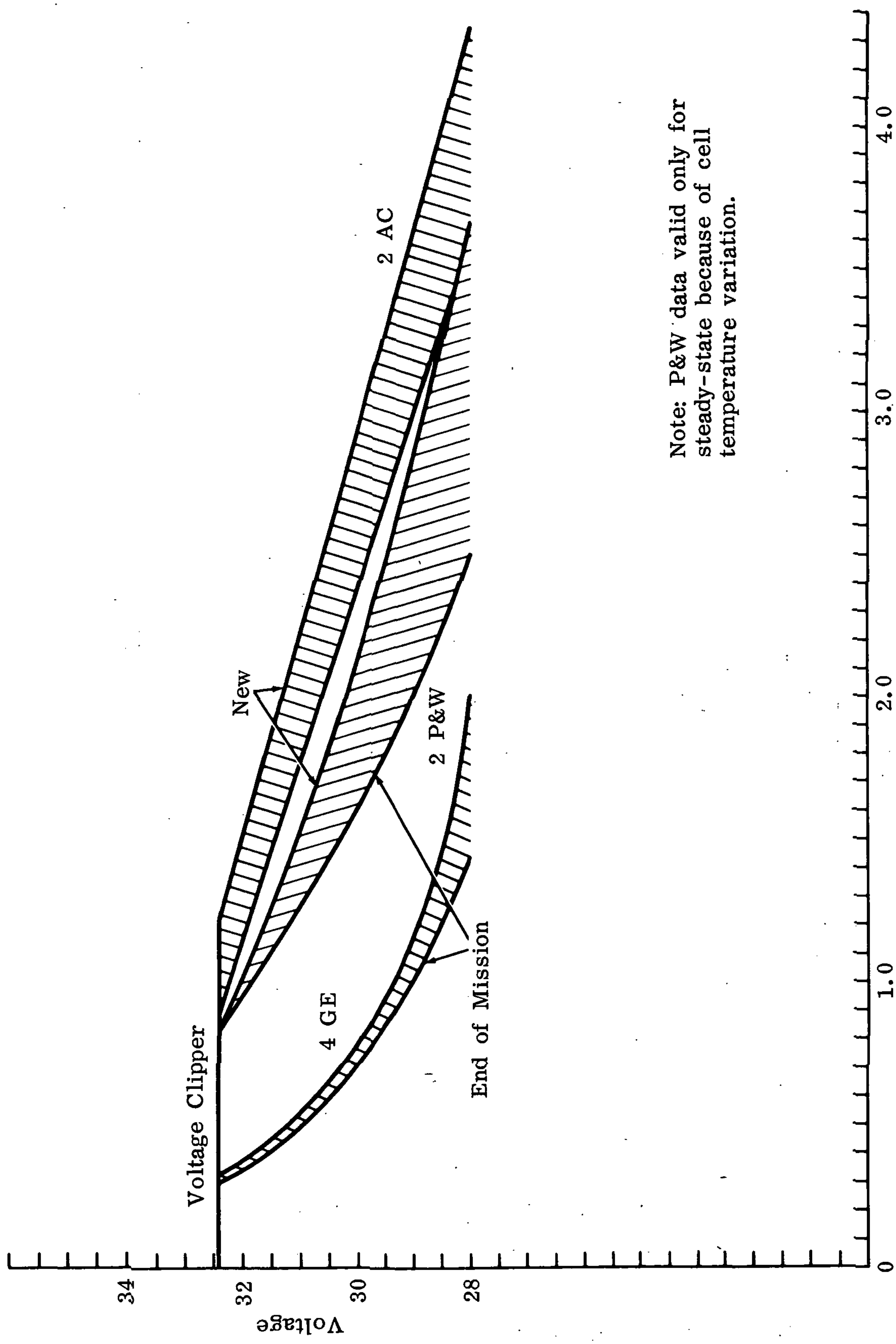


Fig. 5.1-20 Comparative Degradation

5.2 ENVIRONMENTAL CONTROL SUBSYSTEM (ECS)

5.2.1 Groundrules

The following NASA groundrules have been adhered to in the establishment of preliminary ECS functional design requirements and the subsequent development of subsystem configurations for the Phase II Laboratory.

- The CSM ECS shall provide for the removal of carbon dioxide, excess water vapor, odors, trace contaminants and particulate matter from the combined CM/Lab atmosphere during routine flight.
- The CSM shall provide all water required by the crew for drinking, food preparation and personal hygiene.
- The Lab shall provide for recharging the PLSS.
- The Lab shall provide for the exchange of cabin atmosphere between the Lab and CM as required to maintain the former at acceptable humidity, temperature and carbon dioxide concentration levels.
- The Lab atmosphere shall be 70% oxygen and 30% nitrogen at 5 psia. Ambient storage of inert gas shall be employed. A capability shall exist for alternative operation at 5 psia pure oxygen.
- The Lab metabolic and leakage gas requirements shall be supplied by the CSM.
- There shall be no requirement that one crew member be in a pressure suit at all times.
- The CSM shall incorporate a two bed thermal swing molecular sieve for carbon dioxide removal.
- An airlock and associated support equipment shall be integrated into the Lab.

5.2.2 Assumptions and Background Data

During the developement of ECS configurations, it has been necessary to make several assumptions with regard to the functional requirements of Lab equipment. These assumptions have been formulated within the groundrules itemized in Paragraph 5.2.1 and, in general, reflect an attempt to provide a clean interface between Lab and CSM Environmental Control Subsystems.

- Crew metabolic heat loads are apportioned as follows:

  - o CSM ECS: All latent metabolic plus sensible metabolic produced by CM occupants.

  - o Lab ECS: Sensible metabolic produced by Lab occupants.

- The Lab airlock is decompressed to effect egress and is unpressurized during EVA experiments only.
- There are no fluid hardware interfaces between the Lab and CSM.
- The Lab ECS returns cabin gas to the CSM at the same temperature at which it is supplied (nominally 75 ± 5°F).
- The Lab suit circuit performs carbon dioxide, excess moisture, odor and particulate matter removal functions in support of airlock operations only (i.e., PLSS transition).

5.2.3 Recommended Configuration

An ECS capable of satisfying a wide range of requirements associated with experiment payloads has been developed for the recommended Lab configuration. Differences from its LEM counterpart are characterized by the integration of radiator assemblies for the rejection of all but peak thermal loads, provisions for managing water produced by Fuel Cell Assemblies, compatibility with the specified nitrogen-oxygen internal environment and a capability to support all operations associated with EVA experiments. The Lab is synthesized, almost in total, from hardware developed for the LEM program. In those instances where this has proved either impractical or unfeasible, the CSM and Gemini subsystems have been scrutinized for appropriate components. Only when these sources have been exhausted have new components been recommended.

Subsystem flexibility is most apparent in the recommended Heat Transport Section configuration. Selective radiator tube stagnation techniques have been utilized in conjuction with selective radiator panel flow modulation, bypass regeneration and water evaporator controls as described in Paragraph 5.2.3.2. The following paragraphs describe the recommended configurations by subsystem section with emphasis placed on the manner in which they differ from their LEM counterpart.

A portion of the component and subsystem performance data presented has been provided by the Hamilton Standard Division of the United Aircraft Corporation as part of a funded Phase B study subcontract.

5.2.3.1 Atmosphere Revitalization Section (ARS)

The ARS recommended for the Lab is comprised of a slightly modified LEM suit circuit assembly, the LEM atmosphere recirculation assembly and equipment associated with the forced exchange of the Lab and CM internal atmosphere. As indicated in Paragraph 5.2.1, it has been assumed that suit circuit functions are performed by the CSM ECS during routine flight. The LEM suit circuit is retained, however, on the Lab to provide suit ventilation and removal of carbon dioxide, excess water vapor, odor and particulate matter in support of suited operations associated with EVA experiments since the suit circuit is used extensively during checkout procedures associated with the transition to extravehicular life support systems. The functional and operational requirements of this equipment are identical to those of the present LEM except for the addition of a third suit connector station located in the airlock. This station is plumbed in parallel with the two existing Lab stations and consists of a suit umbilical hose assembly and a suit supply crossover valve.

The atmosphere recirculation assembly provides for ventilation and temperature control in the Lab cabin. It consists of two cabin fans and a coolant-to-oxygen heat exchanger equipped with wicking material for the collection and re-evaporation of condensate. This assembly is retained intact and will remove all sensible heat loads introduced into the cabin atmosphere by Lab structure, equipment and occupants.

Since carbon dioxide and excess water vapor are removed by the CSM ECS during routine flight, provisions must be made for the exchange of Lab and CM atmosphere at a rate that will maintain the Lab at acceptable humidity and carbon dioxide concentration levels. A flexible duct, approximately four inches in diameter connected to the cabin heat exchanger fan assembly is recommended. The CSM atmosphere will be drawn through the duct to the Lab cabin and returned through the open docking tunnel hatches.

The Lab ARS is shown schematically in Fig. 5.2-1. One suit circuit lithium hydroxide canister is sufficient to support the EVA capability of the recommended Lab configuration.

5.2.3.2 Heat Transport Section (HTS)

The HTS recommended for the Lab has the following functional capabilities:

- Provide active thermal control for all electronics associated with Lab housekeeping functions.
- Provide active thermal control associated with experimental equipment.
- Provide sensible and latent cooling or heating as required of Atmosphere Revitalization Section oxygen during pre-egress suited operations.
- Provide sensible cooling or heating as required to maintain cabin temperature within predetermined limits.
- Provide for the rejection of waste heat by space radiators supplemented by water evaporation.

The recommended Lab HTS configuration, shown schematically in Fig. 5.2-2, differs from the LEM HTS as follows:

- The coolant pump has been modified to provide for higher performance.
- Radiators and associated control equipment have been added.
- A regenerative heat exchanger and control valve have been added downstream of the radiators to control radiator outlet temperature.
- The secondary heat transport loop has been deleted, since it services only that equipment which is critical to a LEM mission abort mode.
- The battery water evaporator has been deleted due to the incorporation of radiators and fuel cells.
- The battery coldplates have been deleted from the coolant loop.
- The low temperature coldplate network has been modified in accordance with projected equipment cooling requirements.
- The composition of the HTS coolant has been changed to 62.5% glycol and 37.5% water due to the incorporation of radiators.
- A manual valve has been added to the low temperature portion of the coolant network to provide a capability to bypass the Abort Sensor Assembly (ASA) coldplate while the ASA is in a standby mode, thereby reducing the average standby heater requirements from 73 watts to 5 watts.
- An automatic diverter valve has been added upstream of the water evaporator to provide a capability to modulate coolant flow entering the water evaporator.

5.2.3.2.1 Radiator Integration. It is recommended that radiators be used as the primary means by which waste heat is rejected on the Lab. The recommended radiator configuration consists of four panels located vertically on the diagonal shielding of the descent stage as shown in Section 6.0. The panels will have a total surface area of 60 sq ft. The four 15 sq ft panels will be plumbed in a series/parallel arrangement as shown in Fig. 5.2-2. Each panel will be designed with the capability to reduce its heat rejection by means of selective tube stagnation; i.e., as the thermal load is reduced, successive flow paths in the radiator stagnate. To further increase the capability to reduce radiator heat rejection, two radiator control valves have been added to the coolant network. These components are identical to LEM Item 203 except the sensors have lower temperature settings. The valves are located upstream of each of the two parallel radiator circuits. Each valve senses the mixed outlet temperature of its associated circuit and attempts to maintain that temperature at a predetermined value by modulating flow through the radiator's bypass leg. An intermodular control valve, located upstream of the radiator control valves, has been provided to compensate for the effects caused by each radiator circuit being subjected to a different external environment; such as one circuit being sun oriented while the other is oriented in the direction of dark space. The valve modulates coolant flow to each radiator circuit as a function of its outlet temperature in an effort to obtain the same coolant temperature at the exit of each circuit. The intermodular control valve currently used as part of the CSM radiator control could be used directly for this application.

To insure that the coolant leaving the radiator network is above the minimum allowable temperature of 40°F during low load conditions, a regenerative heat exchanger (identical to LEM Item 204) has been added upstream of the radiator. The HTS fluid first enters the regenerative heat exchanger and then flows to the radiator networks. Part of the fluid leaving the radiator network is diverted back to the regenerative heat exchanger by a modulating control valve. The valve senses and controls the mixed temperature of regenerated fluid and bypassed fluid. The component is also identical to LEM Item 203, except that the sensor has a lower temperature setting.

5.2.3.2.2 <u>Recirculation Assembly Performance</u>. An investigation was made to determine methods of increasing the capacity of the LEM Item 290 Coolant Recirculation Assembly in order to meet the following new requirements imposed by the recommended configuration for the Lab ECS Heat Transport Section.

- Integration of the radiator network has imposed the following additional pressure drops:

		(psi)
o	Regenerative Heat Exchanger Hot Side	0.70
o	Intermodular Control Valve	0.80
o	Radiator Control Valve	0.40
o	Radiators	1.00
o	Coolant Temp Control Valve	0.80
o	Regenerative Heat Exchanger Cold Plate	0.31
o	Evaporator Bypass Valve	0.80
	Total	4.81

- The pressure drop has increased on a per item basis by 2 1/2 times due to changing the coolant from the LEM fluid (65% water/35% glycol) to RS 89A (37 1/2% water/62 1/2% glycol).
- The flow and/or pressure drop requirements may increase in the event of extensive per flight experiment cooling requirements.

- The flow requirement must increase in order to maintain the Lab's heat transport capability at the same level as LEM in view of a 15% reduction in specific heat resulting from the use of RS 89A fluid.

The present LEM coolant pump operates at a nominal design point of 3.7 lb/min with a 30 psi pressure rise. Modifications can be made to the existing pump package to allow operation at different weight flows and pressure demands. Figure 5.2-3 defines the penalties associated with operating the pump under various conditions. As noted on the figure, fixed weight includes the entire pump package including three pumps and motors, three relief valves, three check valves, a filter and a pressure sensor. Based on anticipated pump performance requirements 40 watts have been allocated for pump operation indicating the maximum growth point selected in Fig. 5.2-3.

5.2.3.2.3 Equipment Cooling. The coldplate network, shown on Fig. 5.2-2, reflects cooling requirements associated with housekeeping loads only. Coldplates for the thermal control of experiment payloads will be integrated on a per-flight basis as indicated on the schematic. It is recommended that these additional coldplates be incorporated wherever possible into the high temperature portion of the coldplate network downstream of the cabin heat exchanger. This will allow the coolant low temperature requirement to be maintained at its highest allowable level, thus maximizing the heat rejection capability of the radiators. Table 5.2-1 shows housekeeping and basic experiment thermal loads for the recommended Lab. Based on these loads and the heat rejection capability of the system, the recommended configuration has a growth potential of an additional 8000 BTU/hr. However, in view of water usage requirements this cooling capability is for short duration loads only. Figure 5.2-4 shows a maximum instantaneous load heat balance based on the heat loads presented. In order to maintain the cabin at or below the maximum allowable cabin temperature of 80°F, 1195 BTU/hr is rejected by water evaporation in this example. At maximum load conditions the inlet temperature to the water evaporator is 57.9°F. As shown in Fig. 5.2-4 the uncontrolled evaporator heat rejection at this inlet temperature with a normal flow rate of 220 lb/hr is 3200 BTU/hr. This is 2000 BTU/hr higher than the amount required to obtain system balance, consequently excess water usage would result and the overall temperature level would drop. For a maximum growth configuration with experiment payloads having significantly varying duty cycles, the problem is even more significant in that the radiators would have to be larger. For this reason it is recommended that a valve be added to the coolant loop to automatically modulate flow around the water evaporator. The characteristics of the control points selected, as shown in Fig. 5.2-5, indicate that at maximum loads, 60 lb/hr will be directed through the water evaporator and flow will increase with experiment loads.

Figure 5.2-6 shows the proposed temperature setting for the valve sensor. Due to the high temperature of the mixed coolant leaving the water evaporator it is again recommended that all experiment loads be added downstream of the cabin heat exchanger. For maximum growth configurations, the experiment loads shown on Fig. 5.2-2 should also be moved downstream of the cabin heat exchanger. At thermal load conditions at or below the maximum average load of 5133 BTU/hr as tabulated in Paragraph 4.1-3, waste heat rejection will be accomplished by the radiators exclusively, with the water supply valve to the water evaporator being in the "OFF" position.

Figure 5.2-7 shows the minimum load condition with regeneration being required in both regenerative heat exchangers in order to maintain the cabin above acceptable limits. The Heat Transport Section has been sized so that no initial water storage is required, since all water required for evaporative cooling will be obtained as a by-product of fuel cell operation.

5.2.3.3 Water Management Section (WMS)

The functional capabilities of the LEM Water Management Section must be expanded to meet the additional requirements of the Lab which are primarily a result of closed cycle fuel cell integration. Specifically, Lab WMS functional requirements are as follows:

- Delivery of water for PLSS recharge in support of EVA experiments.
- Collection and distribution of metabolic condensate during suited Lab operations associated with EVA experiments.
- Storage of fuel cell product water during peak loads to supplement water requirements during low production periods.
- Provide for overboard venting of water produced in excess of requirements.
- Delivery of water required for the rejection of Lab waste heat.

The CSM is responsible for providing all water required by the crew for drinking, food preparation and personal hygiene and consequently, no such capability will exist in the Lab WMS.

Approximately 1040 lb of water are produced as a by-product of fuel cell operation during the Lab mission. Since 299 lb of water are required to support the EVA capability of 44 excursions that characterizes the recommended Lab configuration, 740 lb of water are available to supplement radiator assemblies in the rejection of waste heat associated with peak loads from both the ECS and EPS heat transport networks. Fuel cell water production is based on the power profiles presented in Paragraph 5.1 exclusive of 20% growth.

A functional schematic of the Lab WMS is shown in Fig. 5.2-8. Water consumption and production exceed each other at various times during the mission, however the total water produced is in excess of total water requirements. An accumulator is therefore required to supplement water production during low production periods. A CSM waste water tank assembly, designed to collect water continuously in the CSM WMS, has ample capacity for this purpose and is incorporated into the recommended configuration. All LEM water tanks, both ascent and descent stage, are deleted. The LEM water control module is retained, but is modified slightly to perform the additional Lab WMS functions. Modifications are facilitated because the basic design of this module allows components to be removed, replaced or rearranged within the circuit.

The modifications to the water control module are as follows:

- A third regulator, used in the LEM module to regulate water pressure for the secondary water evaporator, is not required and has been deleted.
- The water tank selector valve is not used and is replaced in the module by a straight through valve spool at the tank selection ports.

- Another function of the same valve, to route water from the ARS to the selected water evaporator, is deleted. This portion of the valve spool is altered to allow passage of water to the coolant and ARS water evaporators.
- Lines from the FCA's and the water accumulator are joined and enter the module through the descent stage tank inlet port with the check valve removed.
- Ascent stage tank inlet ports are plugged.
- The secondary coolant pressurization isolation valve becomes inoperable with the removal of the tank selector valve and will be capped at the outlet port.
- The secondary water evaporator outlet port is plumbed to the primary water evaporator in order to utilize the manual shutoff valve already in the circuit. The primary evaporator feed port will be capped.

5.2.3.4 Atmosphere Supply and Pressurization Control Section (ASPCS)

The pressure regulating and delivery equipment associated with the LEM ASPCS has been retained on the Lab. Due to the recommended cryogenic storage of ECS oxygen with EPS reactants, the LEM ECS GOX storage capability has been functionally deleted. The LEM descent stage GOX tank and one ascent stage GOX tank are retained however, to perform the following functions:

- The LEM ascent stage GOX tank will function as an oxygen accumulator for airlock repressurization. This is necessitated by the limited gaseous oxygen delivery rates from EPS cryogenic tanks.
- The LEM descent stage GOX tank is retained to store nitrogen to make up losses associated with airlock operation. This tank will store 29.2 lb of gaseous nitrogen at an initial pressure of 1940 psia, which will provide the required 28 lb of usable nitrogen for airlock repressurization.

The following functions are performed by the Lab ASPCS:

- Regulation of oxygen required to support extra vehicular activities (PLSS recharge and airlock operation)
- Regulation of oxygen for suited operation associated with egress and ingress.
- Storage and delivery of nitrogen to support airlock operation.

The recommended configuration is shown schematically in Fig. 5.2-9. To achieve the Lab's basic capability to support 44 EVA experiments, 117 lb of oxygen must be stored in the EPS RSS. Each airlock repressurization requires 1.7 lb of oxygen and it is assumed that a full PLSS recharge (0.91 lb) is required subsequent to each ingress. In addition, 2 lb of oxygen are required to support suited operations associated with egress and ingress.

The functional differences of this equipment from that of the current LEM are the deletion of the oxygen storage capability and tank staging, the addition of nitrogen storage and delivery equipment and provisions for oxygen accumulation. Hardware differences are limited to plumbing changes and the addition of four manual shutoff valves, airlock dump and relief valves and an airlock pressure gauge. In operation, oxygen is delivered from the EPS at 875 to 1000 psia to the oxygen control module where it is filtered and made available for accumulator storage, airlock pressurization, PLSS recharge, and regulation as ARS supply. Oxygen for airlock pressurization is delivered to the airlock through a manual valve on each side of the airlock bulkhead. ECS oxygen requirements are summarized in Table 5.2-2. Nitrogen is delivered directly to the airlock through a modified LEM high pressure oxygen control module and a manual shutoff valve on each side of the airlock bulkhead. Airlock pressurization is a two step procedure. The airlock is first pressurized to 3.5 psia with oxygen, then final pressurization to 5 psia is accomplished with nitrogen. This approach provides a clean functional interface between LEM and CSM atmosphere supply equipment by precluding the simultaneous operation of two sets of cabin pressure maintenance equipments.

5.2.4 Baseline Configuration

The Baseline Lab ECS configuration, developed at mid-study for the purpose of defining program costs and schedules differs somewhat from the configuration described in the previous paragraphs for the following reseaons:

- The baseline ECS configuration did not incroporate provisions for supporting airlock operations.
- The preliminary design of radiator panels and thermal load variation controls has been refined considerably as a result of analysis efforts subsequent to baseline configuration definition.
- The baseline configuration reflected an all oxygen internal environment. Provisions have been made to accommodate the two gas (70% oxygen, 30% nitrogen, 5 psia total pressure) environment since specified.

An airlock has been incroporated in the recommended configuration permitting a considerable expansion of the EVA support capability of the Lab. An airlock suit circuit connector station and provisions for repressurizing the airlock with oxygen and nitrogen subsequent to ingress have been added to the Lab ECS as described in Paragraph 5.2.3.4.

A regenerator bypass and two radiator panel control valves have been added to the radiator circuit to achieve a capability for wide variations in thermal loads. An evaporator bypass has also been incorporated for an even greater capability in this regard. These measures have been taken to provide flexibility in anticipation of a large variation in the thermal control requirements of experimental equipment on a per flight basis. These refinements are shown on Fig. 5.2-2 and described in Paragraph 5.2.3.2.

To provide a capability for making up mixed gas atmosphere losses incurred by airlock operation, nitrogen is stored at ambient temperatures in a descent stage GOX tank as discussed in Paragraph 5.2.3.4. This change has been dictated by the ground-rules itemized in Paragraph 5.2.1.

5.2.5 Separate Experiment Cooling Loops

Integration of all Phase II Laboratory experiment cold plates in the primary HTS coolant loop may not be advisable for the following reasons:

- The servicing of remotely located experiments by the primary HTS would necessitate significant per flight redesigns of this coolant distribution network.

- Restrictions imposed on coolant loop temperature levels by housekeeping requirements would not be imposed on a separate experiment loop(s)
- Variations in housekeeping thermal loads would not affect the cooling available for experiments on a separate loop(s).

It may therefore be desirable to service a portion of the experiment cold plates or the entire experiment cooling load with a separate coolant loop(s). The experiment cooling loop(s) would utilize only components currently being developed for the basic LEM. Depending on the magnitude of the experiment cooling load and associated temperature requirements, these components can be used in several configurations to obtain an optimized configuration for the particular experiment cooling application.

The following components are available for separate coolant loop(s):

- Glycol accumulator (only one LEM version available)
- Primary and/or secondary water evaporator (cooling capacities of these evaporators are shown in Fig. 5.2-10 and 5.2-11, respectively.)
- Basic LEM coolant recirculation assembly or a high-capacity coolant recirculation assembly (Fig. 5.2-3).

The following additional components are not essential to the experiment coolant loop operation, but may be utilized as required:

- One or more 15 sq ft radiator panels
- Automatic glycol pump control
- Radiator bypass control valves (modified cabin temperature control valves)

Water for the experiment cooling loop will be supplied by the Phase II Laboratory WMS. If the capacity of the Lab WMS is exceeded by the experiment cooling loop requirements, a separate WMS can be provided using existing LEM tankage and components.

5.2.6 Alternate Configuration - Deletion of LEM Suit Circuit Assembly

As discussed in Paragraph 5.2.3.1, the LEM Suit Circuit Assembly is retained in Phase II Labs specifically to support egress/ingress procedures and in general to provide suit circuit stations in the Lab cabin to support any suited operations that may be required during a mission. If airlock and cabin suit circuit connector stations can be provided by running lines from the CSM suit circuit assembly to the Lab it would be possible to delete the LEM suit circuit assembly.

Approximately 46 lb and 10 to 12 cu ft weight and pressurized volume savings respectively could be realized at the expense of maintaining both a clean interface between the Lab and CSM and operational simplicity. Since the CSM suit circuit is currently designed to operate with a suit umbilical hose assembly of sufficient length to support crew transfer in the present LEM mission it appears that no additional demands would be imposed on CSM suit circuit compressors. Operational disadvantages exist in that a single suit circuit would be required to support both the Lab-CSM cabins and a crew member making a transition from the 5 psia nitrogen-oxygen cabin to the 3.7 psia 100 percent oxygen Apollo Space Suit Assembly (ASSA).

Retention of the LEM suit circuit would permit the purging of the ASSA with oxygen prior to egress (thus lowering nitrogen partial pressure) to the point where oxygen partial pressure will be above minimum allowable levels when suit pressure is decreased to 3.7 psia without interrupting cabin support.

5.2.7 Alternate Configuration - Elimination of Airlock

A significant weight saving (approximately 100 lb) is realized by incroporating an airlock in the Phase II Lab based on the design capability to support 44 EVA's. The alternate to an airlock is the decompression of the entire Lab cabin during egress. The two approaches are compared on a weight basis in Fig. 5.2-12. Two airlocks, corresponding to the alternate airlock configurations described in Section 6.0 are presented. The cabin dump curve indicates tankage penalties in increments since existing LEM tanks are added as required to extend the cabin repressurization capability. Initially, one nitrogen storage tank (identical to the current LEM descent stage GOX tank) is required. After 22 repressurizations this tank is depleted and a second must be added. No tankage is added for oxygen until the 38th repressurization at which time the EPS reactant oxygen cryogenic tank's capability to support the ECS is exceeded. A LEM descent stage GOX tank is thereby added to contain oxygen at this point.

Table 5.2-1

PHASE II LAB ECS THERMAL LOADS, Btu/hr
2 MEN IN CABIN

Std Config Exper's	Cabin Ht Exch		Max Min	700 175
	Cold Plates	Low Temp	Max Min	515 515
		High Temp	Max Min	2125 0
House-keeping	Cabin Ht Exch	Sensible Metabolic	Max Min	772 594
		Electrical	Max Min	1027 485
		Windows & Structure	Max Min	0 -850
	Cold Plates	Low-Temp Electronics	Max Min	304 87
		High-Temp Electronics	Max Min	766 495
	Coolant Pump		Max Min	136 136

Table 5.2-2

PHASE II LAB ECS OXYGEN REQUIREMENTS

Use	Basis	Quantity
Airlock Repressurization	1.7 lb/repress x 44 repress	74.8
PLSS Recharge	0.91 lb/charge x 44 charges	40.0
Metabolic Consumption (EVA Time)	2.0 lb/man-day x 1 man-day	2.0
Total ECS O_2 Requirement		116.8

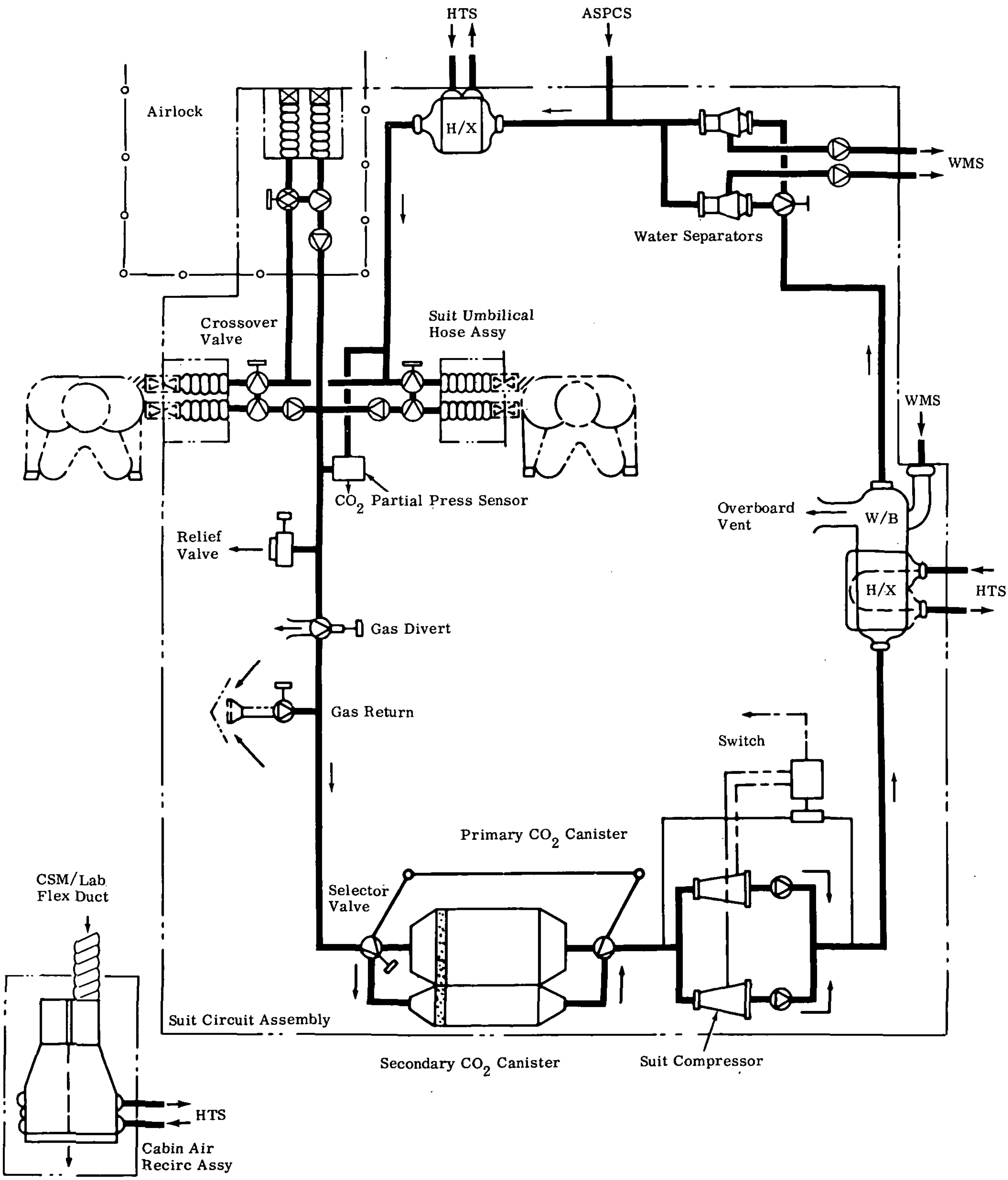
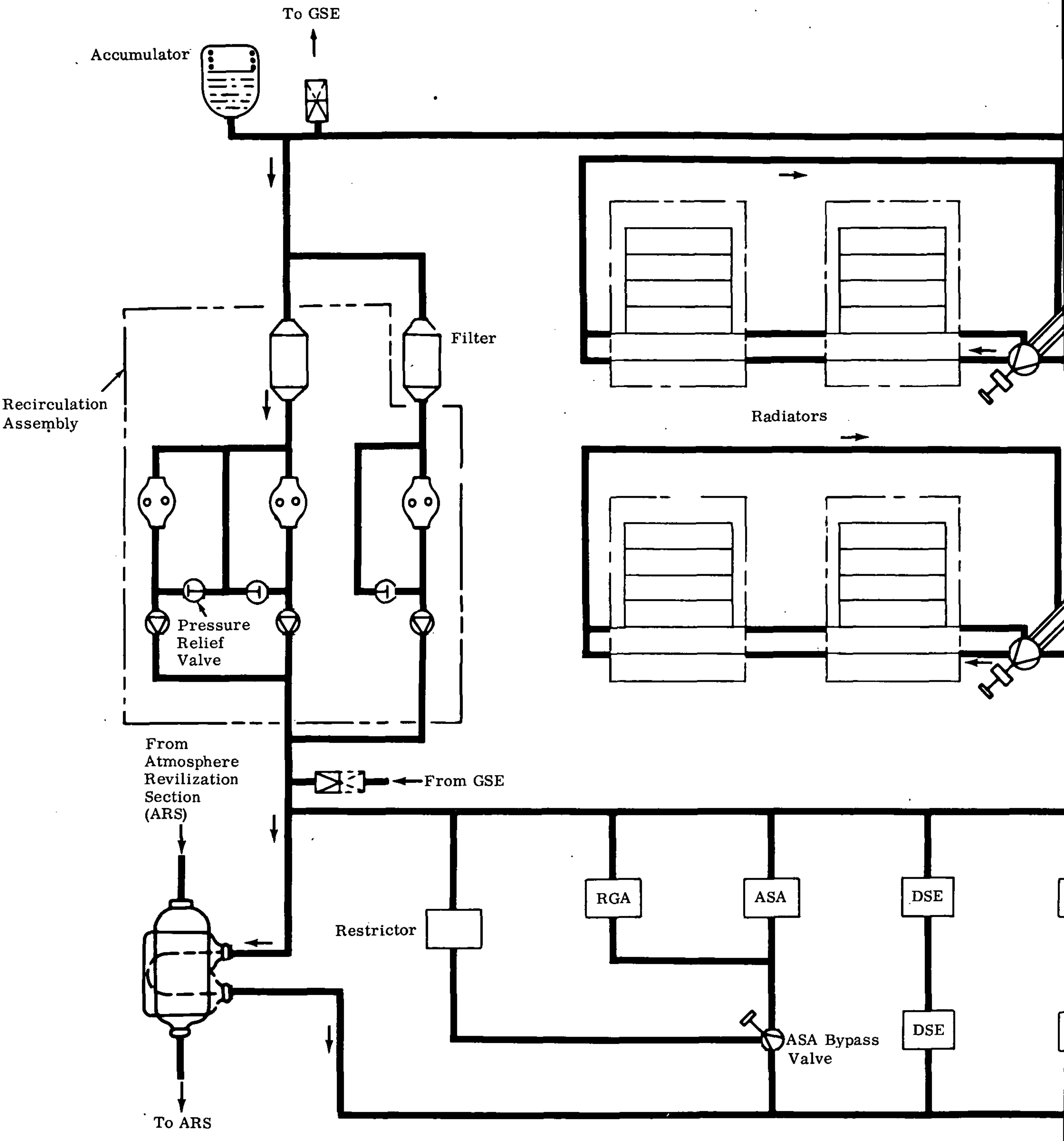
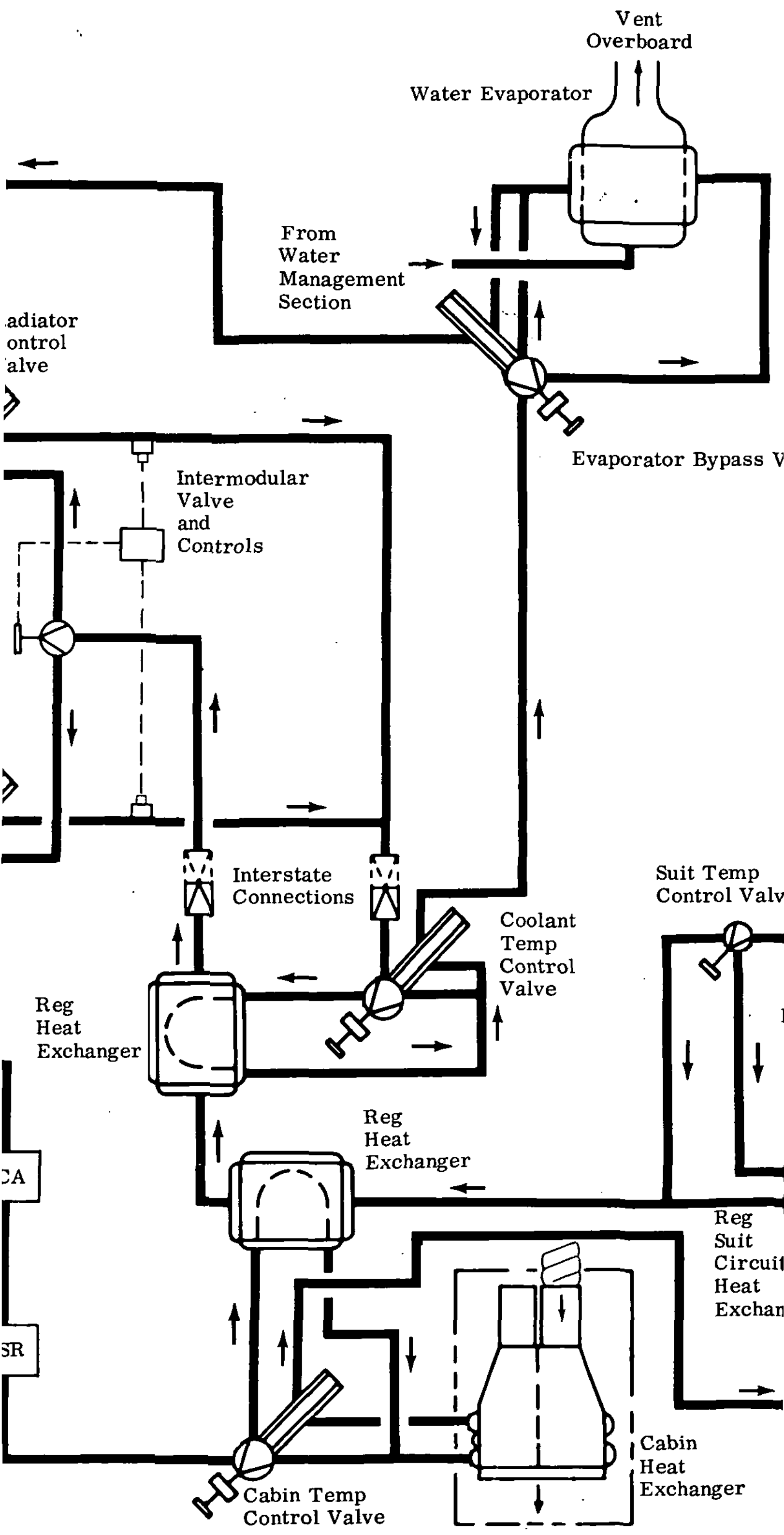


Fig. 5.2-1 Atmosphere Revitalization Section Schematic

(71)



To GSE
Accumulator
Filter
Recirculation Assembly
Radiators
Pressure Relief Valve
From Atmosphere Revilization Section (ARS)
From GSE
Restrictor
RGA
ASA
DSE
DSE
ASA Bypass Valve
To ARS


Vent
Overboard
Water Evaporator
From
Water
Management
Section
adiator
ontrol
alve
Evaporator Bypass V
Intermodular
Valve
and
Controls
Interstate
Connections
Suit Temp
Control Valv
Coolant
Temp
Control
Valve
Reg
Heat
Exchanger
Reg
Heat
Exchanger
CA
Reg
Suit
Circuit
Heat
Exchan
SR
Cabin
Heat
Exchanger
Cabin Temp
Control Valve

2

Abbreviations Used on Heat Transport Diagram

SP	Signal Processor
S-BX	S-Band Transponder
S-BP	S-Band Power Amplifier
VHF	Very High Frequency Communications
AEA	Abort Electronics Assy
INV	Inverter
ATCA	Attitude & Translation Control Assy
CWE	Caution & Warning Assy
SCEA	Signal Conditioning Electronic Assy
PCMTE	Pulse Code Modulation & Timing Equipt
PQGS	Propellant Quantity Gaging System
LCA	Lighting Control Assy
DSE	Data Storage Equipment
RGA	Rate Gyro Assy
ASA	Abort Sensor Assy
VSR	Voice Storage Recorder
P Bat	Peaking Battery
ECA	Electronic Control Assy
(hatched)	Available for Experiments

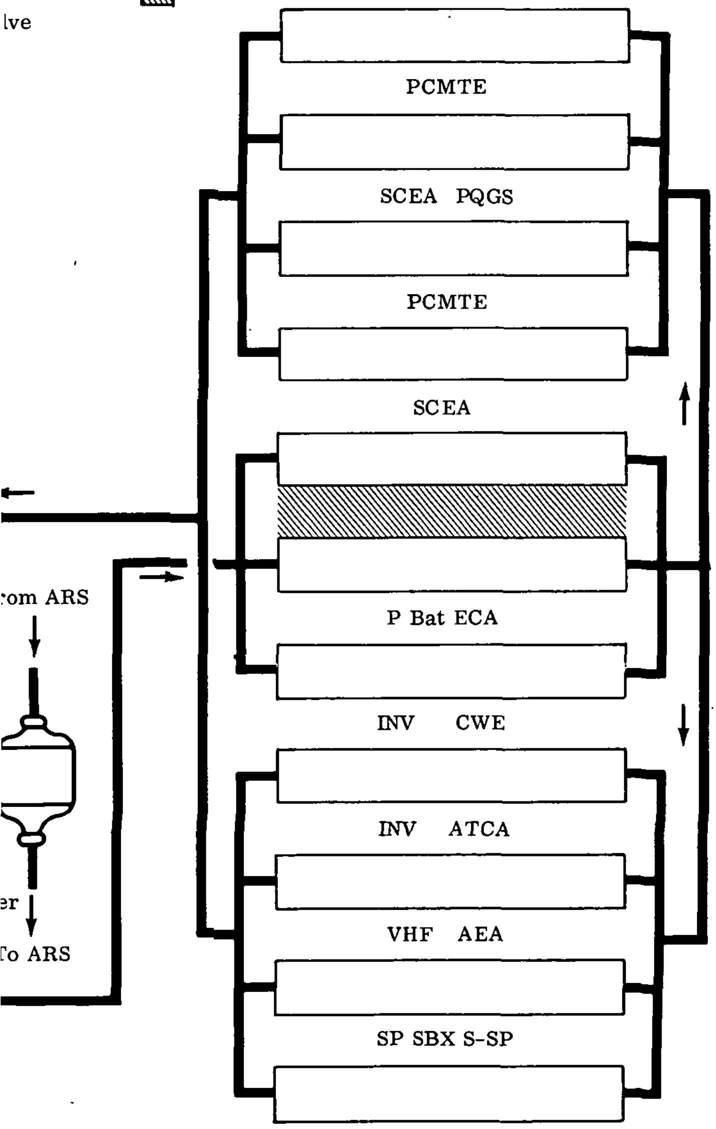


Fig. 5.2-2 Heat Transport Section Schematic

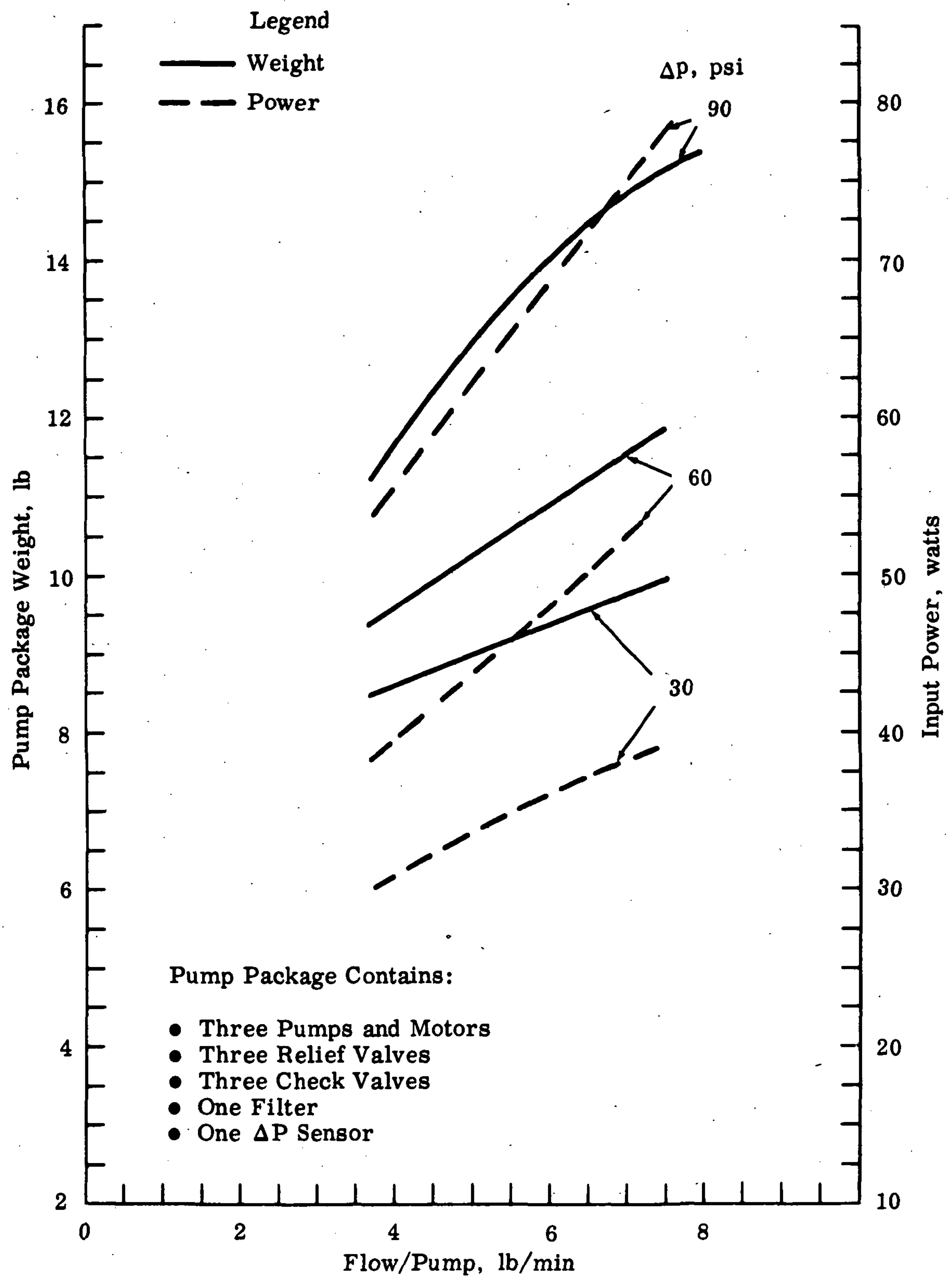


Fig. 5.2-3 Pump Package Growth

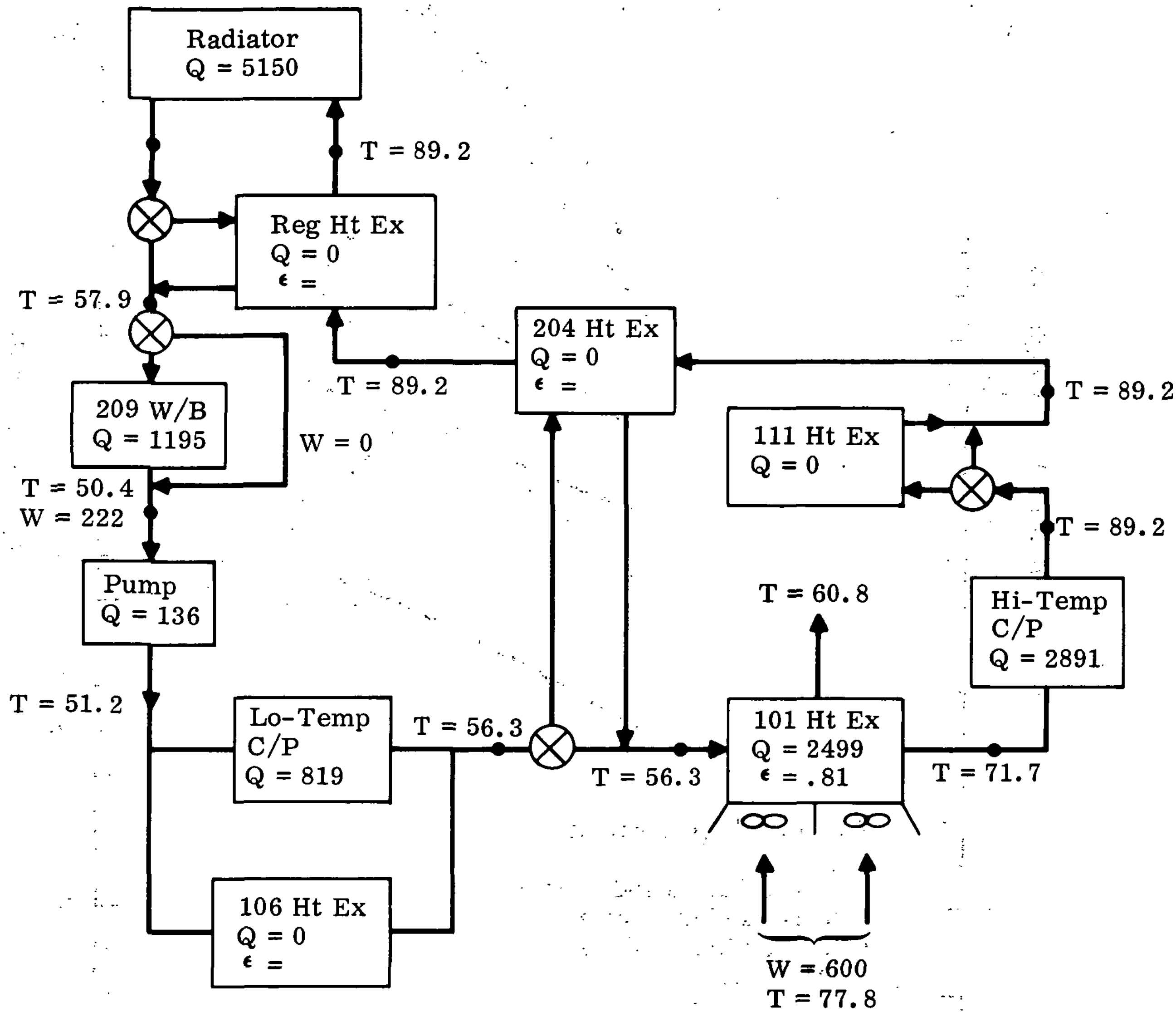


Fig. 5.2-4 Heat Transport Section Performance Maximum Loads - 2 Men in Cabin

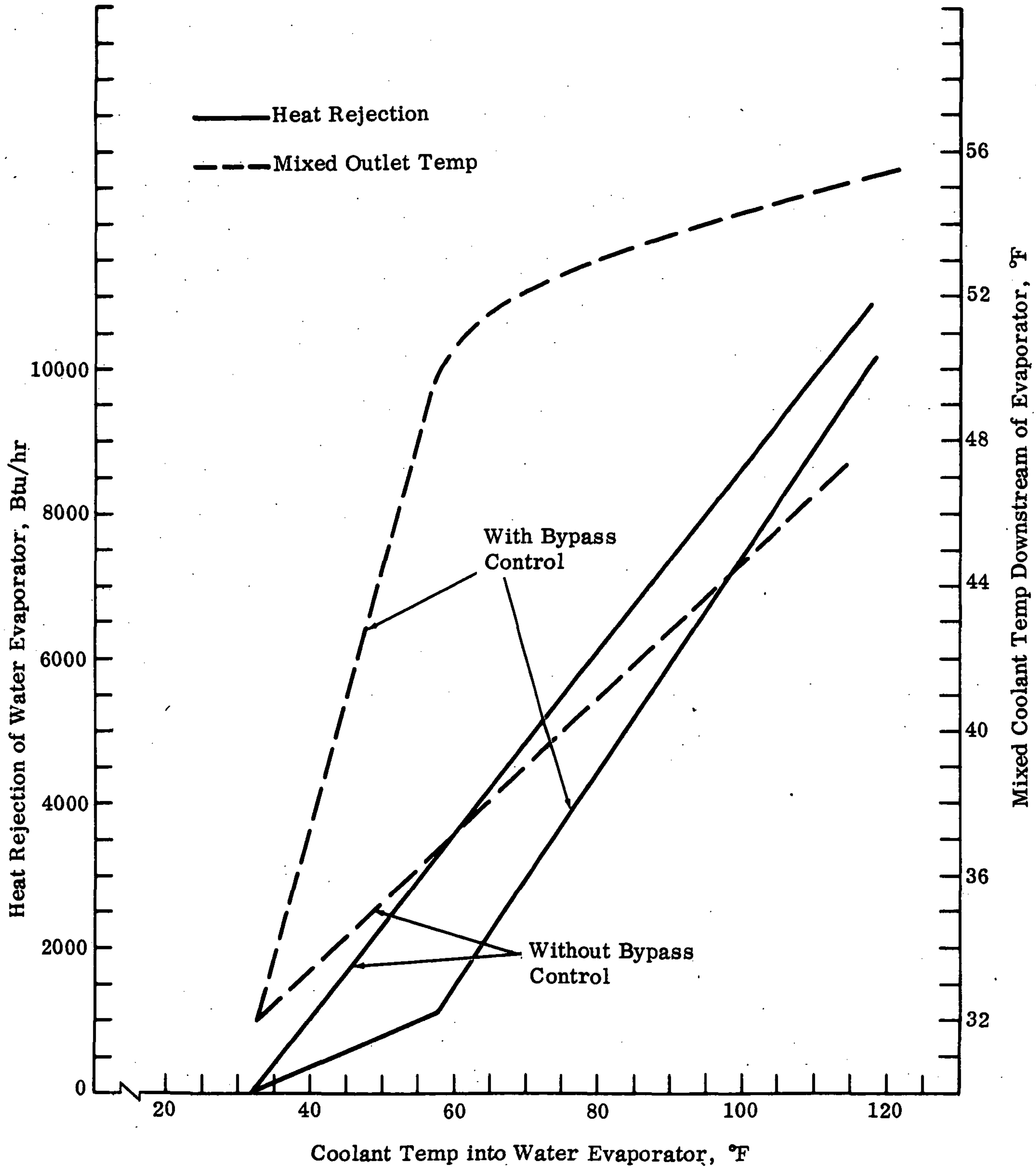


Fig. 5.2-5 Evaporator Control Performance

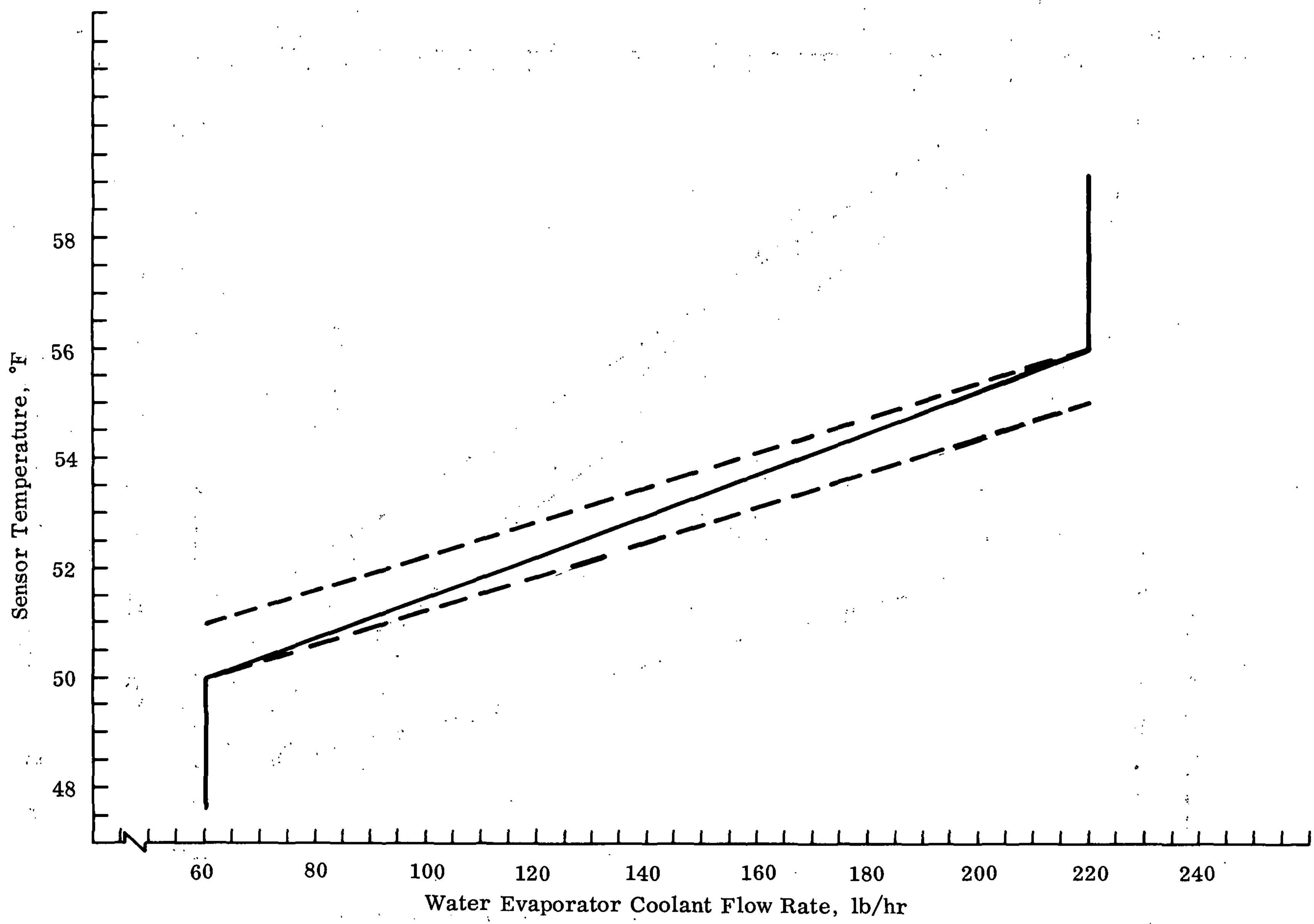


Fig. 5.2-6 Evaporator Control Valve Sensor Characteristics

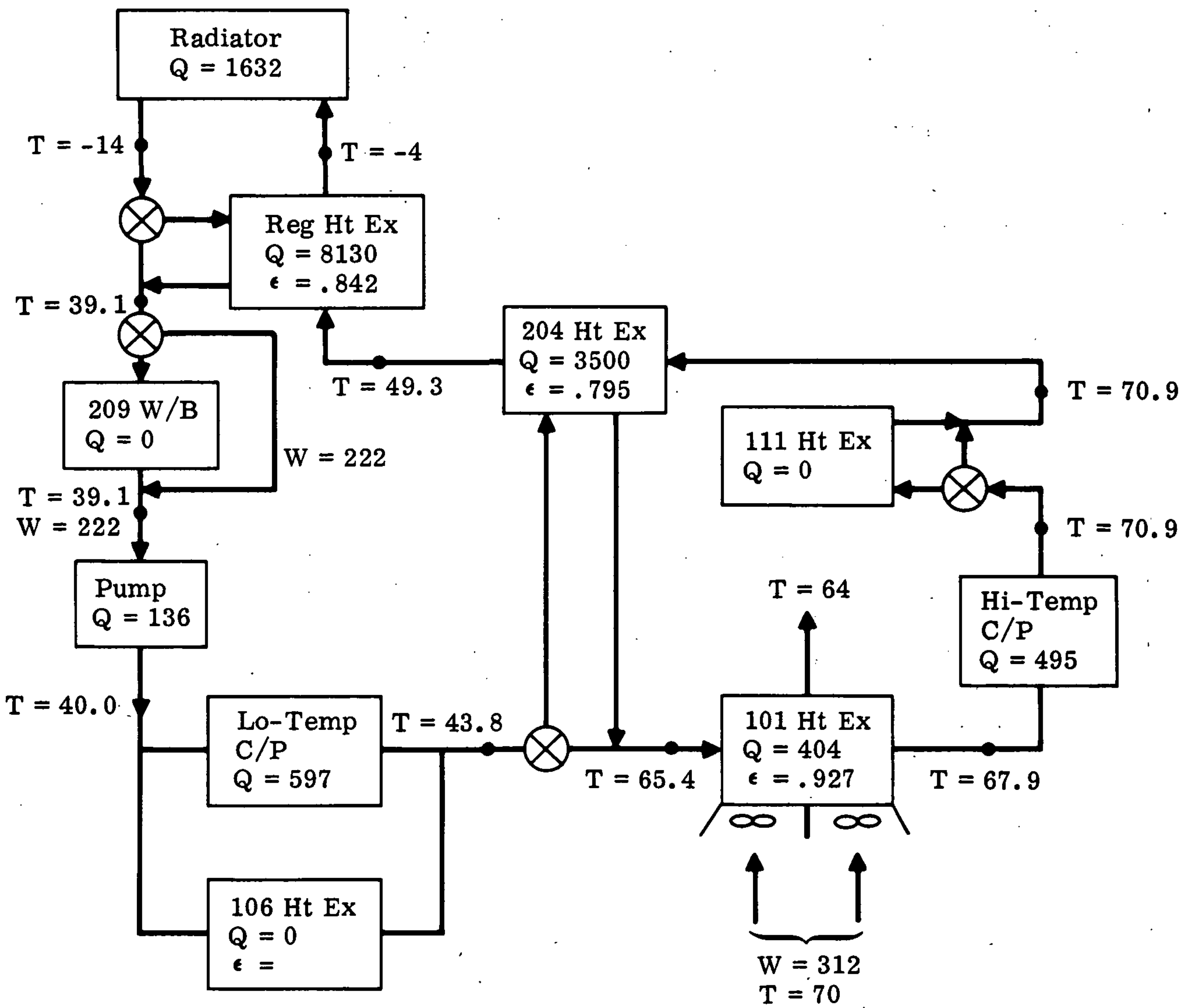


Fig. 5.2-7 Heat Transport Section Performance Minimum Loads - 2 Men in Lab

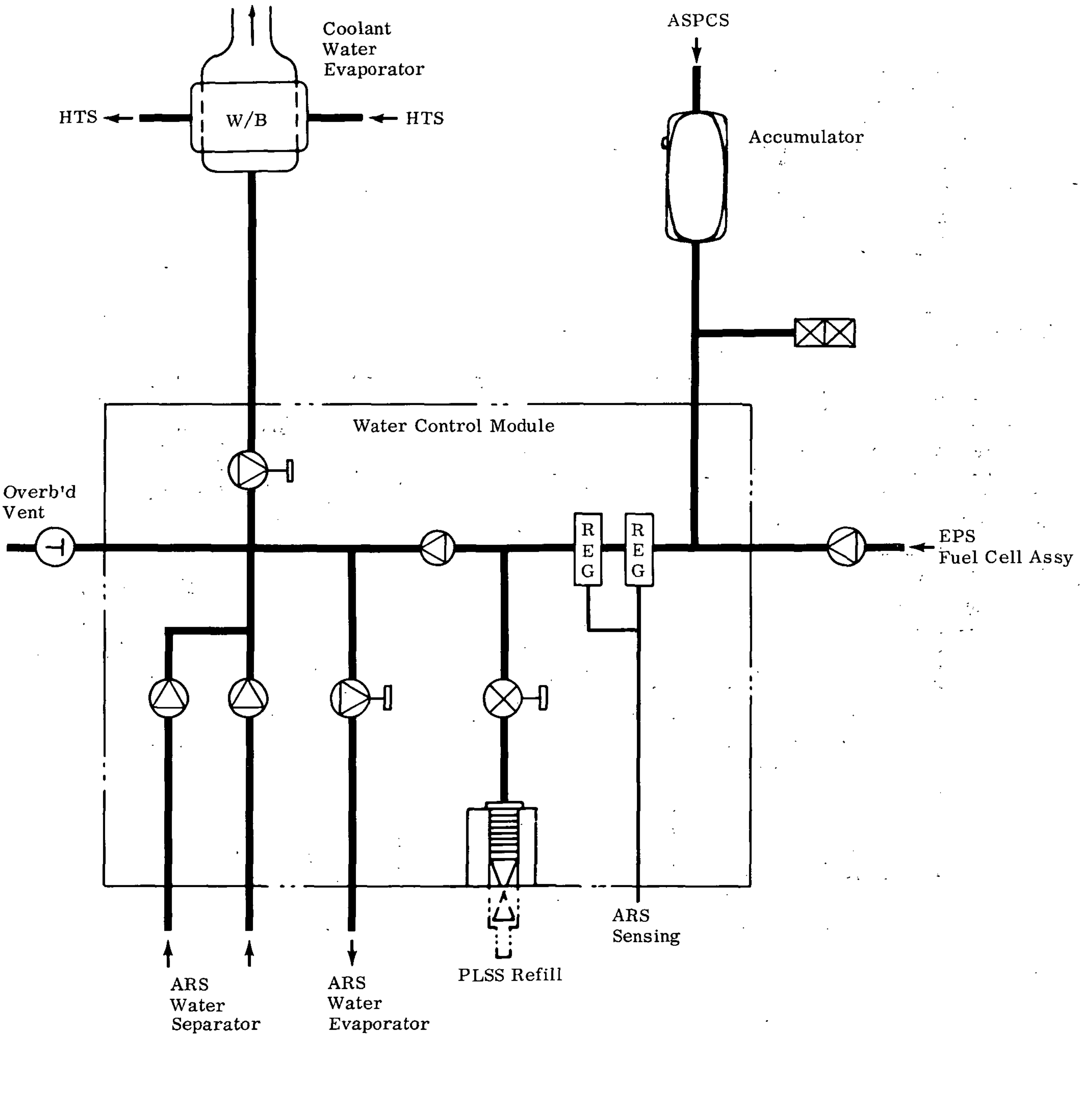


Fig. 5.2-8 Water Management Section Schematic

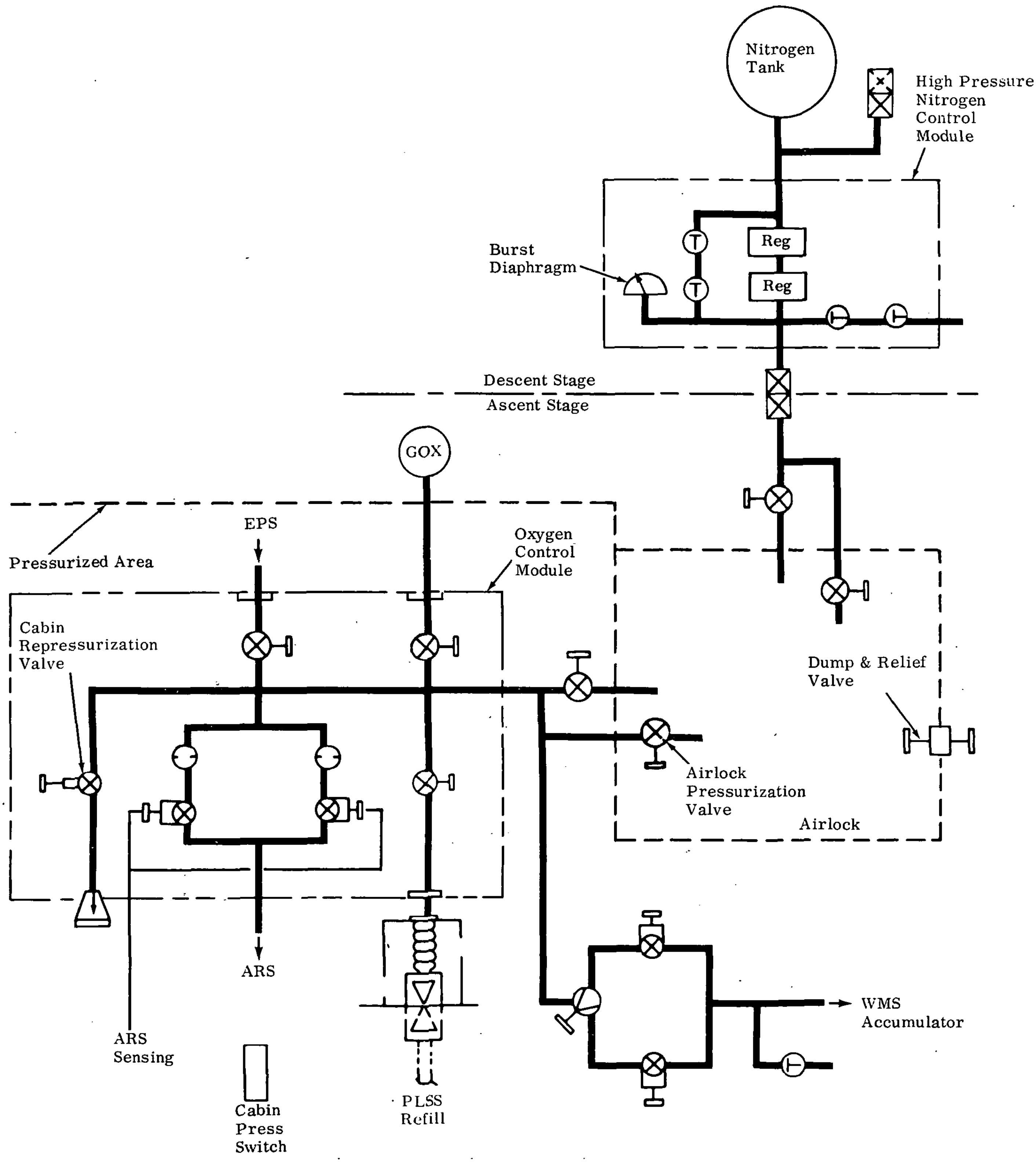


Fig. 5.2-9 Atmosphere Supply and Pressurization Control Section

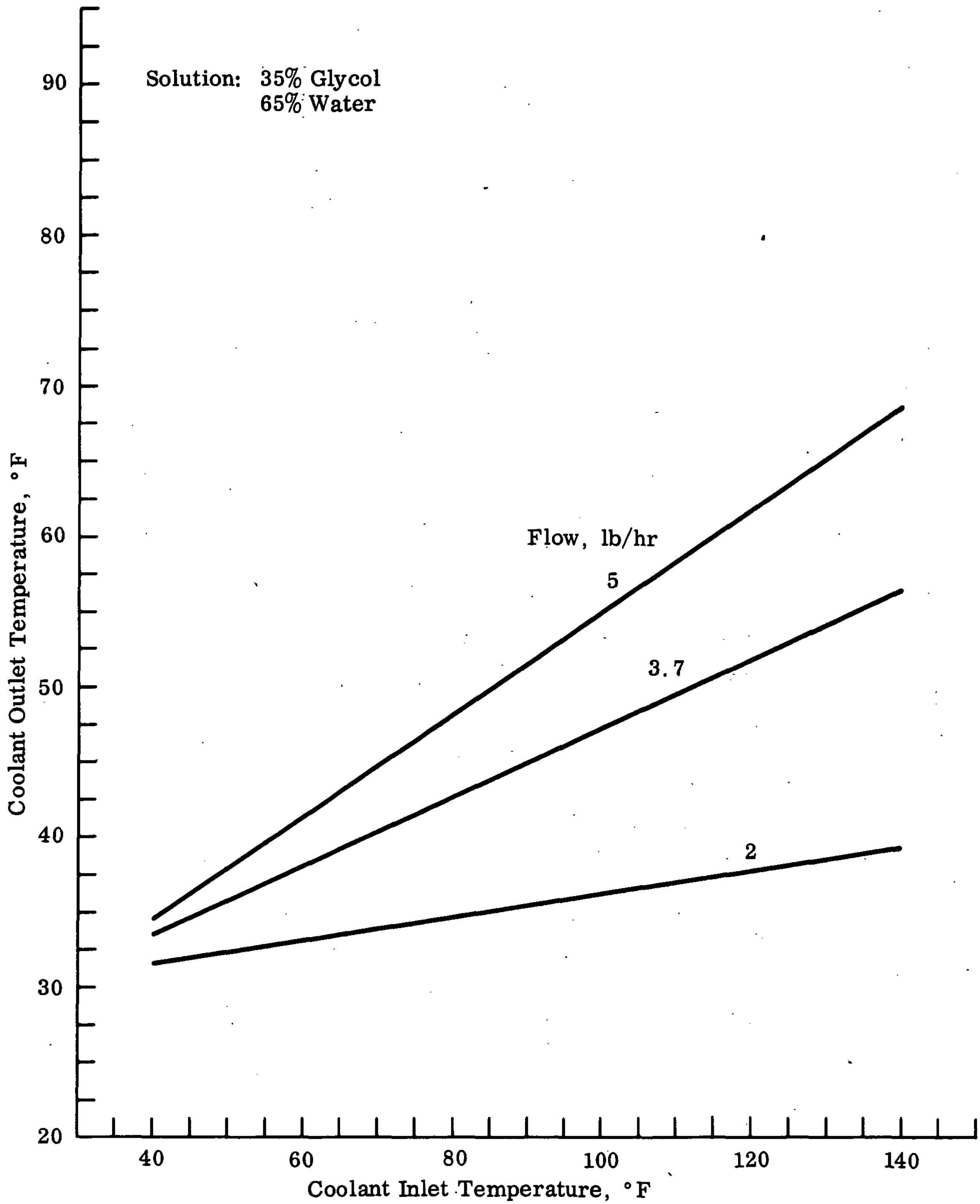


Fig. 5.2-10 Estimated Evaporator Performance LEM Item 209

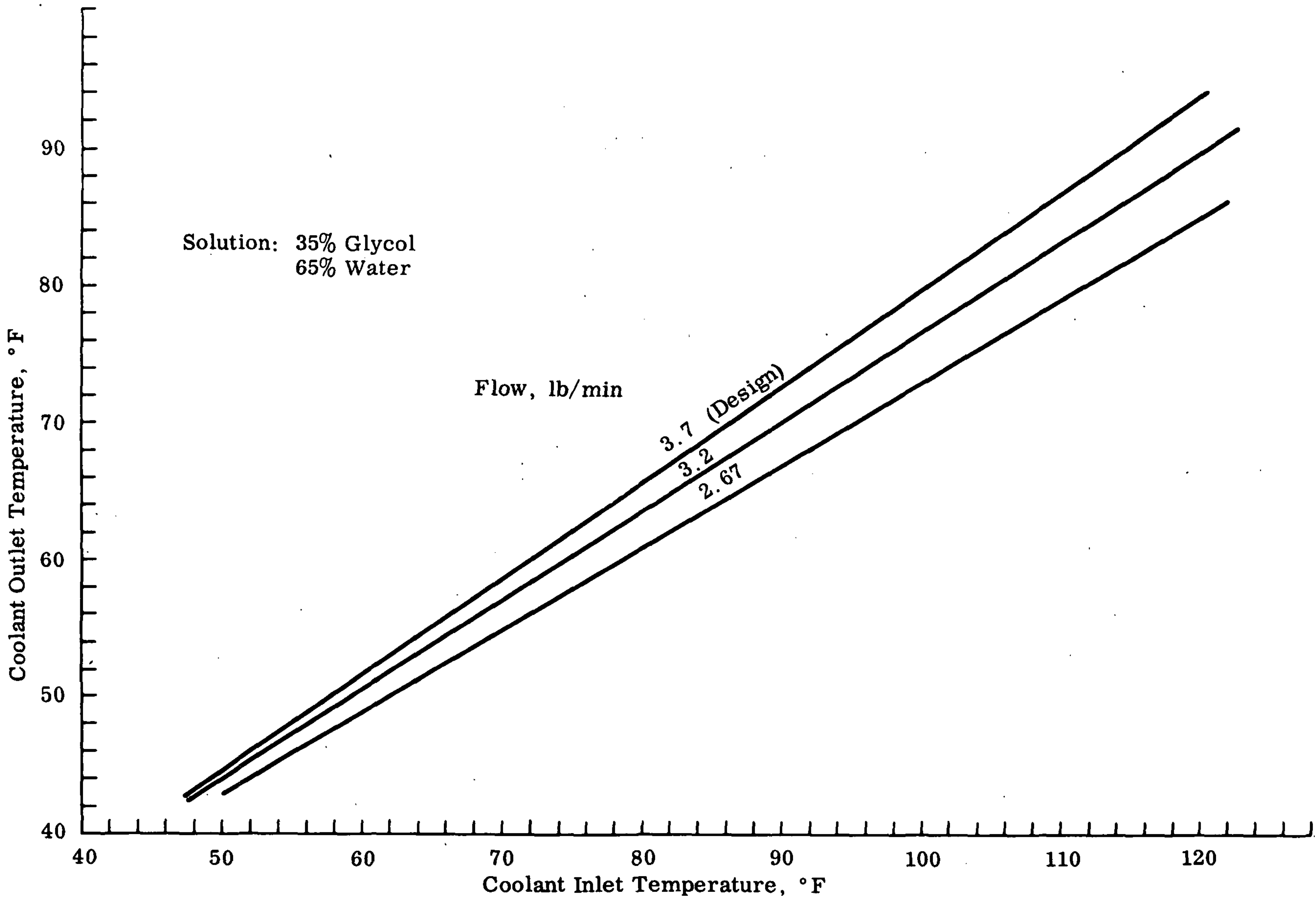


Fig. 5.2-11 Estimated Evaporator Performance LEM Item 224

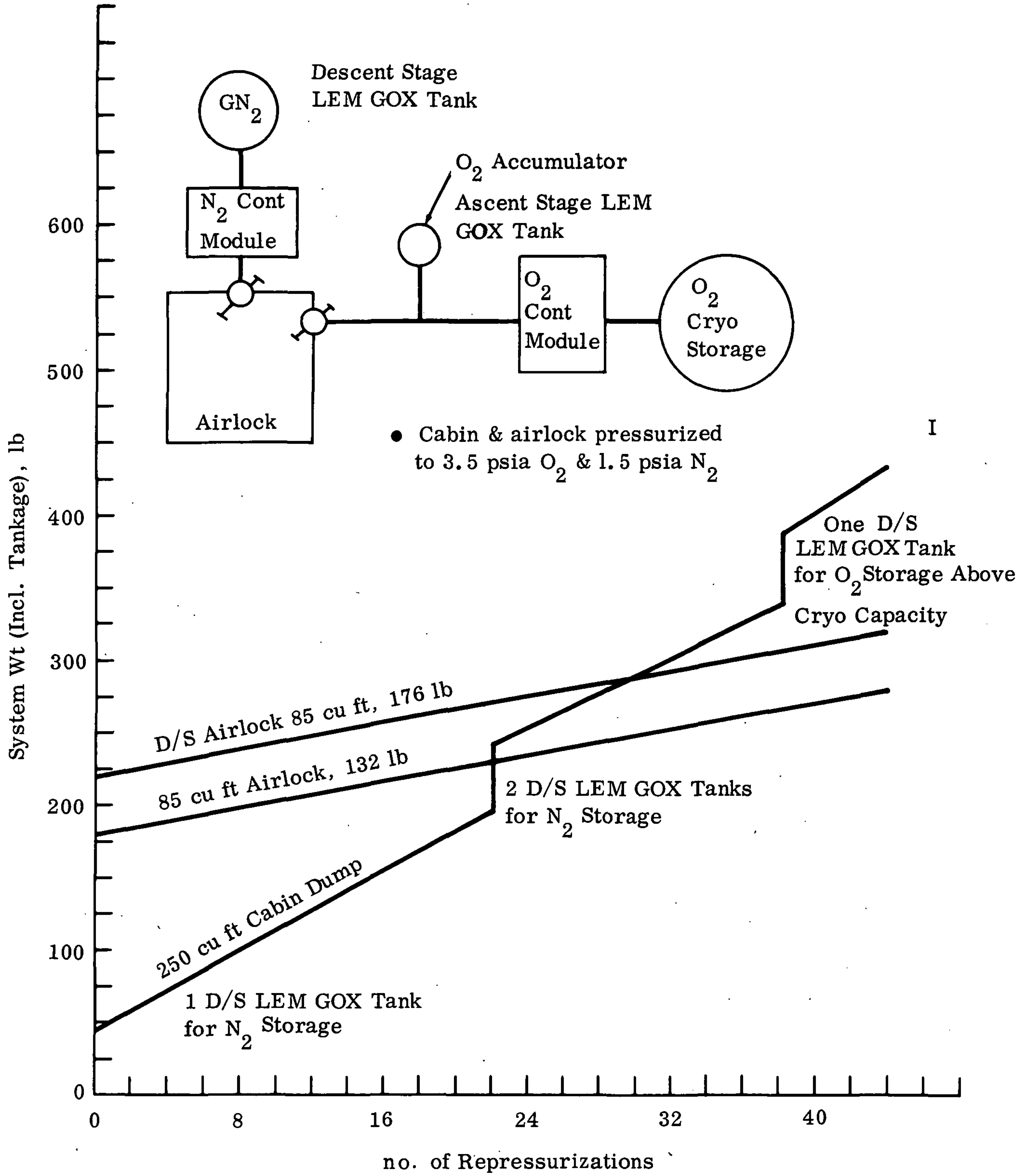


Fig. 5.2-12 Airlock Tradeoff

5.3 GUIDANCE NAVIGATION AND CONTROL (GN&C)

5.3.1 Ground Rules

- All translation and orbital maneuvering capability will be supplied by the CSM.
- The Lab will provide the orbital attitude hold capability within the limits of the recommended configuration. Capability beyond these limits will be supplied by the experiment package.
- There is no electrical interface for control between the Lab and the CSM.
- All missions have RCS in the Lab.
- There is no main propulsion system in the Lab.

5.3.2 Assumptions and Background Data

- The Lab must include a capability to provide an inertial reference.
- The addition of external sensors such as horizon scanners are experiment dependent and, as such, are not included in the vehicle design.

The list of missions from the Phase A study and the "Blue Book" were used as a basis for determining the recommended configuration. The missions can be divided into four categories for purposes of a GN&C evaluation. The first category, being composed largely of medical and biological experiments does not require a control system. The second category requires only rate stabilization. This requirement can be satisfied by the PGNCS or the AGS as configured in the present LEM. The third category requires coarse attitude hold. Again, this requirement can be satisfied by the AGS or PGNCS.

The fourth category of mission requires very accurate attitude hold. The order of magnitude of accuracy required would require a complete redesign of the LEM GN&C subsystem.

The recommended GN&C configuration will provide control for the first, second and third mission categories. Capability to provide control for the fourth category must be a function of the experiment package.

Some of the experiments require earth pointing capability. Two methods of providing this were evaluated. The first uses a horizon scanner or similar type sensor. The second method is to insert a rate bias command from the computer into the control system to provide approximate earth pointing. This bias signal can be updated to provide the required accuracy; however, update frequency may be a problem. The first method requires hardware and the second method requires software changes. This capability must be provided as part of the experiment or on a per-flight basis.

5.3.3 Recommended Configuration

The recommended GN&C subsystem is as shown in Fig. 5.3-1. The configuration is that of a modified AGS with changes to the Rate Gyro Assembly (RGA) and the Attitude and Translation Control Assembly (ATCA). The AGS is recommended on the basis of power and weight parameters. A comparison of the AGS with the PGNCS will be found in Paragraph 5.3.7. At the present time there is no basis for comparison of the reliability of the two systems since the reliability estimates for each system are derived from different bases. A more complete discussion of reliability analysis of these two systems is given in Paragraph 4.5.

The recommended change in the RGA is a shift in the dynamic range of the rate gyros to provide a 0.001 deg/sec. threshold sensitivity. This is a change of 10:1 from the present system and requires a corresponding change in the maximum rate capability from 25 deg/sec to 2.5 deg/sec. Since the Lab is only required to provide attitude hold capability, this maximum rate change is acceptable. A change in the restoring spring constant will provide the necessary range shift while improved selection of wheel bearings will tighten tolerances, if necessary.

The change to the ATCA provides a one-pulse limit cycle for the RCS jets when no disturbance torques are present. This, in conjunction with the increased threshold sensitivity, provides a minimum impulse response to a small rate change, which results in less fuel used and decreased firing cycles for the RCS jets. The proposed modification is a change in the ATCA rate gain from a range of 1 to 4 to a desired range of 1 to 10. The implementation of this change will be determined by Grumman in conjunction with the equipment manufacturer.

The modifications to the Abort Electronics Assembly (AEA) and the Data Entry and Display Assembly (DEDA) are required to permit the use of the Alignment Optical Telescope (AOT) with the AGS as a means of providing initialization and update information for attitude reference in the Lab.

The modification to the AEA consists of adding a star catalog and processing routines to the program complement. A catalog of approximately 45 stars using triple precision coordinates and the necessary processing routines would require an estimated 400 memory locations. The deletion of the Rendezvous Radar and any rendezvous maneuvers releases an estimated 200 memory locations for this catalog. The remaining 200 locations required are provided by a reduction in the memory requirements for alignment, calibration, and explicit guidance of approximately 800 locations.

The modification of the DEDA is the implementation of the AOT discrete signals, Mark X, Mark Y, Mark Bar, and Reject Mark, in the DEDA. The azimuth detent positions and the elevation reading of the AOT will be entered into the AEA through the DEDA.

The system performance will be the same as that specified for the Apollo LEM system with the exception of those changes specified above. This performance is summarized as follows:

	Limit Cycle Operation	Rate Stabilization
Wide	5 deg Deadband	3-1/2 deg/sec Rate Limit
Narrow	0.3 deg Deadband	0.2 deg/sec Rate Limit

AGS Drift Rate 1.1 deg/hr

5.3.4 Baseline Configuration

The differences between the baseline and the configuration recommended in Paragraph 5.3.3 are that in the baseline configuration the ATCA and RGA are both identical to those in the LEM.

This system was not recommended because of the high propellant consumption rates for attitude hold (Paragraphs 4.3 and 5.4).

5.3.5 Alternate Configuration - Deriving Rate Information From ASA

An alternate configuration consists of replacing the RGA by deriving rate information in the AEA from the Abort Sensor Assembly (ASA). As presently configured, (Fig. 5.3-2) each of the three gyros in the ASA generates a gated pulse train which is sent to an input register in the AEA. The AEA provides for the continuous accumulation of these pulses and their processing every 20 msec. Program control provides a true positive or negative angular increment. The accumulated pulses are processed in the AEA to update a coordinate transformation matrix. These rotations, together with initial conditions, are combined with orientation commands and processed through the inverse transformation matrix to yield body axis components of attitude error. Therefore, data are available within the AGS which will allow the computation of the components of angular velocity. By using the gyro pulse outputs accumulated within the AEA input section and suitably processing it, angular rate data can be provided in an explicit form and the rate information from each gyro is independent of that of the other gyros. This prevents loss of all rate information in the event of a malfunction of one of the gyros.

There are two methods of providing angular velocity components from the gyro pulses. The first processes the data through the computer memory logic and the second processes the data through circuitry that is independent of this logic. This second method provides the capability of deriving rate data during times when the computer is not activated. However, the first method requires the least change to the present AEA and is therefore the approach considered.

The rate data derived by the computer can be used in one of two ways. One method (System I) is to multiply the rate data by the rate feedback gain and combine it with the attitude error signals within the computer to form the total error. The total error can then be converted to the proper analog signal. For the Rate Command Mode, the hand controller signals are introduced directly into the AEA (Fig. 5.3-3). Within the ATCA, the logic and pulse modulation circuits would be the same as the present design. For the second method (System II), the derived rate data and the attitude error data are separately converted to proper analog signals and combined in the ATCA (Fig. 5.3-4). The remainder of the system is the same as the present design; the rate gain change as a function of dead band will be handled in the ATCA.

Hardware Requirements: Systems I and II require additional A/D or D/A converters and interface changes as shown in Fig. 5.3-4.

Software Requirements: The software requirements are based on the assumption that the gains, limits and deadband requirements are the same for all channels. In System I, additional mode switch requirement is included to provide deadband min-max selection (Fig. 5.3-3). The running time of the program is not significantly increased (due to deadband selection) but there will be an increase in memory locations required. The mechanization of System I is based on the equations shown below for one channel. System II requires the same basic computation and timing.

$$\beta_{in} = K_D \epsilon_{in}, \qquad \left| K_D \epsilon_{in} \right| < \left| \beta_{iL} \right|$$

$$\text{if } K_D \epsilon_{in} \geq \beta_{iL}, \qquad \beta_{in} = +\beta_{iL}$$

$$\text{if } K_D \epsilon_{in} \leq \beta_{iL}, \qquad \beta_{in} = -\beta_{iL}$$

$$\overset{o}{\theta}_n = \frac{K_R}{\tau} \left(\sum_{\tau} \Delta a_i \right)$$

where τ is the computation interval in the $\overset{o}{\theta}_n$ loop $\epsilon_{in} = \beta_{in} - \overset{o}{\theta}_n$.

The programming flow chart is shown in Fig. 5.3-5. Approximately 1 msec. is required for the added programming running time for both Systems I and II. System I requires 60-75 memory locations and System II requires 40-50 memory locations.

Table 5.3-1 indicates that there is memory core area available for this additional program.

The Lab as presently configured requires a threshold sensitivity of 0.001 deg/sec angular rate. The AGS subsystem as configured for LEM has a 25 deg/sec maximum vehicle rate capability. The gyro electronics package has a 32,000 pps data pulse rate.

$$\text{Value of one pulse from ASA} = \frac{25 \text{ deg/sec}}{32{,}000 \text{ pps}} = 0.00087 \text{ deg/pulse}$$

$$\frac{\text{Value of one pulse}}{\text{Minimum angular rate}} = \frac{0.87 \times 10^{-3} \text{ deg/pulse}}{1 \times 10^{-3} \text{ deg/sec}} = 0.870 \text{ sec/pulse}$$

This means that under present LEM configuration a pulse from the ASA will reach the AEA computer every 870 msec. Computations in the AEA's digital loop will add 40 msec for a total of 910 msec between pulses to the RCS engines.

The studies set forth here lead to the following conclusions: The AEA computer has enough memory capacity, as the program is described above, to fulfill the software requirements of an internally derived rate program. The existing LEM AEA using ASA gyro information can provide a pulse to the RCS jets at the rate of 890 to 910 msec per pulse, while attempting to hold a 0.001 deg/sec angular vehicle rate. The computation time of the AEA is sufficient for the above derived vehicle angular rate program. The independent variable for increasing response time of the rate loop is the scaling of the ASA gyros. Further studies by GN&C Analysis and Integration, incorporating computer simulation, are needed in order to define the Lab guidance requirements. These studies will take into account the increased sensitivity requirements, rate filter, loop stability, moment unbalance, increased inertia, and RCS propellant conservation.

5.3.6 Alternate Configuration - New RGA

An alternate configuration would be the baseline configuration with a new RGA, using rate integrating gyros to provide an improved threshold sensitivity. This approach uses torquing amplifiers to null the gyros. Since the precession rate of the gyro is proportional to the torque applied, the torquing current would provide a direct measurement of the input rate. The threshold of this system would be a function of the sensitivity of the torquer amplifier, its current measuring device, and the gyro drift rate. Assuming good electronics, most of the gyros considered (Table 5.3-2) have at least a factor of 10 better threshold sensitivity than the present gyro without sacrificing maximum rate input. However, all of these gyros are larger than the rate gyros now used in the LEM RGA. This approach would require a redesign of the RGA in addition to including an electronics package.

5.3.7 Alternate Configuration - Use of Primary Navigation Guidance and Control Section

Another alternate would be the use of the PGNCS instead of the AGS. This system was not recommended for the following reasons:

- Power requirements for the PGNCS are more than twice that required for the AGS (Table 5.3-3)
- Weight of the PGNCS is approximately three times that of the AGS (Table 5.3-3)
- The PGNCS has the possibility of a gimbal lock occurring in the IMU when the middle and outer gimbal axes coincide or come within 20 deg of each other during a vehicle attitude maneuver. The gimbal lock warning light goes on when the angle between the middle and outer gimbals is greater than ±55 deg. Using the AGS there are no singularities in the equations used to derive the attitude error signals and there is no possibility of a gimbal lock.
- The PGNCS requires the use of a Gimbal Angle Sequence Transformation Assembly (GASTA) to provide a rotation of the angular coordinate system used by the IMU to that used by the FDAI. This transformation is not required for the AGS.

5.3.8 Alternate Configuration - Control Moment Gyros

There are two basic reasons for considering Control Moment Gyros (CMG):

- Excessive RCS fuel consumption due to flight length and disturbance torques.
- Very accurate vehicle pointing requirements.

Preliminary performance requirements indicate each CMG would need an angular momentum of approximately 7×10^9 gm-cm-sec. For this value, preliminary sizing was established at 2.7 ft diameter, 80 lb, and 24 watts for each CMG. For three axis space craft control, six units would be required, therefore the total weight would be 480 lb and the total power would be 144 watts. The totals do not include the dc to ac power supply, mounting hardware or ECS requirements.

The state of the art indicates feasibility in implementing the CMG, but detailed analysis is required to establish mechanical installation, wheel unloading and performance requirements. A detailed mechanization will depend on MSC direction to complete the studies outlined above.

5.3.9 Potential Per Flight Modification

For improved system performance, a reduced limit cycle deadband is desirable. The present deadband is 0.3 deg and a desired deadband is 0.1 deg. Inasmuch as the LEM system had a 0.1 deg deadband at one time, this should not be a problem. A brief look at the total null error voltages confirms the feasibility of a 0.1 deg deadband (Fig.5.3-6). An output signal of 0.21 vdc corresponds to 0.1 deg attitude input. The null signals from the various sources are:

RGA (in Phase) 1.4 mv Deadband X 22.5	= 31.5	mv
ACA No spec on in-phase, but assume 1.4 mv	= 31.5	mv
AEA 10 mv (in phase) x 7	= 70	mv
In Phase Total Null.............	133	mvdc

From this, the 0.1 deg deadband is feasible; however, Grumman in conjunction with the equipment manufacturer, must determine equipment modification requirements.

5.3.10 Discussion of Configuration Choices

With no requirement for an abort capability in the Lab, the minimum non-redundant system capable of accomplishing a reasonable percentage of the mission requirements was the criterion for recommendation. The AGS instead of PGNCS was recommended due to its lighter weight, approximately 100 lb less; and its lower power consumption, approximately 240 w less.

The modifications recommended to the AEA, DEDA, RGA and ATCA provide an improved mission capability without changing the power requirements or weight of the system.

As mentioned previously, no comparison of reliability estimates is possible at the present time, due to the difference in the reliability base used in the two systems. The AGS may have an advantage in that there are fewer components in this system than in the primary system.

Table 5.3-1

PROGRAM LENGTH

Function	LEM Flight Program	LEM Interim Program	AES Labs
Attitude Ref & Display	346	358	346
Alignment	155	135	50
Input Processing & Compensation	172	172	172
Calibration	100	100	0
Initialization	130	130	130
Navigation	194	324	194
Explicit Guidance	830	0	0
Steering	375	0	375
Radar Filter	153	0	0
CSM Acquisition	46	0	0
Telemetry	49	0	49
Executive & Housekeeping	467	0	467
Self - Tests	245	780	245
DEDA Processing	250	0	250
Service Subroutines	109	119	109
Star Catalog	0	0	400
AES Guidance	0	0	200
TOTAL	3621	2118	2987
15% Estimating Factor			450
"Scratch Pad"			500
			3937
Remainder			159
TOTAL MEMORY CAPACITY			4096

Table 5.3-2

RATE INTEGRATING GYROS

Manufacturer	Designation	Dimensions Dia. x length, in.	Random Drift Rate, Deg/hr	Max. Torgue Rate, Deg/sec
Honeywell	GG 8001	2.0 x 2.8	0.02	3.5
Honeywell	GG 250	1.6 x 3.2	7.2	150
Kearfott	C702516	1.8 x 2.8	0.03	5.5
Nortronics	GI-K7	1.6 x 2.5	0.05	17
Reeves	12IG	1.3 x 2.5	0.1	20/40
Sperry	SYG 1040	2.0 x 2.8	0.5	20
Systron Donner (Greenleaf Div.)	HIG-3	1.3 x 2.1	4	30
Kearfott	LEM Rate Gyro	1.0 x 2.1	36*	25

* Rate Threshold Sensitivity

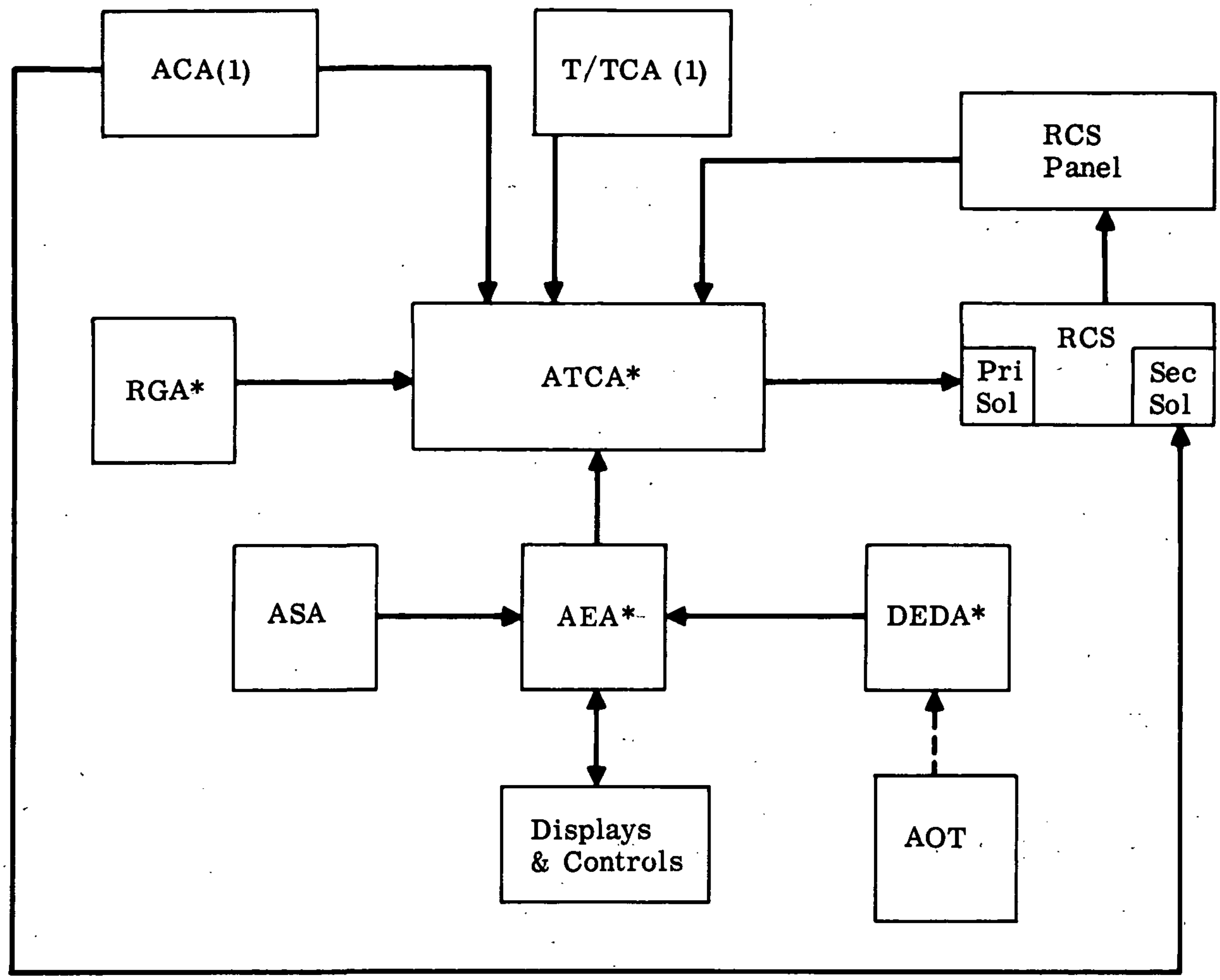
Table 5.3-3

AES LABS PGNCS COMPARISON

PGNCS	Power, Watts		Weight lb	AGS	Power watts	Weight lb
CDU			36.8	ASA	76.0	21.0
IMU		430	41.3	AEA	90.0	32.0
PTA	283.8		14.8	DEDA	8.0	8.0
PSA			20.1	RGA	8.5	1.8
LGC	105		70.0	SCS (Panel)	3.0	6.0
DSKY			17.5			
GASTA	5.63 Steady-State DC		7.4			
	17.8 Steady-State AC					
Totals	412.23 to 453.43 *		207.9	Totals	176.5	68.8

* Information not clear if 412.23 includes CDU's.

Note: Harness "A" & "B", weighing 23.5 lb, must be added to PGNCS; harness required by AGS not included.



*Modified Units

Deleted from LEM

ACA (1)
T/TCA (1)

DECA
GDA
LR
RR
IMU
DSKY
LGC
PTA
PSA
CDU

Legend

AOT Alignment Optical Telescope
ATCA Attitude & Translation Control Assy
ASA Abort Sensor Assy
AEA Abort Electronics Assy
ACA Attitude Control Assy
RGA Rate Gyro Assy
DEDA Data Entry & Display Assy
RCS Reaction Control System
T/TCA Thrust/Translation Control Assy

Fig. 5.3-1 Recommended Configuration

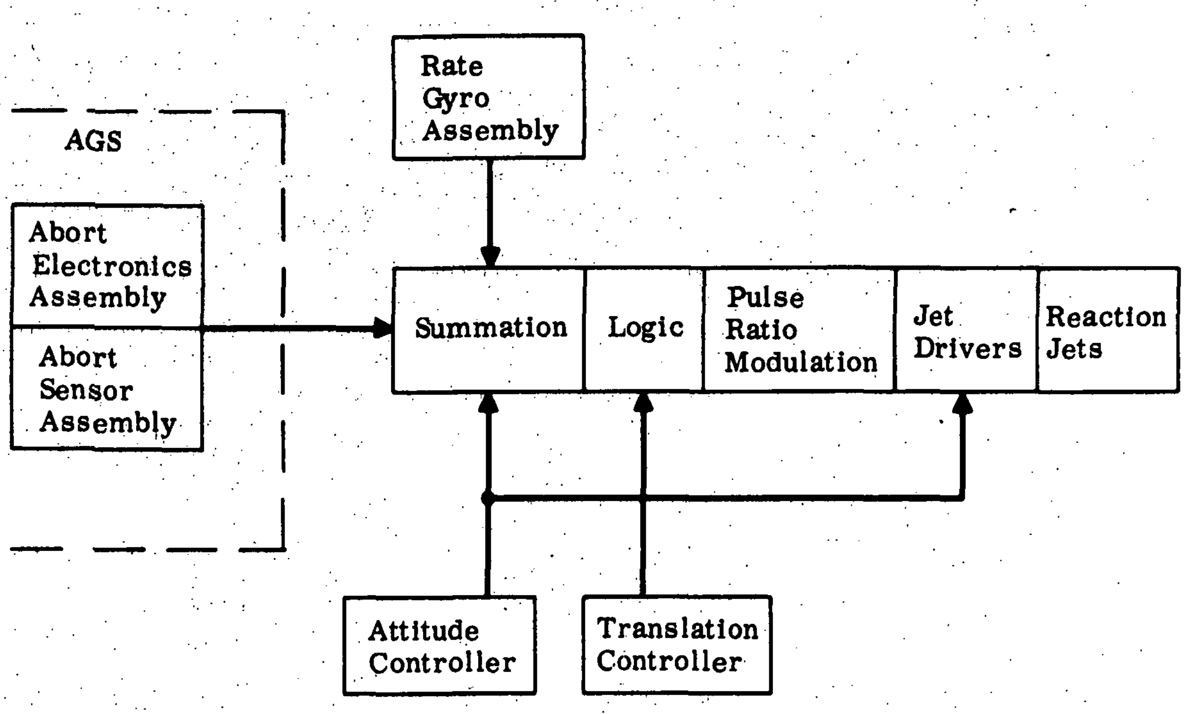
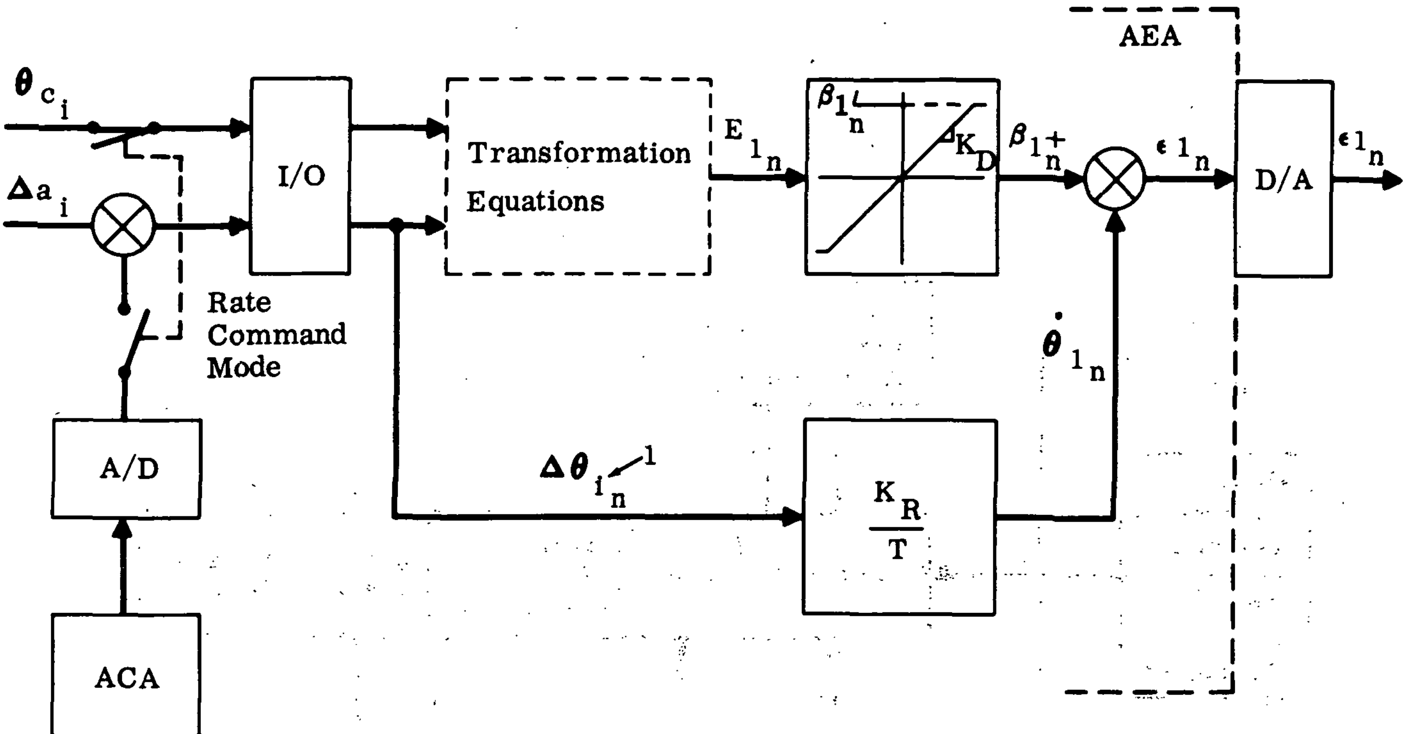


Fig. 5.3-2 Present AES Lab CES Configuration



Legend

$\theta^{c}{}_{i}$	Attitude Information
Δa_i	Incremental Rotation
$\beta 1_n$	Computer Attitude Output
K_D	Attitude Gain
$\epsilon\ 1_n$	Computer Rate + Attitude Output
$\beta 1_n^{\ L}$	Limit of Angular Rate
K_R	Rate Gain (Function of Selected Dead-Band)
T	Sampling Period in $\dot{\theta}$ Loop
$\dot{\theta} 1_n$	Computer Rate Output

Fig. 5.3-3 Rate Deriv. System I

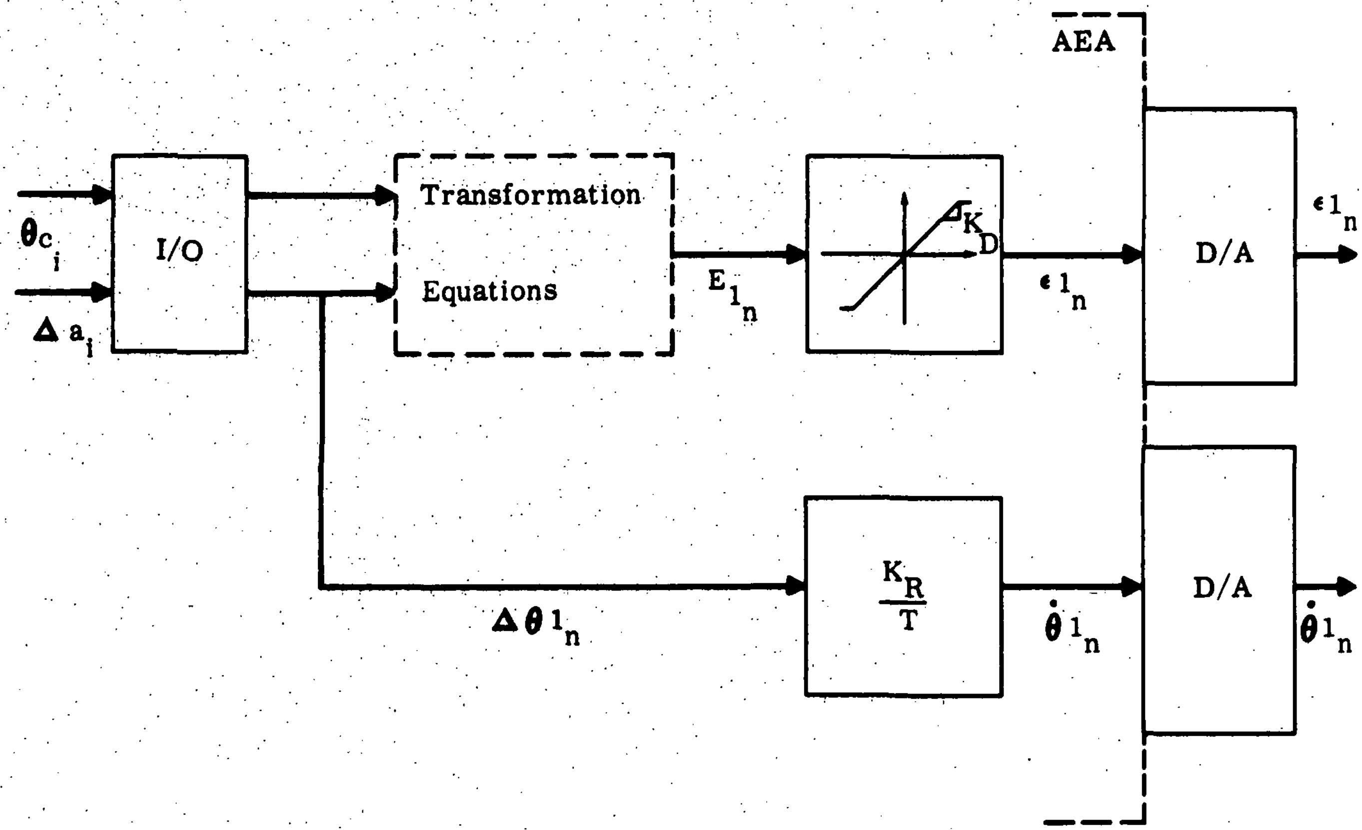


Fig. 5.3-4 Rate Deriv. System II

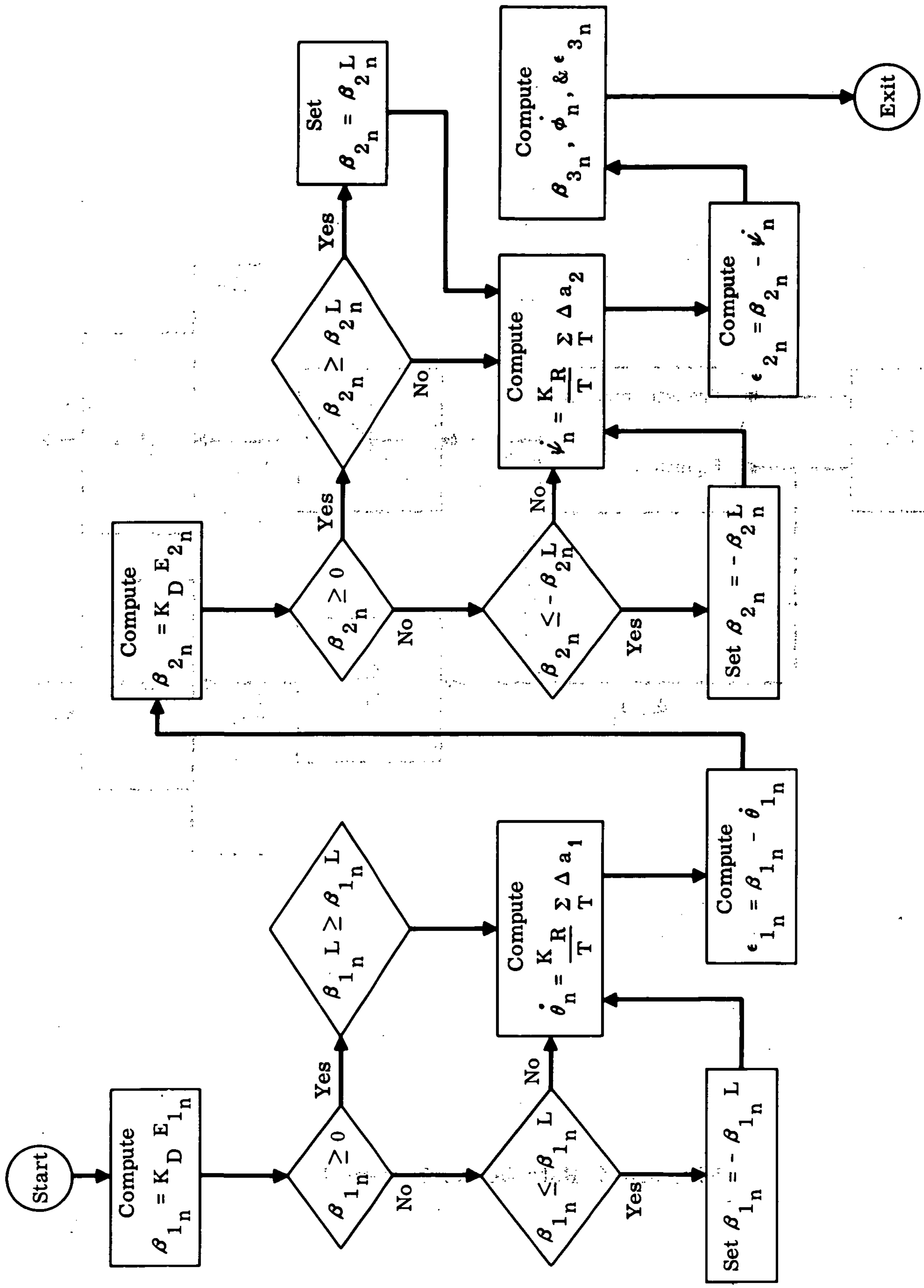
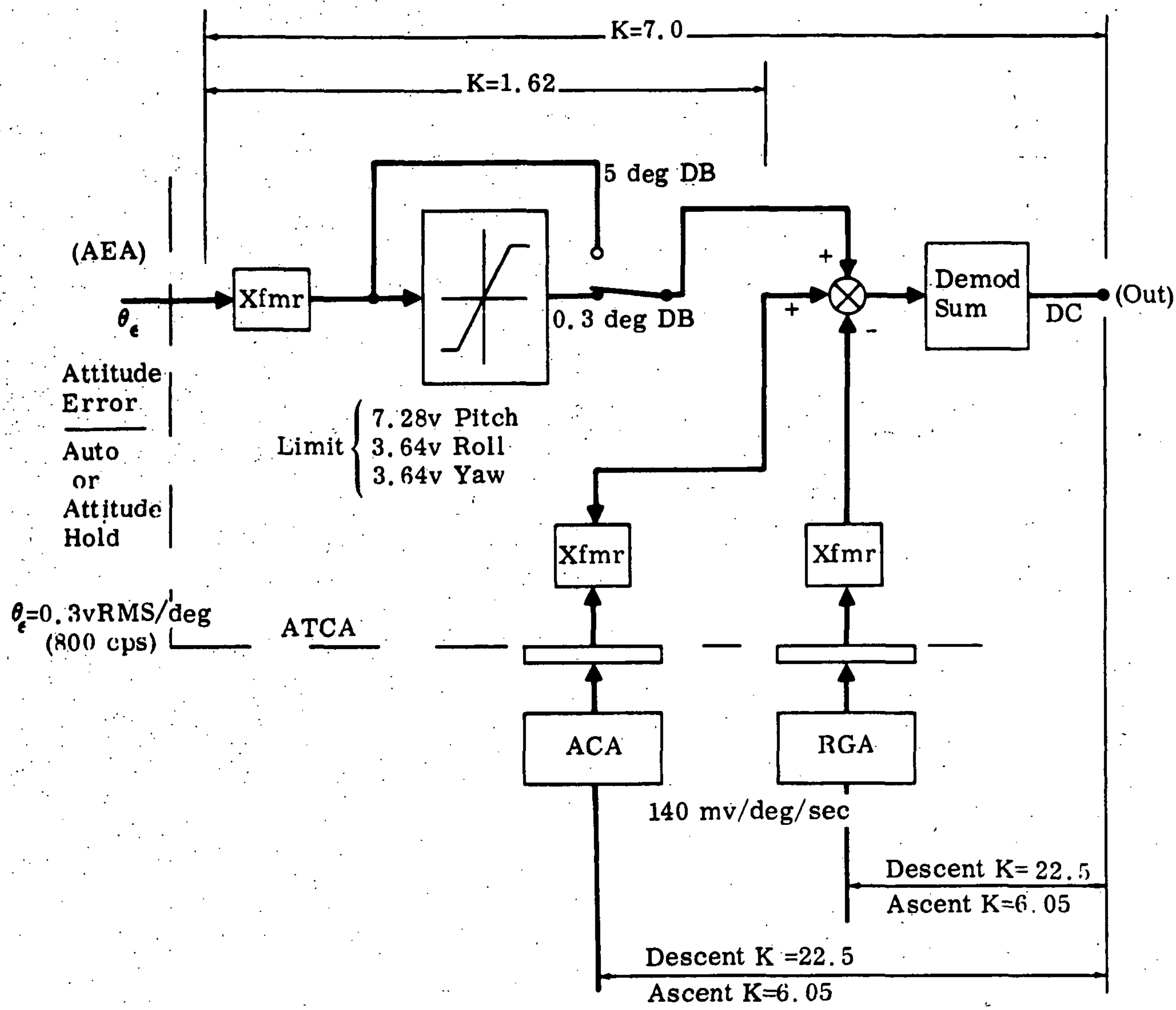


Fig. 5.3-5 Program Flow Chart



Null Signal Summary

RGA	Threshold	0.01 deg/sec = 1.4mv
	Null	30 mv RMS (Noise, Quad, Harmonics)
ACA	Total	30 mv RMS
AEA	Attitude Error Signals	10 mv In Phase 50 mv Total 17 mv Harmonic

Fig. 5.3-6 Block Diagram - ATCA Deadband Calculations

5.4 REACTION CONTROL & PROPULSION

5.4.1 Ground Rules

a) The Lab shall be capable of providing for all attitude hold functions associated with the conduct of mission experiments.
b) The CSM shall be used for transit and orbital slewing functions including rolling operations.
c) Ascent and descent propulsion subsystems will be deleted.

5.4.2 Assumptions and Background Data

RCS functional requirements will be similar to those of the Phase I Lab for attitude hold control with exception of the doubled propellant tankage requirements and increased mission duration of 45 days. Two sets of propellant tanks appear to satisfy the majority of missions, as discussed in Paragraph 4.3.

The 45 day mission duration is not expected to present serious storage or compatibility problems of the hardware with the liquid and gas phases of the propellants. However, it is expected that some testing will be required to assure compatibility and proper operation for the full mission duration.

The most recent estimates of thruster firing cycle requirements for the Phase II Lab, employing two sets of basic LEM propellent tanks, show that the specification life requirements of 10,000 cycles will be exceeded by a factor of approximately 2. Although these requirements are considerably greater than the thruster specification life, recent information received from the vendor (Marquardt) indicates that no serious problems are anticipated. However, a recommendation has been made by the vendor that some additional testing be conducted to verify proper operation during prolonged propellant exposure periods in a hard vacuum.

5.4.3 Recommended Configuration

5.4.3.1 Reaction Control Subsystem

The basic LEM sixteen thruster RCS system as shown in Fig. 5.4-1 and 5.4-2, with double the LEM propellant and helium tankage capacity and the LEM helium pressurization feed system offers the optimum RCS choice for the Phase II Lab. The fuel and oxidizer tanks will, however, be interchanged, either physically or by replumbing to achieve an increase in usable propellant capacity. Separate propellant quantity gaging systems will also be provided. By interchanging oxidizer and fuel lines, 1048 lb of usable propellant can be provided instead of the 846 lb. obtained by simply doubling LEM tankage.

This propellant capacity is not equal to twice that of the LEM due to the fact that the RCS engine operates on the LEM duty cycle at an average O/F ratio of 2:1, whereas, the LAB duty cycle results in a O/F ratio of 1.3:1. This phenomenon occurs because the mixture ratio is a function of electrical pulse width, and the attitude hold operation for the LAB mission requires only minimum width pulsing.

The LEM tanks are sized to accommodate the different propellant densities at an O/F of 2:1. Therefore, operation at an O/F of 1.3:1 cannot use all of the oxidizer and some may be off-loaded, as shown in the following table.

RCS Propellant Tankage Capacity

	O/F	Ox	Fuel	Total (lb)
a.	2:1	736	368	1104
b.	1.3:1	478	368	846
c.	1.3:1	592	456	1048

a. Twice present LEM usable Propellants (REF)

b. LAB, using present LEM Tankage arrangements and off-loading oxidizer

c. LAB, using Ox tanks for Fuel and Fuel tanks for Ox.

By coincidence, interchanging the Fuel and Ox tanks will give almost exactly the correct volume ratio for 1.3:1 O/F. This change is permissible since the tanks are compatible with either fluid. The effective interchange of tanks would probably be accomplished by interchanging propellant lines rather than physical movement of tanks. Development work on the LEM RCS Oxidizer tankage is still continuing, and it is possible that the material used in the final design will differ from the fuel tanks due to compatibility requirements. If this should be the case, simple interchange of tanks may not be possible and this feature will require re-evaluation.

Feeding the engine fuel through the present oxidizer supply system and vice versa would lead to very "hard starts" and engine failure, due to the internal design of the engine which requires a fuel lead for proper operation. It is necessary to maintain the present engine oxidizer and fuel feed lines at the engine interface as described above.

As a design consideration, an attempt will be made to utilize common fill and drain points for the increased tankage arrangement.

Optimum methods of "marrying" the additional propellant tankage to the basic system are being considered. In this light, Giannini Controls Corp. was requested to study whether the Propellant Quantity Gaging System is capable of providing accurate measurements when several propellant tanks are arranged in close proximity to each other. In addition, they were requested to evaluate the effect of the extended mission requirements on propellant gaging hardware. Giannini submitted a technical proposal defining areas of additional study and development effort associated with the requirement for increasing the number of propellant tanks as well as extended mission time. Generally, the effort encompasses additional analytical effort including computer analysis and trade-off studies substantiated by laboratory demonstration tests. Present planning calls for this effort being accomplished during Phase D. Preliminary vendor data indicates that if interaction or "cross-talk" problems should occur due to close proximity of additional propellant tanks, an adequate system can still be designed with some slight penalty in system accuracy, or with added weight due to shielding.

During this period, other RCS component vendors were similarly requested to review their equipments from the viewpoint of meeting the extended mission requirements. Although the vendor responses reviewed to date do not indicate any serious hardware problems, the need for additional analysis and testing to verify the equipments capability for meeting mission requirements has been stressed. Studies of alternate tank arrangement will be continued, considering effects on fill procedure, quantity gaging and RCS plumbing.

5.4.3.2 Ascent Propulsion

No Ascent Propulsion is carried

5.4.3.3 Descent Propulsion

No Descent Propulsion is carried

5.4.4 Baseline Configuration

There is no difference between the baseline and recommended configurations.

5.4.5 Alternate Configuration - Multiple RCS Feed Systems

The alternate configuration of RCS for the Phase II Lab as shown in Fig. 5.4-3 offers additional redundancy and operational flexibility over the recommended configuration in that each feed system is complete within itself, feeding into a common manifold. Each system contains its own pressurization feed components, propellant tank shut-off valves and helium tank initiating valves. The redundant shut-off valves would afford the flexibility for selection of propellant and helium tanks during normal as well as failure mode of operation. Selection of each propellant supply system may be made independently thereby exposing only one feed leg to propellants at any one time. In this manner the helium initiating valves need not be fired until the system is required for use. System components exposure will be reduced to one quarter of 45 days, which would be approximately the same as the Phase I mission requirement. The propellant tanks would be the only exception since they would be exposed to propellants for 45 days. For this configuration, the use of squib-actuated vent valves, one in parallel with each pressure relief valve, would be considered to depressurize the helium and propellant tanks after use.

The negative factors of this configuration are increased weight, additional installation volume requirements, additional display requirements, additional checkout requirements and increased hardware costs.

5.4.6 Alternate Configuration - Low Level Thrusters

An improvement in propellant consumption with a corresponding increase in attitude hold duration could be achieved by using RCS engines with smaller minimum impulse bit firing capability than the LEM engines. Changes in the control system would be required to take advantage of this feature. Actually, only the undisturbed limit cycle propellant consumption would be reduced; consumption due to disturbance torques such as aerodynamic and gravity gradient would not be affected. To assist in studying this possibility, the following information on alternate lower level thruster configurations was obtained:

A. Marquardt - 5 lb thrust (developed for Syncom)
Min. impulse bit - 0.05 lb-sec (0.010 sec pulse width)
Nominal Specific Impulse - 195 sec (pulsing)
Propellants - N_2O_4/50% UDMH, 50% N_2H_4

B. Marquardt - 22 lb thrust (developed for Advent)
Min impulse bit - 0.20 lb-sec (.010 sec pulse width)
Nominal Specific Impulse - 215 sec(pulsing)
Propellants - N_2O_4/MMH

C. Rocketdyne - 25 lb thrust (used on Gemini OAMS)
Min Impulse bit - 0.35 lb - sec (0.015 sec pulse width)
Nominal Specific Impulse - 170 sec (pulsing)
Propellants - N_2O_4/MMH

Although a comprehensive industry survey was beyond the scope of this study, a trend of minimum impulse bit vs. thrust is indicated by these data.

There appear to be no technical problems in adapting smaller thrusters to the LEM Lab, although further studies would be required if a particular thruster were selected, and it appears likely that some additional development work would be required to insure adequate thruster life. New tankage, or less efficient utilization of present tankage, might be required if the O/F ratio differed considerably from the LEM design value of 2:1.

5.4.7 Potential Modification per Flight

5.4.7.1 Additional RCS Tankage

Additional propellant and helium pressurization tanks, up to a total of four LEM sets, may be provided if required. The third set of tanks, as depicted in Paragraph 6.2.5.3, would provide a total of 1572 lb of usable propellant. A fourth set of tanks, providing a total of 2096* lb of usable propellant, could be installed on the aft bulkhead as described in Paragraph 6.2.7.3. Thruster firing cycle requirements for the three tank configuration would be approximately 30,000 cycles or 3 times their specification life whereas the four tank configuration would yield approximately 40,000 cycles and 4 times thruster specification life. Requalification would be required, although no design changes are believed necessary.

5.4.7.2 Use of Descent Propulsion

Consideration of the use of descent propulsion for attaining synchronous orbit was generated by the mission profile originally described in the NASA Blue Book. This requirement has since been deleted by NASA directive (Ref Paragraph 4.5.1 Configuration Selection, Revision K of Blue Book dated 24 September 1965), but is reported herein should a future requirement for this operation be created.

The propellant loading requirement was established by Table XVII of the Blue Book as 16,290 lb compared with the descent tanks capacity of 17,360 lb of usable propellant.

\- - - - - - -

* These values assume the fuel and ox tanks will be interchanged either physically or by re-plumbing to achieve an increase in usable propellant capacity.

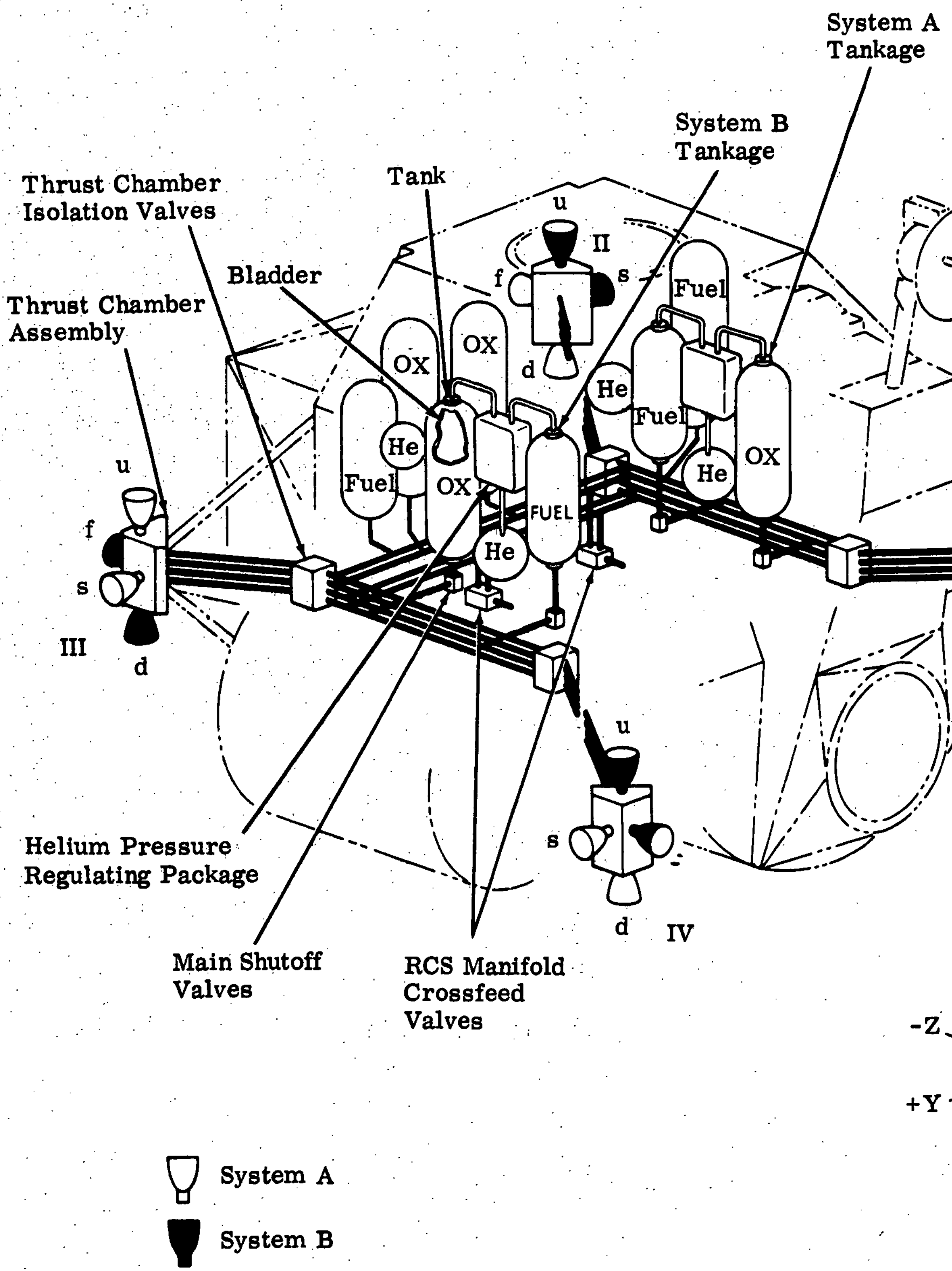
The subsystem would be identical to LEM's with the exception that the propellants would be off-loaded and vent valves would be added to depressurize the helium and propellant tanks after engine shutdown. The use of vent valves to depressurize the helium and propellant tanks is dictated by the desire to eliminate uncontrolled (random) venting of the tanks and safety considerations. Without additional vent valves, the cold helium used to pressurize the propellant tanks will increase in temperature with a corresponding increase in tank pressure. Within approximately 24 hours, the pressure will be sufficient to rupture the burst disc and open the relief valve. Subsequently, random venting of pressure will occur. It is desirable to control this venting to eliminate unwanted disturbance torques which may affect the experiments being conducted. The main problem from the viewpoint of safety is the prevention of catastrophic failure of the tanks. Tank failures can occur in at least two ways: an increase in tank pressure from increased helium temperature combined with a failed-closed relief valve, and micrometeoroid penetration of a tank at pressures higher than 40 psi. Based on the helium and propellant 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. The use of vent valves to depressurize shortly after descent engine shutdown will eliminate these problems.

A preliminary review of the descent engine capability to meet the synchronous orbit requirements indicates it will be able to fulfill these requirements. A full thrust engine burn of approximately 535 sec is required. The LEM Descent Engine Test Plan requires a demonstration of the engine capability to burn 17,931 lb of propellants at full thrust (approx. 590 sec burn time).

The use of descent propulsion for the synchronous orbit would require a revision to at least one LEM operational procedure. Since the descent engine controls must be on the Lab (no control interfaces between Lab and CSM), it is necessary to enter the Lab prior to attaining the final orbit. The ramifications of this procedure were not explored.

5.4.8 Discussion of Configuration Choice

The Phase II Lab RCS as shown in Fig. 5.4-1 and 5.4-2 has been proposed on the basis of it being able to satisfactorily accomplish the probable mission requirements. The doubled tankage will provide a total of 1048 lb of usable propellant at an O/F of 1.3 when the fuel and oxidizer tanks have been interchanged. If the tanks were not interchanged, only 846 lb of usable propellant would be available at an O/F of 1.3 which is the effective O/F ratio for minimum impulse bit pulsing.



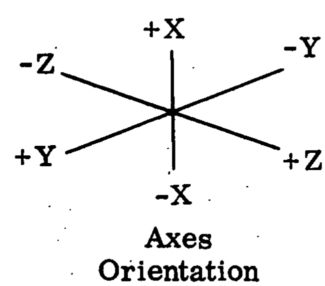
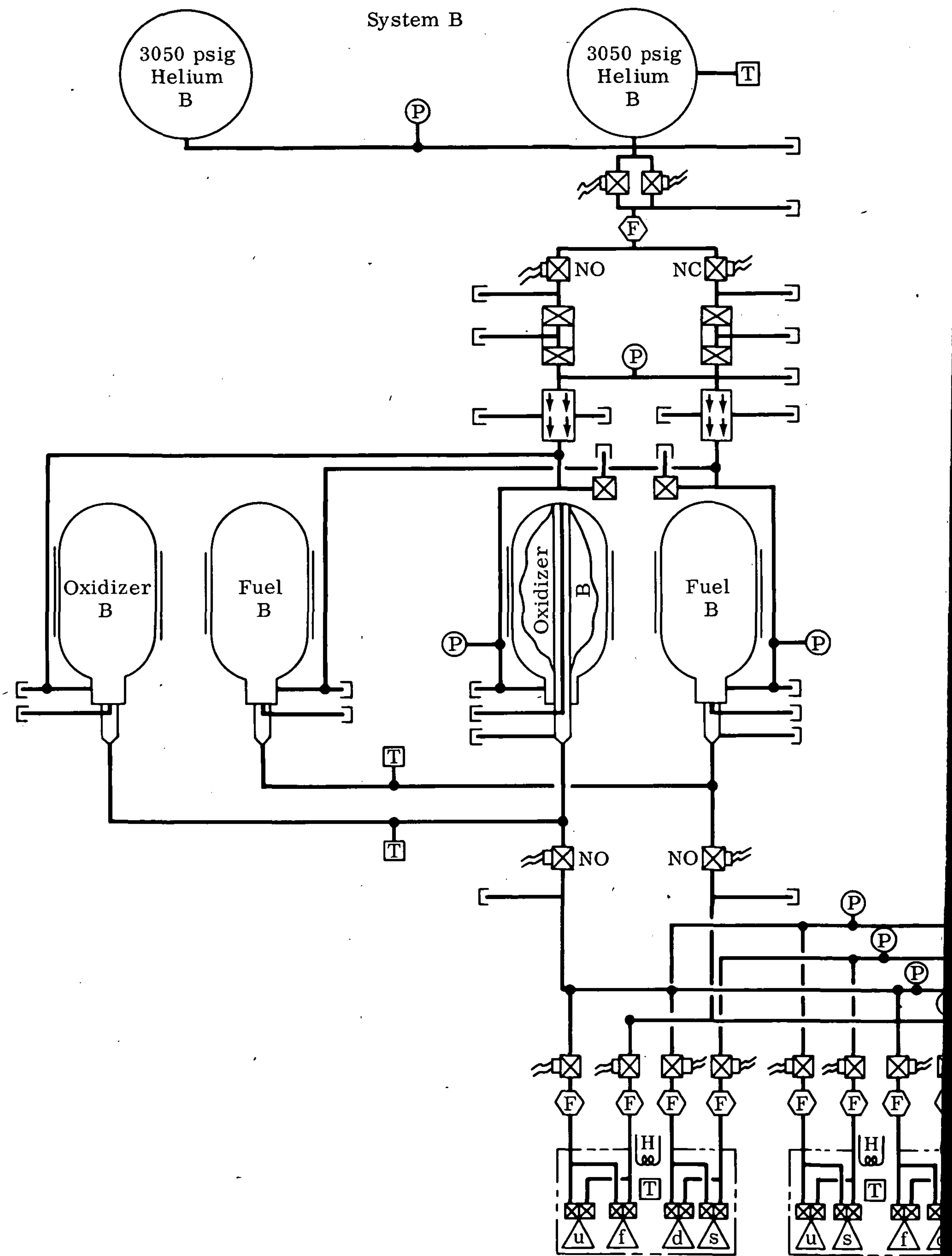
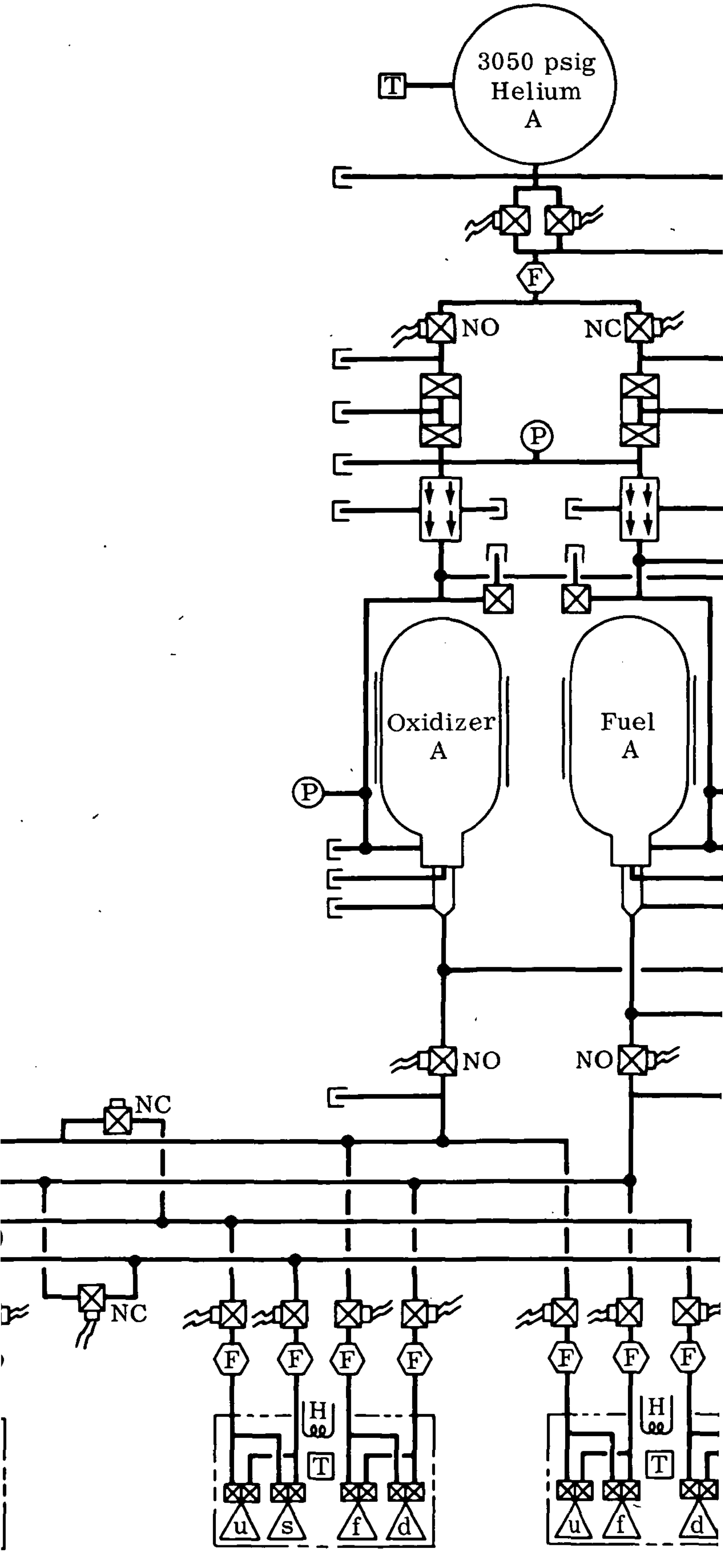


Fig. 5.4-1 RCS General Arrangement Phase II Lab



System B
3050 psig
Helium
B
3050 psig
Helium
B
T
P
F
NO
NC
P
Oxidizer
B
Fuel
B
Oxidizer
B
Fuel
B
P
P
T
T
NO
NO
P
P
P
F
H
T
u
f
d
s
H
T
u
s
f


3050 psig
Helium
A
T
F
NO
NC
P
Oxidizer
A
Fuel
A
P
NO
NO
NC
NC
F
H
T
u
s
f
d
u
f
d

2

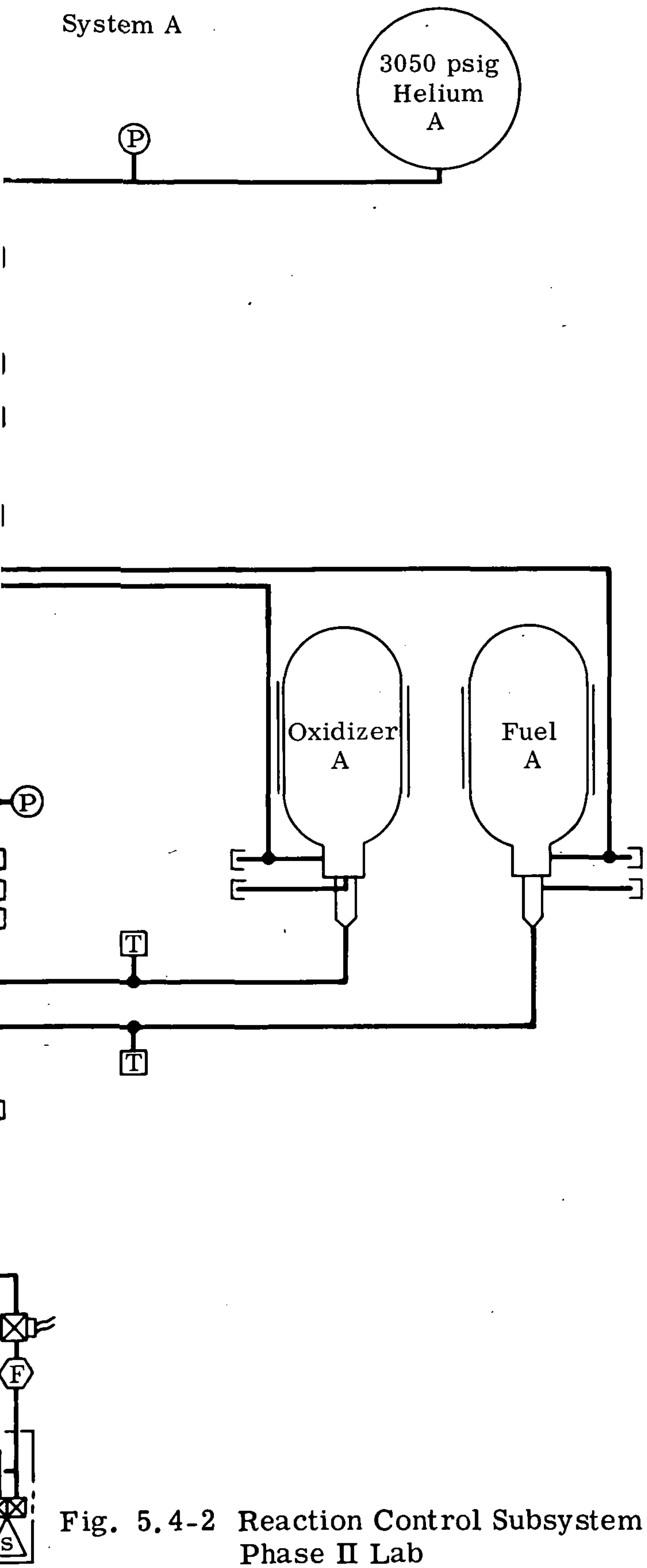
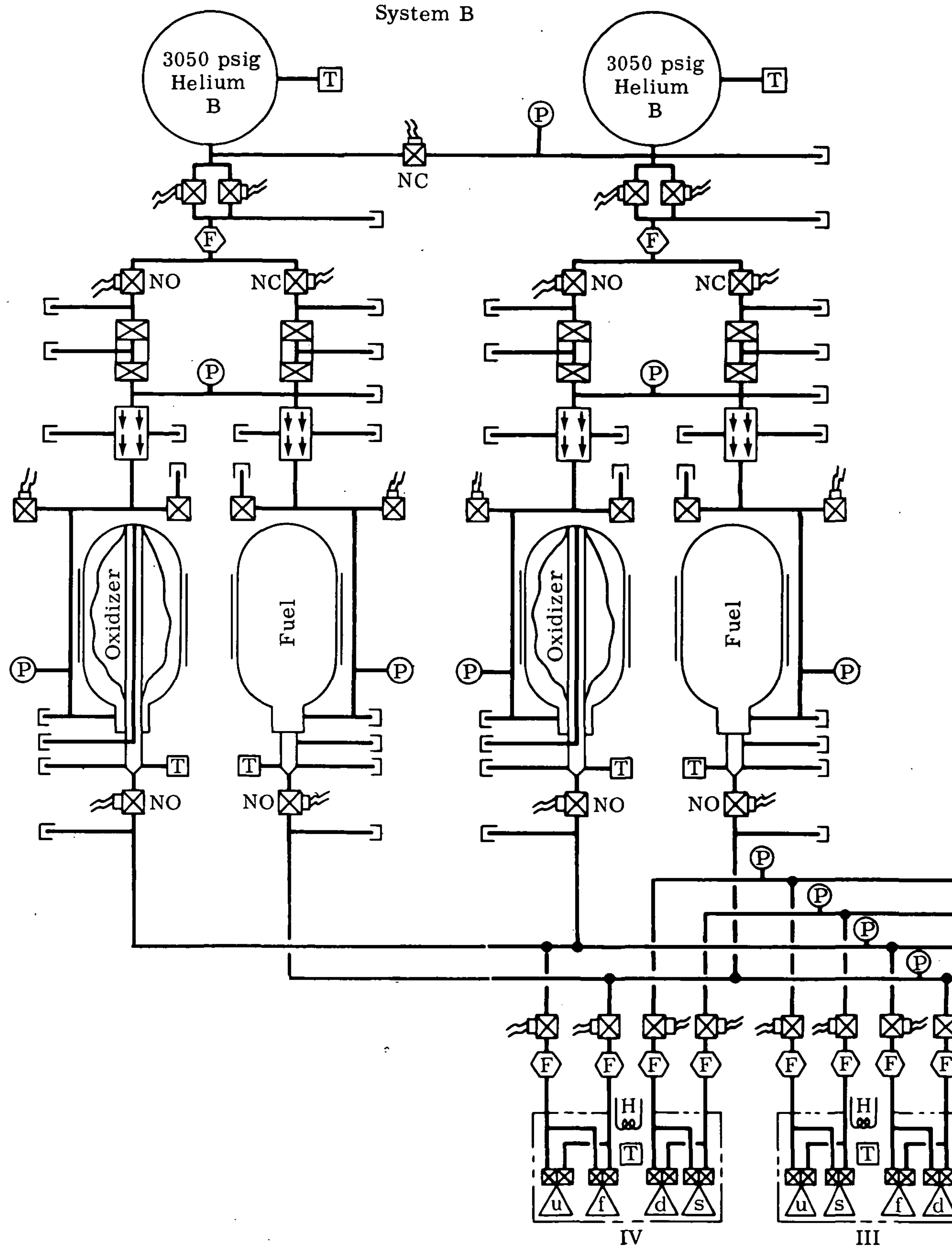


Fig. 5.4-2 Reaction Control Subsystem
Phase II Lab

(107)


System B
3050 psig
Helium
B
T
P
NC
F
NO
NC
Oxidizer
Fuel
H
u
f
d
s
IV
III

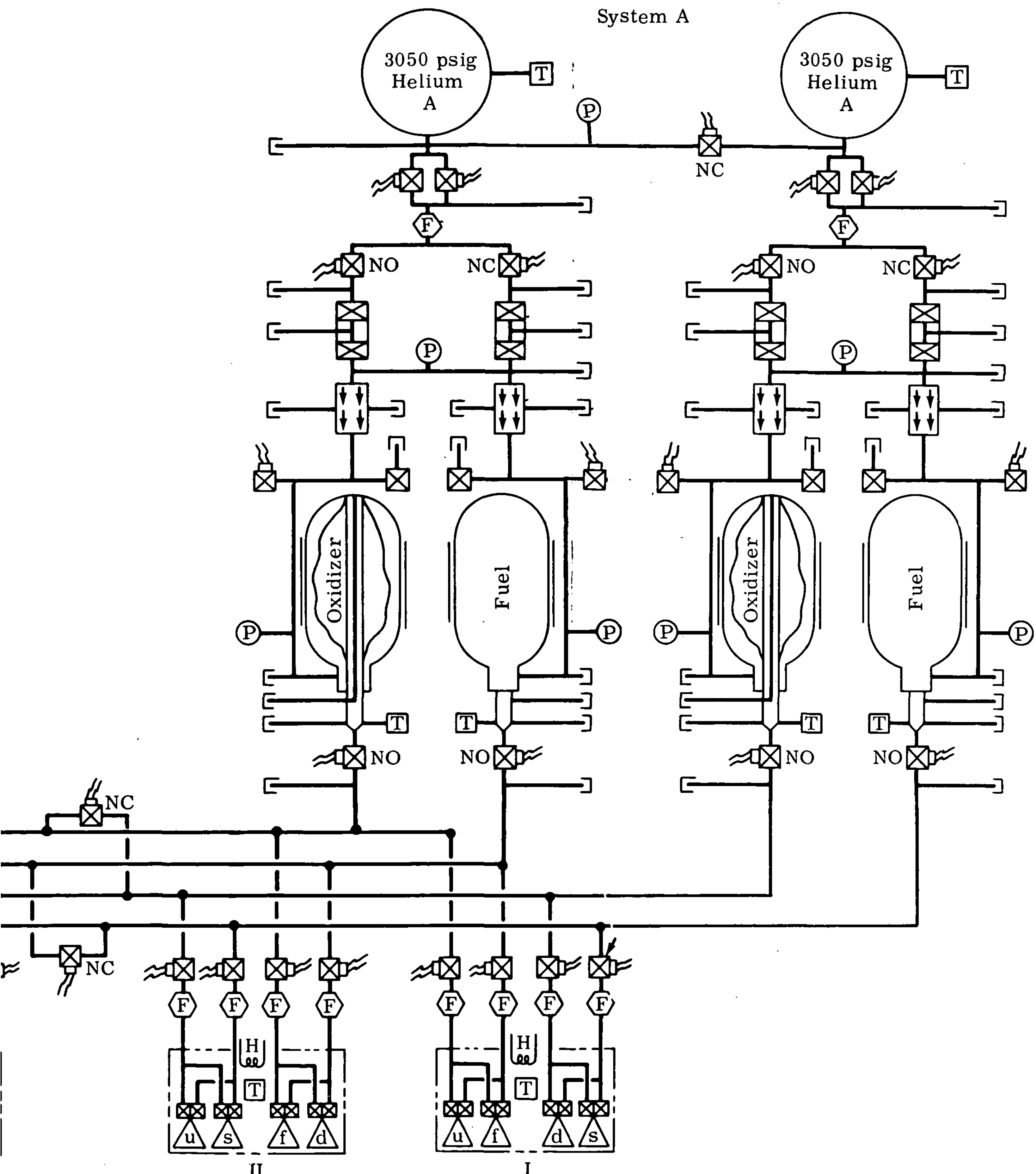


Fig. 5.4-3 Reaction Control Subsystem Phase II - Lab Alternate Configuration

5.5 COMMUNICATIONS

5.5.1 Ground Rules

- There is no data interface between the CSM and Lab
- Lab communications and telemetry subsystems are not dependent on CSM
- Maximum use shall be made of Apollo hardware with minimum modification
- TV transmission will be via the CSM S-Band link to Earth (real time only)
- TV requirements will be satisfied by the present Apollo GFE TV camera. This camera will be deployed from the CSM through the hatches to the Lab, with the power cable extending from the camera to the CSM-S Band subsystem.
- There will be a hardline intercommunications system between the CSM and Lab. The hardline can be used when the Lab is depressurized and the CSM pressurized.

5.5.2 Assumptions and Background Data

5.5.2.1 Assumptions

- There are no TV or data uplink requirements.
- All three astronauts will have continuous audio capabilities.
- EVA communication to the CSM or Lab will be via the VHF link.
- Earth S-band communication link is always available regardless of the intercommunications mode.
- Lab status data will be transmitted to the ground during line-of-sight mission phases.

5.5.2.2 Background Data

The following is a brief description of the LEM communications capabilities upon which the Lab communications are based.

5.5.2.2.1 Communications. Figure 5.5.-1 is a block diagram of the LEM Communications Subsystem showing the changes which convert it to a Lab system. In particular, the S-Band section provides capabilities for:

- Transmission of voice, biomedical data, and telemetry to Earth.
- Aid in tracking and ranging - receives and re-transmits, in phase coherence, a pseudo random noise (PRN) coded signal to enable the MSFN to track the LEM during deep space phases.
- Receiving voice transmission.

The Earth is used as a relay station at S-Band to extend the range of communications between the LEM and CSM. The S-band section is a replica of the unified S-Band concept (i.e., voice, bio-med and telemetry are multiplexed on a common S-Band carrier).

The PM modulators are used for the coherent operational mode, whereas the FM modulator is used for the non-coherent transmission mode. Transmission of both modes or simultaneous operation of the driver-multipler chains are both precluded. Only one power amplifier is used at a time.

The VHF section is used for LEM/EVA and LEM/CSM communications. The VHF operational modes are:

- Duplex voice with CSM or EVA
- Receive voice/bio-med from EVA.
- Transmit 1600 bits/sec data to the CSM.

The VHF B transmitter (259.7 mc) is the only one capable of transmitting PCM data. Either voice or data can be transmitted at one time (not simultaneously). The VHF receiver (259.7 mc) is the only one capable of receiving EVA voice and bio-med data. These are received simultaneously. The LEM/EVA operational modes can be summarized as follows:

- Primary Mode:

  - o VHF B = 259.7 mc, duplex-EVA voice and bio-med to LEM (EMU)
  - o VHF A = 296.8 mc, duplex voice only LEM to EVA

- Back-up Mode:

  - o VHF A = 296.8 mc, duplex voice only EVA to LEM
  - o VHF B = 259.7 mc, duplex voice only LEM to EVA

The LEM/CSM link via the antenna system (no hardline).

The signal Processing Assembly (SPA) consists of the pre-modulation processor (PMP) and the two audio centers. The SPA provides the switching and processing for signals within the communications subsystem.

5.5.2.2.2. Antenna System. The LEM antennas applicable to the Phase II Lab are:

- S-band steerable antenna - This is a 26-in. diameter dish antenna mounted on the LEM. It is highly directional and is used for the AES lunar and synchronous orbiting missions.
- Two VHF in-flight antennas - These support the VHF link between the EVA and Lab. These antennas are used for the CSM and Lab link when the vehicles are separated. Only one antenna is used at a time, the operational antenna being selected by the astronaut.
- Two S-band in-flight antennas - These are used as a back-up system to the S-band steerable antenna. For the AES Lab near-Earth orbiting missions, this antenna system is the predominant one. Only one antenna can be used at a time; the astronaut selects the antenna for operation.

To define antenna performance accurately, it is necessary to illustrate and define the radiated signal strength distribution over the spherical surface enveloping the LEM. Figure 5.5-2 illustrates the LEM at the center of the radiation sphere and the superposition of the rectangular and spherical coordinate systems used to describe antenna performance. Also indicated are the locations of reference points on the two dimensional display of the spherical surface which describes antenna radiation distribution plots. With this geometrical scheme, it is possible to determine the effect of vehicle attitude on the Earth communication link. All the diagrams in the further discussion of antennas angular coverage and radiation patterns use this reference coordinate system.

The S-band steerable antenna is a gimballed, circularly polarized antenna which has a gain of 20 db. Angular coverage is approximately 330 by 150 deg (Fig. 5.5-3). The angular coverage is predominately on one side of the LEM. Consequently, during any Lab mission the vehicle may roll to a position requiring use of the S-band in-flight antennas. For synchronous orbit missions, the in-flight antennas can be used for only a limited number of communication operating modes. For the lunar orbiting Lab, the Earth link could be lost because of vehicle roll, since at lunar distances, the in-flight antennas cannot maintain the Earth link.

The S-band in-flight antennas are two circularly polarized log conical spirals mounted on the LEM ascent stage, one along the +Z axis, the other along the -Z axis. Each antenna theoretically provides hemispherical radiation on each side of the vehicle, producing spherical composite coverage. The specified radiated signal strength distribution of these antennas is: "....gain shall be greater than -3 db with respect to right-handed circularly polarized isotrope over no less than 85% of the sphere". The requirement of 85% spherical coverage is met when the radiation patterns of each antenna are superimposed over the sphere.

Figures 5.5-4 and 5.5-5 are composites of antenna model test radiation distribution plots taken with the Apollo LEM at the transmitting and receiving frequencies. The legs are extended and, although the Labs do not have landing legs, these same interference effects may be created by typical experiments. Figure 5.5-6 is a plot of percent coverage vs signal strength relative to an isotropic source. As indicated, there is greater than -3 db gain over 85% of the sphere. These patterns substantiate use of the S-band in-flight antennas for Lab near-Earth orbiting missions.

The VHF in-flight antennas are circularly polarized and have the requirement that antenna gain be greater than -6 db with respect to a linear isotrope over no less than 85% of the sphere. The VHF antennas are used for the LEM/EVA and LEM/CSM (when separated) links. Although antenna test patterns are not presently available, early Apollo experimental test patterns indicated radiation distribution similar to the S-band in-flight antennas. These antennas are adequate for the Lab.

5.5.2.2.3 Ground Station Performance and Capability.

- 200-n.mi Earth Orbit - The following ground stations were used to determine the available communication time (ground station coverage) for inclinations of 28.5, 50 and 90 deg: Antigua, Ascension, Bermuda, Cape Kennedy, Carnarvon, Grand Canary Island, Guam, Grand Bahama Island, Guaymas, Hawaii, and Corpus Christi. These stations each utilize a 30-ft dish antenna capable of tracking the Lab up to 5 deg above the horizon. Since the tracking rate of the 85-ft dishes (3 deg/sec) at other ground stations encompasses the angular rate of a 200-n.mi Lab (approx 0.7 deg/sec), slightly greater ground coverage could be achieved by including these other ground stations (Canberra, Goldstone, and Madrid).

A computer program used for determining ground station coverage indicated the time available for line-of-sight (LOS) communications to Earth from the Lab. An analysis was also done to determine the corresponding operating time of the transmitter.

Figure 5.5-7 illustrates the method used to develop Table 5.5-1. The "ON" step indicates that the S-band transceiver equipment is On, but not in communications with Earth. This table summarize the communications time and equipment operating time for the various Earth orbits. Figures 5.5-8 through 5.5-10 provide a detailed communications timeline for each of the cases of interest.

- Lunar Orbiting Lab - All of the lunar orbits provide communications time to earth at least equal to 50% of the time. Since telemetry will be transmitted to earth at a bit rate either equal to or greater than that recorded in the Lab, the availability of communication time is not a problem.
- Earth Synchronous Orbiting Lab - For this mission continous communication time is available. Restrictions imposed by vehicle attitude will govern the time available for communication.

5.5.3 Recommended Configuration

The recommended configuration for the Lab maintains the Apollo LEM Communication and Antenna Subsystems, with the following two minor modifications:

- Modified SPA to accommodate the hardline intercom
- Provision of an additional PCM data channel

These modifications and the resulting performance characteristics follow.

5.5.3.1 Modified SPA

The audio control center portion of the SPA will be modified to accept the intercom input from the CSM and to provide the Lab signal to the CSM (Fig. 5.5-11).

This system provides a variable output intercom system (ICS) amplifier for each vehicle. By turning down the ICS amplifier, the intercom can be disabled to allow an astronaut to sleep undisturbed in the CM. The ICS amplifier may be turned up, and the astronaut in the CM aroused, if required. With this system, each occupant can contact the other vehicle or carry on normal operation without disturbing the routine in the other vehicle.

5.5.3.2 Additional PCM Data Channel

For the earth orbiting Lab missions, the data handling capabilities of the S-band section may be inadequate. To increase the data handling capability, an additional data channel is provided by using the TV baseband spectrum of 0 to 500 kc. This design approach is available because the AES TV requirements will be satisfied via the CSM S-band RF link. The proposed system provides greatly extended Lab telemetry capability with no modification to the communication subsystem.

Previously, a bit rate of 409.6 kilobits/sec (kb/s) had been selected for this additional data channel. A final value depends on further mission requirement analysis and the equipment modifications that are acceptable. Figure 5.5-13 shows bit rates (NRZ data) vs bandwidth for various bandwidth/bit rate ratios. Using the LEM/BR value of 2.94, the available LEM TV baseband bandwidth of 500 kc will provide a data handling capability of 340 kb/s. Using the AES recommended value of 2.35, the system provides a capability of 410 kb/s. It should be noted that the NRZ bit rate is divided by 2 (bits/cycle) to obtain the fundamental frequency of the data.

The design approach is illustrated in Fig. 5.5-12 which reflects a recently incorporated change in the Apollo LEM communication hardware. The figure shows the 410-kb/s data input in place of the TV input for AES PCM data use. This method bypasses the SPA and feeds the PCM signal directly into the S-band FM modulator. The matrixed signals from the PMP FM mixing network (PCM 51.2 kb/s and voice bio-med) are fed through a high-pass filter to remove intermodulation distortion. This clean composite signal is then combined with the PCM signal in the linear adder circuit to form a new complex composite signal. This signal is applied to the voltage controlled oscillator (VCO), where frequency modulation is effected, i.e., the changing input signal volage yields a changing output frequency from the VCO. This output is then passed through a power FM limiter to remove any residual amplitude variations and then proceeds to the S-band driver multiplier chain. As indicated in Fig. 5.5-12, no modifications to the equipment are required, and an additional FM PCM data-channel of 410 kb/s is provided. The only requirement presently forseen for this approach is the assurance of matched impedances at the present TV input and compatible signal levels.

5.5.3.3 Performance Characteristics

The AES Lab communication subsystem is illustrated in Fig. 5.5-1 and the operational modes indicated in Fig. 5.5-14. Frequency allocation is designated in Fig. 5.5-15. The following operational formats are selected:

- PRN Ranging - This mode is on PM and involves a received and retransmitted signal to ground (Paragraph 5.5.2.2.). The PRN ranging will not be required when the Lab and CSM are docked. The CSM will provide range information via its S-band system. This will allow the Lab to use the full FM mode as required when a large quantity of experimental data is being accumulated.
- Lab Spacecraft Status Data - This is transmitted by FM or PM on a 1.024-mc subcarrier (51.2 kb/s normally) to ground when in LOS.
- Recorded Experiment Data - This data is transmitted by FM at the rate of 410 kb/s over the TV baseband (0 to 500 kc) in place of the LEM TV mode.
- Voice Bio-Med - Voice is received on a 30-kc subcarrier from ground. Astronauts' voice and bio-med are transmitted to ground simultaneously on a 1.25-mc subcarrier. This mode can include an EVA. A PM back-up mode exists on the 0 to 14 kc band. Bio-med of only one of the Lab occupants can be accommodated at one time

The full FM mode consists of experiment data, status data, and voice/bio-med transmitted simultaneously. The full PM mode consists of PRN ranging, status data, and voice/bio-med transmitted simultaneously.

During EVA when the two vehicles are docked, the hardline intercom will be used for the inter-vehicle voice link and the EVA astronaut will utilize the VHF link to both vehicles.

In addition to this general operational format, further consideration is given to mission related circuit margins and antenna characteristics.

5.5.3.3.1. <u>Mission Related Circuit Margins.</u> Circuit performance margins were determined for the 200-n.mi and sychronous Earth orbit missions, as well as the lunar orbit mission. The analysis is that presently used on the Apollo LEM (LIS 380-15006). The same modulation index is used for the additional data channel (410 kb/s) as that used for the LEM TV. In the analysis, assigned antenna gains are 20 db for the S-band steerable and -3 db for the S-band in-flight antennas. The listed circuit performance margins are greater than the S/N system requirements.

- 200-n.mi Altitude Orbit - A 30-ft dish antenna at the ground station is assumed.

  o Full FM mode: PCM (410 kb/s)/PCM (51.2 kb/s)/voice and bio-med

  - 20 watts to steerable

C/N	+46.6 db
S/N (410)	+58.9 db
S/N (51.2)	+50.9 db
S/N (voice, bio-med)	+49.2 db

  - 3/4 watt to steerable

C/N	+30 db
S/N (410)	+42.4 db
S/N (51.2)	+44.4 db
S/N (voice, bio-med)	+32.6 db

  - 20 watts to in-flight antennas

C/N	+21.5 db
S/N (410)	+33.9 db
S/N (51.2)	+35.9 db
S/N (voice, bio-med)	+24.1 db

  - 3/4 watt to in-flight antennas

C/N	+ 4.9 db
S/N (409.6)	+17.3 db
S/N (51.2)	+19.3 db
S/N (voice, bio-med)	+ 7.5 db

  o Full PM mode: PRN ranging/PCM (51.2 kb/s)/voice

  - 3/4 watt to in-flight antennas

C/N	+42.3 db
S/N (PRN)	+25.3 db
S/N (51.2)	+14.4 db
S/N (voice)	+15.8 db

- Synchronous Orbit - The circuit performance margins presented are those for a 30-ft dish antenna at the ground unless otherwise indicated. Where the 30-ft dish is used, the circuit margins can be updated for larger dishes by adding 9 db for an 85-ft dish, and 18 db for the 210-ft dish.

  o Full FM mode: PCM (410 kb/s)/PCM (51.2 kb/s)/voice and bio-med

  - 20 watts to steerable

C/N	+ 6.6 db
S/N (410)	+18.9 db
S/N (51.2)	+10.4 db
S/N (voice, bio-med)	+ 9.2 db

- 3/4 watt to steerable, 210-ft ground dish
  C/N + 8.0 db
  S/N (410) +20.4 db
  S/N (51.2) +11.8 db
  S/N (voice, bio-med) +27.2 db
- 20 watts to in-flight antennas, 210-ft ground dish
  C/N - 0.4 db
  S/N (410) +11.9 db
  S/N (51.2) + 3.3 db
  S/N (voice, bio-med) + 2.1 db

o PCM mode: PCM (51.2 kb/s)/voice

- 3/4 watt to steerable, 85-ft ground dish
  C/N +38.8 db
  S/N (51.2) +10.8 db
  S/N (voice) +12.2 db
- 20 watts to in-flight, 210-ft ground dish
  C/N +39.3 db
  S/N (51.2) +12.7 db
  S/N (voice) +13.5 db

o PM mode: PCM (1.6 kb/s)/voice, bio-med

- 20 watts to steerable
  C/N +46.4 db
  S/N (1.6) +26.6 db
  S/N (voice, bio-med) +23.9 db
- 3/4 watt to steerable
  C/N +29.8 db
  S/N (1.6) + 9.9 db
  S/N (voice bio-med) + 7.3 db
- 20 watts to in-flight antennas, 85-ft ground dish
  C/N +30.3 db
  S/N (1.6) +10.5 db
  S/N (voice, bio-med) + 7.8 db

These circuit performance margins illustrate the inherent flexibility for accommodating unfavorable vehicle attitudes during experiment operation. Communications and telemetry capability always exists for this mission.

- Lunar Orbit

  o Full FM mode: PCM (410 kb/s)/PCM (51.2 kb/s)/voice and bio-med

  - 20 watts to steerable, 210-ft ground dish
    C/N + 4.6 db
    S/N (410) +16.9 db
    S/N (51.2) + 8.4 db
    S/N (voice, bio-med) + 7.2 db

o PM mode: PCM (51.2 kb/s/voice

- 20 watts to steerable, 85-ft ground dish

C/N	+35.4 db
S/N (51.2)	+ 8.8 db
S/N (voice)	+ 9.5 db

o Full PM mode: PRN ranging/PCM (51.2 kb/s)/voice

- 20 watts to steerable, 210-ft ground dish

C/N	+43.3 db
S/N (PRN)	+23 db
S/N (51.2)	+14 db
S/N (voice)	+ 9.3 db

Although this mission is limited in operational modes some operating flexibility is made available because of the longer communication time available.

5.5.3.3.2 Mission-Related Antenna Characteristics. The antenna system is sensitive to the Lab experiment payload package in that radiation can be obstructed and destructive interference can be caused by multiple reflections. In addition, the mated vehicle configuration can produce unfavorable results. The proposed antenna system can only be confirmed after antenna model tests.

The EVA backpack antenna is a monopole with linear polarization. (Backpack has a transmitting power of 75 mw.) Since both the CSM and Lab have circularly polarized antennas, there will be a variable power loss due to the differences in polarization. The maximum one-way power loss vs voltage axial ratio is plotted in Fig. 5.5-16. The radiation distribution plot, in the vicinity of the descent stage and the power loss due to arbitrary polarization, will require analysis to insure that signal strength is adequate to maintain the EVA link.

The data presented (antenna patterns and circuit margins) indicate that the S-band in-flight antennas can be used as the primary antenna system for the 200-n.mi Earth orbit mission, thereby placing a minimum constraint on vehicle attitude.

5.5.4 Baseline Configuration

The baseline configuration was based on using the PM mode for incorporating the additional PCM data channel. This involved a modification to the PMP portion of the SPA. Recent developments in the Apollo Program allow the use of the TV baseband in the FM mode with no modification to the SPA.

The resulting operational format changes, particularly for the 200-n.mi Earth orbit missions, are:

- FM is now the primary full operational mode for communications and telemetry.
- The Lab will provide PRN ranging only as a back-up to the CSM (contingency mode) or when the Lab and CSM are separated.

5.5.5 Alternate Configuration - Coupled S-Band/VHF In Flight Antennas

The S-band in-flight antenna patterns and circuit margins presented earlier substantiate the use of these antennas for the 200-n.mi Earth orbit missions. It appears desirable to couple these antennas and remove the need for manual switching from one antenna to another.

A system of coupling the two antennas can be devised and developed. In particular, systems of two, three, and four in-flight antennas were analyzed to determine their radiation characteristics. Each system's antennas were distributed symmetrically about the vehicle. Utilizing ray theory and vector summation, distribution patterns were derived. These studies indicated that the two-antenna system is the more practical for the Lab missions. The circuit performance margins would allow the -3-db loss. The radiation distribution for this system is shown in Fig. 5.5-17. A computer program is being used to determine the pattern envelope in more detail and accuracy over the regions ranging from 260 to 280 deg and 80 to 100 deg. Some pattern scalloping should be realized in these regions. Determining the nature and extent of the scalloping requires the vector summation to be taken over finer intervals of 1 deg, whereas 5-deg intervals were chosen for the initial analysis.

Similarly, the VHF in-flight antennas could be coupled to remove the need for antenna switching. Although the coupled VHF mutifiliar helix antennas were not analyzed, an approach similiar to that used for the S-band antennas could be used. The resultant determined radiation would not be as free from nulls as with the S-band patterns, since early experimental tests indicated that the VHF radiation distribution contains null areas.

5.5.6 Alternate Configuration - S-Band Transceiver Cycling

As stated previously, the preceding ground station will notify the Lab as to the time interval of the next ground station contact. The S-band transceiver is then cycled manually by the astronaut, or cycling may be provided automatically by the addition of a timer-relay to the equipment. The astronaut could use this additional component when required (intervals between ground stations greater than 15 min). The automatic cycling is more practical due to the anticipated amount of astronaut activity during the Lab missions.

5.5.7 Alternate Configuration - Addition of Internal TV Jack

The addition of an internal TV jack to the Lab will allow for TV transmission directly from the vehicle. TV transmission would be time shared with the 410-kb/s data channel in the full FM mode. Additional cables and switching would be required.

5.5.8 General Discussion and Conclusions

The recommended communications systems satisfy the requirements of the Lab. Table 5.5-2 summarizes the approaches to providing the additional data channel.

Table 5.5-1

COMMUNICATIONS TIME

Orbit Alt, n.mi	200		200		200	
Inclination, deg	28.5		50		90	
Rev No.	Transit Time, min	T/R On, min	Transit Time, min	T/R On, min	Transit Time, min	T/R On, min
1	17.43	73	0	0	11	14
2	16.38	36	8.96	19	1.78	5
3	39.23	68	17.88	39	6.21	9.5
4	38.62	53	33.2	49.5	13.39	22.5
5	17.9	29	14.5	17.5	4.69	15.5
6	13.52	19	10.75	14	11.61	18.5
7	10.79	23.5	3.66	7	15.85	20
8	8.33	15	6.28	9.5	7.55	10
9	4.67	8	6.36	9.5	7.43	10.5
10	7.27	10.5	7.51	10.5	4.87	8
11	6.7	10	7.27	10.5	4.17	7.5
12	2.92	6	10	16	7.9	14
13	7.1	10.5	7.35	13.5	13.36	19
14	21.23	32	17	23	7.52	11
15	24.44	35	11	14	16.7	23
16	29.85	39	14.5	17.5	12	18
17	27.89	39	13	19	7.5	11
18	33.31	52	18	32	0	0
19	36.22	57	19.1	37	7.53	11
20	32.76	55	22.16	32.5	0	0
21	19.45	34	23.3	38	21.12	29
22	11.96	23	6.8	10	6.29	16
23	7.19	10.5	2.76	6	15.38	22
24	4.22	17.5	7.5	10.5	7.4	10.5
25	13	19	0	0	7.54	11
26	14.72	21	11.78	18	0	0
27	0	0	16.5	25	7.22	10.5
28	6.54	10	7.3	10.5	13.35	19.5
29	16.89	27	14.37	20.5	7.73	11
30	24.29	31.5	12.5	18.5	15	22
31	25.66	36	18.5	21.5	16	22.5
32	26.41	36.5	9.75	16	7.54	11
33	33.35	54.5	9	15	5.74	9
34	34.87	52	17.5	33	3.16	6.5
35	38.25	51	12.9	27	6.37	10
36	29.4	48	22.5	34	8	17
37	13	23	8.85	12	13.48	19
38	9	22	0	0	13.6	20
39	12	27	4.5	7.5	18	25
40	12	18	2.6	4	8	11
41	8.5	14.5	6.17	11.5	6.78	10
42	9	12	7.29	10.5	0	0
43	5	8	15.03	21.5	7.26	10.5
44	15.5	27	9.23	19	0	0
45	21	32	14.6	18	21.9	29.5
46	26	36.5	16.4	22.5	.97	4
47					18.21	24.5
48					7.63	11
	Per 46 Revs		Per 46 Revs		Per 47 Revs	
Max. Comm Time Available, min	833.76		543.86		417.1	
Total Xcvr Time On, min	1362.0		820.5		629.5	
On-Off Cycles	68		64		58	

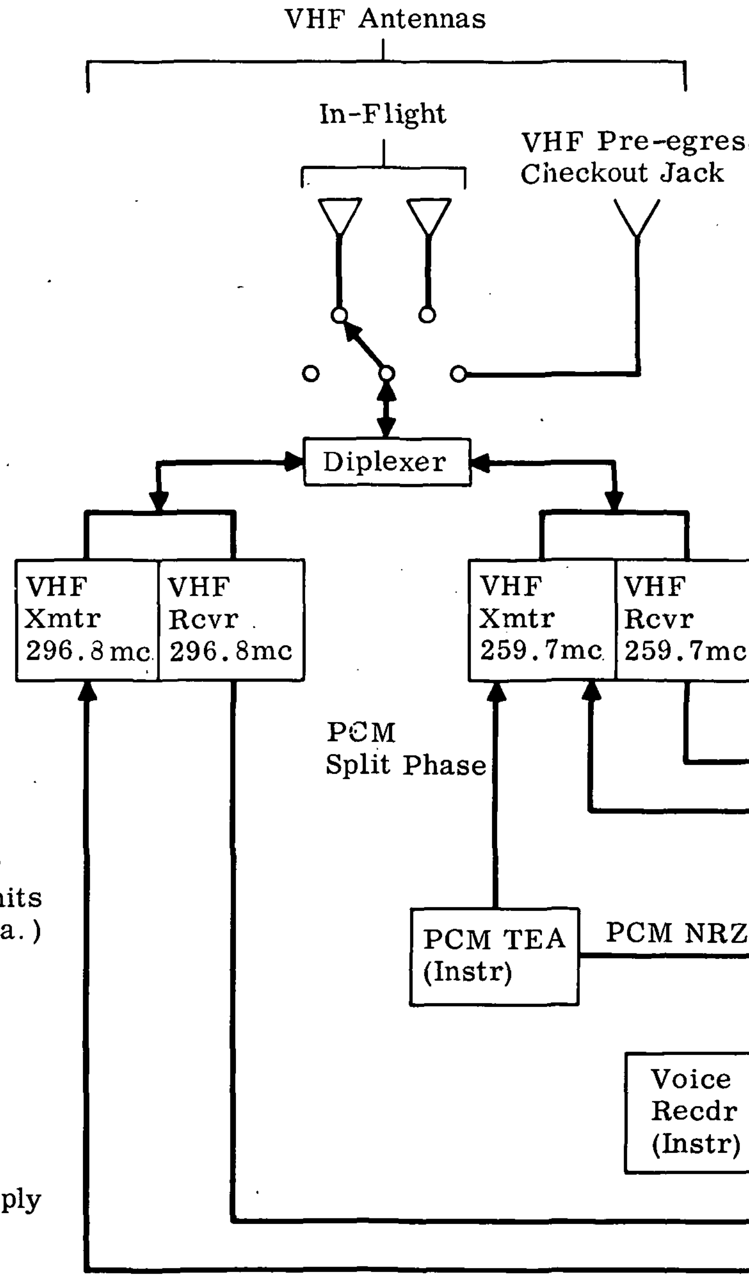
Table 5.5-2

SUMMARY OF POSSIBLE MODES OF ADDITIONAL DATA TRANSMISSION

Mode	Data Rate, k-bits/sec	Mods	To be Determined or Reqd
1. PM • On 500-kc baseband	402.6	To SPA	• Ability of ground to handle wideband data in PM mode. • Details of mod.
2. FM • On 500-kc baseband (RECOMMENDED)	409.6	None	• Ability of ground to track 200 n.mi Lab in FM mode. • Exact nature of added hardware. • See Note.

Note: It is assumed that the ground stations can process the FM wideband data because of their ability to receive and process the Apollo TV signal.

121



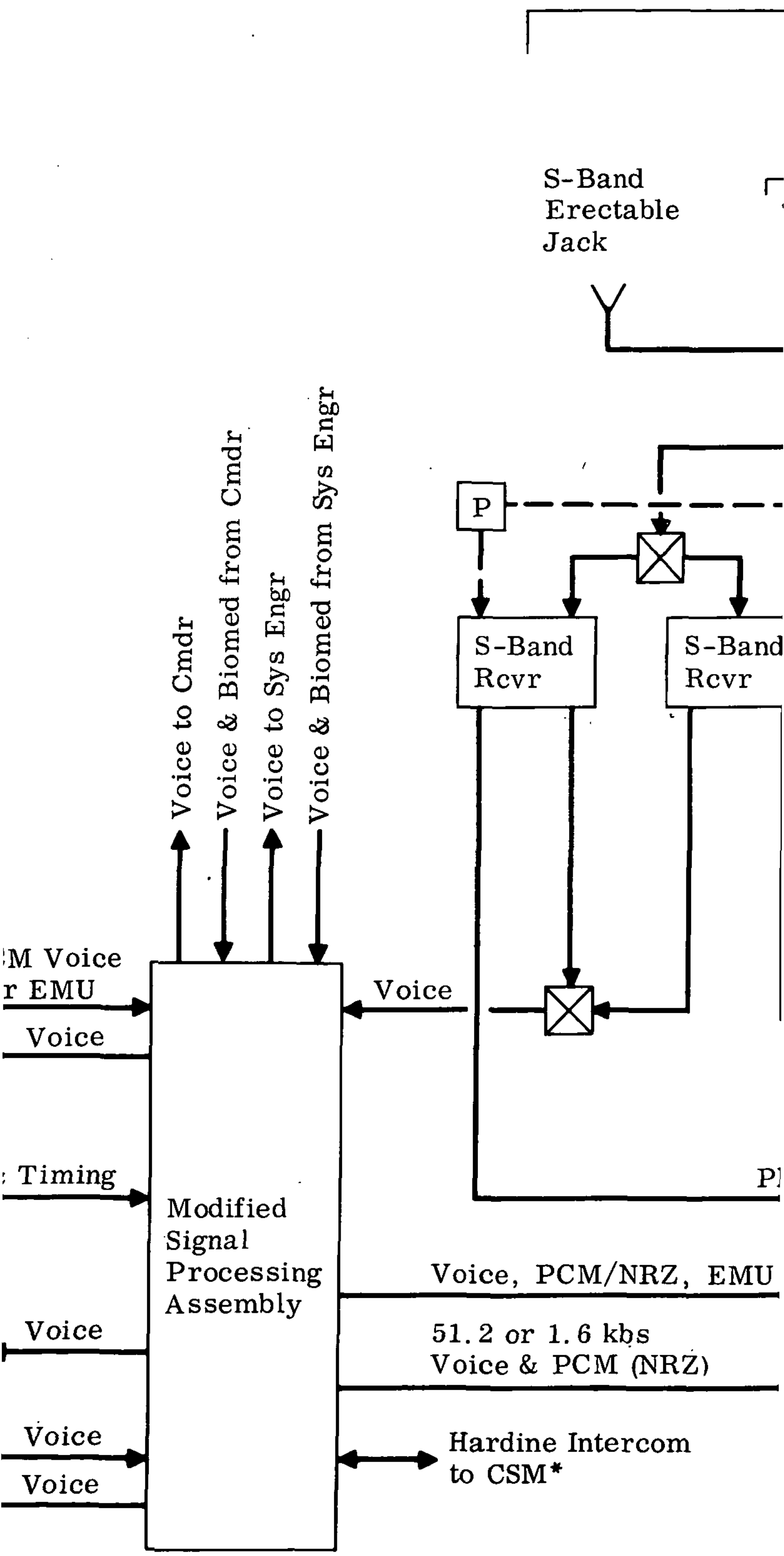
Note: EMU (Extravehicular Mobility Unit Transmits both EVA voice & data.)

*Change from present LEM system.

Key

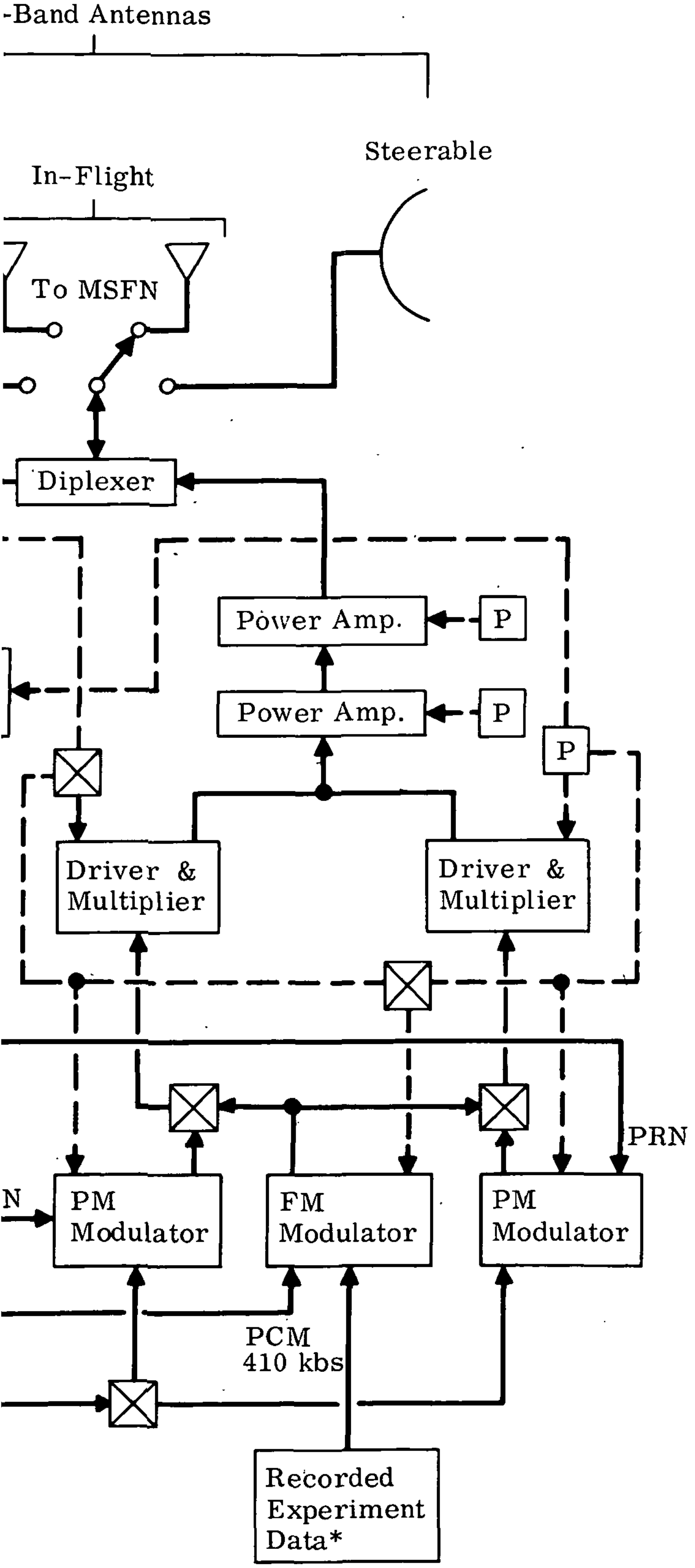
P → Power Supply

→ Signal


S-Band
Erectable
Jack
P
S-Band
Rcvr
S-Band
Rcvr
Voice to Cmdr
Voice & Biomed from Cmdr
Voice to Sys Engr
Voice & Biomed from Sys Engr
M Voice
r EMU
Voice
Timing
Voice
Voice
Voice
Voice
Modified
Signal
Processing
Assembly
Voice, PCM/NRZ, EMU
51.2 or 1.6 kbs
Voice & PCM (NRZ)
Hardine Intercom
to CSM*

2

Fig



5.5-1 Communications System Schematic

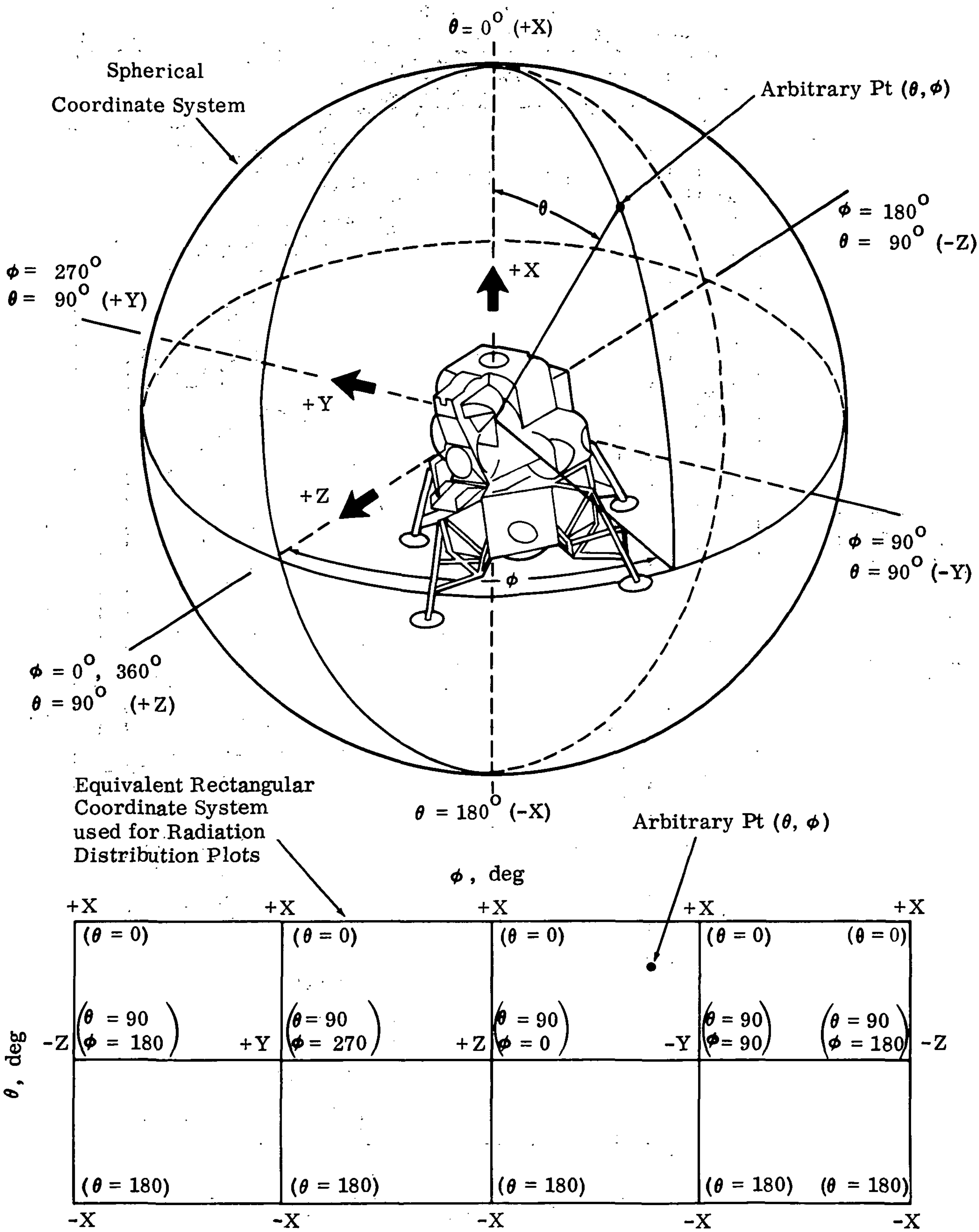


Fig. 5.5-2 Sphereical/Rectangular Coordinate Transformation

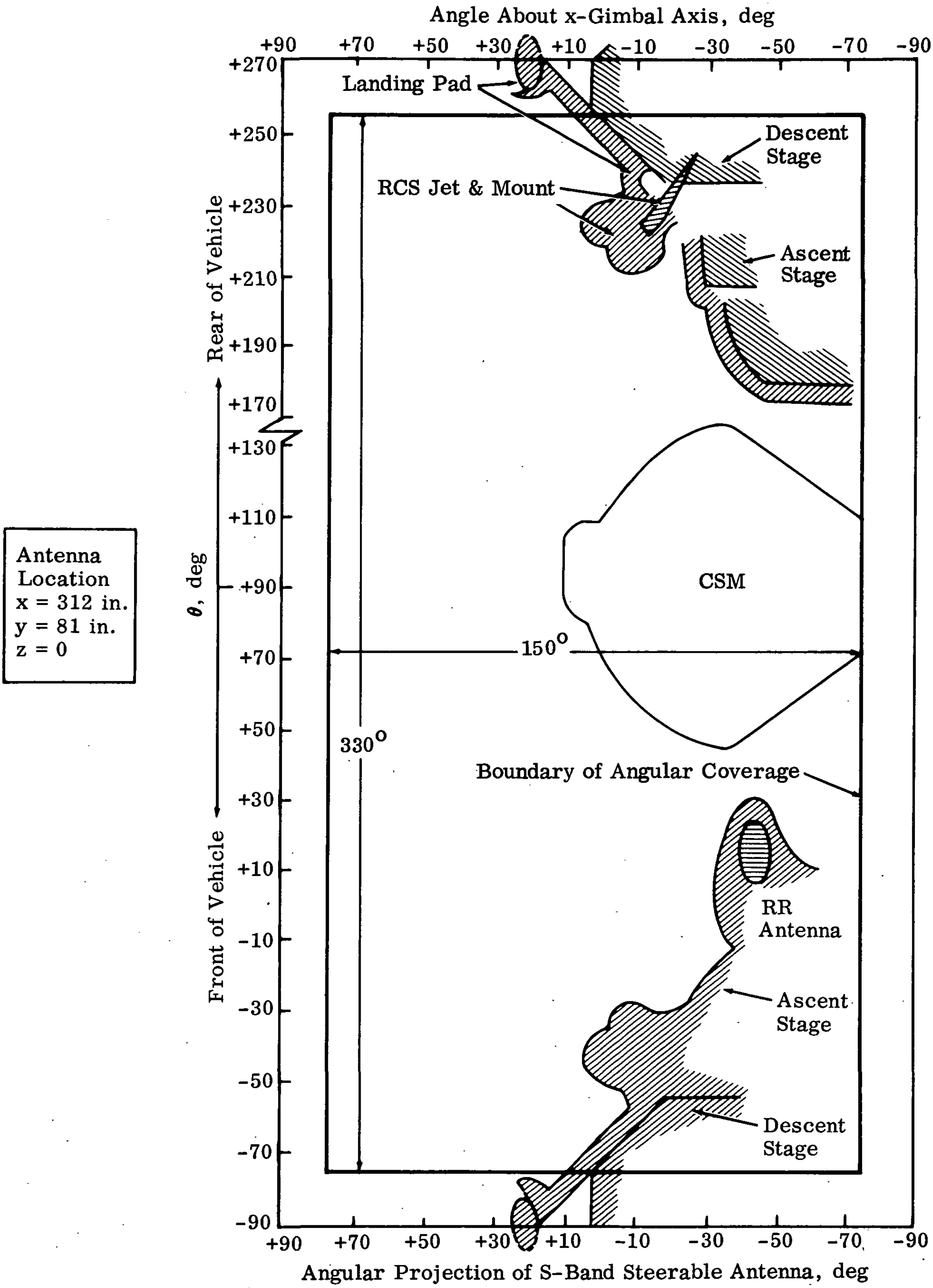
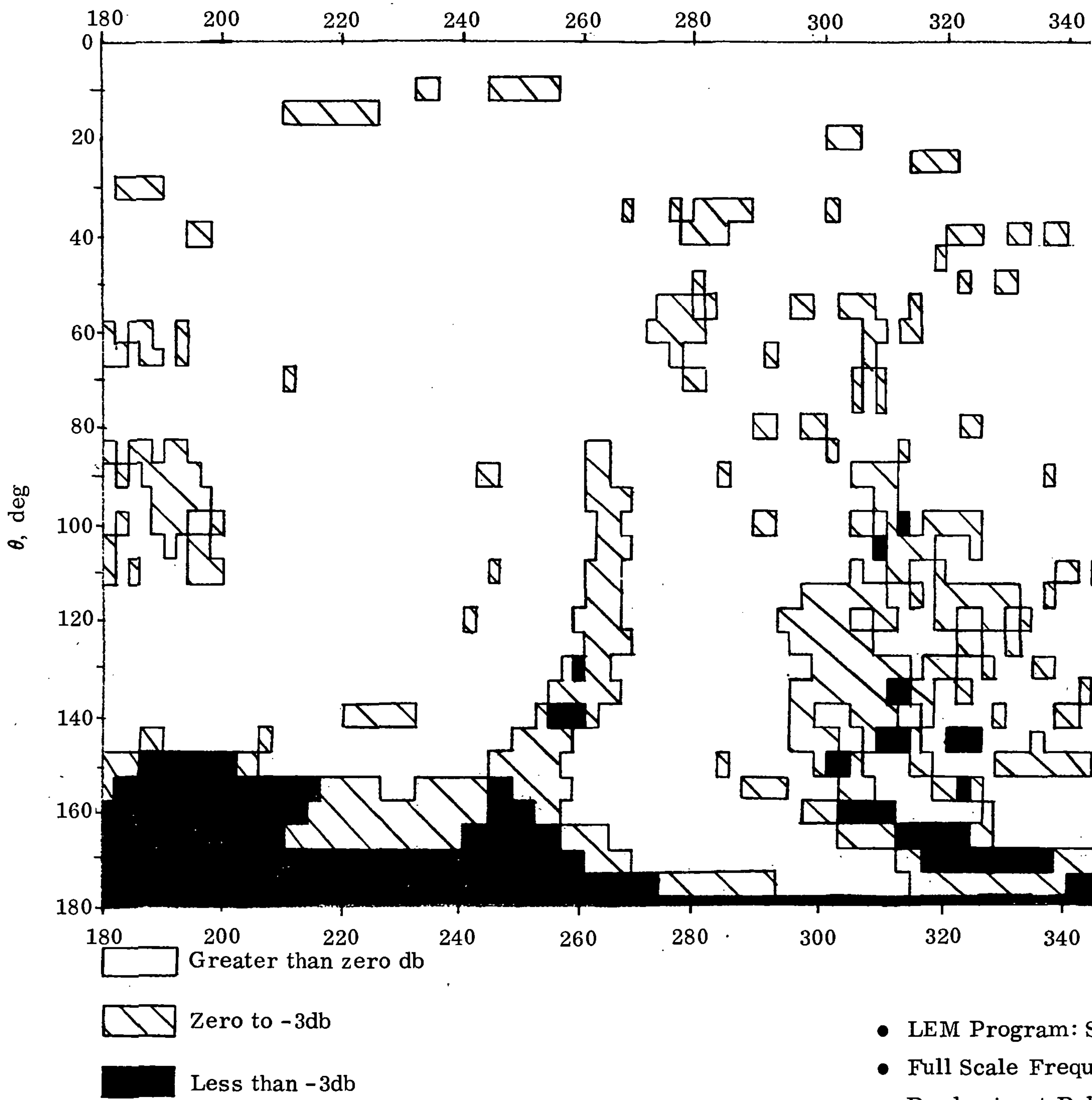
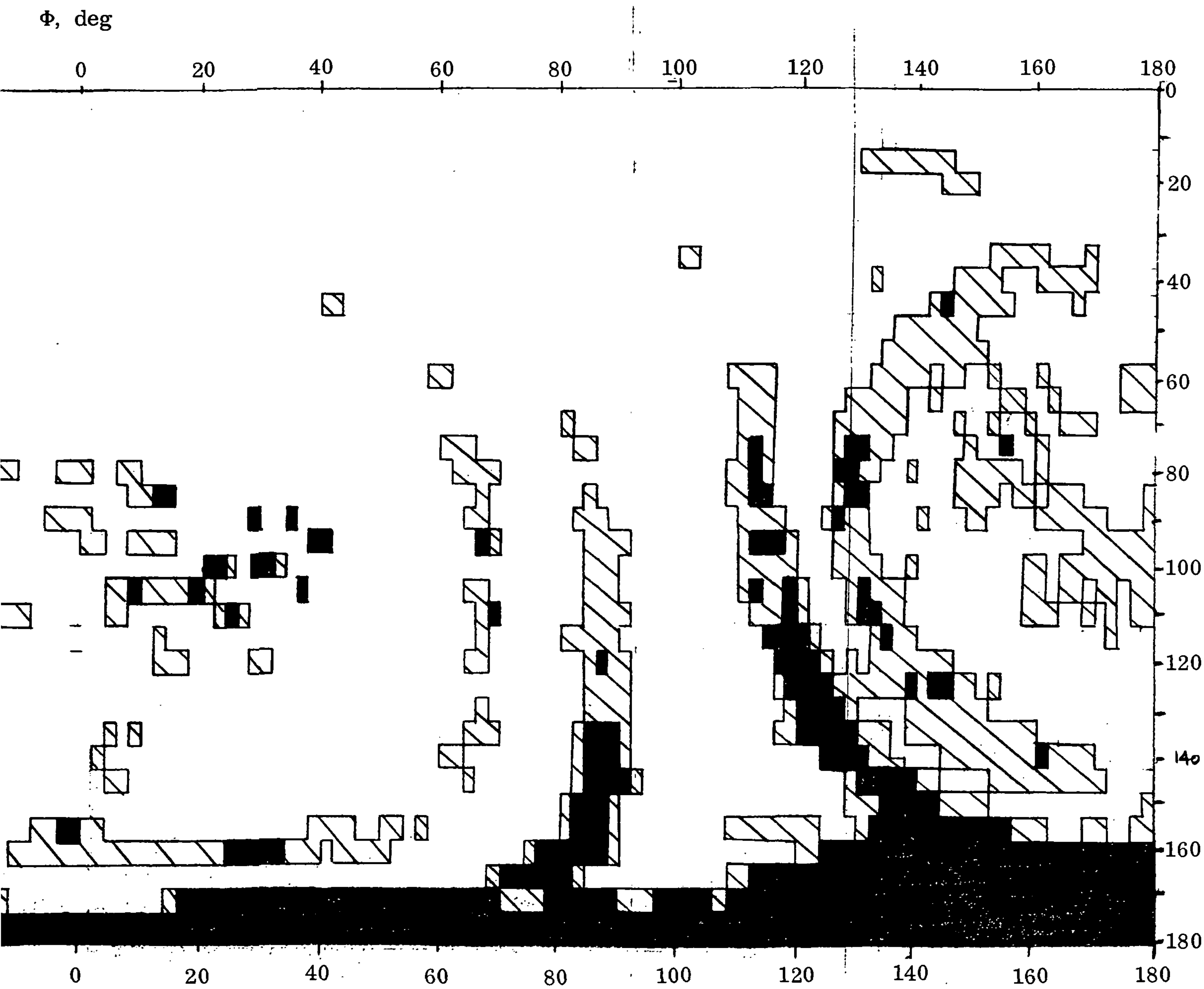


Fig. 5.5-3 S-Band Steerable Antenna Angular Coverage on a Projection of 2 Sphere



- LEM Program: S
- Full Scale Frequ
- Predominant Pol
- Antenna Type: C
- Model Scale: 1/6
- Model Scale Fre



·Band System
ncy: 2101mc
rization: RCP
ıical Log Spiral

ıency: 12.6 Gc

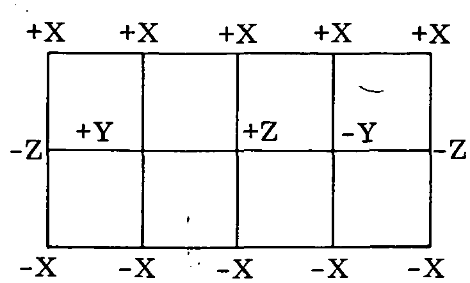
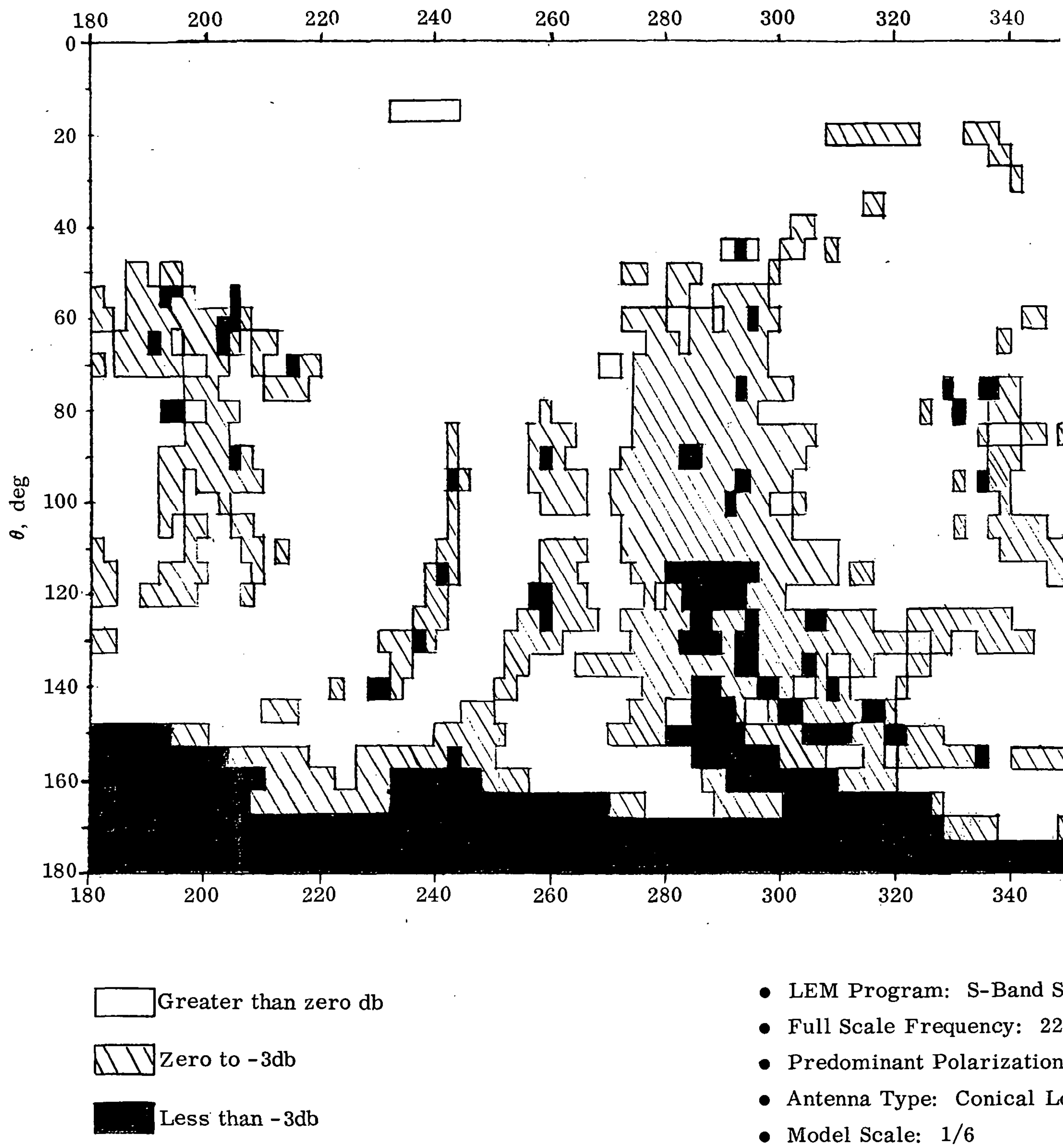
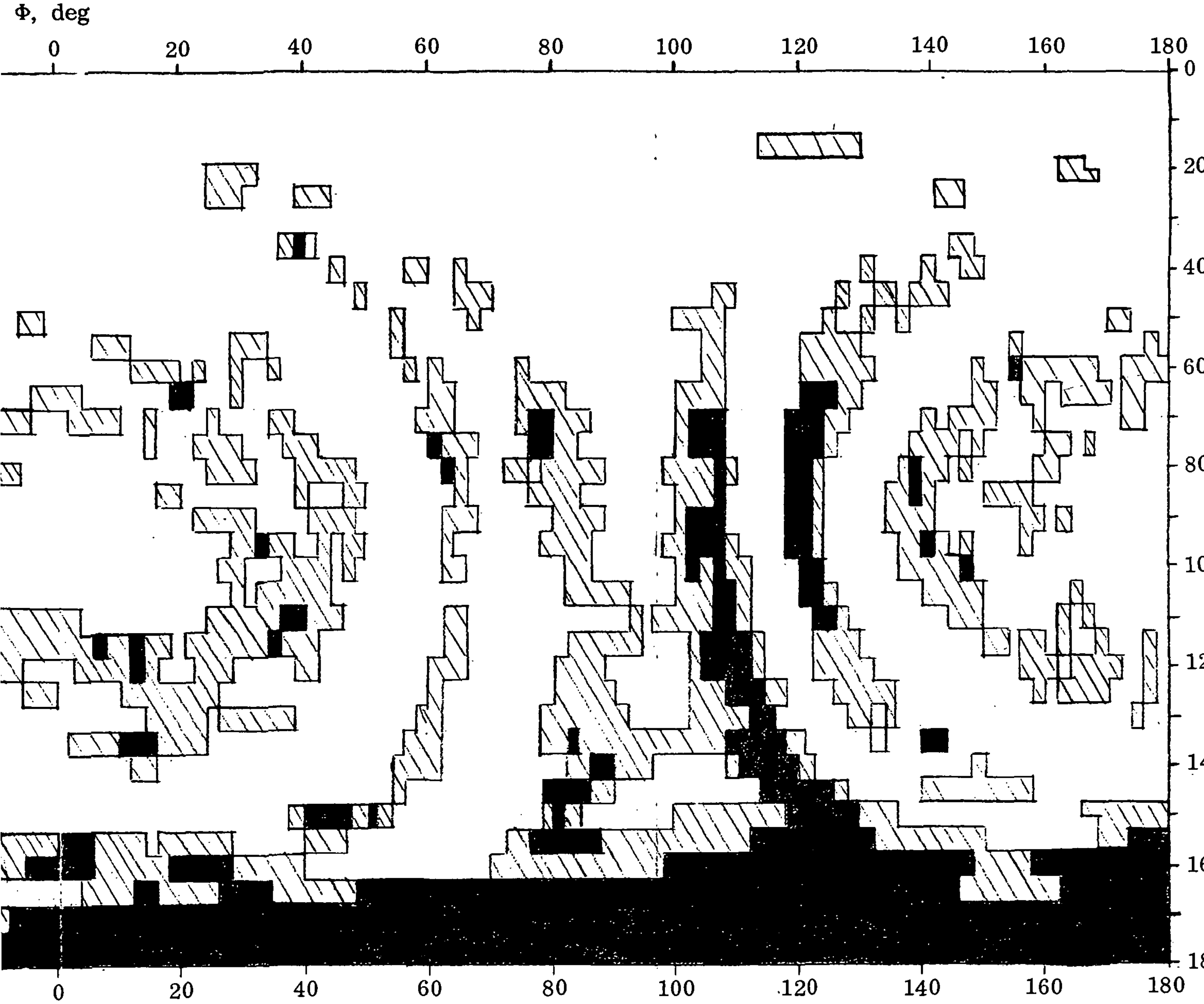


Fig. 5.5-4 S-Band In-Flight Antenna Receive

(127)



- LEM Program: S-Band S
- Full Scale Frequency: 22
- Predominant Polarization
- Antenna Type: Conical L
- Model Scale: 1/6
- Model Scale Frequency:



stem

2 mc

RCP

g Spiral

3.7 Gc

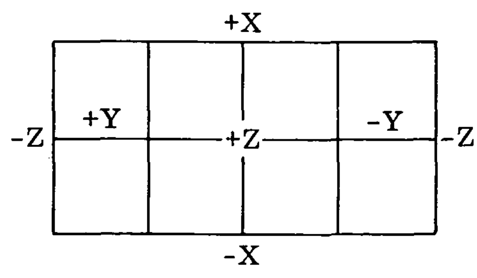


Fig. 5.5-5 S-Band In-Flight Antennas Transmit

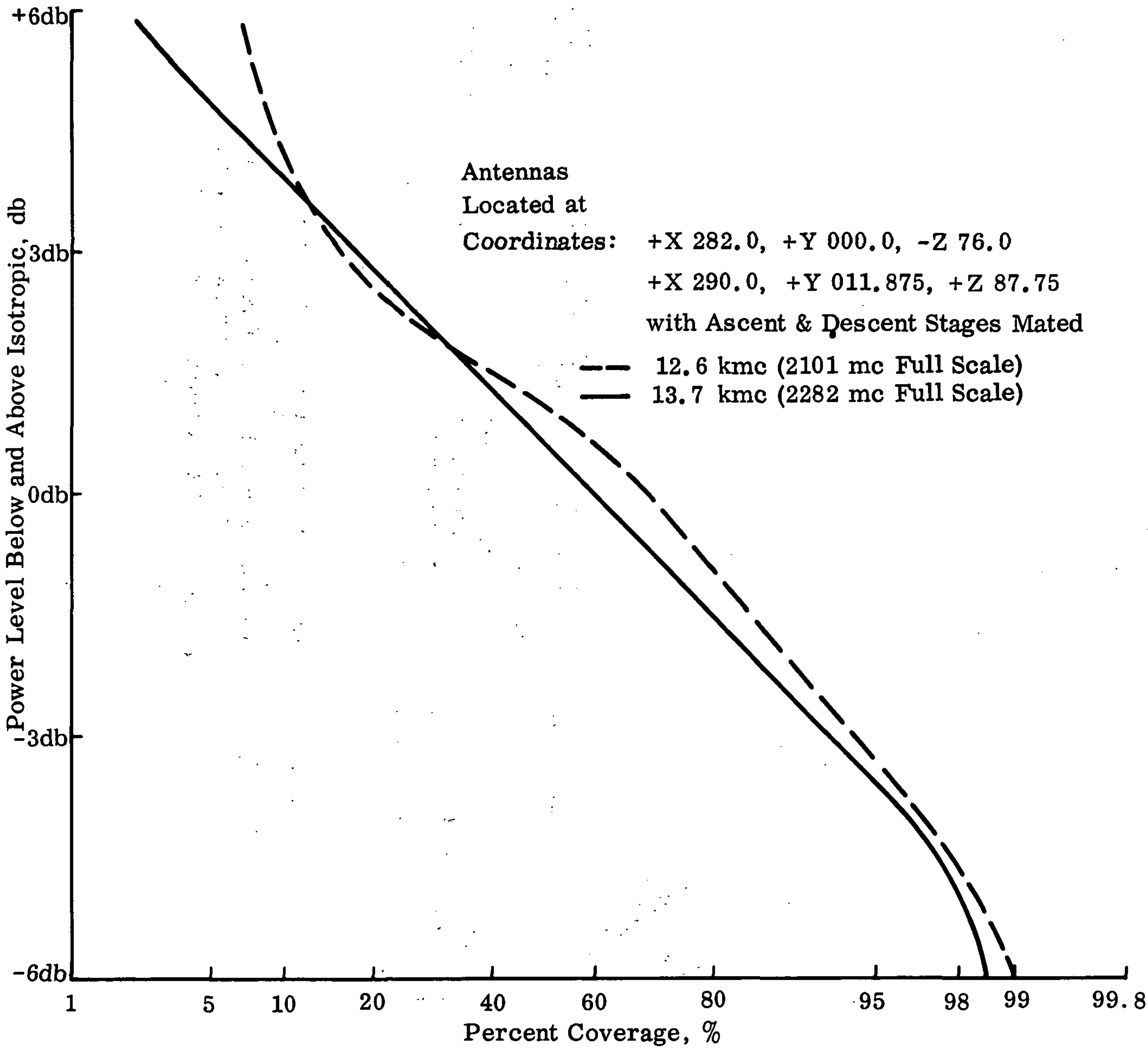
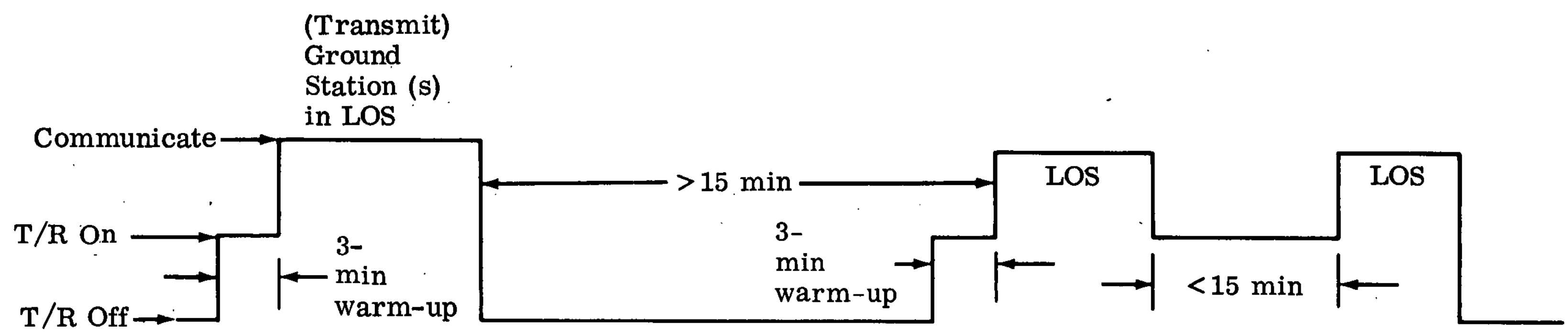


Fig. 5.5-6 S-Band In-Flight Antennas, Percent Coverage



Assumptions:

- Transmitter Warm-Up Time = 3 min
- When the Interval Between Ground Stations is Less Than 15 min, the Equipment is Left On To Reduce Off-On Cycling.

Fig. 5.5-7 Time Line Code

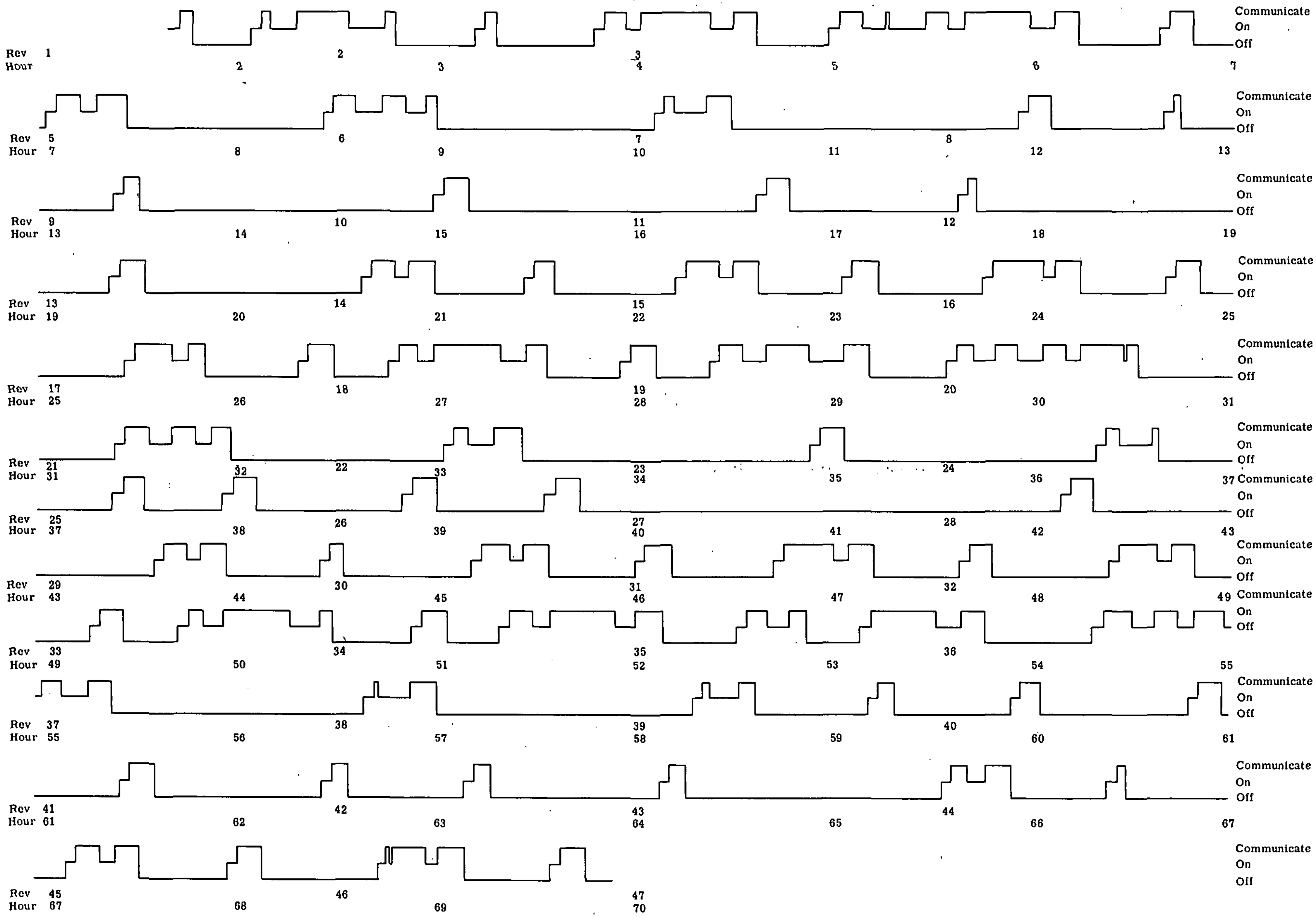


Fig. 5.5-8 Communication Profile - 200 N. Mi and 28.5° Inclination

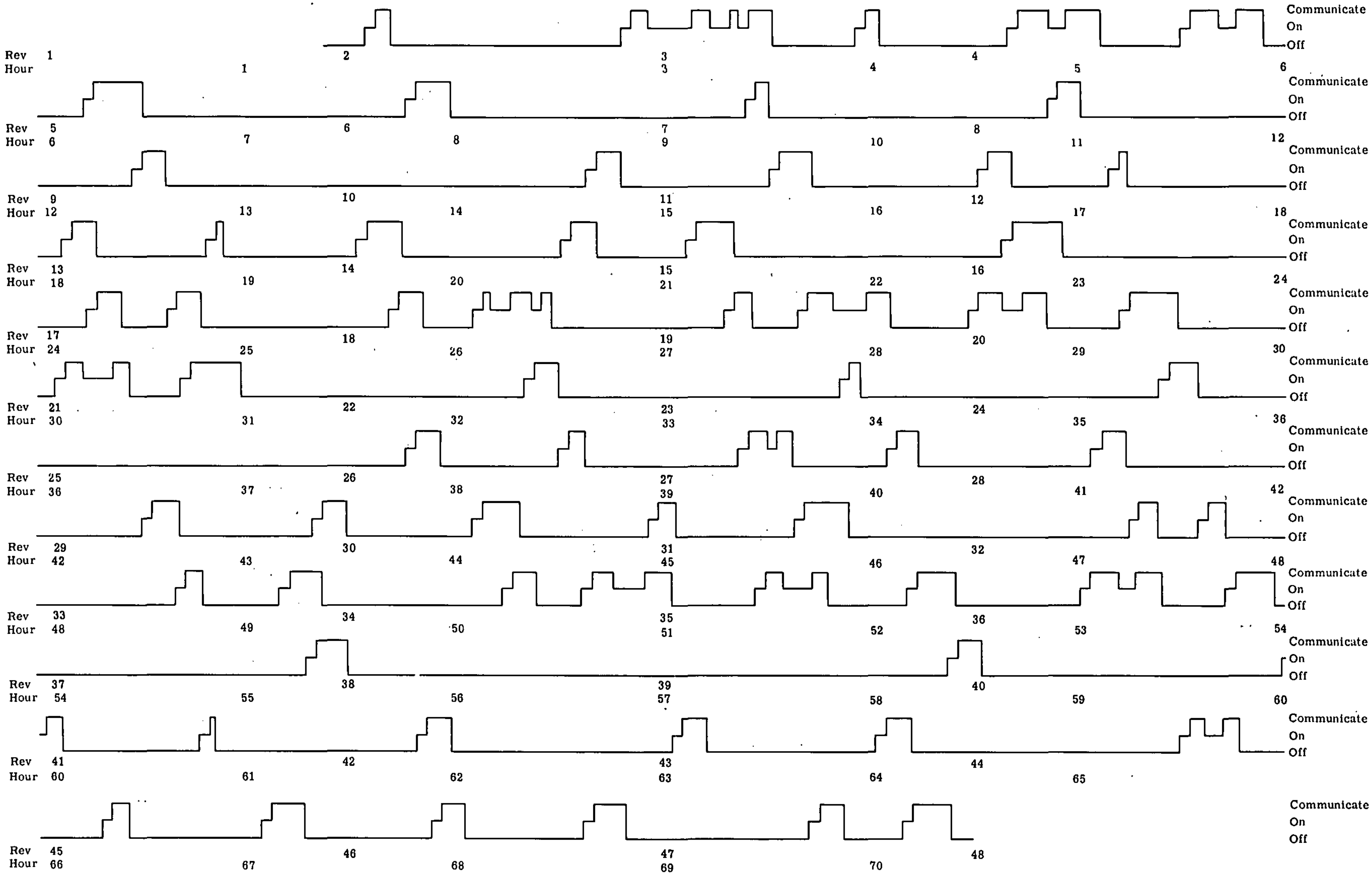


Fig. 5.5-9 Communication Profile - 200 N. Mi and 90° Inclination

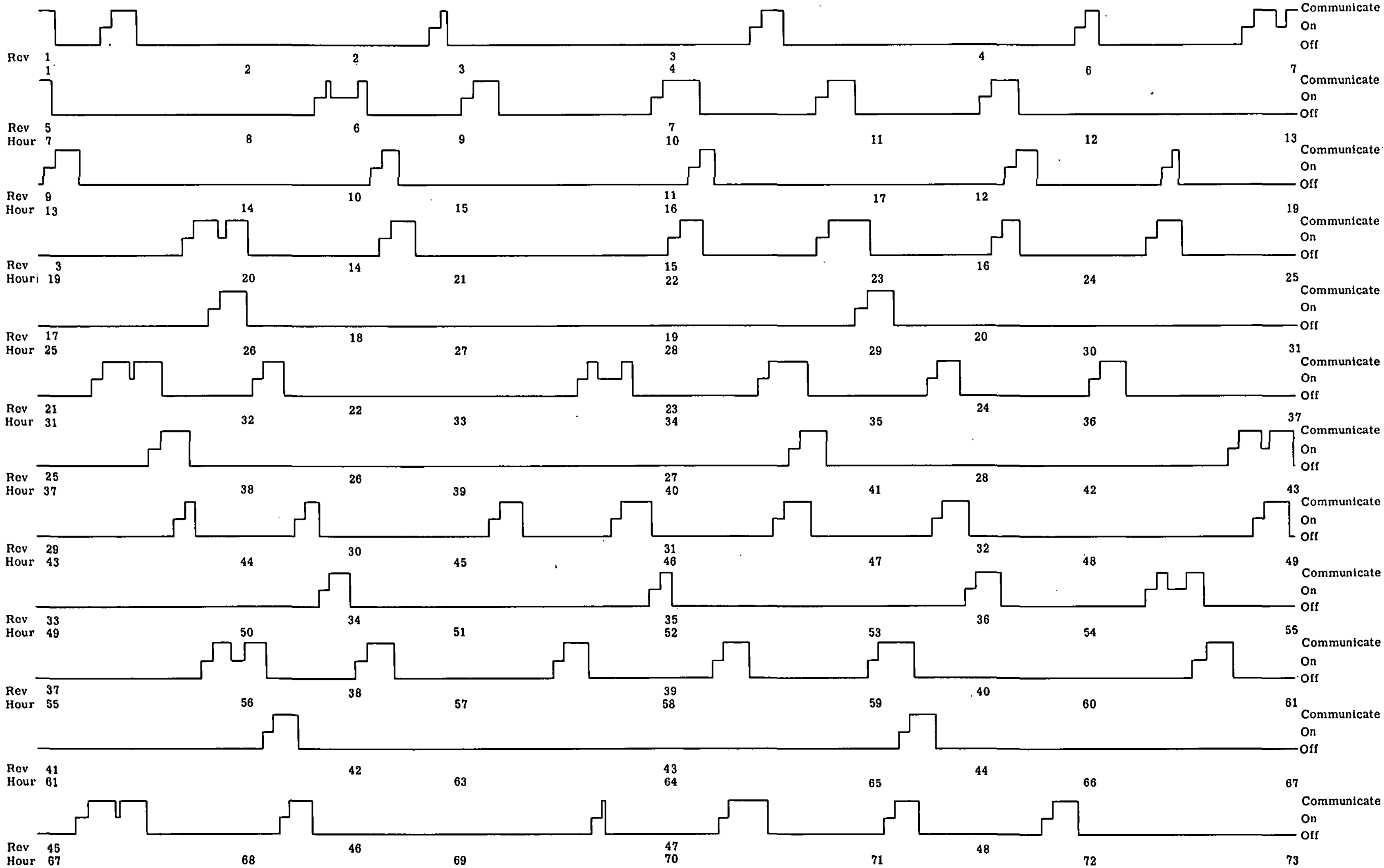


Fig. 5.5-10 Communication Profile - 200 N. Mi and 90° Inclination

Grumman

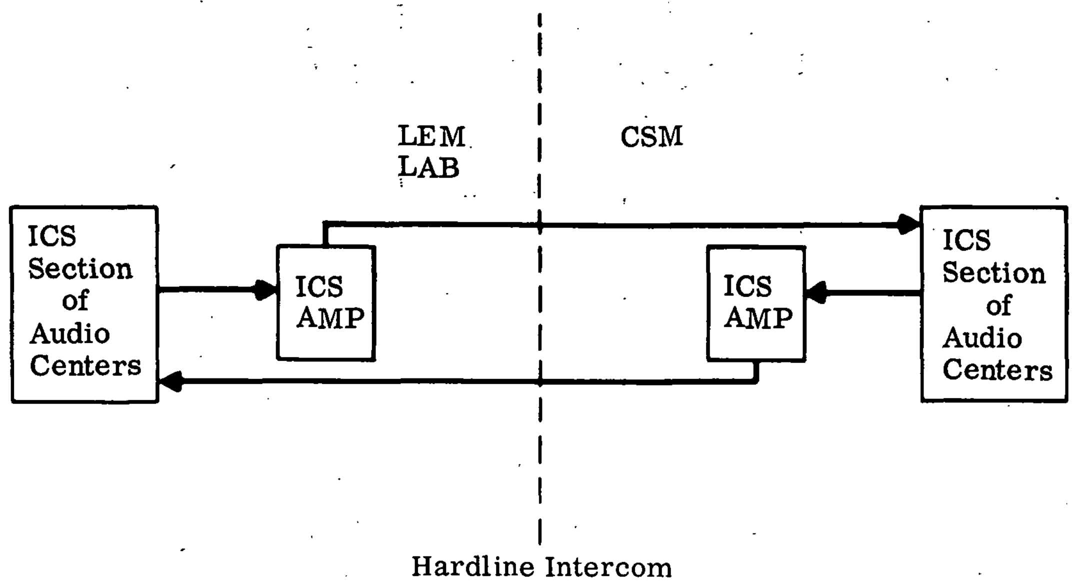


Fig. 5.5-11 CSM/Lab Intercom

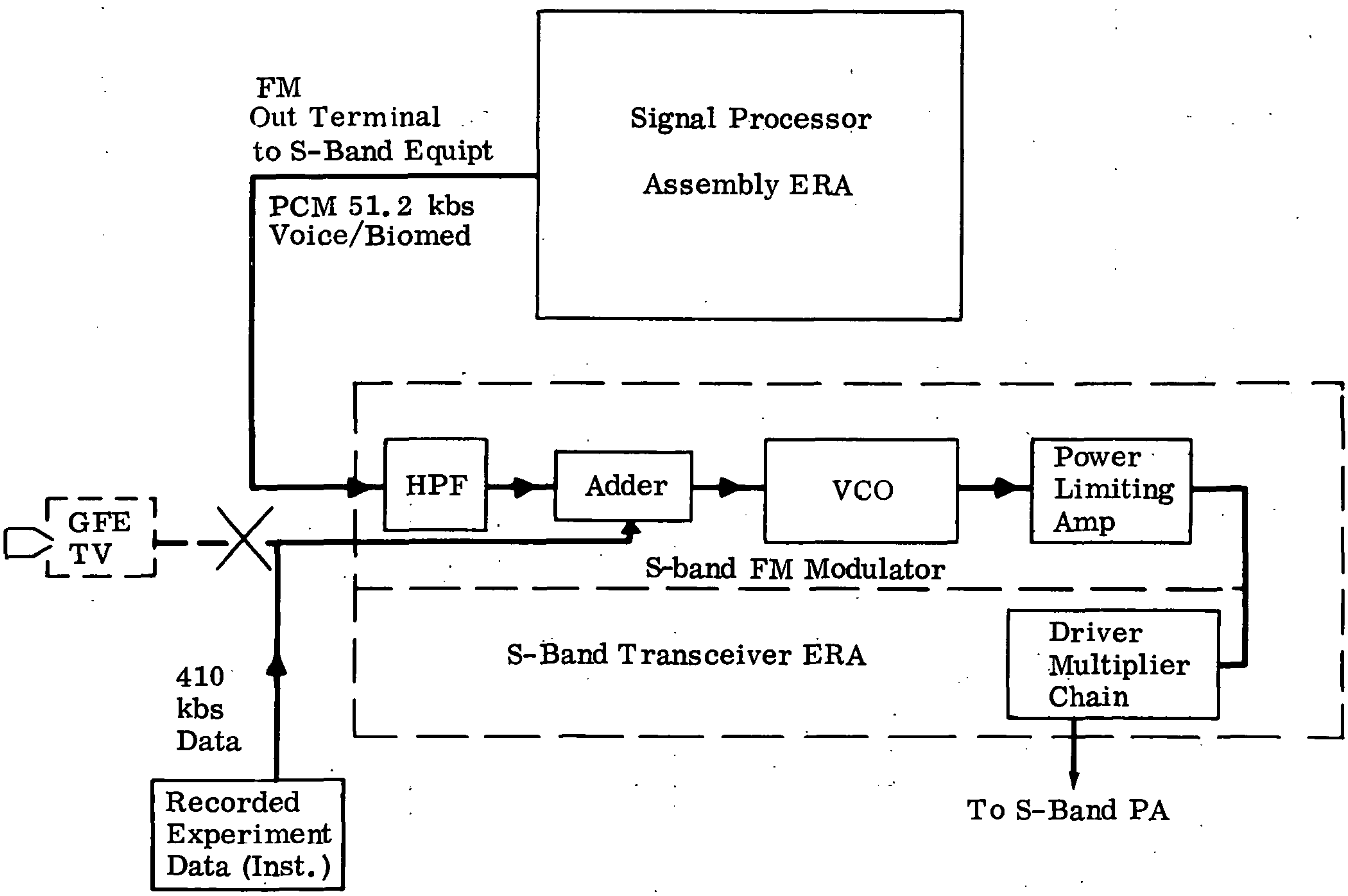


Fig. 5.5-12 Additional PCM Data Channel

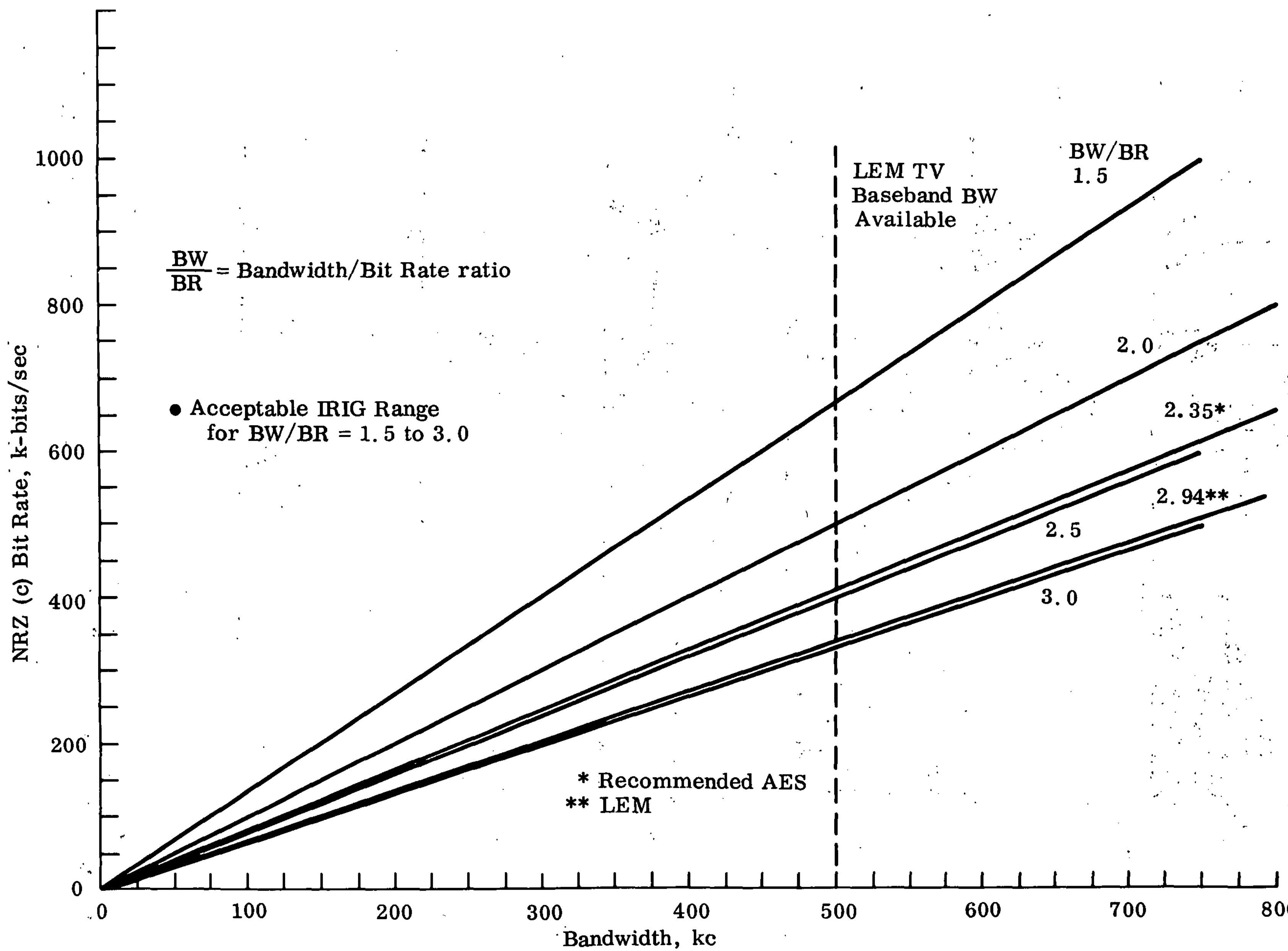
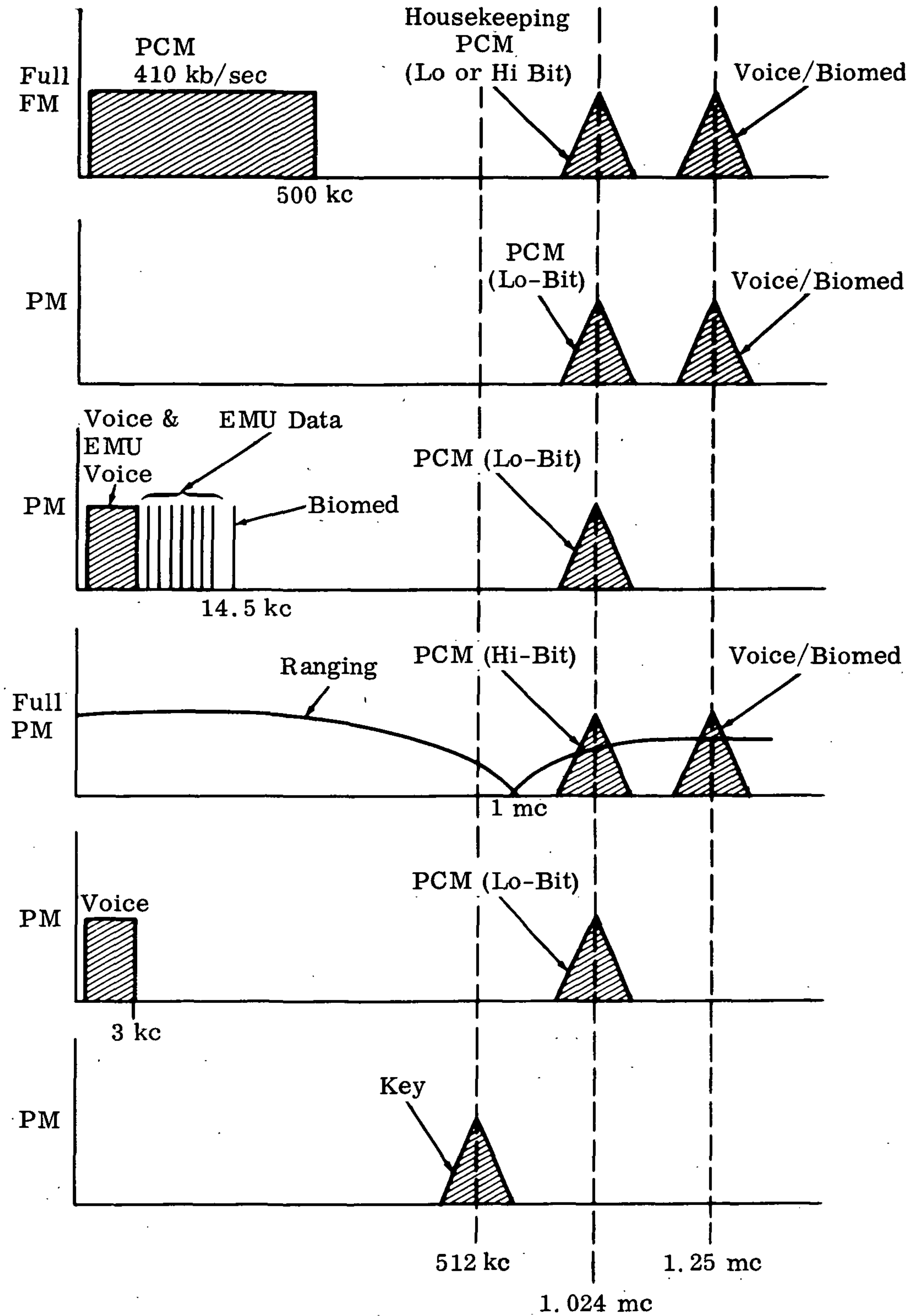


Fig. 5.5-13 Bandwidth and NRZ (C) Bit Rates for Various Bandwidth to Bit Rate Ratios



Hi bit = 51.2 kilo bits per second
Lo bit = 1.6 kilo bits per second

Note:
Where Lo-Bit Rate is Indicated, the Hi-Bit Rate May be Substituted.

Fig. 5.5-14 Lab Operation Modes

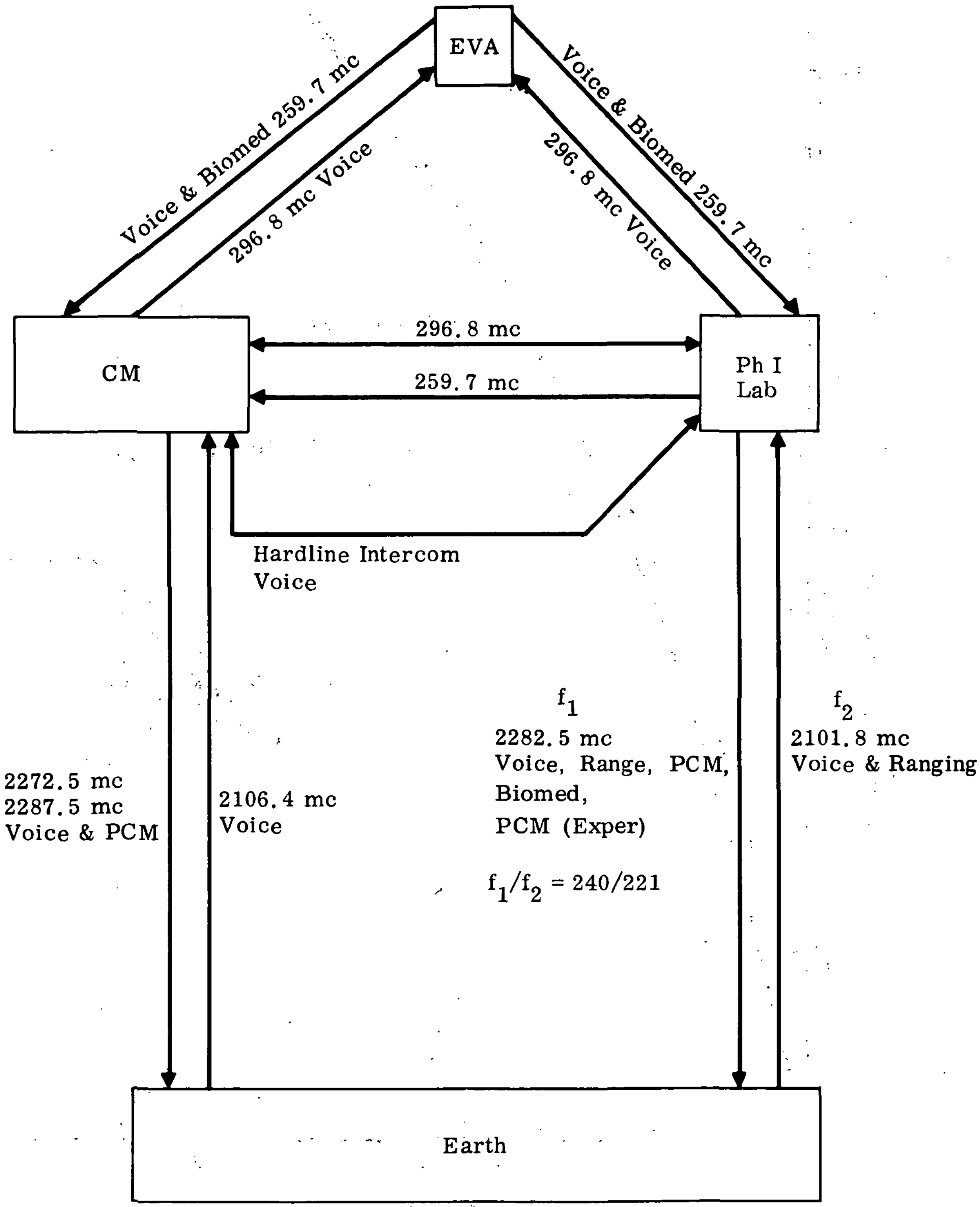


Fig. 5.5-15 Lab Frequency Allocation

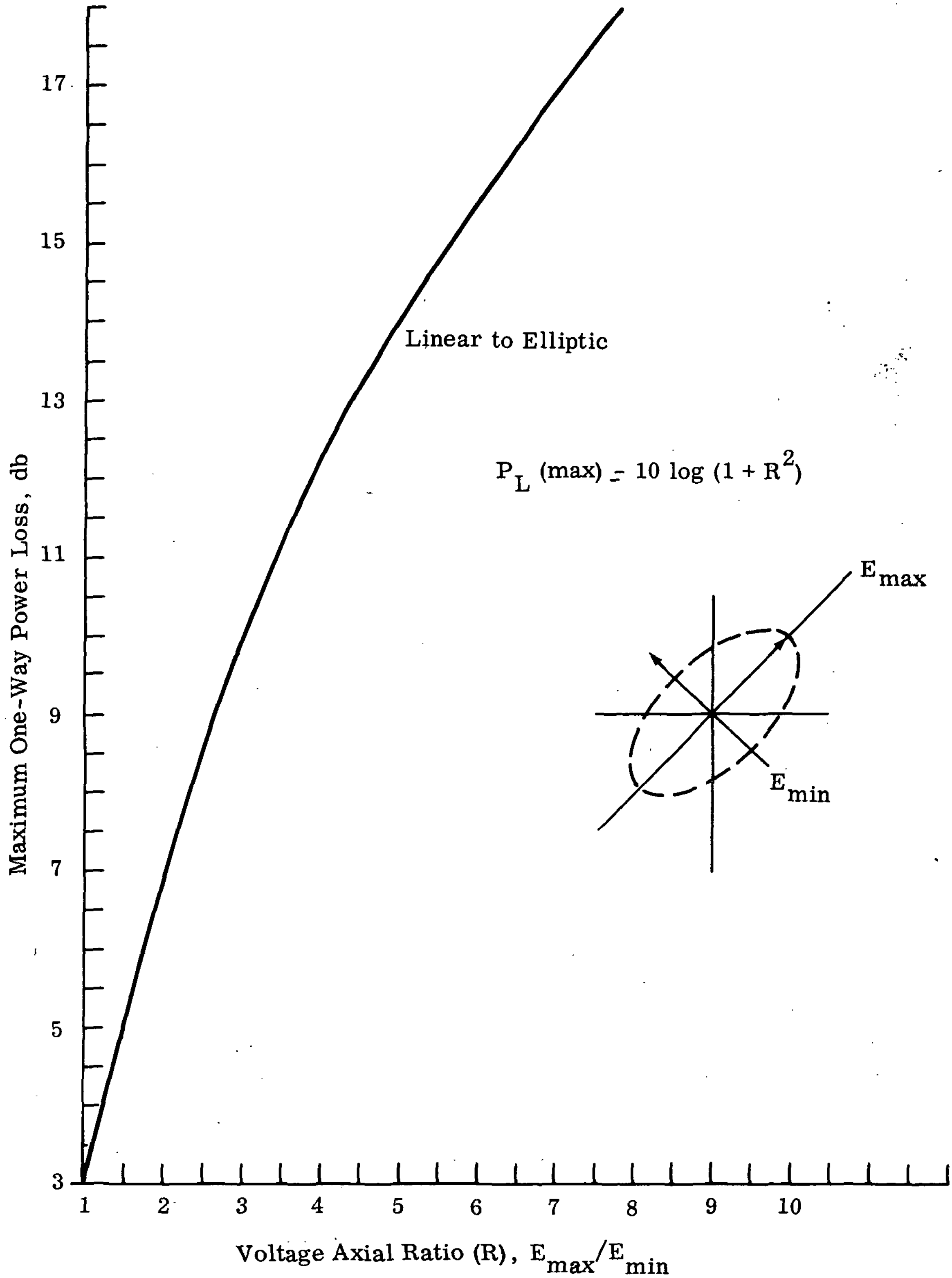


Fig. 5.5-16 Maximum One Way Power Loss VS Voltage Axial Ratio

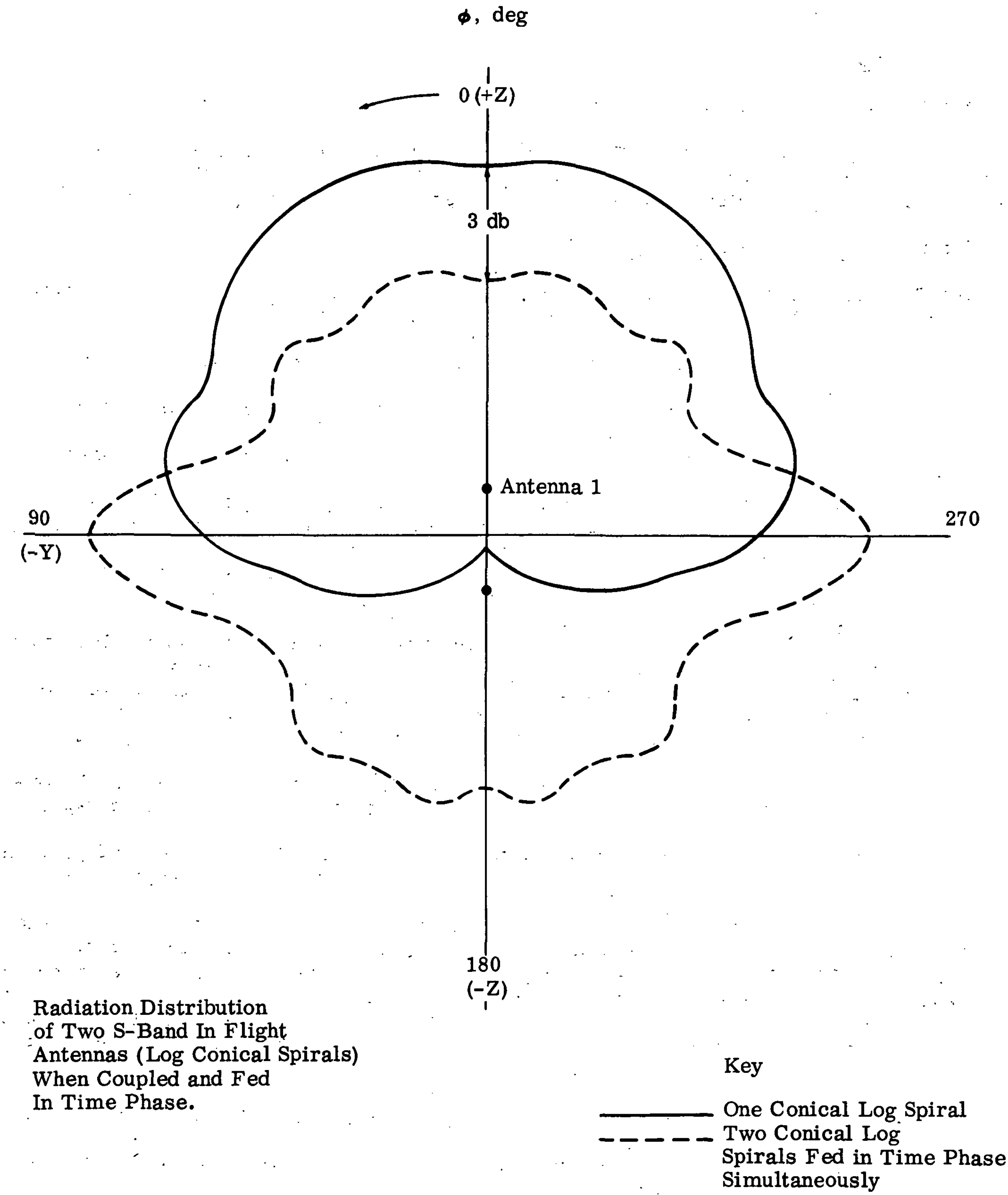


Fig. 5.5-17 Coupled Omni - Antenna Radiation Pattern

5.6 INSTRUMENTATION

5.6.1 Ground Rules

The following is a list of ground rules used for the Phase "B" effort:

- The Lab Module carries its own Communications and Data Handling System
- There will be no data interface between the Lab and the CSM.
- Video Transmission will be through the CM-S-Band Line (real time only)

5.6.2 Assumptions and Background Data

The following assumptions were used in standardizing an approach for the operational and experiment acquisition sections of the Phase II vehicles:

- Any changes in the operational measurements will not exceed the present Lunar LEM measurements.
- Maximum utilization of the crew for redundancy monitoring and failure mode corrections/operations will be used.
- All Operational data will be presented to the ground during line-of-sight mission phases only. (Real time)
- There will be no on-board recording capability for operational data.
- All vendor supplied experiments will provide their own signal conditioning compatible with the AES experiment acquisition system.
- All experiment data will be considered "passive" for ground reduction (not requiring real time display). On-board display of selected experiment parameters will be available to the astronauts.
- The data record, dump or re-dump requirements will be the responsibility of the astronauts and will not require any ground uplink control.
- All experiment data to be routed to other subsystems in addition to the Instrumentation Subsystem shall be done so through separate outputs.
- Experiment data will be on-board recorded during periods of flight not covered by line-of-sight.
- Experiment data set-up, pre or post calibration and operation will be on-board controlled and will not require any ground uplink support capabilities.
- Experiments requiring analog data recovery will utilize the analog portion of the experiment tape system or it is assumed part of the experiment.

The primary function of the Operational Instrumentation Section is to acquire and present spacecraft housekeeping data to the astronauts and ground monitoring personnel (Fig. 5.6-1). In reviewing the measurement requirements of the standard vehicle, it was concluded that the existing LEM equipment would continue to fulfill this task. The handling capabilities remaining are sharply limited and handling of experiment data within the system cannot be performed for the following reasons:

- The Operational Section is tailored to support the spacecraft subsystems and provides no provisions for growth.
- The present system offers no data storage or recording and would limit any experiment operation.
- The remaining PCMTEA input channels are few and the experiments would be required to conform to its fixed format.

An independent experiment data acquisition system was chosen to handle experiment data (Fig. 5.6-2). Based on investigation of preliminary data requirements and maximum use of existing Apollo hardware, the use of a modified LEM PCMTEA has been selected to provide the multiplexing, timing and encoding functions because it

- Has suitable mechanical configuration
- Is qualified for expected environment
- Is capable of operating without external timing inputs
- Has diversity of data handling capability

The prevalence of experiment data acquisition requirements in the absence of ground station coverage indicates the need for experiment data storage capabilities. An investigation of available qualified flight tape recorders yielded the result that two modified Apollo CM tape recorders can provide substantial data storage capability for the support of Phase II experiments. Some of the major advantages of these recorders over the others investigated are that they:

- Are existing Apollo hardware
- Have in-flight reloading capability
- Have suitable mechanical configuration
- Are qualified for the expected environment
- Accept LEM PCMTEA data directly
- Provide data compression capability

The requirement for two recorders stems from the fact that the time duration of data storage for some experiments exceeds the record time capability of a single recorder. The loss of data during rewind and dump or possibly tape reloading intervals is avoided by use of a second recorder.

5.6.3 Recommended Configuration

5.6.3.1 Spacecraft Operational Section

The recommended Operational Instrumentation Section for the Phase II Lab is mainly comprised of existing LEM assemblies having a certain built-in flexibility which allows for some minor configuration changes. The measurements list (Table 5.6-8) prepared for the standard vehicle 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 5.6-1.

5.6.3.1.1 Transducers. The sensors of the Phase II Lab 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

New spacecraft subsystem measurement requirements demand additional transducers, and consideration will be given first to LEM proven units. For any measurement unique to the Phase II Labs which requires a transducer not previously used on LEM, new transducers will be selected having similar characteristics 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 Phase II Lab appears in Table 5.6-2. Allocated transducer weight and power consumption is listed on the enclosed measurements list (Table 5.6-8).

5.6.3.1.2 Signal Conditioning Electronic Assembly (SCEA). The SCEA as presently designed for LEM, is a unit which conditions the signals from transducers and numerous signal monitoring points throughout the spacecraft and properly routes them to the Operational PCMTEA, Caution and Warning Electronics Assembly (C&WEA) or on-board displays. The SCEA assemblies fulfills these basic functions:

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

The SCEA is comprised of two separate chassis assemblies. Each assembly can accommodate up to twenty-four (24) separate sub-assembly modules. Once the measurements are determined for a given AES mission an analysis will be performed on each measurement in order to assign a signal conditioning circuit to that measurement. The total number of signal conditioning sub-assemblies for the mission are then packaged into the two assemblies. The Phase II Lab measurements list (Table 5.6-8) reflects deletion of some existing LEM measurements and the addition of new measurements required for the AES. A review of this listing indicates that the changing requirements for measurements can still be accommodated within the existing SCEA using adapation techniques presently employed by LEM. No modification to either the assembly or its sub-assemblies, as now used by LEM is anticipated, based on the measurements summarized in Table 5.6-3. However, each unit will require a new configuration of sub-assemblies. In the SCEA:

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

5.6.3.1.3 Caution and Warning Electronic Assembly (C&WEA). This assembly advises the astronauts of the spacecraft subsystem status by continual monitoring of critical parameters. During the mission the C&WEA performs two basic functions:

- The caution function advises the astronaut of a malfunction which requires his action to correct
- The warning function advises the astronaut of crew safety items requiring immediate action.

The C&WEA accepts inputs from the SCEA or pre-conditioned signal sources from the subsystems. These inputs are compared to preset reference signals within the C&WEA to detect out-of-tolerance conditions. When an out-of-tolerance condition exists, an appropriate indication is initiated. The C&WEA as now used for the Lunar LEM operates on discrete voltage changes or switch closures. Deletion of some subsystems from the Phase II Labs will make available some monitoring channels for the additional subsystem requirements.

5.6.3.1.4 Pulse Code Modulation and Timing Electronic Assembly (PCMTEA). The PCMTEA in the recommended configuration consists of an unmodified Lunar LEM assembly. The data acquisition capability of this unit include the multipliexing, 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 5.6-4. The unit operates at a normal data rate of 51,200 bits per second and a reduced data rate (commanded remotely) of 1,600 bits per second. The PCMTEA will operate as it does in the Lunar LEM including accepting a time reference from 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. Operation of the PCMTEA in the reduced data rate mode is not anticipated in Phase II missions.

5.6.3.1.5 Voice Storage Recorder. This magnetic tape recorder, originally referred to as the "Data Storage Electronics Assembly", provides a time correlated voice recording of comments and conversation between the astronauts during EVA's. This assembly employs automatic sequential record head switching with four tracks to provide up to a total of 10 hr of recording time. The compact recorder is generally used with voice actuation circuits to run only for a required recording time. The recorder is used:

- To support egress from CM to module
- To support EVA's
- To record comments of vehicle status when off station coverage
- To record proprietary information

5.6.3.1.6 Operational Measurements. The measurement requirements for the Phase II Lab are shown in Table 5.6-8. These measurements were initiated by the various AES-LEM 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 Section. 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 vehicle's subsystems. These measurements support the Spacecraft's performance and management plus providing sufficient information to:

- Enable normal spacecraft operations to be performed
- Provide the capability for decision making by the astronaut
- Monitor crew safety functions
- Provide status of expendable items
- Provide status of operational events

An Apollo Biomedical System Supports EVA's by monitoring such items as electrocardiograms and impedance pneumograms (respiration) with associated power converters, vest, harness and electrodes. This information is transmitted via the VHF link to the CM or the Lab for re-transmission to Earth. During the on-board stay however, only the electrocardiogram is monitored for transmission to Earth.

5.6.3.2 Experiment Instrumentation Section

The Experiment Instrumentation Section is an independent section of the Instrumentation Subsystem which offers the capability for acquisition and storage of experiment data. The Experiment/Pulse Code Modulation and Timing Electronic Assembly (E/PCMTEA) provides the acquisition capability, and the Experiment/Data Storage Equipment (E/DSE) provides the data storage capability. The weight and power requirements of this section are presented in Table 5.6-1.

5.6.3.2.1 Transducer and Signal Conditioners. The Experiment Instrumentation Section accepts isolated preconditioned signals only. All transducers, signal conditioners, and isolation buffers required in support of an experiment are considered to be provided by the experiment package. The isolation requirements fall into two basic categories:

- o Outputs to Other Subsystems: All signals to be monitored by other subsystems in addition to the Instrumentation Subsystem shall be presented to the Instrumentation Subsystem through a separate isolated output.
- o Multiple Signals: The isolation between signals and signal grounds to be monitored by the E/PCMTEA shall conform with the LEM PCMTEA input requirements.

5.6.3.2.2 Experiment/Pulse Code Modulation and Timing Electronic Assembly (E/PCMTEA). In the recommended configuration the E/PCMTEA consists of a LEM assembly with format and data rate modifications. The unit operates at a normal bit rate of 51.2 kbps and a modified reduced bit rate (commanded remotely) of 12.8 kbps. The 51.2 kbps increased input format is expanded by the separation of formerly redundant multiplexer gates. The 12.8 kbps RATE replaces the 1.6 kbps RATE of the standard LEM unit. The number of channels, sampling rates, and word lengths available for each of the three data forms are presented in Table 5.6-5. Although an optimum 12.8 kbps format cannot be finalized until more information becomes available on the specific experiment requirements for Phase II missions, the possible format presented is useful in indicating the increased capabilities offered by this modification. A major advantage of the 12.8 kbps data rate is that the data handling capabilities of the Experiment/Data Storage Equipment are significantly improved (see Paragraph 5.6.3.2.3). The E/PCMTEA will operate independent of an external timing reference. When operating in this fashion the timing stability is accurate to two parts per million. The NRZ(C) data output is routed either to the FM Modulator of the Communication Subsystem for direct transmission, or to the E/DSE for data storage, depending upon the ground station coverage available at the time.

5.6.3.2.3 Experiment/Data Storage Equipment (E/DSE). The E/DSE consists of two identical Experiment/Data Storage Units (E/DSU - 1 and E/DSU-2). Each E/DSU is a basic Apollo CSM Block II tape recorders which have been modified as follows:

- Operate from the LEM single phase AC power rather than three phase source.
- Record NRZ(C) data on 9 digital tracks (8 data and 1 clock). By increasing the number of digital data tracks from four to eight, the record speeds can be halved without increasing the bit packing density requirements (per track) of the recorder. Decreasing the record speeds increases the

available record time for the fixed length of tape. This increase in record time will either decrease or eliminate (depending on specific mission profiles and ground station coverage) the requirement for in-flight tape reloading. The additional four digital tracks will be obtained by converting four of the analog tracks presently available in the CSM recorders for digital use.

- Record 51.2 kbps data at 7.5 ips. The present CSM Block II tape recorders record 51.2 kbps data on 4 tracks (plus 1 clock track) at a tape speed of 15 ips. Under this condition the bit packing density is 853.3 bits per inch per track (51.2 kbps/4 tracks X 1/15 ips = 853.3 bpi/track). By doubling the number of data tracks and halving the record speed, the bit packing density remains the same (51.2 kbps/8 tracks X 1/7.5 ips = 853.3 bpi/track).
- Record 12.8 kbps NRZ(C) data at 1.875 ips. The present CSM Block II tape recorders record 1.6 kbps data on four tracks at a tape speed of 3.75 ips which results in a packing density of only 106.7 bpi/track, well below the capability. By recording 12.8 kbps data on 8 tracks at a tape speed of 1.875 ips, the packing density increases to 853.3 bpi/track, the same as encountered with 51.2 kbps recordings. Under this scheme, the tape recorders are operating at their maximum capability at either of the two data rates, thus minimizing tape and maximizing data storage capabilities. This modification is extremely attractive and each recorder will be capable of providing 4 hr of uninterrupted recording at a data rate of 12.8 kbps. The E/PCMTEA, operating with an optimum 12.8 kbps format, should be capable of supporting many of the Phase II experiments at this data rate.
- Dump NRZ(C) data at 60 ips. The output data rate of the recorders when dumping at 60 ips is 409.6 kbps for each of the above recording modes. With this modification a fully recorded tape (12.8 kbps for 4 hr or 51.2 kbps for 1 hr) can be dumped in 8 min.
- Be capable of driving a remote tape quantity display. This modification provides a visual reference by which an astronaut can determine the available record time available on a reel of tape. It also provides a data location index thereby enabling an astronaut to initiate the dumping or redumping of specific portions of a given recording.
- Elimination of automatic dump speed selection electronics. With the inclusion of the fifth modification above, the dump speed is fixed at 60 ips.

As indicated in Fig. 5.6-2 the E/PCMTEA NRZ(C) output (including a data rate timing signal) is routed to the E/DSE through a remotely activated switch (PCM record select). The appropriate E/DSU is placed in the record mode at a tape speed compatible with the E/PCMTEA data rate; (Low 1.875 ips) for 12.8 kbps and normal (7.5 ips) for 51.2 kbps. When a recording is to be dumped, the appropriate E/DSU output is routed to the Communications Subsystem (SPA) by means of a second remotely activated switch (data output select). While one tape is being dumped it is possible to continue recording experiment data on the second recorder. With the aid of an appropriate handtool, each E/DSU can be reloaded in flight within the record time capability of the other recorders. The requirement for in-flight reloading, however, is not anticipated on the majority of Phase II missions due to the increased data storage capability provided by the aforementioned modifications. Each E/DSU is capable of recording one channel of analog data directly, with provisions for the addition of four more analog channels, if required. The Communication Subsystem in its present configuration cannot simultaneously support both digital and analog data from the experiment section. Therefore, no provisions are made for the routing of the E/DSE analog outputs to the FM Modulator. Analog, recordings will be physically returned cia the CM. A summary of the E/DSE data handling capabilities is presented in Table 5.6-6.

The external controls for the E/DSE are located in the Controls & Displays Subsystem. Switches actuate the appropriate relays in each E/DSU to provide the following operating modes:

- Electronic Control
    - Record - energizes record electronics
    - Off - de-energizes E/DSU electronics
    - Dump - Energizes reproduce electronics
- Direction Control
    - Forward - starts tape moving in forward direction
    - Stop - stops tape in any direction
    - Reverse - starts tape moving in reverse direction at 120 ips and de-energizes electronics
- Speed Control
    - High - Commands E/DSU to move taps at 120 ips
    - Normal - Commands E/DSU to move tape at 7.5 ips
    - Low - Commands E/DSU to move tape at 1.875 ips

The E/DSE also provides internal controls in each E/DSU as follows:

- Internal protection against altering recorded data in rewind mode
- End-of-tape sensing and automatic transport shut off in both directions without loss of tape threading
- Interlocks to prevent erroneous or damaging operation of the E/DSE

5.6.4 Baseline Configuration

5.6.4.1 Spacecraft Operational Section

The baseline configuration used for the Phase II Lab is the same as the recommended configuration.

5.6.4.2 Experiment Instrumentation Section

The E/PCMTEA portion of the baseline configuration is identical to that of the recommended configuration. The E/DSE in the baseline configuration is the same as that described under the alternate configuration below except that 12.8 kbps data is recorded at 3.75 ips rather than 1.6 kbps data normally recorded at this speed and except that the single phase motor mod. has not been incorporated.

5.6.5 Alternate Configuration

5.6.5.1 Spacecraft Operational Section

There were no alternate configurations studied because the existing LEM system can satisfactorily perform all the described tasks.

5.6.5.2 Experiment Instrumentation Section

The alternate configuration of the Phase II Experiment Instrumentation Section is identical to the Phase I recommended configuration. The alternate configuration consists of the following:

5.6.5.2.1 Transducers and Signal Conditioners. Identical to the requirements described under the recommended configuration presented above.

5.6.5.2.2 E/Pulse Code Modulation and Timing Equipment. The E/PCMTEA, in the alternate configuration consists of an unmodified lunar LEM assembly. The data acquisition capability of this assembly includes the multiplexing, encoding, and timing of analog, parallel digital, and serial digital data. The unit operates at a normal bit rate of 51,200 bits per second. The number of channels, sampling rates, and word lengths available for the three data forms are presented in Table 5.6-4. The E/PCMTEA will operate independent of an external time reference. When operating in this fashion the timing stability is accurate to two parts per million. The NRZ(C) data output is routed either to the FM Modulator of the Communications Subsystem for real time transmission, or to the E/DSE for data storage, depending upon the ground station coverage available at the time.

5.6.5.2.3 E/Data Storage Equipment. The E/DSE consists of two idnetical Experiment/Data Storage Units (E/DSU-1 & E/DSU-2). Each E/DSU is an Apollo CSM Block II tape recorder which has been modified as follows:

- Operate from the LEM single phase AC power rather than three phase source.
- Dump 51.2 kbps NRZ(C) data recorded at 15 ips at an output rate of 409.6 kbps (ie 120 ips). The implicit 8:1 data compression ratio is needed since the 51.2 kbps record time requirements greatly exceed the ground station coverage on many of the Phase II flights. The modification sharply reduces the necessity for in-flight tape reloading and physical return of recorded tape via the CSM.
- Be capable of driving a remote tape quantity display. This modification provides a visual reference by which an astronaut can determine the available record time available on a reel of tape. It also provides a data location index thereby enabling an astronaut to initiate the dumping or redumping of specific portions of a given recording.
- Elimination of automatic dump speed selection electronics. With the inclusion of the second modification above, the dump speed is fixed at 120 ips.

As indicated in Fig. 5.6-2 the E/PCMTEA NRZ(C) output (including a data rate timing signal) is routed to the E/DSE through a remotely activated switch (PCM record select). The appropriate E/DSU is placed in the record mode at a tape speed compatible with the E/PCMTEA data rate; Low (3.75 ips) for 1.6 kbps and normal (15 ips) for 51.2 kbps. When a recording is to be dumped, the appropriate E/DSU output is routed to the Communications Subsystem (FM) by means of a second remotely activated switch (data output select). While one tape is being dumped it is possible to continue recording experiment data on the second recorder. With the aid of an appropriate hand tool, each E/DSU can be reloaded in flight within the record time capability of the other recorder. Continuous recording is possible, therefore, under conditions where the total E/DSE record time capability is exceeded by the time interval between available ground station coverage. Each E/DSU is also capable of recording experiment analog data directly. The

Communication Subsystem in its present configuration cannot simultaneously support both digital and analog data from the experiment section. Therefore, no provisions are made for the routing of the E/DSE analog outputs to the FM Modulator. Analog recordings will be physically returned via the CM. A summary of the E/DSE data handling capabilities is presented in Table 5.6-7.

The external controls for the E/DSE are located in the Controls & Displays subsystem. Switches actuate the appropriate relays in each E/DSU to provide the following operating modes.

- Electronic Control
  - Record - energizes record electronics
  - Off - de-energizes E/DSU electronics
  - Dump - energizes reproduce electronics
- Direction Control
  - Forward - starts tape moving in forward direction
  - Stop - stops tape in any direction
  - Reverse - starts tape moving in reverse direction at 120 ips and de-energizes electronics
- Speed Control
  - High - Command E/DSU to move tape at 120 ips
  - Normal - Commands E/DSU to move tape at 15 ips
  - Low - Commands E/DSU to move tape at 3.75 ips

The E/DSE also provides internal controls in each E/DSU as follows:

- Internal protection against altering recorded data in rewind mode
- End-of-tape sensing and automatic transport shut off in both directions without loss of tape threading
- Interlocks to prevent erroneous or damaging operation of the E/DSE

5.6.6 Potential Modifications (Per Flight)

5.6.6.1 Spacecraft Operational Section

There are no recommended modifications envisioned for this vehicle based on a review of existing measurement requirements and the capabilities of the existing system.

5.6.6.2 Experiment Instrumentation Section

The wiring between the inputs of the Experiment Instrumentation Section and the data outputs of the experiments will have to be designed for each specific flight. Other potential pre-flight modifications involve changes to the input format of the E/PCMTEA in order to comply with unusual experiment data requirements.

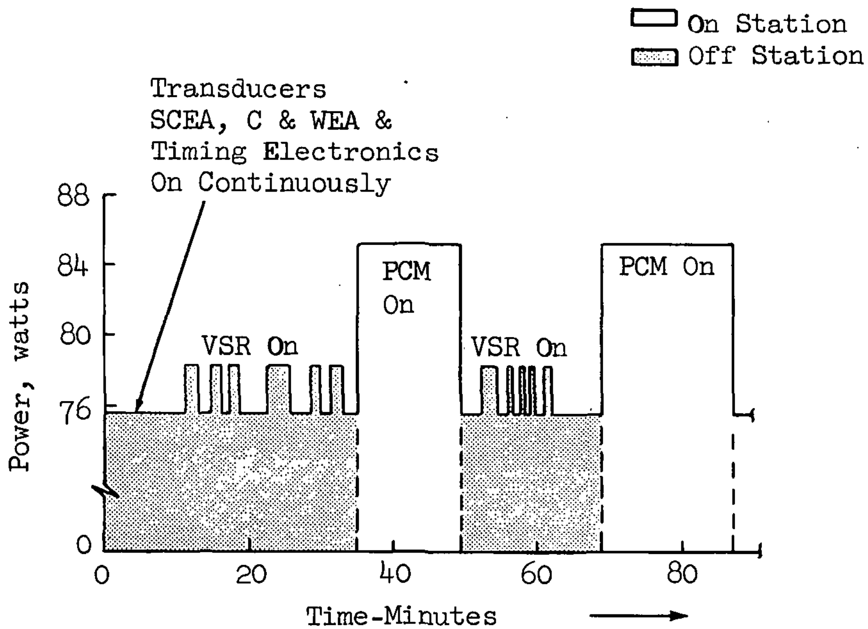
5.6.7 Discussion of Configuration Choices - (Experiment Instrumentation Section)

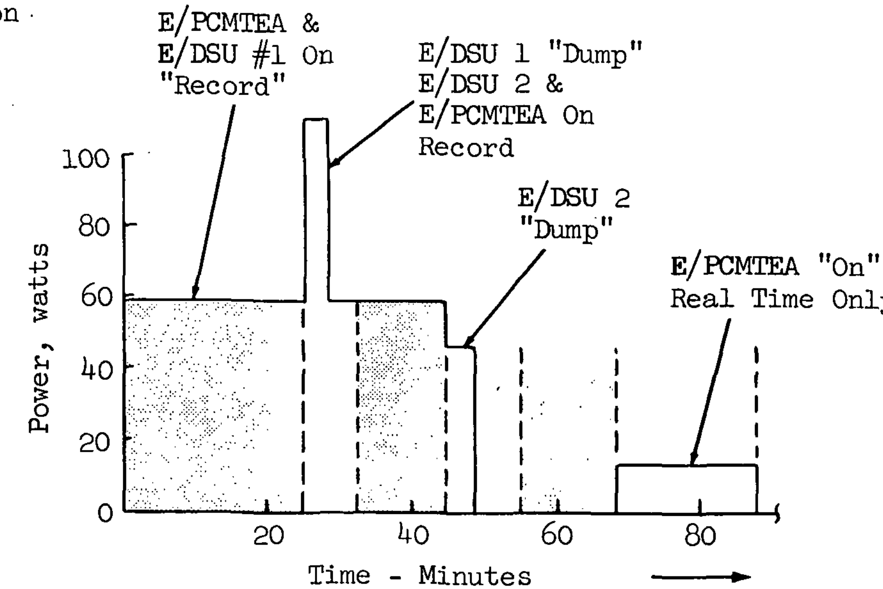
A comparison of the capabilities of the alternate and recommended Experiment Instrumentation Section configuration points out these significant differences between the two approaches. The substitution of a 12.8 kbps data rate in place of the 1.6 kbps greatly increases the data handling capacity of the equipment. The limited capability of the 1.6 kbps format indicates that it will be capable of handling a minimum number of experiments. On the other hand, the 12.8 kbps approach provides a substantial increase in data acquisition capacity and should be capable of supporting most of the experiments. Therefore, the recommended configuration will be operating at 12.8 kbps in many instances where the alternate configuration, due to the limited capacity of its 1.6 kbps format, would be operating at 51.2 kbps. The increased acquisition efficiency of the recommended configuration substantially enhances the data storage capacity of the E/DSE. The recommended E/DSE can record 12.8 kbps data for 4 hrs per E/DSU (Total of 8 hrs continuous recording). At 51.2 kbps, the alternate E/DSE maximum record time is 30 min per E/DSU. For any severe cases where the 12.8 kbps format cannot support the experiment requirements, the recommended E/PCMTEA provides a 51.2 kbps format which, has an increased data acquisition capacity over the alternate E/PCMTEA, by the modification to delete the internal multiplexer redundancy. The advantage of the alternate configuration lies in the fact that it is identical to the Phase I recommended configuration.

Section		Trans-ducers	SCEA		C & WEA	PCMTEA		VSR	E/DSE		E/PCMTEA	Total
			ERA I	ERA II		PCM	TEA		E/DSU 1	E/DSU 2		
Oper'l	Weight, lb	16.8	40	34.4	25.0	37.0		5.0 (2)				158.8
	Power, watts	11.1	18.8	18.2	22	7.4	5.5	2.3				85.3
Exper	Weight, lb								40	40	37	117
	Power, watts								46*	46*	12.9	104.9

* Denotes Recorder Powered By Single-Phase AC.

Table 5.6-1
PHASE II LAB. - ELECTRICAL POWER
Instrumentation Subsystem





Subsystem \ Parameter	Acceleration	Phase	Current	Vibration	Power	Frequency	Force
Structures							
Thermodynamics							
Electrical Power			2			1	
Environ Control							
Nav & Guid							
Radars							
S & C - CES							
S & C - AGS							
Instrumentation						2	
Propulsion - Ascent							
Propulsion - Descent							
Reaction Control							
Communications		1			4		
Pyrotechnics							
Totals		1	2		4	3	

1. P.&W. Fuel Cells (2) were used fo

Table 5.6-2

PHASE II LAB OPERATIONAL MEASUREMENT SUMMARY

Position	Biemedical	Radiation	Velocity	Mass	Res./Cont.	Pressure	Quantity	Rate	Strain	Temperature	Combination	Voltage	Time	Descrete	Acoustic	Ph-Acidity	Undefined	Stimuli	Total S/S Measurements	TM Total	C&W & DISP	Prelaunch C/O
						10	1	4		12		15		8		2			55	53	51	5
						15	1	2		7	2	8		25					60	33	21	48
												38		12					50	30	29	36
										1		24		2			14		41	3	22	18
												5	2	33			8		50	16	32	21
						64	16			16	21	16		54					187	79	133	97
	2											5					9		21	5	1	18
	2					89	18	6		36	23	111	2	134		2	31		464	219	289	243

this sizing

Table 5.6-3
PHASE II LAB SCEA SUMMARY

	SCEA Subassembly Type LSP-360-													
	502-2	502-3	503-2	503-3	504-1	504-2	504-3	504-4	504-5	505-1	506-2	507-1	503-1	TOTAL
Total Measurement Circuits	16	2	4	1	21	16	20	48	27	1	31	3	8	198
Circuits/Subassy	4	4	3	3	4	10	12	12	12	3	4	4	3	N/A
Quantity of Subassys Reqd	4	1	2	1	6	2	2	4	3	1	8	1	3	38
No. Spare Circuits	-	2	2	2	3	4	4	-	9	2	1	1	1	31
ERA No. 1	4	-	-	1	6	-	-	-	-	1	7	1	0	20
ERA No. 2	-	1	2	-	-	2	2	4	3	-	1	-	3	18

Table 5.6-4

OPERATIONAL PCMTEA INPUT DATA CAPABILITY
(This config also used as alternate E/PCMTEA)

Data Format: 51,200 bits/sec Output Rate				
Data Form	No. Channels	Samples/sec	bits/word	words/sec
Analog - High Level	5 17 6 35 137	200 100 50 10 1	8 8 8 8 8	1000 1700 300 350 137
Digital - Parallel	1 3 4 1 37	200 100 50 10 1	16 8 8 8 8	400 300 200 10 37
Digital Serial	1 1	50 50	40 24	250 150
TOTAL	248			4834
Partial Format: 1,600 bits/sec Output Rate				
Analog - High Level Digital Parallel	59 15	1 1	8 8	59 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.

Table 5.6-5

E/PCMTEA INPUT DATA CAPABILITY

Data Form	No. Channels	Samples/sec	bits/word	Words/sec*
Data Format: 51,200 bits/sec Output Rate				
Analog High Level	7 22 8 45 195	200 100 50 10 1	8 8 8 8 8	1400 2200 400 450 195
Digital Parallel	1 4 5 1 54	200 100 50 10 1	16 8 8 8 8	400 400 250 10 54
Digital Serial	1 1	50 50	40 24	250 150
TOTAL	344			6159
Possible Format: 12,800 bits/sec Output Rate				
Analog High Level	2 16 20 60	100 50 10 1	8 8 8 8	200 800 200 60
Digital Parallel	2 1 7 30	50 10 10 1	8 16 8 8	100 20 70 30
Digital Serial	1	10	24	30
TOTAL	139			1510

* Normalized to 8 bit. words

Table 5.6-6 E/DSE DATA HANDLING CAPABILITY

The E/DSE consists of two E/DSUs each with the following capability:

- Record/Dump one channel of NRZ (C) E/PCMTEA data including data rate clock.

  Nine tracks; serial data is converted to parallel and stored on eight tracks. A synchronization signal is stored on the ninth track.

- Record one channel of analog data (one track).

- Has provisions for the addition of four additional analog channels (four tracks).

Data Form	NRZ (C) & Clock		Analog	
No. Channels	1 (9 tracks)		1 (1 track)	
Data Rate	12.8kb/s	51.2kb/s	12.5 cps to 3,125 cps*	25 cps to 12,500 cps*
Record Speed, ips	1.875	7.5	1.875	7.5
Record Time, hr	4	1	4	1
Dump Speed, ips	60	60	RECORD ONLY Analog recordings are physically returned to Earth via CSM.	
Dump Time, min	8	8		
Dump/Record Ratio	32:1	8:1		
Dump Data Rate, kbps	409.6	409.6		

*Analog frequency responses are estimated.

TABLE 5.6-7 E/DSE DATA HANDLING CAPABILITY

The E/DSE consists of two E/DSUs each with the following capability:

- Record/Dump one channel of NRZ (C) E/PCMTEA data including data rate clock. Five tracks; serial data is converted to parallel and stored on four tracks. A synchronizati..n signal is stored on the fifth track.
- Record two channels of analog type A data (two tracks) and three channels of analog type B data (three tracks).
- Has provisions for the addition of four additional analog type B channels (four tracks).

Data Form	NRZ (C) & Clock		Analog Type A		Analog Type B	
No. Channels	1 (5 tracks)		2 (2 tracks)		3 (3 tracks)	
Data Rate	1.6kb/s	51.2kb/s	300 cps to 2,800 cps	300 cps to 2,800 cps	12.5 cps to 6,250 cps	50 cps to 25,000 cps
Record Speed, ips	3.75	15	3.75	15	3.75	15
Record Time, hr	2	1/2	2	1/2	2	1/2
Dump Speed, ips	120	120	RECORD ONLY			
Dump Time, min	4	4	Analog recordings are physically returned to Earth via CSM.			
Dump/Record Ratio	32:1	8:1				
Dump Data Rate, kbps	51.2	409.6				

Table 5.6-8
MEASURMENTS LIST

```
X X X X X X X X X X X
X       LEM-AES       X
X       PHASE 2       X
X      BASELINE       X
X       E.O.LAB       X
X PHASE B     FORM A X
X X X X X X X X X X X
```

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 2
NOVEMBER 8,1965

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 P 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	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
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

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 3
NOVEMBER 8,1965

ID CODE | MEASUREMENT NAME AND LOCATION | INTEREST RANGES LOW NORM HIGH | UNIT | FREQ OR RATE | A C C | S C P | 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

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 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 4
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	FREQ OR RATE	A C C	S C R	S / S	S 1 G	B I T	G P 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	C T A C C	DSY NIP DGF	XDCR -PWR	XDCR WT.	REFERENCES OF NOTES

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.

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 5
NOVEMBER 8,1965

```
                                                                                              C T                        C
                                   INTEREST      FREQ A S S S B G D M MH C F A X   XDCR    FREQ A DSY                REFERENCES  H
 ID          MEASUREMENT            RANGES        OR  C C / I I R P C S/ / / / X   RANGES    OF  C VIP 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 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.D.LAB PHASE 2

PAGE NUMBER 6
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW NORM HIGH UNIT	FREQ OR RATE	A'S C C	S C F	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

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.

Grumman

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 7
NOVEMBER 8,1965

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	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N 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 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 8
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	ELECTRICAL POWER FREQ OR RATE	A C C	S C P	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	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EC0071-V	VOLTAGE,INVERTER BUS	105	115	125	VRMS	SS	5	S	1	H	8	B	2	R	L	C		A		0	130	SS		3-3	--	--	EL4046	
EC0155-F	FREQ,INVERTER BUS	390	400	410	CPS	SS	.5	S	1	H	8	B	2	R	L	C				380	420	SS		5-1	--	--	EL4046	
EC0301-V	VOLT COMMANDER'S BUS	20		40	VDC	SS	4	S	1	H	8	B	2	P	L			A		0	40	SS		2-3	--	--		
EC0301-V	VOLT COMMANDER'S BUS	26.5			VDC											C						SS		-	--	--	EL4042	
EC0302-V	VOLT SYSTEM ENGR'S BUS	20		40	VDC	SS	4	S	1	H	8	B	2	P	L			A				SS		2-3	--	--		
EC0302-V	VOLT SYSTEM ENGR'S BUS	26.5			VDC								2			C						SS		-	--	--	EL4042	
EC8001-V	VOLT,FCA NO1,NEUTRAL				VRMS	SS		S	1	H	8			R	H			A				SS		3-1	0	0		
EC8002-V	VOLT,FCA NO1,PHASE A				VRMS	SS		S	1	H	8				H			A				SS		3-1	0	0		
EC8003-V	VOLT,FCA NO1,PHASE B				VRMS	SS		S	1	H	8				H			A				SS		3-1	0	0		
EC8004-V	VOLT,FCA NO1,PHASE C				VRMS	SS		S	1	H	8				H			A				SS		3-1	0	0		
EC8005-V	VOLT,FCA NO2,NEUTRAL				VRMS	SS		S	1	H	8			R	H			A				SS		3-1	0	0		
EC8006-V	VOLT,FCA NO2,PHASE A				VRMS	SS		S	1	H	8				H			A				SS		3-1	0	0		
EC8007-V	VOLT,FCA NO2,PHASE B				VRMS	SS		S	1	H	8				H			A				SS		3-1	0	0		
EC8008-V	VOLT,FCA NO2,PHASE C				VRMS	SS		S	1	H	8				H			A				SS		3-1	0	0		
EC8009-X	FCA NO1 H2 CLOSED					SS			1	F	1				H		L					SS		4-4	0	0		
EC8010-X	FCA NO1 O2 CLOSED					SS			1	E	1				H		L					SS		4-4	0	0		
EC8011-X	FCA NO2 H2 CLOSED					SS			1	E	1				H		L					SS		4-4	0	0		
EC8012-X	FCA NO2 O2 CLOSED					SS			1	F	1				H		L					SS		4-4	0	0		
EC8013-X	FCA NO1 O2 PURGE CLOSED					SS			1	E	1			R	H		L					SS		4-4	0	0		
EC8014-X	FCA NO1 H2 PURGE CLOSED					SS			1	F	1			R	H		L					SS		4-4	0	0		
EC8015-X	FCA NO2 O2 PURGE CLOSED					SS			1	E	1			R	H		L					SS		4-4	0	0		
EC8016-X	FCA NO2 H2 PURGE CLOSED					SS			1	E	1			R	H		L					SS		4-4	0	0		
EC8017-R	RATE,H2 FLOW,FCA NO1	.018		.223	PPH	SS			1	H	8			R	H							SS		-				
EC8018-R	RATE,H2 FLOW,FCA NO2	.018		.223	PPH	SS			1	H	8			R	H							SS		-				
EC8019-R	RATE,O2 FLOW,FCA NO1	.0		1.27	PPH	SS			1	H	8			R	H							SS		-				

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 9
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	ELECTRICAL POWER FREQ OR RATE	ACC	SCR	S/S	S/IG	BIT	GRD	OPS	MC	MH S/SL	C/W	F/L	A/D	X/X	XDCR RANGES LOW	HIGH	FREQ OR RATE	ACC	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EC8020-R	RATE O2 FLOW,FCA NO2	.0		1.27	PPH	SS			1	H	8			R	H							SS		-				
EC8021-T	TEMP,FCA1 CONDENSER EXIT					SS			1	H	8				H			A				SS		6-2				
EC8022-T	TEMP,FCA2 CONDENSER EXIT					SS			1	H	8				H			A				SS		5-2				
EC8023-T	TEMP,FCA NO1 SKIN	300	500	550	DEGF	SS			1	H	8				H			A				SS		6-2				
EC8024-T	TEMP,FCA NO2 SKIN	300	500	550	DEGF	SS			1	H	8				H			A				SS		5-2				
EC8025-Z	WATER FACTOR PH,FCA 1					SS			1	H	8				H			A				SS		-				
EC8026-P	PRESS,H2 REGULATOR OUT 1		60		PSIA	SS			1	H	8			R	H			A				SS		-				
EC8027-P	PRESS,H2 REGULATOR OUT 2		60		PSIA	SS			1	H	8			P	H			A				SS		-				
EC8028-P	PRESS,O2 REGULATOR OUT 1		60		PSIA	SS			1	H	8			P	H			A				SS		-				
EC8029-P	PRESS,O2 REGULATOR OUT 2		60		PSIA	SS			1	H	8			R	H			A				SS		-				
EC8030-P	PRESS,N2 REGULATOR OUT 1		52		PSIA	SS			1	H	8			P	H			A				SS		-				
EC8031-P	PRESS,N2 REGULATOR OUT 2		52		PSIA	SS			1	H	8			R	H			A				SS		-				
EC8032-Z	WATER FACTOR PH,FCA 2					SS					8				H			A				SS		-				
EC8033-P	PRESS,H2 TANK NO1					SS			1	H	8			R	SL			A						-				
EC8034-P	PRESS,O2 TANK NO1					SS			1	H	8			R	SL			A						-				
EC8035-T	TEMP,FCA1 RADIATOR OUTLET										8			P	H			A				SS		6-2				
EC8036-T	TEMP,FCA1 RADIATOR OUTLET										8			R	H			A				SS		6-2				
EC8037-V	VOLT,FCA NO1 OUTPUT	0	28	50	VDC	SS				H	8			R	H			A		0	50	SS		2-2				
EC8038-V	VOLT,FCA NO2 OUTPUT	0	28	50	VDC	SS				H	8			R	H			A		0	50	SS		2-2				
EC8039-C	CURR,FCA NO1 OUTPUT	0		100	AMPS	SS					8			F	H			A		0	100	SS		-				
EC8040-C	CURR,FCA NO2 OUTPUT	0		100	AMPS	SS					8			R	H			A		0	100	SS		-				
EC8041-T	TEMP H2 TANK NO 1					SS			1		8			R	SL			A						6-2				
EC8042-T	TEMP H2 TANK NO 2					SS			1		8			R	SL			A						6-2				
EC8043-P	PRESS H2 TANK NO 2										8			R	SL			A						-				
EC8044-P	PRESS O2 TANK NO 2										8			R	SL			A						-				

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB.PHASE 2

NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	ELECTRICAL POWER FREQ OR RATE	ACC	SCR	S/S	SIG	BIT	GRD	OPS	MCC	MH S/ SL	C/W	F/L	A/D	X/X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	ACC	CT DSY NIP DCE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EC8045-T	TEMP O2 TANK NO 1					SS			1		8			R	SL			A						6-2				
EC8046-T	TEMP O2 TANK NO 2					SS			1		8			R	SL			A						6-2				
EC8047-Q	QUANT WATER TANK NO 1	0		100	PCT	SS			1		8				H			A		0	99	SS		-				
EC8048-T	TEMP O2 HX OUTLET					SS			1		8			R	H			A				SS		6-2				
EC8049-T	TEMP H2 HX OUTLET					SS			1		8			R	H			A				SS		6-2				

Grumman

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 11
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	ENVIRONMENTAL CONTROL FREQ OR RATE	A C C	S C R	S 7 S	S I G	B I T	G R D	O P S	M C C	MH S7 SL	C 7 W	F 7 L	A 7 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	CHNG
EF1081-X	PRIME SUIT COMP. SELECT	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	0		
EF1082-X	SPARE SUIT COMP. SELECT	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	0		
EF1083-X	PRIME SUIT COMPRESS.FAIL	CONTACT		CLUSURE		SS		S	1	E	1	B	2	R	H	C				CC		SS		4-3	0	0		
EF1084-X	SPARE SUIT COMPRESS.FAIL	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	H	W				CC		SS		4-3	0	0		
EF1087-X	SELECT SUIT COMPRESS FAIL	CONTACT		CLOSURE		SS											L			CC		SS		4-4	0	0		
EF1111-R	RATE,H2O SEPERATOR NO 1	600		3500	RPM	SS		S								C	L			500	3600	SS		-	.25	.23	EF9999	
EF1112-R	RATE,H2O SEPERATOR NO 2	600		3500	RPM	SS		S								C	L			500	3600	SS		-	.25	.23	EF9999	
EF1201-X	SUIT INLET VPI NO1 CLOSED	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF1202-X	SUIT INLET VPI NO2 CLOSED	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF1211-X	SUIT PRESS.RLF VPI CLOSED	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF1212-X	SUIT PRESS.RLF VPI OPEN	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF1221-X	SUIT DIVERTER VPI CLOSED	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	H					CC		SS		4-5	0	.13		
EF1231-X	CABIN GAS RETURN VPI CLD	CONTACT		CLOSURE		SS		S	1	E	1	B	2		L					CC		SS		4-5	0	.13		
EF1232-X	CABIN GAS RETURN VPI OPEN	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF1241-X	CO2 CARTRIDGE IN SEC POS	CONTACT		CLOSURE		SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF1242-X	CO2 CARTRIDGE IN SEC POS	CONTACT		CLOSURE		SS											L			CC		SS		4-4	0	.13	EF9993	
EF1251-X	H2O SEPARATOR NO2 SELECT	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	L					CC		SS		4-5	0	0		
EF1281-T	TEMP,SUIT INLET	30	60	100	DEGF	SS		S	1	H	8	B	2	R	L			A		30	110	SS		6-2	0	.12		
EF1291-T	TEMP,SUIT NO.1 OUTLET	30	80	100	DEGF	SS		S	1	L	8	B	2		H					30	110	SS		6-2	0	.12		
EF1292-T	TEMP,SUIT NO.2 OUTLET	30	80	100	DEGF	SS	5	S	1	L	8	B	2		H					30	110	SS		6-2	0	.12		
EF1301-P	PRESS,SUIT OUTLET	0	5	10	PSIA	SS	5	S	1	H	8	B	2	R	L					0	10	SS		4-1	.28	.31		
EF1301-P	PRESS,SUIT OUTLET	0		10	PSIA	SS												A		0	10	SS		-	--	--		
EF1301-P	PRESS,SUIT OUTLET	3.2			PSIA	SS										W				3.2		SS		-	--	--		
EF1521-P	PRESS,CO2 PARTIAL	0	2	30	MMHG	SS	5	S	1	H	8	B	2	P	L	C	L			0	30	SS		4-1	1.00	2.70	EF9993	
EF1522-P	PRESS,CO2 PARTIAL	0		30	MMHG	SS												A		0	30	SS		-	--	--		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 12
NOVEMBER 8, 1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	HIGH	FREQ OR RATE	A C C	CT OSY NIP OGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EF1651-T	TEMP,CABIN	50	80	110	DEGF	SS	5	I	1	H	8	B	2	R	L			A		30	110	SS		6-2	0	.12		
EF2021-P	DEL P,COOLANT PUMPS	0	45	50	PSID	SS	5	S	1	H	8	B	2	R	L					0	50	SS		-	.28	.31		
EF2041-X	COOLANT ACC.FLUID LO LVL	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	L	C				CC		SS		4-3	0	0		
EF2072-X	COOLANT PUMP NO.2 SELECT	CONTACT	CLOSURE			SS		S	1	E	1	B	2		L					CC		SS		4-5	0	0		
EF2581-T	TEMP,MAIN W/B COOL.OUT	30	40	160	DEGF	SS		I								C		A		0	160	SS		-	0	.12	EF9998	
EF2741-P	PRESS,PUMP DISCHRG	0	50	60	PSIA	SS		I										A		0	60	SS		-	.28	.28	EF9997	
EF2931-X	COOLANT PUMP FAIL	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	L	C				CC		SS		4-3	0	0		
EF2935-X	SELECT COOL PUMP FAIL	CONTACT	CLOSURE			SS		S	1	E	1	B	2		L	L				CC		SS		4-4	0	0		
EF3071-X	O2 REG VLV 306A CLOSED	CONTACT	CLOSURE			SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF3072-X	O2 REG VLV 306A OPEN	CONTACT	CLOSURE			SS		S	1	E	1	B	2		L					CC		SS		4-5	0	.13		
EF3073-X	O2 REG VLV 306B CLOSED	CONTACT	CLOSURE			SS		S	1	E	1	B	2		H					CC		SS		4-5	0	.13		
EF3074-X	O2 REG VLV 306B OPEN	CONTACT	CLOSURE			SS		S	1	E	1	B	2		L					CC		SS		4-5	0	.13		
EF3081-X	EMERGENCY O2 VPI OPEN	CONTACT	CLOSURE			SS		S	1	E	1	B	2	F	H	W				CC		SS		4-3	0	.13		
EF3571-P	PRESS,CABIN	0	5	10	PSIA	SS	5	I	1	H	8	B	2	F	H					0	10	SS		-	.28	.28		
EF3571-P	PRESS CABIN	0		10	PSIA	SS		I										A		0	6	SS		-	--	--		
EF3572-X	EMER.O2 VLV ELECT OPEN	CONTACT	CLOSURE			SS		S	1	E	1	B	2	F	L	W				CC		SS		4-3	0	.13		
EF3582-P	PRESS ASCENT O2 TANK NO1		TBA			SS			1	H	8	B	2									SS		-	.28	.28		
EF3584-P	PRESS DESC N2 TANK		TBA			SS			1	H	8	B	2									SS		-	.28	.28		
EF3591-P	PRESS,SAFETY VLV 1 SERVO	0		25	PSIA	SS	5	I	1	H	8	B	2							0	25	SS		-	.28	.28		
EF3592-P	PRESS,SAFETY VLV 2 SERVO	0		25	PSIA	SS	5	I	1	H	8	B	2							0	25	SS		-	.28	.28		
EF4101-P	DEL P SUIT/WATER MAIN	0	1	2	PSIA	SS		I	1	H	8	B	2		H					0	2	SS		-	.28	.31		
EF4511-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		
EF4580-Q	QUANTITY,FCA WATER TANK	0		100	PCT	SS	4	I	1	H	8	B	2	R	L			A		0	100	SS		4-1	.50	.75		
EF8507-V	VOLT SUIT DIVERT VLV POS	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
EF8509-V	VOLT O2 REG ULV A/B TEST	0		28	VDC	SS						B	2							0	28	SS		-	--	--		

Grumman

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 13
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	HIGH	FREQ OR RATE	A C C	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EF8521-V	VOLT CABIN FAN NO1	0		15	VDC	SS						B	2							0	15	SS		-	--	--		
EF8522-V	VOLT CABIN FAN NO1	0		15	VDC	SS						B	2							0	15	SS		-	--	--		
EF8523-V	VOLT CABIN FAN NO2	0		15	VDC	SS						B	2							0	15	SS		-	--	--		
EF8524-V	VOLT CABIN FAN NO2	0		15	VDC	SS						B	2							0	15	SS		-	--	--		
EF8535-V	VOLT SUIT FAN NO2	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
EF8536-V	VOLT SUIT FAN NO2	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
EF8701-T	TEMP COOLANT RAD INLET	30	70	160	DEGF	SS						B	2					A				SS						
EF9993-U	LIOH SEL/HI CO2 7OS6 ADV	CONTACT CLOSURE				SS											L			CC		SS		4-4	0	0		
EF9999-U	RATE,SELECT H2O SEPARATOR	600		3500	RPM	SS			1	H	8	B	2	R	L	C	L			500	3600	SS		4-1	--	--		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE F.O.LAB PHASE 2

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	STABILITY AND CONTROL-CES FREQ OR RATE	A C C	S C P	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
EH1204-X	ACA OUT OF DETENT	CONTACT CLOSURE				SS			1	E	1			F								SS		4-5	0	0		
EH1240-V	VOLT,'X' TRANS.CMD	-10	OR	+10	VDC	2C			10H		8	B	2	R								2C		2-2	0	0		
FH1241-V	VOLT,'Y' TRANS.CMD	-10	OR	+10	VDC	2C			10H		8	B	2	R								2C		2-2	0	0		
EH1242-V	VOLT,'Z' TRANS.CMD	-10	OR	+10	VDC	2C			10H		8	B	2	R								2C		2-2	0	0		
EH1247-V	VOLT,PULSE YAW CMD	-13	+.5	+13	VDC	2C	2		10H		8	B	2									2C		2-2	0	0		
EH1248-V	VOLT,PULSE PITCH CMD	-13	+.5	+13	VDC	2C	2		10H		8	B	2									2C		2-2	0	0		
EH1249-V	VOLT,PULSE ROLL CMD	-13	+.5	+13	VDC	2C	2		10H		8	B	2									2C		2-2	0	0		
EH1401-V	VOLT RGA SPN MTR A PH.8KC	-26		+26	VRMS											W								3-2	0	0		
EH1402-V	VOLT RGA SPN MTR B PH.8KC	-26		+26	VRMS											W								3-2	0	0		
EH1403-V	VOLT RGA SPN MTR C PH.8KC	-26		+26	VRMS											W								3-2	0	0		
EH1405-V	VOLT RGA PICKOFF EXCT.8KC	-28		+28	VRMS											W								3-2	0	0		
EH1406-V	VOLT +15V DC SUPPLY			+15	VDC											W								2-2	0	0		
EH1407-V	VOLT -15V DC SUPPLY	-15			VDC											W								2-2	0	0		
EH1408-V	VOLT +4V DC SUPPLY			+4	VDC											W								4-1	0	0		
EH1418-V	VOLT,JET 1 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1419-V	VOLT,JET 2 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
FH1420-V	VOLT,JET 3 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1421-V	VOLT,JET 4 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1422-V	VOLT,JET 5 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1423-V	VOLT,JET 6 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
FH1424-V	VOLT,JET 7 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1425-V	VOLT,JET 8 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1426-V	VOLT,JET 9 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
FH1427-V	VOLT,JET 10DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		
EH1428-V	VOLT,JET 11DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 /	28			4-2	0	0		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 15
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	D P S	M C C	MH S/ SL	C / W	F / L	A / D	X / X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	CT DSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EH1429-V	VOLT,JET 12DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 / 28				4-2	0	0		
EH1430-V	VOLT,JET 13DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 / 28				4-2	0	0		
EH1431-V	VOLT,JET 14DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 / 28				4-2	0	0		
EH1432-V	VOLT,JET 15DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 / 28				4-2	0	0		
EH1433-V	VOLT,JET 16DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H	W				0 / 28				4-2	0	0		
EH1461-V	VOLT,YAW RG SIG (.8KC)	-3.5		+3.5	VRMS	2C	2		10H		8	B	2	R	L					-3.5	+3.5	2C		7-1	0	0		
EH1462-V	VOLT,PITCH RG SIG (.8KC)	-3.5		+3.5	VRMS	2C			10H		8	B	2	R	L					-3.5	+3.5	2C		7-1	0	0		
EH1463-V	VOLT,ROLL RG SIG (.8KC)	-3.5		+3.5	VRMS	2C	2		10H		8	B	2	R	L					-3.5	+3.5	2C		7-1	0	0		
EH1492-V	VOLT -4VDC SUPPLY	-4			VDC	SS										W						SS		4-1	0	0		
EH1493-V	VOLT +6VDC SUPPLY			+6	VDC	SS										W						SS		2-2	0	0		
EH1494-V	VOLT -6VDC SUPPLY	-6			VDC	SS										W						SS		2-2	0	0		
EH1497-V	VOLT YAW RGA SIG (.8KC)	-3.5		+3.5	VRMS	2C												A		-3.5	+3.5	2C		-	--	--		
EH1498-V	VOLT PITCH RGA SIG(.8KC)	-3.5		+3.5	VRMS	2C												A		-3.5	+3.5	2C		-	--	--		
EH1499-V	VOLT ROLL RGA SIG (.8KC)	-3.5		+3.5	VRMS	2C												A		-3.5	+3.5	2C		-	--	--		
EH1603-X	DEADBAND SELECT	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1608-X	SCS MODE SELECT (AUTO)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1609-X	SCS MODE SELECT(ATT HOLD)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1615-X	ROLL ATT CONT SEL(PULSED)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1616-X	PITCH ATT CONT SEL(PULSED)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1617-X	YAW ATT CONT SEL(PULSED)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1618-X	ROLL ATT CONT SEL(DIRECT)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1619-X	PITCH ATT CON SEL(DIRECT)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1620-X	YAW ATT CONT SEL(DIRECT)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
EH1893-X	'X'TRANS OVERRIDE	TBA				SS			1	E	1	B	2		H							SS		4-5	0	0		
EH1896-X	UNBALANCED COUPLES	TBA				SS			1	E	1	B	2		H							SS		4-5	0	0		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE F.O.LAB PHASE 2

STABILITY AND CONTROL-AGS

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES 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	X/X	XDCR RANGES LOW	HIGH	FREQ OR RATE	AC/C	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
E10001	DIGITAL WORD								50S			B	2											-	--	--		
E13137-V	VOLT +/-Y DELTA VELOCITY											B	2											-	--	--		
E13138-V	VOLT +/-Z DELTA VELOCITY											B	2											-	--	--		
E13151-V	VOLT DISP TOT,SIN ALP.8KC	-26		+26	VRMS													A		-26	+26			-	--	--		
E13152-V	VOLT DISP TOT,COS ALP.8KC	-26		+26	VRMS													A		-26	+26			-	--	--		
E13153-V	VOLT DISP TOT,SIN BET.8KC	-26		+26	VRMS													A		-26	+26			-	--	--		
E13154-V	VOLT DISP TOT,COS BET.8KC	-26		+26	VRMS													A		-26	+26			-	--	--		
E13155-V	VOLT DISP TOT,SIN GAM.8KC	-26		+26	VRMS													A		-26	+26			-	--	--		
E13156-V	VOLT DISP TOT,COS GAM.8KC	-26		+26	VRMS													A		-26	+26			-	--	--		
E13166-V	VOLT YAW ATT ERR TO DIS																	A						-	--	--		
E13167-V	VOLT PITCH ATT ERR TO DIS																	A						-	--	--		
E13168-V	VOLT ROLL ATT ERR TO DIS																	A						-	--	--		
E13171	YAW INCREMENTAL ANGLE											B	2											-	--	--		
E13172	ROLL INCREMENTAL ANGLE											B	2											-	--	--		
E13173	PITCH INCREMENTAL ANGLE											B	2											-	--	--		
E13175	ASA CLOCK		TBA		TBA							B	2											-	--	--		
E13176	BLOCK TEMP REFERENCE		TBA		TBA							B	2											-	--	--		
E13184	PNGS T/M DNLINK DATA PUL		TBA		TBA							B	2											-	--	--		
E13185	1024 CLOCK		TBA		TBA							B	2											-	--	--		
E13201-V	VOLT +DELTA V TO DISPLAY																	D						-	--	--		
E13202-V	VOLT -DELTA V TO DISPLAY																	D						-	--	--		
E13203-V	VOLT ALT TO DISPLAY																	A						-	--	--		
E13204-V	VOLT ALT RATE TO DISPLAY																	A						-	--	--		
E13205-V	VOLT LAT VEL TO DISPLAY																	A						-	--	--		
E13214-V	+32 VDC ASA		32		VDC											W								2-2	0	0		

Grumman

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 17
NOVEMBER 8,1965

STABILITY AND CONTROL-AGS

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	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
E13215-V	+12 VDC ASA		12		VDC											W								2-2	0	0		
E13216-V	-12 VDC ASA		-12		VDC											W								2-2	0	0		
E13217-V	+6 VDC ASA		6		VDC											W								2-2	0	0		
E13218-V	+4 VDC ASA		4		VDC											W								4-1	0	0		
E13219-V	-2 VDC ASA		-2		VDC											W								4-1	0	0		
E13221-V	AGS POWER SUPPLY FAIL															W								4-1	0	0		
E13232	AFA TEST MODE FAIL															W								4-1	0	0		
E13301-T	TEMP,ASA	TBA						S				B	2	R	L									6-2	0	.13		
E13305-X	AGS MODE (WARMUP).					SS		S	1	E	1			R	H							SS		-	--	--		
E13306-X	AGS MODE (STANDBY)							S	1	E	1			R	H							SS		-	--	--		
E13311-V	VOLT +/-X DELTA VELOCITY											B	2											-	--	--		
E13340	YAW ATTITUDE ERROR NULL											B	2															
E13341	PITCH ATT ERROR NULL											B	2															
E13342	ROLL ATTITUDE ERROR NULL											B	2															
E13343	ASA X AXIS SMRD											B	2															
E13344	ASA Y AXIS SMRD											B	2															
E13345	ASA Z AXIS SMRD											B	2															

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 18,
NOVEMBER 8,1965

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	R I T	G P D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X / X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP OGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
EL0300	FRAME SYNCH + ID								1	P	32	B	2	R	L									-	--	--		
EL0300-	FRAME SYNCH + ID								50	P	32	B	2	R	H									-	--	--		
EL0302	FORMAT ID								1	P	8	B	2	R	L									-	--	--		
EL0401	CALIB 85 PCT HL	4.24	4.25	4.26	VDC	SS			1	H	8	B	2	R	L					0	5	SS		-	--	--		
EL0401-	CALIB 85 PCT HL	4.24	4.25	4.26	VDC	SS			10	H	8	B	2	R	H					0	5	SS		-	--	--		
EL0402	CALIB 15 PCT HL	.741	.75	.759	VDC	SS			1	H	8	B	2	R	L					0	1	SS		-	--	--		
EL0402-	CALIB 15 PCT HL	.741	.75	.759	VDC	SS			10	H	8	B	2	R	H					0	1	SS		-	--	--		
EL0411	OUTPUT REG ALL ZERO CK								1	P	8	B	2		L									-	--	--		
EL0501-W	TIME,GREENWICH MEAN		TIME						1	P	32	B	2	P	L									-	--	--		
EL0501-W	TIME,GREENWICH MEAN		TIME						10	P	32	B	2	P	H									-	--	--		
EL0801-V	VOLT PCMTE 1024KC TIM SIG					SS						B	2									SS		-	--	--		
EL4021-X	(6DS1) TBA	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4025-X	6DS5 TBA	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4026-X	CES AC PWR SUPP FAIL(6DS6)	CONTACT CLOSURE				SS			1	E	1		2		H					CC		SS		-	--	--		
EL4026-X	CES AC PWR SUP FAIL(6DS6)W	CONTACT CLOSURE				SS			1	E	1		2		L		L			CC		SS		4-4	0	0		
EL4027-X	CES DC PWR SUP FAIL(6DS7)W	CONTACT CLOSURE				SS			1	E	1		2		L		L			CC		SS		4-4	0	0		
EL4028-X	AGS PWR SUPP FAIL (6DS8) W	CONTACT CLOSURE				SS			1	E	1		2		L		L			CC		SS		4-4	0	0		
EL4031-X	6DS11 RCS TCA JET FAIL W	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4032-X	6DS12 PR RCS HE REG A OUTW	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4033-X	6DS13 PR RCS HE REG B OUTW	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4034-X	6DS14 TBA W	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4035-X	6DS15 TBA W	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4036-X	6DS16 CABIN WARNING W	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4037-X	6DS17 SUIT/FAN WARNING W	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		
EL4038-X	6DS18 RNDZ RADAR DATA NG W	CONTACT CLOSURE				SS											L			CC		SS		-	--	--		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE F.O.LAB PHASE 2

PAGE NUMBER 19
NOVEMBER 8,1965

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	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	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
EL4040-X	6DS20 TBA W	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4043-X	6DS23 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
FL4044-X	6DS24 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4046-X	6DS26 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4047-X	6DS27 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4048-X	6DS28 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4049-X	6DS29 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4050-X	6DS30 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4051-X	6DS31 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4052-X	6DS32 PCS CAUTION C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4053-X	6DS33 HEATER CAUTION C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4054-X	6DS34 TBA C	CONTACT		CLOSURE		SS			1	E	1	B	2		L		L			CC		SS		-	--	--		
EL4055-X	6DS35 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4056-X	6DS36 ECS CAUTION C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4057-X	6DS37 ECS O2 ACCUM PRES C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4058-X	6DS38 GLYCOL CAUTION C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4059-X	6DS39 DES-ASC H2O QUAN C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
FL4060-X	6DS40 TBA C	CONTACT		CLOSURE		SS											L			CC		SS		-	--	--		
EL4069-X	C+WF MASTER ALARM ID					SS			1	E	1	B	2		L		L					SS		-	--	--		
EL4111-V	VOLT C+WE WRN IN REF V 1	-4.995	-5	-5.005	V	SS						B	2							0	-5	SS		-	--	--		
FL4112-V	VOLT C+WE WRN IN REF V 2	-4.995	-5	-5.005	V	SS						B	2							0	-5	SS		-	--	--		
EL4113-V	VOLT C+WF WRN IN REF V 3	-4.995	-5	-5.005	V	SS						B	2							0	-5	SS		-	--	--		
EL4114-V	VOLT C+WF CAUT IN REF V	-4.995	-5	-5.005	V	SS						B	2							0	-5	SS		-	--	--		
EL4201-F	FREQ OSEA MONI HD OUTPUT	.3	3KCPS			3KC						A	1											-	--	--		
EL4202-F	FREQ OSEA BIAS OSC OUTPUT	36	36KCPS			TBA						A	1											-	--	--		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 20
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	HIGH	FREQ OR RATE	A C C	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
ER1101-P	PRESSURE,HELIUM TANK A	3000	3050	3250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	3500	SS		4-1	.28	.25		
ER1101-P	PRESS HELIUM TANK A	0		1000	PSIA	SS										C				0	1000			-	--	--		
ER1102-P	PRESSURE,HELIUM TANK B	3000	3050	3250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	3500	SS		4-1	.28	.25		
ER1102-P	PRESS HELIUM TANK B	0		1000	PSIA	SS										C		A		0	1000	SS		-	--	--		
ER1103-P	PRESSURE,HELIUM TANK C	3000	3050	3250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	3500	SS		4-1	.28	.25		
ER1103-P	PRESS HELIUM TANK C	0		1000	PSIA	SS										C				0	1000			-	--	--		
ER1104-P	PRESSURE,HELIUM TANK D	3000	3050	3250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	3500	SS		4-1	.28	.25		
ER1104-P	PRESS HELIUM TANK D	0		1000	PSIA	SS										C				0	1000			-	--	--		
ER1121-T	TEMP,HELIUM TANK A	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER1122-T	TEMP,HELIUM TANK B	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER1123-T	TEMP,HELIUM TANK C	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER1124-T	TEMP,HELIUM TANK D	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER1201-P	PRESS,HE REGULATOR A OUT	171	191	250	PSIA	SS	3	I	1	H	8	B	2	P	L					0	350	SS		4-1	.28	.25		
ER1201-P	PRESS HE REG A OUTPUT	0		175		SS										W				0	175	SS		-	--	--		
ER1202-P	PRESS,HE REGULATOR B OUT	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	350	SS		4-1	.28	.25		
ER1202-P	PRESS HE REG B OUTPUT	0		175		SS										W				0	175	SS		-	--	--		
ER1203-P	PRESS,HE REGULATOR C OUT	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	350	SS		4-1	.28	.25		
ER1203-P	PRESS HE REG C OUTPUT	0		175		SS										W				0	175	SS		-	--	--		
ER1204-P	PRESS,HE REGULATOR D OUT	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	350	SS		4-1	.28	.25		
ER1204-P	PRESS HE REG D OUTPUT	0		175		SS										W				0	175	SS		-	--	--		
ER1461-X	HE SHUTOFF VLV A-1,CLOSE	CONTACT CLOSURE				SS		S	1	E	1	B	2	R			F			CC		SS		4-4	0	Z.05		
ER1462-X	HE SHUTOFF A-2 NOT CLOSED	CONTACT CLOSURE				SS		S	1	E	1	B	2	R			F			CC		SS		4-4	0	Z.05		
ER1463-X	HE SHUTOFF VLV B-1,CLOSE	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	H		F			CC		SS		4-4	0	Z.05		
ER1464-X	HE SHUTOFF B-2 NOT CLOSED	CONTACT CLOSURE				SS		S	1	E	1	B	2	P	L		F			CC		SS		4-4	0	Z.05		
ER1465-X	HE SHUTOFF VLV C-1,CLOSE	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	H		F			CC		SS		4-4	0	Z.05		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 21
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	REACTION CONTROL 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	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
ER1466-X	HE SHUTOFF C-2 NOT CLOSED	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	L		F			CC		SS		4-4	0	Z.05		
ER1467-X	HE SHUTOFF VLV D-1,CLOSE	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	H		F			CC		SS		4-4	0	Z.05		
ER1468-X	HE SHUTOFF D-2 NOT CLOSED	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	L		F			CC		SS		4-4	0	Z.05		
ER2101-P	PRESSURE,FUEL TANK A	171	191	250	PSIA	SS		I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER2102-P	PRESSURE,FUEL TANK B	171	191	250	PSIA	SS		I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER2103-P	PRESSURE,FUEL TANK C	171	191	250	PSIA	SS		I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER2104-P	PRESSURE,FUEL TANK D	171	191	250	PSIA	SS		I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER2121-T	TEMPERATURE,FUEL TANK A	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER2122-T	TEMPERATURE,FUEL TANK B	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER2123-T	TEMPERATURE,FUEL TANK C	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER2124-T	TEMPERATURE,FUEL TANK D	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER2141-Q	QUANTITY,FUEL TANK A	0		99	PCT	SS		S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER2142-Q	QUANTITY,FUEL TANK B	0		99	PCT	SS		S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER2143-Q	QUANTITY,FUEL TANK A	0		99	PCT	SS												D		0	99	SS		-	--	--		
ER2144-Q	QUANTITY FUEL TANK B	0		99	PCT	SS												D		0	99	SS		-	--	--		
ER2145-Q	QUANTITY,FUEL TANK C	0		99	PCT	SS		S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER2146-Q	QUANTITY FUEL TANK C	0		99	PCT	SS												D		0	99	SS		-	--	--		
ER2147-Q	QUANTITY,FUEL TANK D	0		99	PCT	SS		S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER2148-Q	QUANTITY FUEL TANK D	0		99	PCT	SS												D		0	99	SS		-	--	--		
ER2201-P	PRESS,A FUEL MANIFOLD	171	191	250	PSIA	SS	3	I	1	H	8	B	2	F	H			A		0	350	SS		4-1	.28	.25		
ER2202-P	PRESS,B FUEL MANIFOLD	171	191	250	PSIA	SS	3	I	1	H	3	B	2	F	H			A		0	350	SS		4-1	.28	.25		
ER2203-P	PRESS,C FUEL MANIFOLD	171	191	250	PSIA	SS	3	I	1	H	8	B	2	F	H			A		0	350	SS		4-1	.28	.25		
ER2204-P	PRESS,D FUEL MANIFOLD	171	191	250	PSIA	SS	3	I	1	H	8	B	2	F	H			A		0	350	SS		4-1	.28	.25		
ER2361-X	FUEL MNFL XFEED VLV NO CL	CONTACT	CLOSURE			SS		S							*		F			CC		SS		-	0	Z.05	ER9613	
ER2362-X	OXID MNFL XFEED VLV NO CL	CONTACT	CLOSURE			SS		S							*		F			CC		SS		-	0	Z.05	ER9613	

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 22
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	HIGH	FREQ OR RATE	A C C	CT USY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
ER2461-X	FUEL MAIN FEED S/O A CL	CONTACT CLOSURE				SS		S							*		F			CC		SS		-	0	Z.05	ER9609	
ER2462-X	FUEL MAIN FEED S/O B CL	CONTACT CLOSURE				SS		S							*		F			CC		SS		-	0	Z.05	ER9610	
ER2463-X	FUEL MAIN FEED S/O C CL	CONTACT CLOSURE				SS		S							*		F			CC		SS		-	0	Z.05	ER9609	
ER2464-X	FUEL MAIN FEED S/O D CL	CONTACT CLOSURE				SS		S							*		F			CC		SS		-	0	Z.05	ER9609	
ER3101-P	PRESSURE,OXIDIZER TANK A	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER3102-P	PRESSURE,OXIDIZER TANK B	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER3103-P	PRESSURE,OXIDIZER TANK C	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER3104-P	PRESSURE,OXIDIZER TANK D	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L			A		0	350	SS		-	.28	.25		
ER3121-T	TEMP,OXIDIZER TANK A	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER3122-T	TEMP,OXIDIZER TANK B	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER3123-T	TEMP,OXIDIZER TANK C	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER3124-T	TEMP,OXIDIZER TANK D	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L			A		20	120	SS		6-2	0	.16		
ER3141-Q	QUANTITY,OXID.TANK A	0		99	PCT	SS	3	S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER3142-Q	QUANTITY,OXID.TANK B	0		99	PCT	SS	3	S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER3143-Q	QUANTITY OXIDIZER TANK A	0		99	PCT	SS	3											D		0	99	SS		-	--	--		
ER3144-Q	QUANTITY OXIDIZER TANK B	0		99	PCT	SS	3											D		0	99	SS		-	--	--		
ER3145-Q	QUANTITY,OXID.TANK C	0		99	PCT	SS	3	S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER3145-Q	QUANTITY OXIDIZER TANK C	0		99	PCT	SS	3											D		0	99	SS		-	--	--		
ER3146-Q	QUANTITY,OXID.TANK D	0		99	PCT	SS	3	S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
ER3146-Q	QUANTITY OXIDIZER TANK D	0		99	PCT	SS	3											D		0	99	SS		-	--	--		
ER3201-P	PRESSURE,OXID.MNFLD A	171	191	250	PSIA	SS	3	I	1	H	8	B	2	P	H			A		0	350	SS		-	.28	.25		
ER3202-P	PRESSURE,OXID.MNFLD B	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	H			A		0	350	SS		-	.28	.25		
ER3203-P	PRESSURE,OXID.MNFLD C	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	H			A		0	350	SS		-	.28	.25		
ER3204-P	PRESSURE,OXID.MNFLD D	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	H			A		0	350	SS		-	.28	.25		
ER3461-X	OXID MAIN FEED S/O A CLSD	CONTACT CLOSURE				SS		S							*		F			CC		SS		-	0	Z.05	ER9609	

Grumman

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 23
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW NORM 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 HIGH	FREQ OR RATE	A C C	C T OSY NIP OGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
ER3462-X	OXID MAIN FEED S/O B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9610	
ER3463-X	OXID MAIN FEED S/O C CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9609	
ER3464-X	OXID MAIN FEED S/O D CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9609	
ER4261-X	TCA ISOL FUEL VLV 1A CLSD	CONTACT CLOSURE	SS		S									F			CC	SS		4-4	0	Z.05		
ER4262-X	TCA ISOL FUEL VLV 1B CLSD	CONTACT CLOSURE	SS		S									F			CC	SS		4-4	0	Z.05		
ER4263-X	TCA ISOL FUEL VLV 2A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9663	
ER4264-X	TCA ISOL FUEL VLV 2B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9664	
ER4265-X	TCA ISOL FUEL VLV 3A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9665	
ER4266-X	TCA ISOL FUEL VLV 3B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9666	
ER4267-X	TCA ISOL FUEL VLV 4A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9667	
ER4268-X	TCA ISOL FUEL VLV 4B CLSD	CONTACT CLOSUER	SS		S							*		F			CC	SS		-	0	Z.05	ER9668	
ER4269-X	TCA ISOL OXID VLV 1A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9661	
ER4270-X	TCA ISOL OXID VLV 1B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9662	
ER4271-X	TCA ISOL OXID VLV 2A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9663	
ER4272-X	TCA ISOL OXID VLV 2B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9664	
ER4273-X	TCA ISOL OXID VLV 3A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9665	
ER4274-X	TCA ISOL OXID VLV 3B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9666	
ER4275-X	TCA ISOL OXID VLV 4A CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9667	
ER4276-X	TCA ISOL OXID VLV 4B CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9668	
ER4277-X	TCA ISOL FUEL VLV 1C CLSD	CONTACT CLOSURE	SS		S									F			CC	SS		4-4	0	Z.05		
ER4278-X	TCA ISOL FUEL VLV 1D CLSD	CONTACT CLOSURE	SS		S									F			CC	SS		4-4	0	Z.05		
ER4279-X	TCA ISOL FUEL VLV 2C CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9663	
ER4280-X	TCA ISOL FUEL VLV 2D CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9664	
ER4281-X	TCA ISOL FUEL VLV 3C CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9665	
ER4282-X	TCA ISOL FUEL VLV 3D CLSD	CONTACT CLOSURE	SS		S							*		F			CC	SS		-	0	Z.05	ER9666	

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES
ER4283-X	TCA ISOL FUEL VLV 4C CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9667
ER4284-X	TCA ISOL FUEL VLV 4D CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9668
ER4285-X	TCA ISOL OXID VLV 1C CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9661
ER4286-X	TCA ISOL OXID VLV 1D CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9662
ER4287-X	TCA ISOL OXID VLV 2C CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9663
ER4288-X	TCA ISOL OXID VLV 2D CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9664
ER4289-X	TCA ISOL OXID VLV 3C CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9665
ER4290-X	TCA ISOL OXID VLV 3D CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9666
ER4291-X	TCA ISOL OXID VLV 4C CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9667
ER4292-X	TCA ISOL OXID VLV 4D CLSD	CONTACT		CLOSURE		SS		S							*		F			CC		SS		-	0	Z.05	ER9668
ER5001-X	O/F RATIO A OUT,TOLER	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	H	C				CC		SS		4-3	0	Z.05	
ER5002-X	O/F RATIO B OUT,TOLER	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	H	C				CC		SS		4-3	0	Z.05	
ER5003-X	O/F RATIO C OUT,TOLER	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	H	C				CC		SS		4-3	0	Z.05	
ER5004-X	O/F RATIO D OUT,TOLER	CONTACT		CLOSURE		SS		S	1	E	1	B	2	R	H	C				CC		SS		4-3	0	Z.05	
ER5011-P	PRESS TCA FUEL INLT PR 1A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5012-P	PRESS TCA FUEL INLT PR 1B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5013-P	PRESS TCA FUEL INLT PR 2A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5014-P	PRESS TCA FUEL INLT PR 2B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5015-P	PRESS TCA FUEL INLT PR 3A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5016-P	PRESS TCA FUEL INLT PR 3B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5017-P	PRESS TCA FUEL INLT PR 4A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5018-P	PRESS TCA FUEL INLT PR 4B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5019-P	PRESS TCA OXID INLT PR 1A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5020-P	PRESS TCA OXID INLT PR 1B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	
ER5021-P	PRESS TCA OXID INLT PR 2A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--	

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE E.O.LAB PHASE 2

PAGE NUMBER 25
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	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	HIGH	FREQ OR RATE	A C C	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
ER5022-P	PRESS TCA OXID INLT PR 2B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5023-P	PRESS TCA OXID INLT PR 3A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5024-P	PRESS TCA OXID INLT PR 3B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5025-P	PRESS TCA OXID INLT PR 4A	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5026-P	PRESS TCA OXID INLT PR 4B	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5027-P	PRESS TCA FUEL INLT PR 1C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5028-P	PRESS TCA FUEL INLT PR 1D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5029-P	PRESS TCA FUEL INLT PR 2C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5030-P	PRESS TCA FUEL INLT PR 2D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5031-P	PRESS TCA FUEL INLT PR 3C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5032-P	PRESS TCA FUEL INLT PR 3D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5033-P	PRESS TCA FUEL INLT PR 4C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5034-P	PRESS TCA FUEL INLT PR 4D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5035-P	PRESS TCA OXID INLT PR 1C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5036-P	PRESS TCA OXID INLT PR 1D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5037-P	PRESS TCA OXID INLT PR 2C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5038-P	PRESS TCA OXID INLT PR 2D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5039-P	PRESS TCA OXID INLT PR 3C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5040-P	PRESS TCA OXID INLT PR 3D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5041-P	PRESS TCA OXID INLT PR 4C	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER5042-P	PRESS TCA OXID INLT PR 4D	171	191	250	PSIA	SS	3	S									F			0	175	SS		-	--	--		
ER6001-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		
ER6002-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		
ER6003-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		
ER6004-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		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE C.O.LAB PHASE 2

PAGE NUMBER 26
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	REACTION CONTROL FREQ OR RATE	ACC	SCF	S/S	S/IG	BIT	GRD	DPS	MCC	MH S/SL	C/W	F/L	A/D	X/X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	ACC	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
ER7121-V	VOLT SEC FUEL + OX INJT 1	0	28	32	VDC							B	2							0	35			-	--	--		
ER7122-V	VOLT SEC FUEL + OX INJT 2	0	28	32	VDC							B	2							0	35			-	--	--		
ER7123-V	VOLT SEC FUEL + OX INJT 3	0	28	32	VDC							B	2							0	35			-	--	--		
ER7124-V	VOLT SEC FUEL + OX INJT 4	0	28	32	VDC							B	2							0	35			-	--	--		
ER7125-V	VOLT SEC FUEL + OX INJT 5	0	28	32	VDC							B	2							0	35			-	--	--		
ER7126-V	VOLT SEC FUEL + OX INJT 6	0	28	32	VDC							B	2							0	35			-	--	--		
ER7127-V	VOLT SEC FUEL + OX INJT 7	0	28	32	VDC							B	2							0	35			-	--	--		
ER7128-V	VOLT SEC FUEL + OX INJT 8	0	28	32	VDC							B	2							0	35			-	--	--		
ER7129-V	VOLT SEC FUEL + OX INJT 9	0	28	32	VDC							B	2							0	35			-	--	--		
ER7130-V	VOLT SEC FUEL + OX INJT10	0	28	32	VDC							B	2							0	35			-	--	--		
ER7131-V	VOLT SEC FUEL + OX INJT11	0	28	32	VDC							B	2							0	35			-	--	--		
ER7132-V	VOLT SEC FUEL + OX INJT12	0	28	32	VDC							B	2							0	35			-	--	--		
ER7133-V	VOLT SEC FUEL + OX INJT13	0	28	32	VDC							B	2							0	35			-	--	--		
ER7134-V	VOLT SEC FUEL + OX INJT14	0	28	32	VDC							B	2							0	35			-	--	--		
ER7135-V	VOLT,SEC FUEL + OX INJT15	0	28	32	VDC							B	2							0	35			-	--	--		
ER7136-V	VOLT,SEC FUEL + OX INJT16	0	28	32	VDC							B	2							0	35			-	--	--		
ER9609-U	MAIN PROP.VALVE A CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	F	H					CC		SS		4-4	--	--		
ER9610-U	MAIN PROP.VALVE B CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	R	H					CC		SS		4-4	--	--		
ER9613-U	MNFLD XFEED VLVS N/C	CONTACT	CLOSURE			SS			1	E	1	B	2	R	L					CC		SS		4-4	--	--		
ER9614-U	MAIN PROP.VALVE C CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	F	H					CC		SS		4-4	--	--		
ER9615-U	MAIN PROP.VALVE D CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	R	H					CC		SS		4-4	--	--		
ER9661-U	TCA ISOL VLVS 1A CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	R	H					CC		SS		4-4	--	--		
ER9662-U	TCA ISOL VLVS 1B CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	R	H					CC		SS		4-4	--	--		
ER9663-U	TCA ISOL VLVS 2A CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	R	H					CC		SS		4-4	--	--		
ER9664-U	TCA ISOL VLVS 2B CLOSED	CONTACT	CLOSURE			SS			1	E	1	B	2	R	H					CC		SS		4-4	--	--		

Table 5.6-8 (cont.)

CONTRACT NUMBER NAS9-4983
BASELINE L.O.LAB PHASE 2

PAGE NUMBER 27
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW NORM 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 HIGH	FREQ OR RATE	A C C	C T OSY NIP DGF	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
ER9665-U	TCA ISOL VLVS 3A CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9666-U	TCA ISOL VLVS 3B CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9667-U	TCA ISOL VLVS 4A CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9668-U	TCA ISOL VLVS 4B CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9669-U	TCA ISOL VLVS 1C CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9670-U	TCA ISOL VLVS 1D CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9671-U	TCA ISOL VLVS 2C CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9672-U	TCA ISOL VLVS 2D CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9673-U	TCA ISOL VLVS 3C CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9674-U	TCA ISOL VLVS 3D CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	F	H					CC	SS		4-4	--	--		
ER9675-U	TCA ISOL VLVS 4C CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	R	H					CC	SS		4-4	--	--		
ER9676-U	TCA ISOL VLVS 4D CLOSED	CONTACT CLOSURE	SS			1	E	1	B	2	F	H					CC	SS		4-4	--	--		

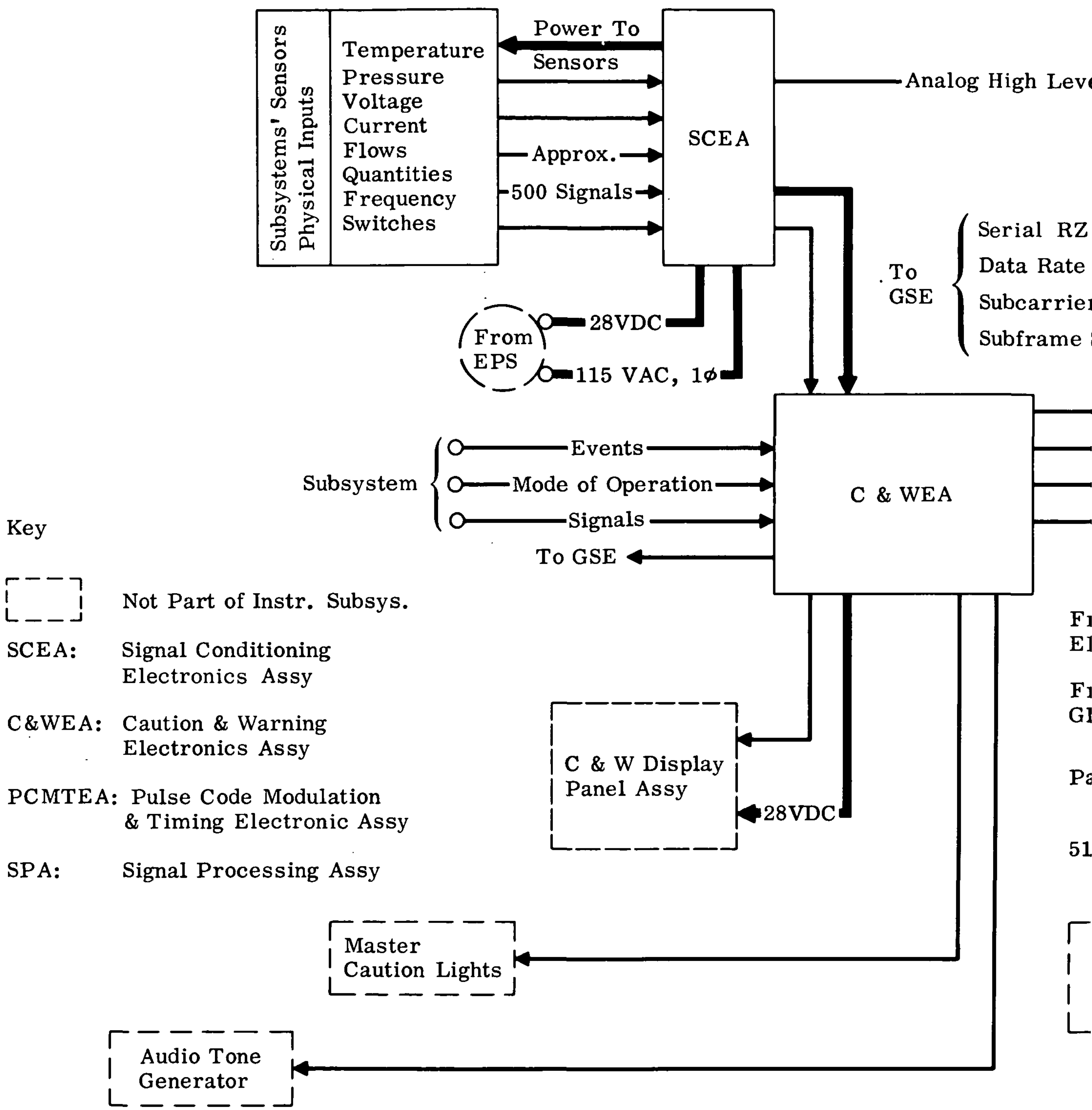
Table 5.6-8 (cont.)

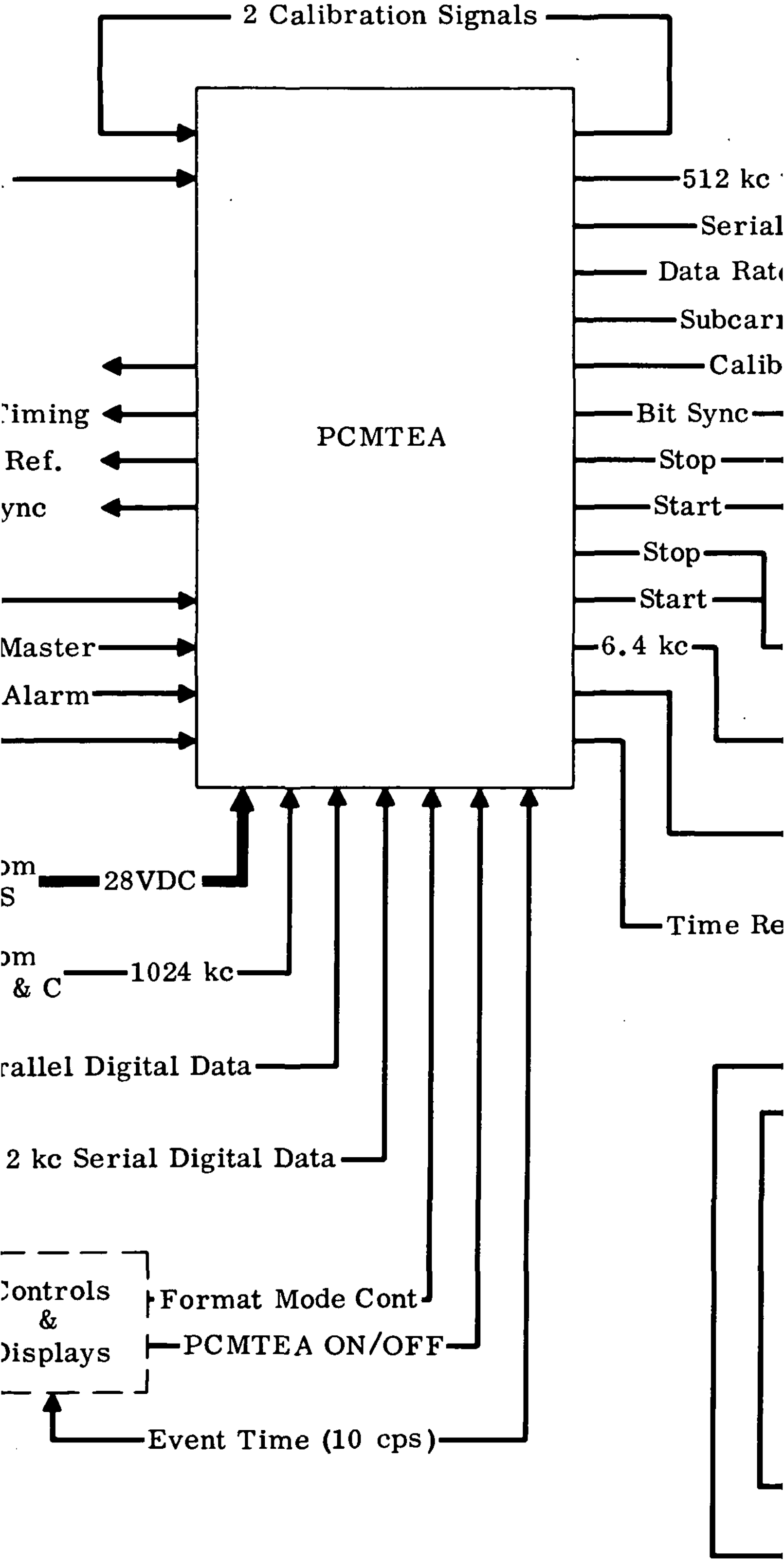
CONTRACT NUMBER NAS9-4983
BASELINE F.O.LAB PHASE 2

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	FREQ OR RATE	COMMUNICATIONS 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 USY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
ET0105	PCM NRZ DATA INPUT		TBA									A	1											-	--	--		
ET0106	TE 512KC SYNC IN		TBA									A	1											-	--	--		
ET0107	PCM SPLIT PHASE IN		TBA									A	1											-	--	--		
ET0108	512KC SUBCARRIER REF IN		TBA									A	1											-	--	--		
ET0161-V	VOLT,PMP BACK-UP VOICE		TBA									A	1											-	--	--		
ET0163	VHF RCVD VOICE IN A		TBA									A	1											-	--	--		
ET0164	VHF RCVD VOICE IN B		TBA									A	1											-	--	--		
ET0201-E	POWER,SBAND PA RF PWR OUT	0	18	25	WATTS	SS		S	1	H	8	B	2	R	L							SS		-	--	--		
ET0202-F	PWR,SBAND PA RF REFLECTED	0	.3	.5	WATTS	SS		S	1	H	8	B	2		H							SS		-	--	--		
ET0226-E	PWR VHF XMTR A+B RF OUT		TBA									B	2											-	--	--		
ET0504-V	VOLT,SBAND RCVR AGC	0		4.2	VDC													A		0	5			-	--	--		
ET0511	SBAND XPNDR FM INPUT		TBA									A	1											-	--	--		
ET0513	SBAND XPNDR PM INPUT		TBA									A	1											-	--	--		
ET0555	S BD RCVR SBCAR WVFORM OT		TBA									A	1											-	--	--		
ET0604-V	VOLT,VHF RCVR A AGC	0		4.2	VDC	SS						B	2							0	5	SS		-	--	--		
ET0605-V	VOLT,VHF RCVR B AGC	0		4.2	VDC	SS						B	2							0	5	SS		-	--	--		
ET0992-B	PHASE,ST PH ER,SLCTD S/B	-15	0	+15	DEG	2C		S	10	H	8	B	2	R	L							2C		-	--	--		
ET0993-E	PWR,SLCTD SBAND XMTR RF	.5	.75	1	WATT	SS		S	1	H	8	B	2	R	L							SS		-	--	--		
ET0994-V	VOLT,SLCTD SBAND RCVR AGC	0		4.2	VDC	2C		S	10	H	8	B	2	R	L					0	5	2C		-	--	--		
ET8801-P	PRESS,AIRLOCK	0	5	10	PSIA	SS												A				SS						
ET9991-J	7 SPACE SUIT/PLSS MPX OUT 4KC			12.4K																				-	--	--	SBAND	
ET9999-J	ELECTROCARDIOGRAM NO.1/2		14.5K																					-	--	--	SBAND	

Grumman

187


Subsystems' Sensors
Physical Inputs
Temperature
Pressure
Voltage
Current
Flows
Quantities
Frequency
Switches
Power To
Sensors
Approx.
500 Signals
SCEA
From
EPS
28VDC
115 VAC, 1ϕ
To
GSE
Serial RZ
Data Rate
Subframe
Subsystem
Events
Mode of Operation
Signals
To GSE
C & WEA
C & W Display
Panel Assy
28VDC
Master
Caution Lights
Audio Tone
Generator
Key
Not Part of Instr. Subsys.
SCEA: Signal Conditioning Electronics Assy
C&WEA: Caution & Warning Electronics Assy
PCMTEA: Pulse Code Modulation & Timing Electronic Assy
SPA: Signal Processing Assy


2 Calibration Signals
PCMTEA
512 kc
Serial
Data Rat
Subcar
Calib
Bit Sync
Stop
Start
Stop
Start
6.4 kc
Time Re
iming
Ref.
ync
Master
Alarm
28VDC
1024 kc
& C
rallel Digital Data
2 kc Serial Digital Data
ontrols
&
isplays
Format Mode Cont
PCMTEA ON/OFF
Event Time (10 cps)

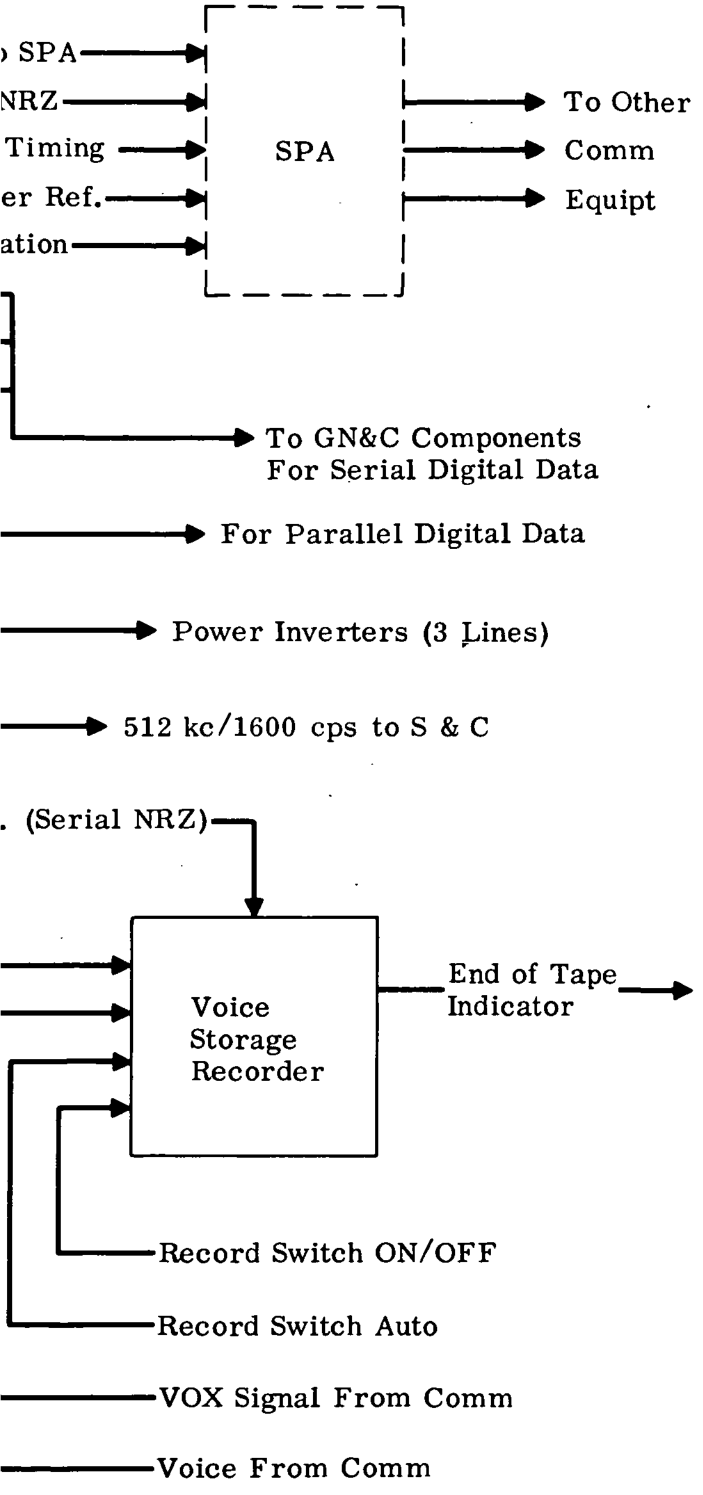


Fig. 5.6-1 Operational System Schematic Diagram

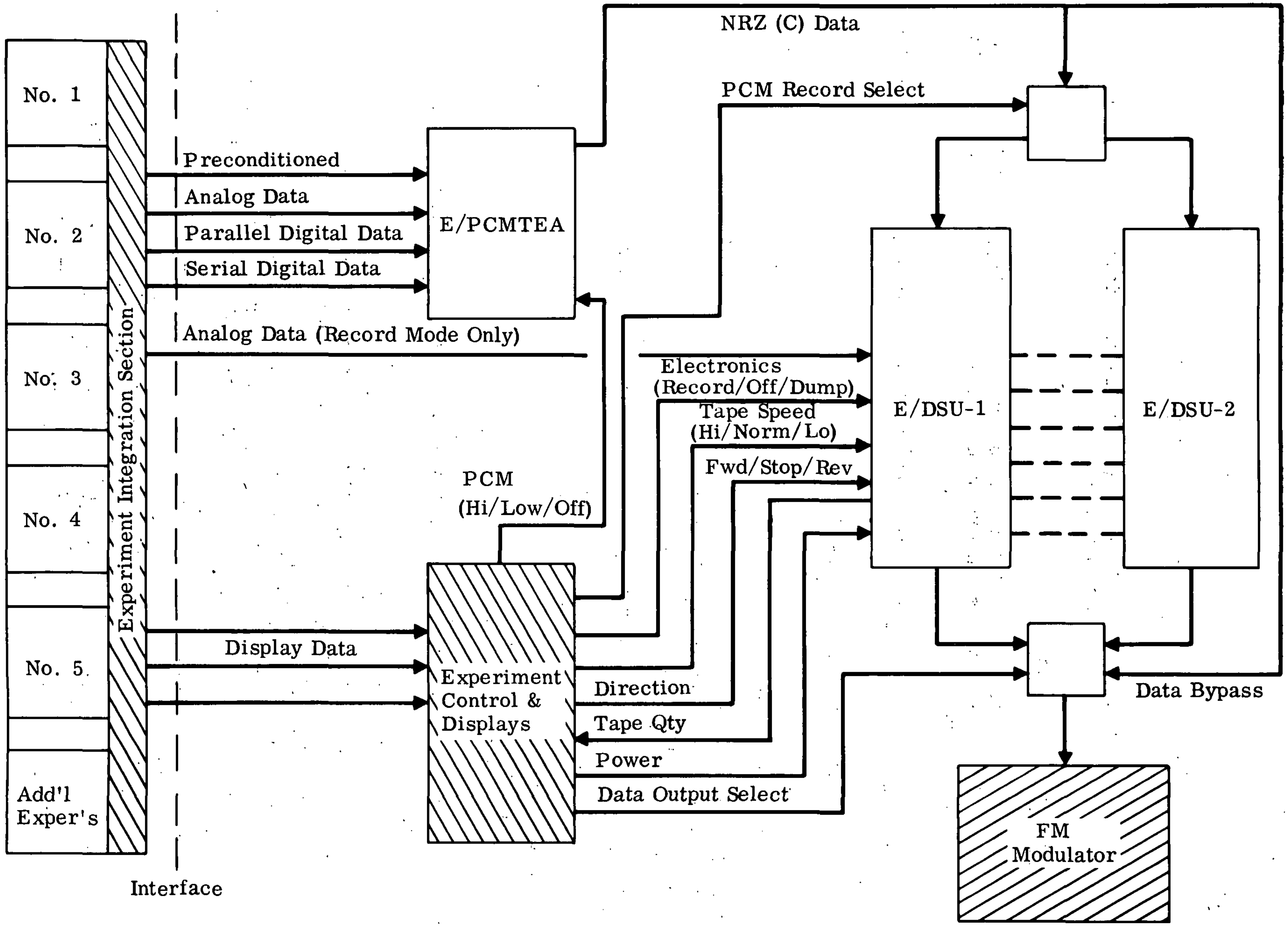


Fig. 5.6-2 Experiment System Schematic Diagram

5.7 CONTROLS AND DISPLAYS

5.7.1 Ground Rules

- The required Lab displays should be incorporated with a minimum of modification to the existing console layout
- Maximum use should be made of LEM type controls and displays for modifications and new equipment employed in the Lab

5.7.2 Recommended Configuration

Requirements for the Phase II Lab differ only slightly from the present LEM and in general, the required displays are incorporated in the basic Lab configuration with a minimum of console modification.

The following LEM controls and displays, or modification thereof, are recommended for integration into the Phase II Lab:

- o Navigation and Guidance (modified)
- o Stabilization and Control
- o Reaction Control
- o Instrumentation (modified)
- o Communications
- o Electric Power (New)
- o Environmental Control (modified)
- o Caution and Warning

The mission-oriented controls and displays are grouped as follows:

- o Biomedical
- o Behavioral
- o Radiation Monitoring
- o Communications Hardline
- o Data Handling Package

Figure 6.3-2 shows the Commander's and System Engineer's controls and displays. On the Commander's side:

- o Panel number 4 consists of circuit breaker panels that have circuit breakers for instrumentation, flight displays, subsystem displays, Electrical Power Subsystem, Stabilization and Control, internal lighting and signal sensors.
- o The audio controls, (Fig. 5.7-1 & 5.7-2B), enable the audio center to accept received S-band and VHF/AM voice transmission and to route microphone amplifier outputs from within the Lab to the premodulation processor for S-band and VHF/AM equipment. The controls also enable reception and transmission of voice signals via the intercom system, establishing a voice conference capability between the extravehicular astronaut and the astronaut in the Lab, and provide power to the voice operated transmission (VOX) control circuitry in the audio center.
- o The abort guidance panel #12, (Fig. 5.7-3) provides backup for the Guidance and Navigation Subsystem, using the Lab guidance computer (LGC) for automatic guidance for aborts.

- o The Commander's lighting control panel #7 (Fig. 5.7-4) controls the side console lighting, integral lights and the dome light.
- o The Stabilization and Control panel #3 (Fig. 5.7-5) permits selection of five modes of attitude control. The automatic mode provides fully automatic attitude control. The attitude hold mode is the primary mode for operating experiments with pointing requirements. The rate command mode is the same as the attitude hold mode, except it does not provide a neutral position. The pulse mode is an open-loop attitude control mode providing full RCS jet thrusting for attitude changes in all three axes.

The Flight Director Attitude Indicator displays the attitude, attitude rates, and attitude errors of the Lab, in all three axes:

- The clock & event timer are controlled from panel 7, (Fig. 5.7-4) and are displayed on panel 1 (Fig. 5.7-1).
  - o The warning indicators (Fig. 5.7-1) warn of an emergency malfunction requiring immediate action. Lighting of a warning indicator (red lights) is accompanied by an audible tone in the astronaut's headset. There are also master alarm switches which light up when a malfunction occurs. Pushing either button will stop the audible tone.

Systems Engineer's Panel:

- The caution indicators, yellow lights, (Fig. 5.7-6) alert the astronaut to a situation or malfunction which requires attention but is not critical at the moment. When the caution lights indicate a malfunction, the two master alarm switch lights and the audible tone both function. The master alarm switch lights are extinguished, and the audible tone is silenced, by pressing either master alarm switch light.
- The Reaction Control panel #2 (Fig. 5.7-6) contains the following controls and displays:
  - o Temperature and pressure indicators for the helium, fuel, and oxidizer tanks, and fuel or oxidizer manifolds of system A and system B.
  - o An additional set of oxidizer and fuel quantity indicators to give separate quantity measurements of the additional parallel tankage system. This will give the astronauts the individual percentage of fuel and oxidizer quantities in each tank (System A,B,), or by adding the two it will give the total percentage of oxidizer and fuel quantities of System A or System B. System A and System B switches and status flags indicate the status of their respective latch-type solenoid valves, four regulator switches and two main shutoff switches.
  - o The thruster pair switches and status flags consist of eight 3-position status flags that indicate the status of their pair of latch-type solenoid valves, and eight thruster pair switches.
  - o The crossfeed switch controls two latch type, solenoid-operated fuel and oxidizer valves that interconnect the propellant valves of system A and B.
  - o The test switch is used to check for a leak in the line downstream of the TCA isolation valves
- The Environmental Control panel #2 (Fig. 5.7-6), contains the following controls and displays:
  - o Suit/cabin temperature and pressure indicators
  - o Displays of carbon dioxide partial pressure in the suit circuit

- o Glycol temp/press indicator display temperature and pressure of the coolant in the heat transport section
- o Gaseous oxygen pressure-water and gaseous oxygen quantity displays gaseous oxygen pressure, gaseous nitrogen pressure, water quantity and gaseous oxygen quantity
- o Suit fan select switch, which selects an operating fan (1 or 2) and a failure light with each position.

- The Systems Engineer's panel #11 (Fig. 5.7-2B), consists of a Communication Panel, Communications Antennas Panel and Data Handling display.
- The Communications Panel has switches and controls that start the operation of the S-band, VHF/AM, emergency key, telemetry control, tape recorder, and selection of backup S-band equipment. The VHF/AM control selects simplex or duplex voice operation; a squelch control establishes the degree on noise limiting in the operating duplex receiver. The telemetry controls permit high-or-low-bit rate premodulation processor transmission. The keyer is energized by setting the EMER. KEY switch to ON. Provisions for a hardline c communications to the CSM for both astronauts have been incorporated enabling either astronaut to talk directly to the CSM.
  - o The Communication Antennas Panel has indicators, selector switches and the pitch and slew control switches for pointing the S-Band steerable antenna toward Earth. The VHF switch selects either of two inflight omnidirectional antennas. The S-band switch selects either the steerable antenna or S-Band in-flight antenna.
  - o The Data Handling Panel #11 (Fig. 5.7-2B) consists of a display for a modified PCM and two tape recorders. The tape recorders have a two-speed switch and digital readouts of tape remaining and a record/dump switch.
  - o The Systems Engineer's Lighting Control Panel #3 (Fig. 5.7-5) consists of exterior lighting switch, lamp tone test switch, docking light and recognition lights. Fig. 5.7-7 shows the Systems Engineer's circuit breaker panels that have circuit breakers for interior lighting, Reaction Control, Electrical Power, Environmental Control, and Communications Subsystems.
  - o The System's Engineer controls the Electrical Power distribution panel (Fig. 5.7-2A), which receives power from two fuel cells and one peaking battery. The monitoring displays for the fuel cells are as follows: DC volts, DC ammeter, H_2, O_2 flow and pressure meters, fuel cell purge, AC inverters, pH and AC volt warning lights, N_2, O_2 and H_2 regulator out pressure warning lights, overtemperature light and fuel cell temperature monitor.
  - o The fuel cell controls allow the fuel cells to be put in normal, off, or standby mode. The standby position allows a fuel cell to remain on, but disconnects it from the bus. The normal position connects the fuel cell on the bus. For each fuel cell there is one status flag to indicate when the fuel cell is on the bus.
  - o The crew safety package located on panel #1 (Fig. 5.7-1), displays respiration rate, heart rate and cabin radiation level, the minimum requirements for crew safety.

The following systems and subsystems have been slightly modified or deleted to meet mission requirements:

- o Main Propulsion
- o Navigation and Guidance
- o Engine Thrust Controls

- Environmental Control
- Electrical Power
- Explosive Devices

Both ascent and descent propulsion subsystems have been deleted, to comply with the mission definitions of the basic Lab. The engine thrust controls work in conjunction with the Main Propulsion System and are therefore also deleted. The panel area left vacant by the propulsion and engine thrust will become available for experiments.

Since Navigation and Guidance has deleted the primary guidance systems there is no need for the GASTA or DSKY computer. There is only one FDAI in the recommended Lab, therefore, the abort guidance system handles GASTA error correction duties.

The radar (both rendezvous and landing radar) has been deleted, since the Lab is an earth orbiter and will not perform a landing rendezvous or docking maneuver. The radars can be added as a per-flight modification when required for experiments.

The Heater Control Panel #3 (Fig. 5.7-5), has been modified to accommodate the S-Band heater controls and the removal of the radar heater controls.

Due to the deletion of the main propulsion ascent and descent engines, the ascent feed switches and lights are removed from the Reaction Control Subsystem.

The Electrical Power Subsystem has been modified to use fuel cells because of increased power requirements for the mission. Each fuel cell must be controlled individually, therefore it is necessary to redesign the controls and displays for two fuel cells and one Peaking Battery.

The explosive devices have been slightly modified to reflect the changes in the systems on board. Explosive devices for the landing gear, ascent pressure, ascent tankage and descent pressure are removed.

The Environmental Control Subsystem has removed the two ascent and one descent H_2O tanks and has replaced them by the CSM Water Management System. The descent GOX tank has been filled with N_2 and the ascent GOX tank acts an an accumulator. Therefore, it becomes necessary to monitor the N_2, O_2 and H_2O pressures by modifying the quantity monitor select switch and O_2 pressure indicator. This will permit monitoring the pressures in each tank.

The circuit breakers (Fig. 5.7-7 and 5.7-8) have been added or deleted in accordance with system and subsystem modifications. The extra circuit breakers will be utilized by experiments.

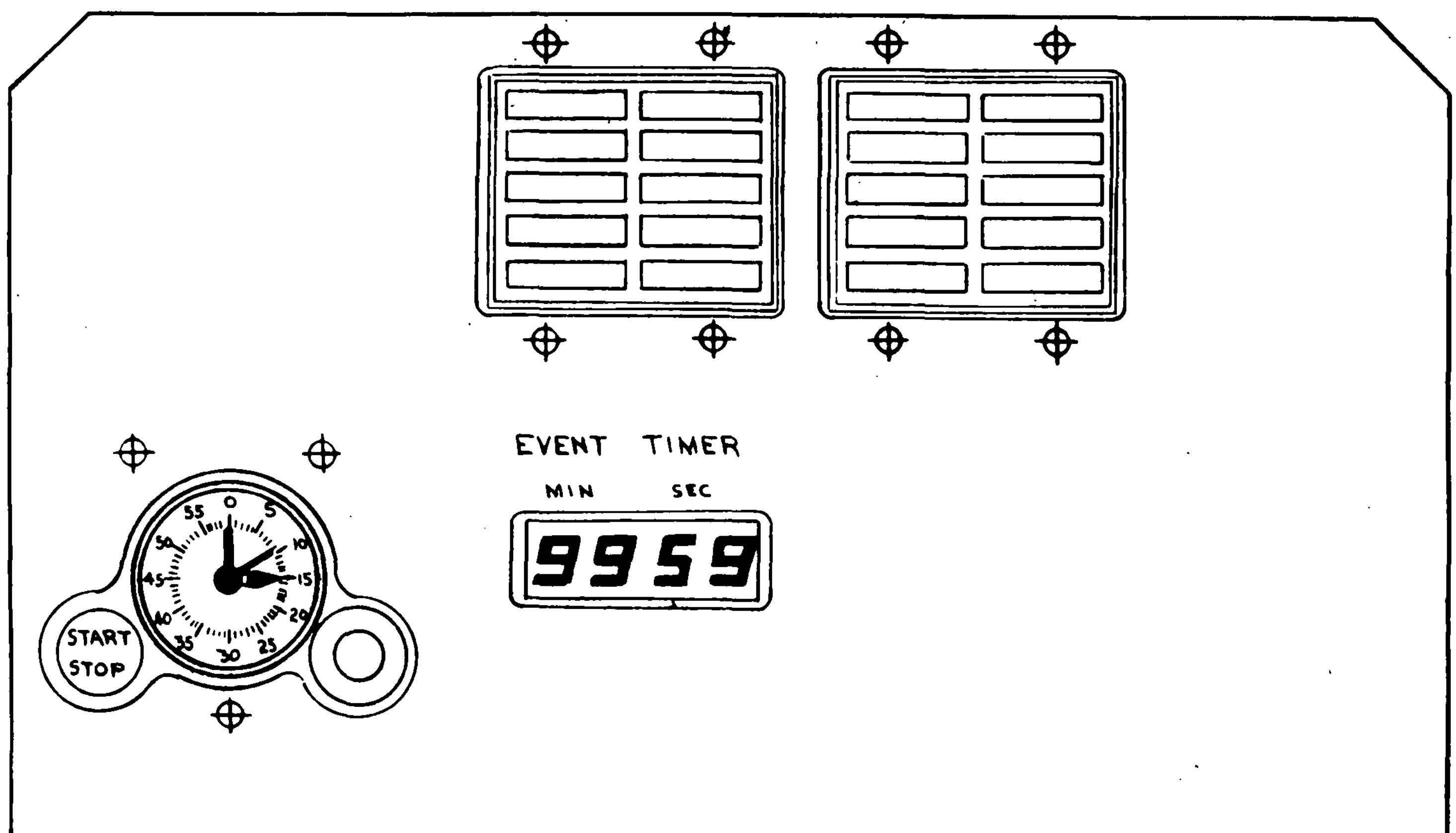
The display and control functions provided should give the Lab flight crew sufficient information and command access to the vehicle systems and subsystems to enable the crew to successfully accomplish the following operations during the mission:

- Manual Lab operation as required under normal mission conditions
- Safe shutdown of the Lab equipment, if necessary
- Recognize malfunctions of the crew, vehicle or mission and display a warning to the crew.
- Monitor the Lab subsystem condition, such as:

- Power sources
- Propellant quantity
- H_2O, N_2 and O_2 quantities

In general, displays that were redundant and which did not affect crew safety, the mission, or control of the vehicle were deleted. Areas made available from modified or deleted equipment have been allocated for experiments integration. The approximate panel area for experiment controls and displays is 781 sq in. If the Rendezvous Radar and DSKY are used, the available area decreases to 605 sq in.

The required Lab displays were incorporated in the basic LEM configuration with a minimum of modification to the existing console layout. New or redesigned display panels were mounted on the same hard points, to provide a commonality between vehicles.


EVENT TIMER
MIN
SEC
9959
START
STOP

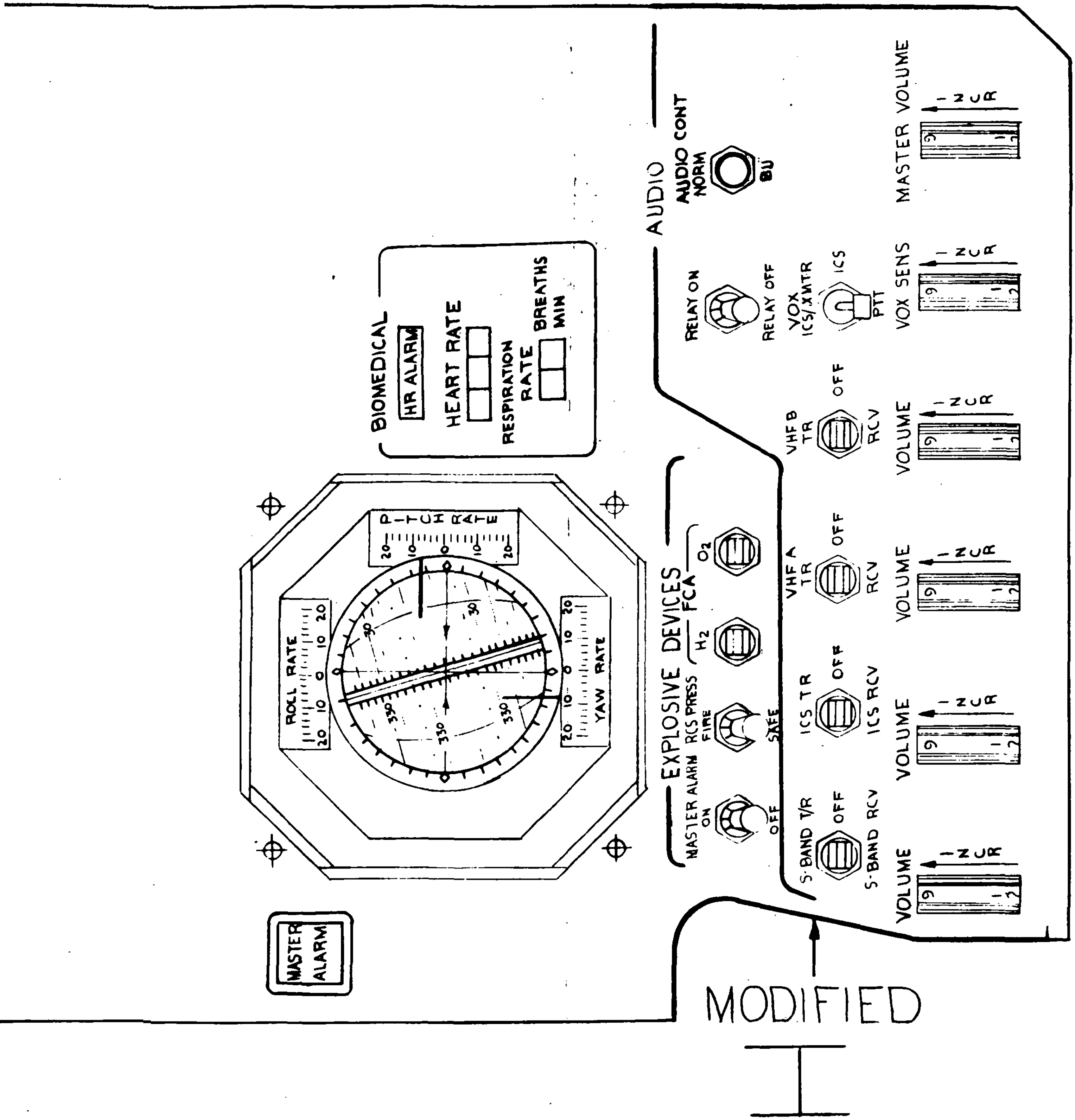
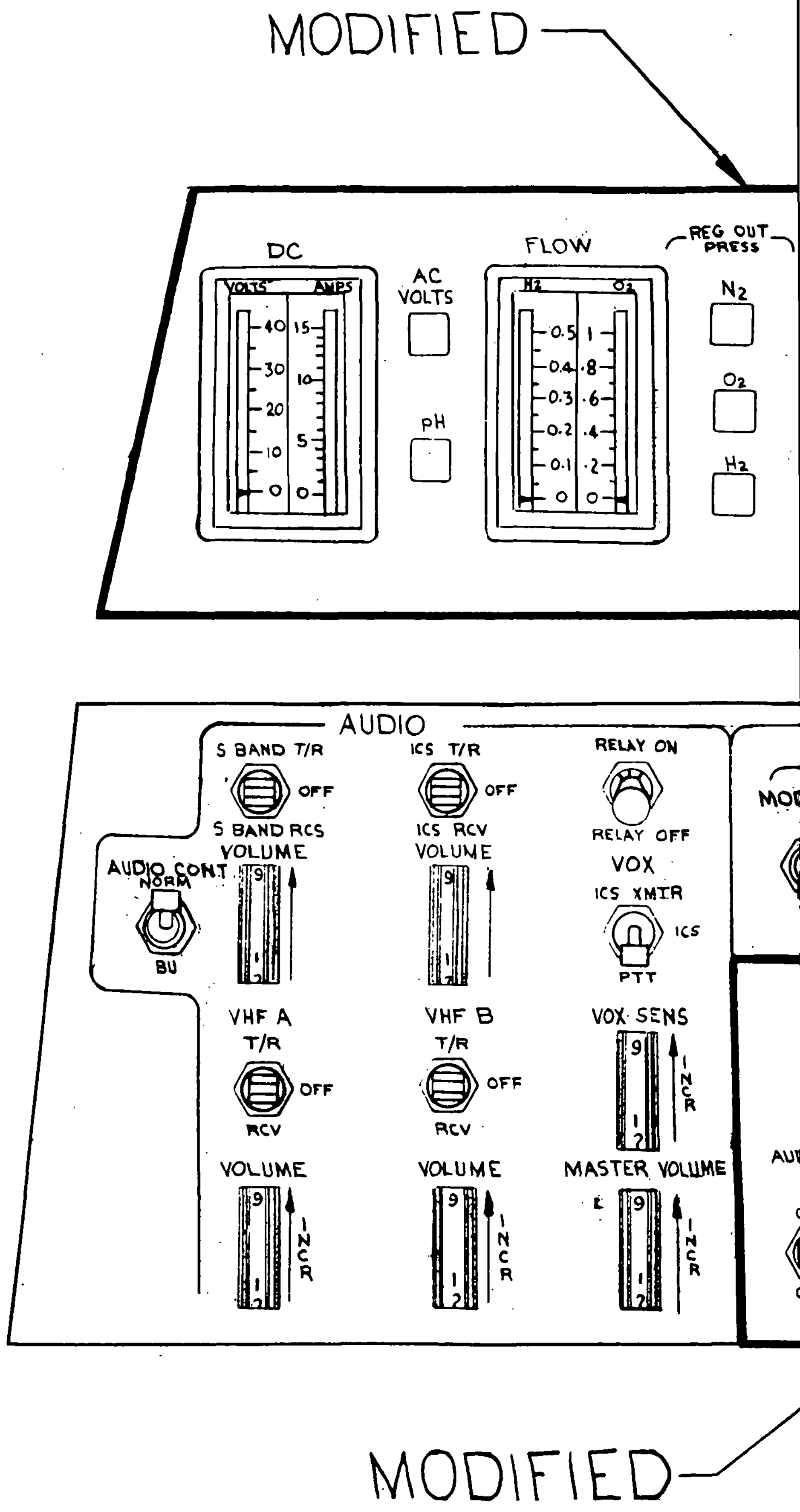
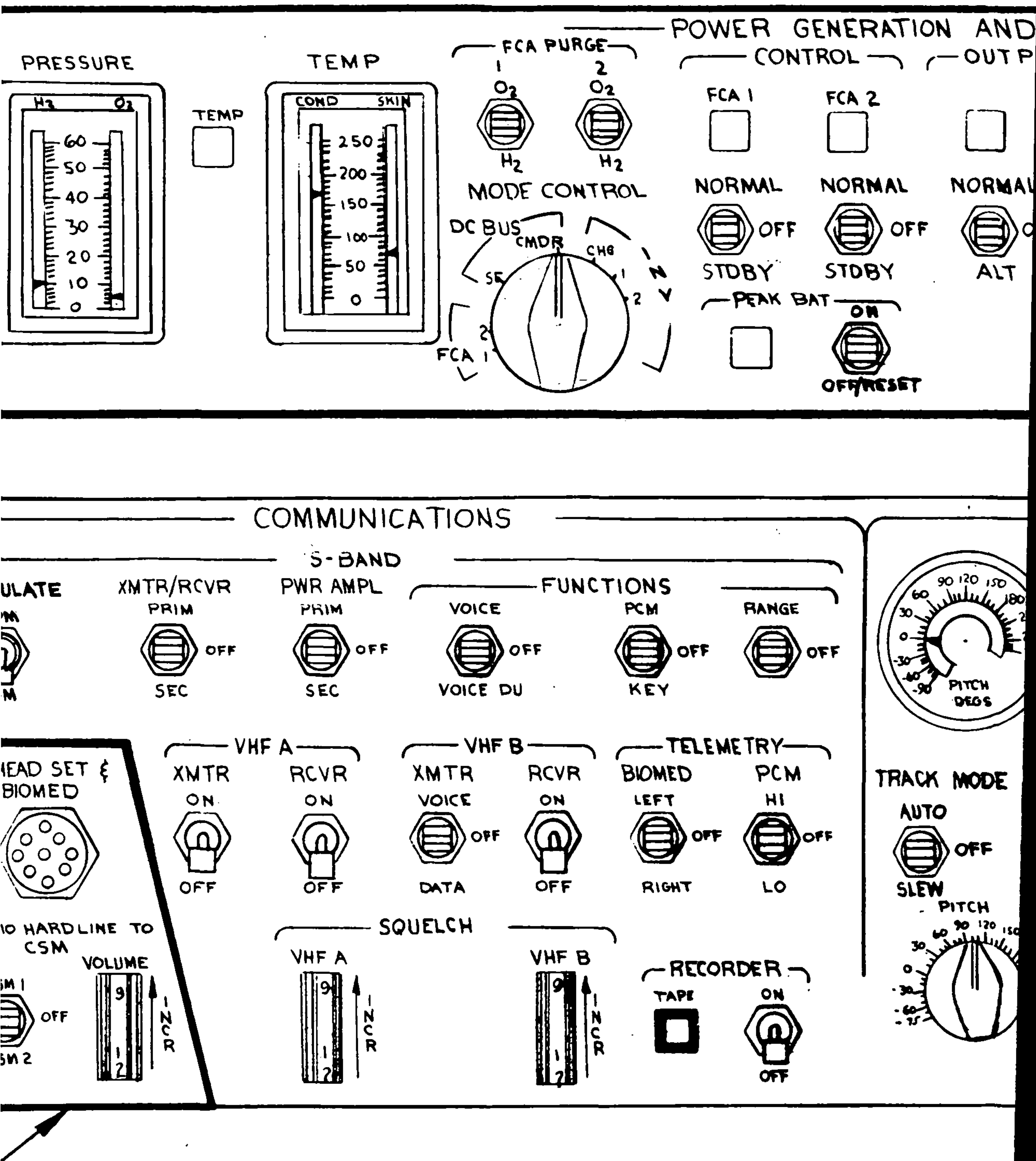


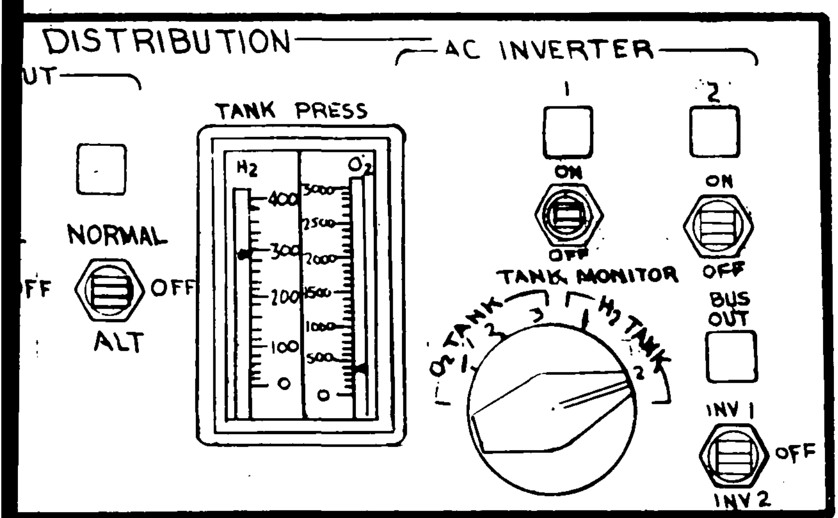
Fig. 5.7-1 Panel 1


MODIFIED
DC
VOLTS
AMPS
AC VOLTS
pH
FLOW
H_2
O_2
REG OUT PRESS
N_2
O_2
H_2
AUDIO
S BAND T/R
OFF
S BAND RCS
VOLUME
ICS T/R
OFF
ICS RCV
VOLUME
RELAY ON
RELAY OFF
VOX
ICS XMTR
ICS
PTT
AUDIO CONT
NORM
BU
VHF A
T/R
OFF
RCV
VHF B
T/R
OFF
RCV
VOX SENS
INCR
VOLUME
INCR
VOLUME
INCR
MASTER VOLUME
INCR
MODIFIED


POWER GENERATION AND
CONTROL
OUTP
PRESSURE
H_2
O_2
60
50
40
30
20
10
0
TEMP
TEMP
COND
SKIN
250
200
150
100
50
0
FCA PURGE
1
2
O_2
H_2
MODE CONTROL
DC BUS
CMDR
CHG
SE
N
V
FCA
FCA 1
FCA 2
NORMAL
OFF
STDBY
ALT
PEAK BAT
ON
OFF/RESET
COMMUNICATIONS
S-BAND
ULATE
XMTR/RCVR
PRIM
SEC
PWR AMPL
FUNCTIONS
VOICE
VOICE DU
PCM
KEY
RANGE
PITCH
DEGS
EAD SET &
BIOMED
VHF A
XMTR
RCVR
ON
VHF B
VOICE
DATA
TELEMETRY
BIOMED
LEFT
RIGHT
HI
LO
TRACK MODE
AUTO
SLEW
HARDLINE TO
CSM
VOLUME
INCR
SQUELCH
RECORDER
TAPE

5.7-2b

(2)



X

Fig. 5.7-2a Panel 10

XI

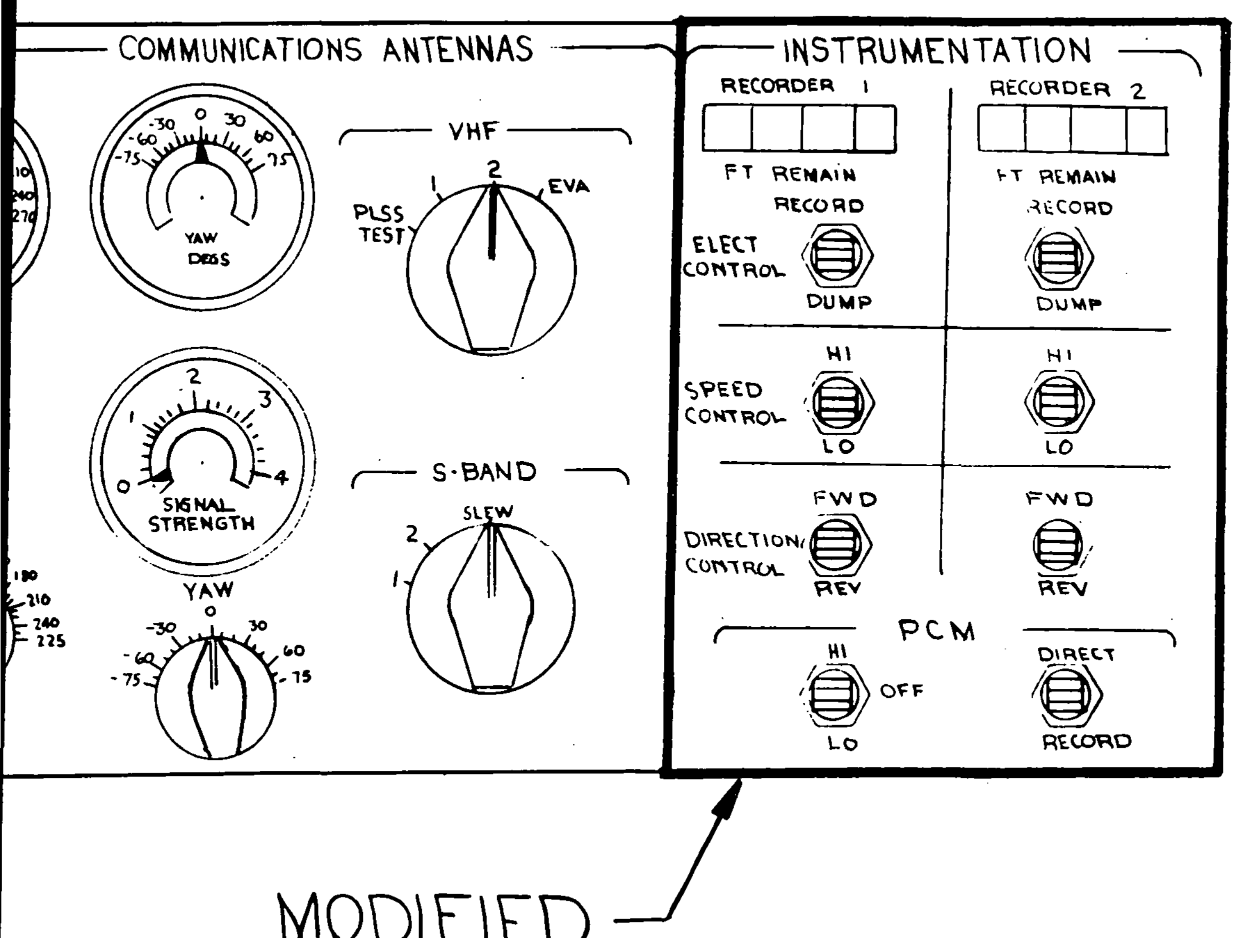


Fig. 5.7-2b Panel 11

XII

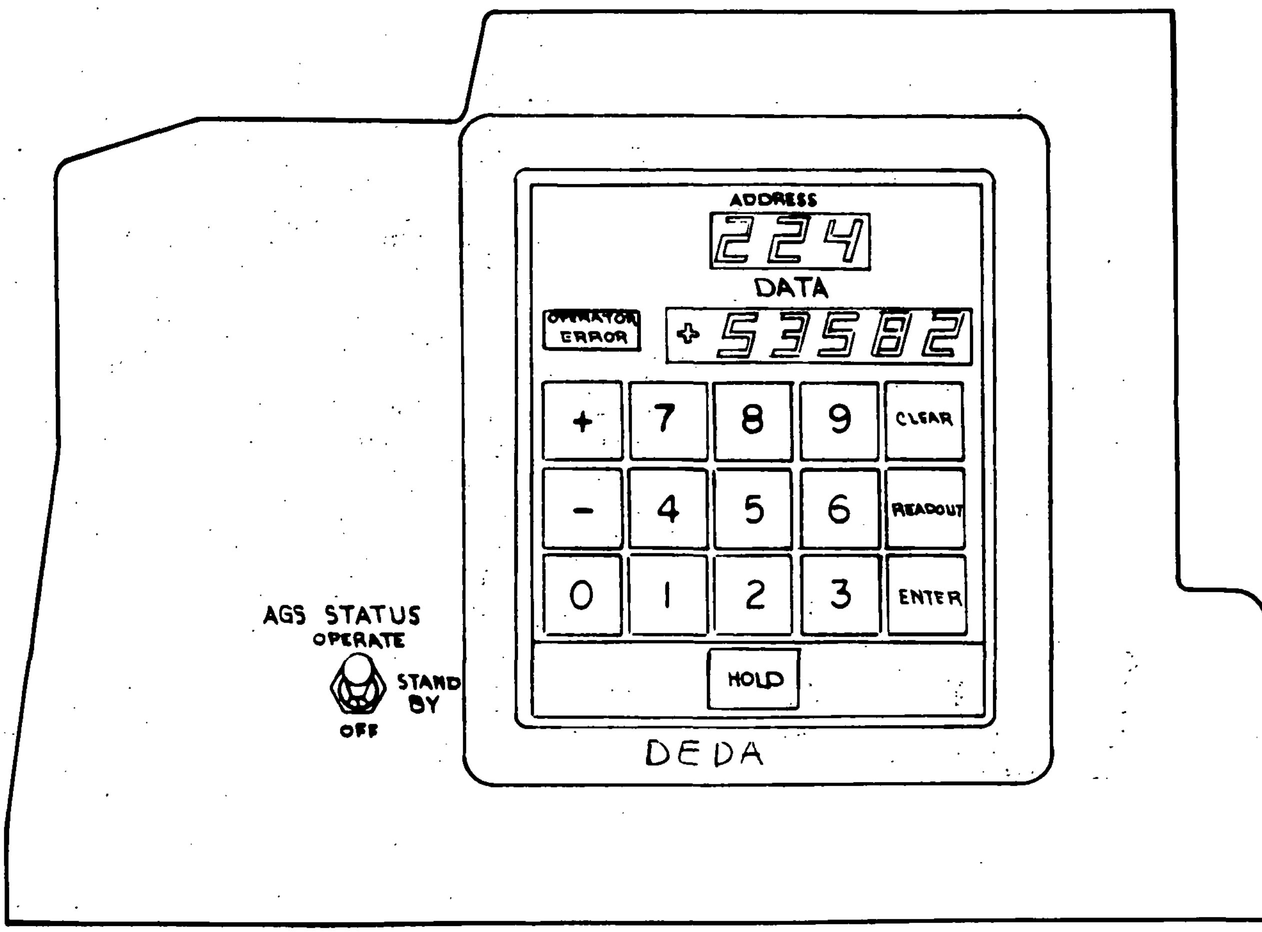


Fig. 5.7-3 Panel XII

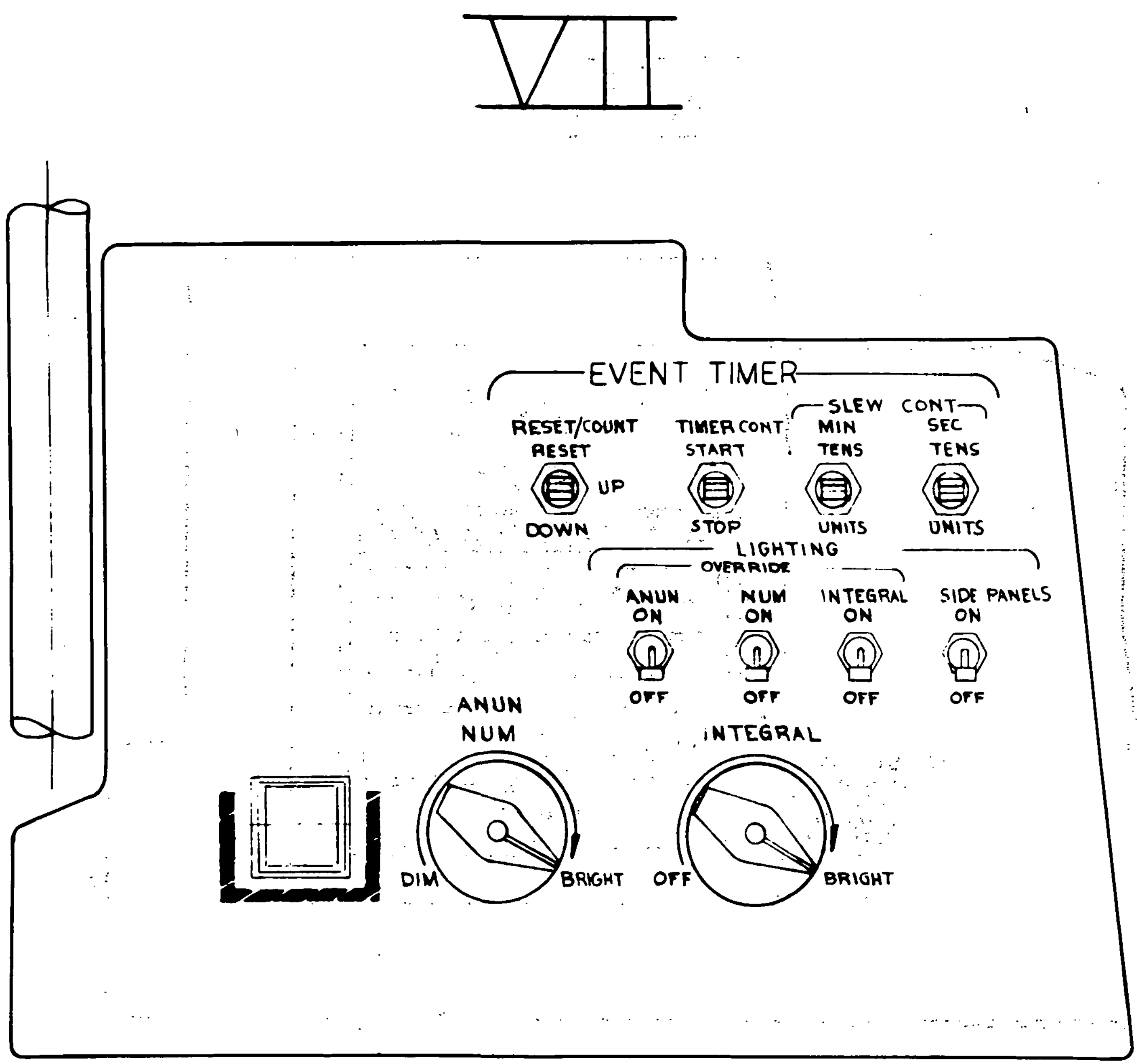


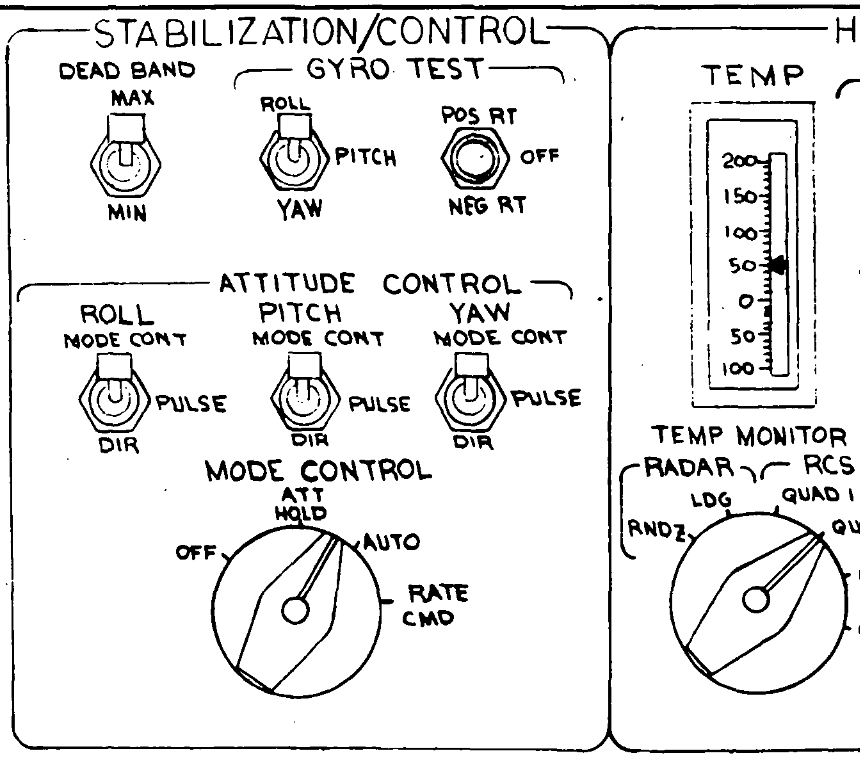
Fig. 5.7-4 Panel VII

AVAILABLE E
RENDZ RAD

5.7.5
(1)

III

KCEPT WHEN
AR IS USED



5.7.5 (2)

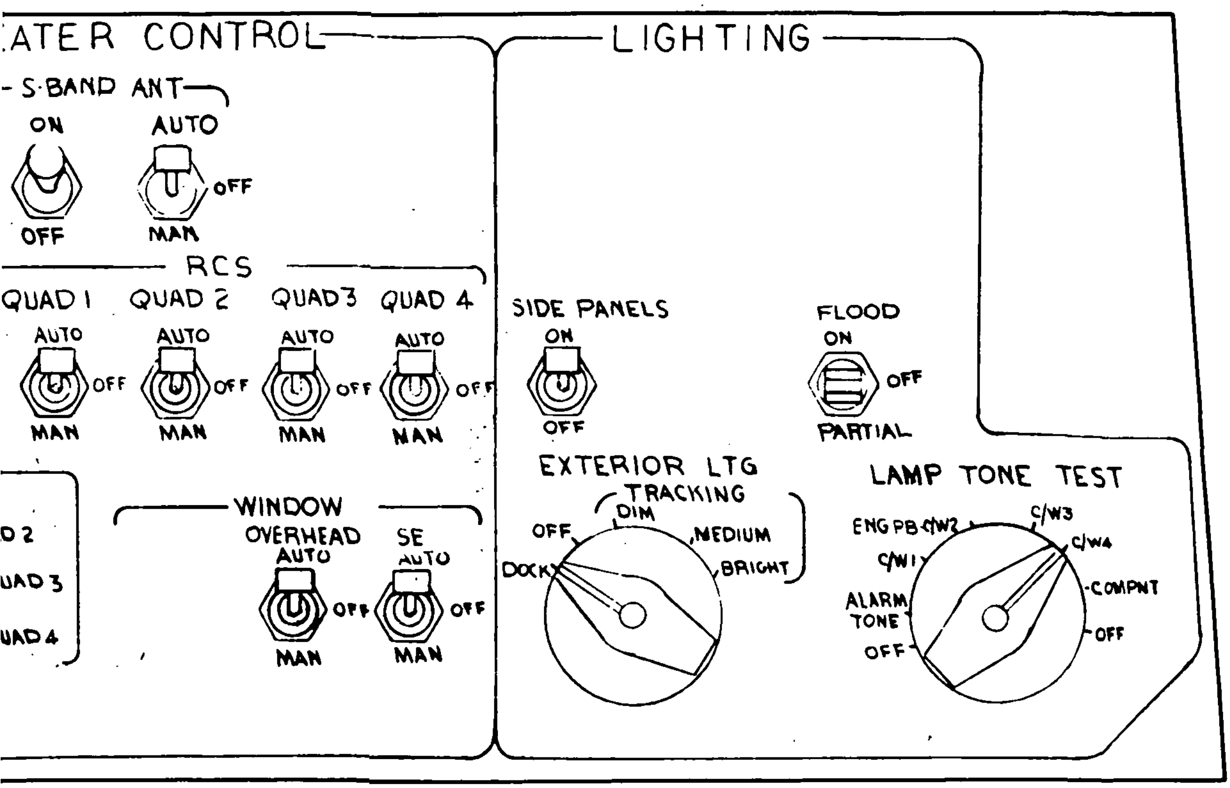


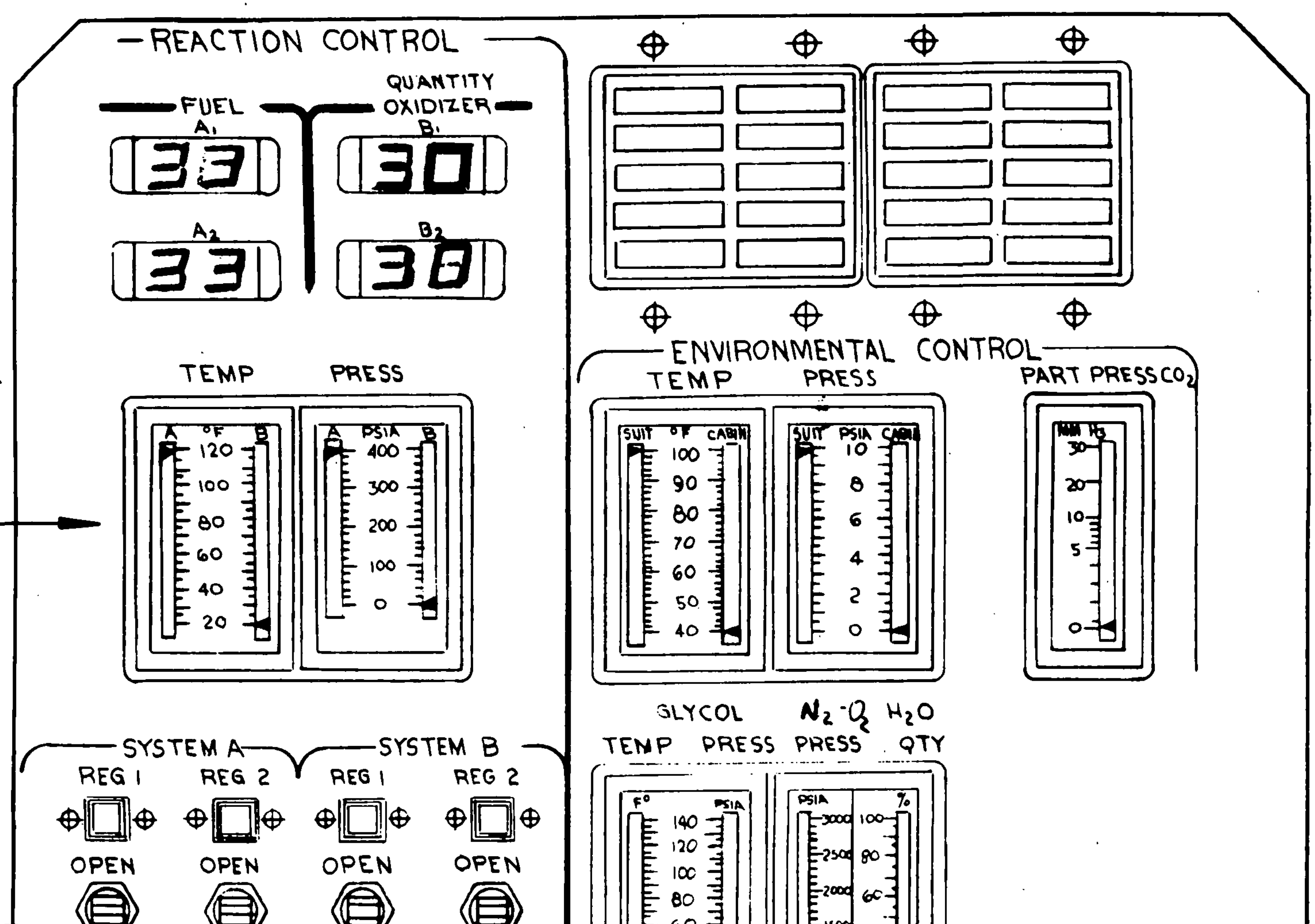
Fig. 5.7-5 Panel III

(3)

203

MODIFIED

II



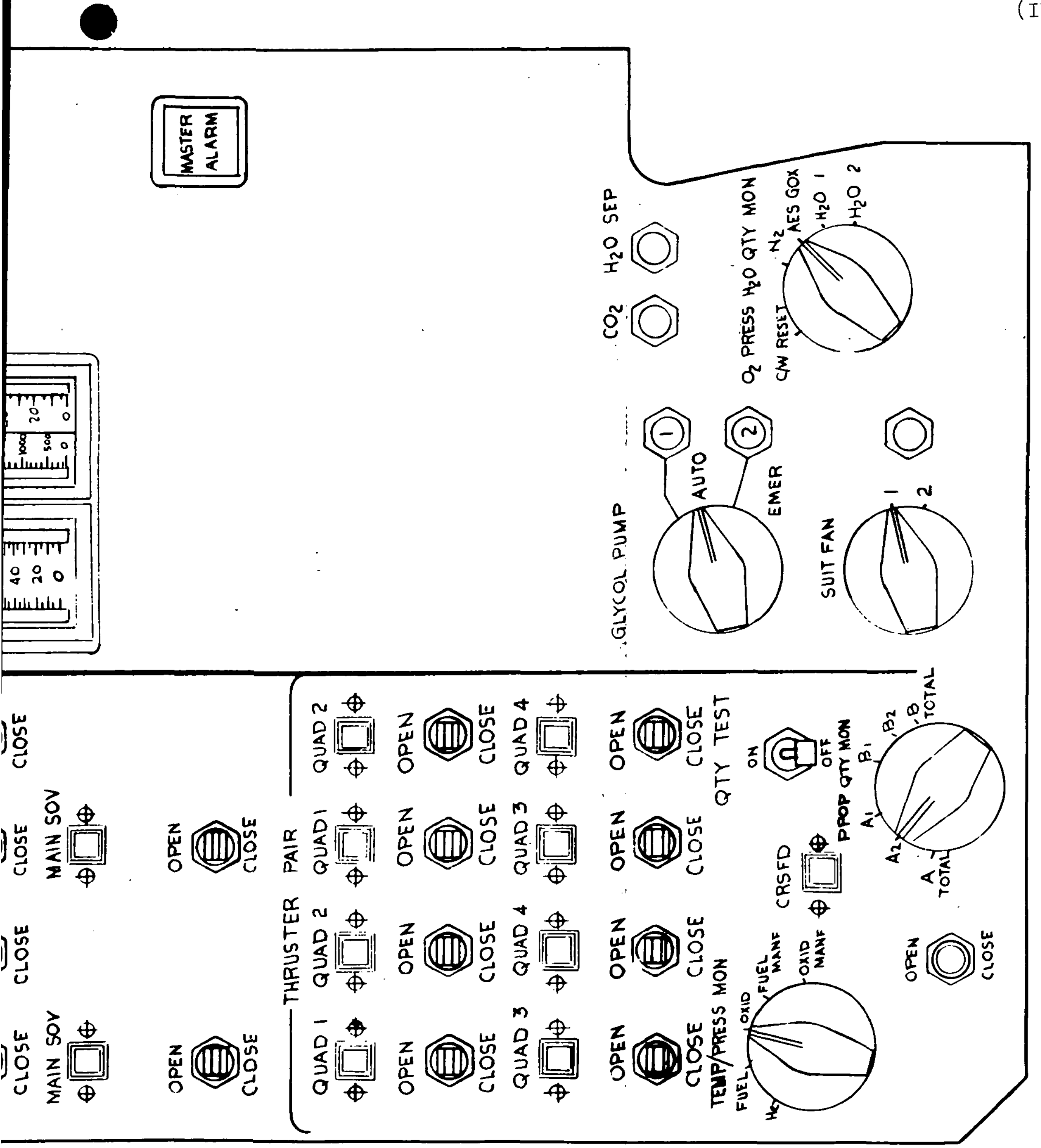
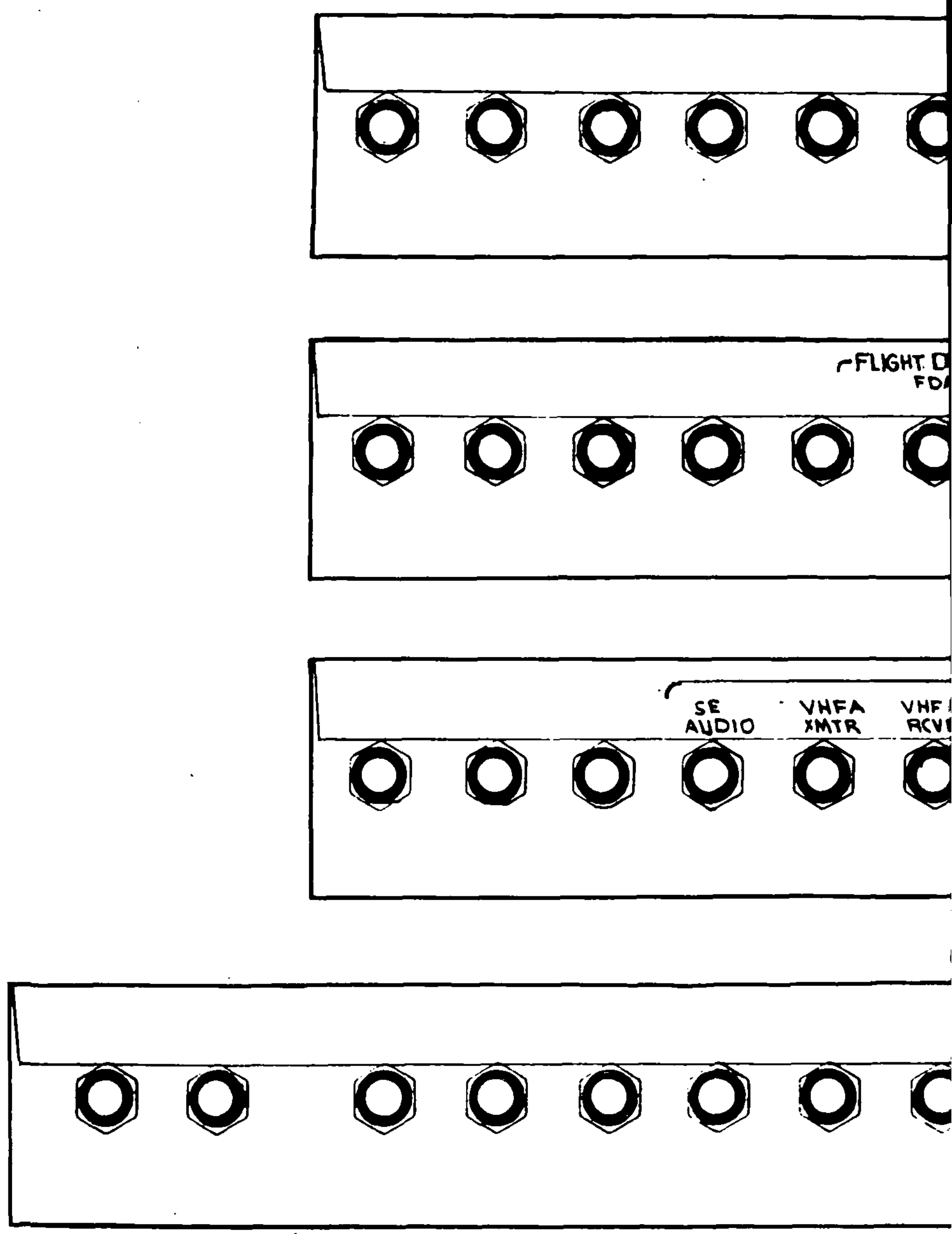


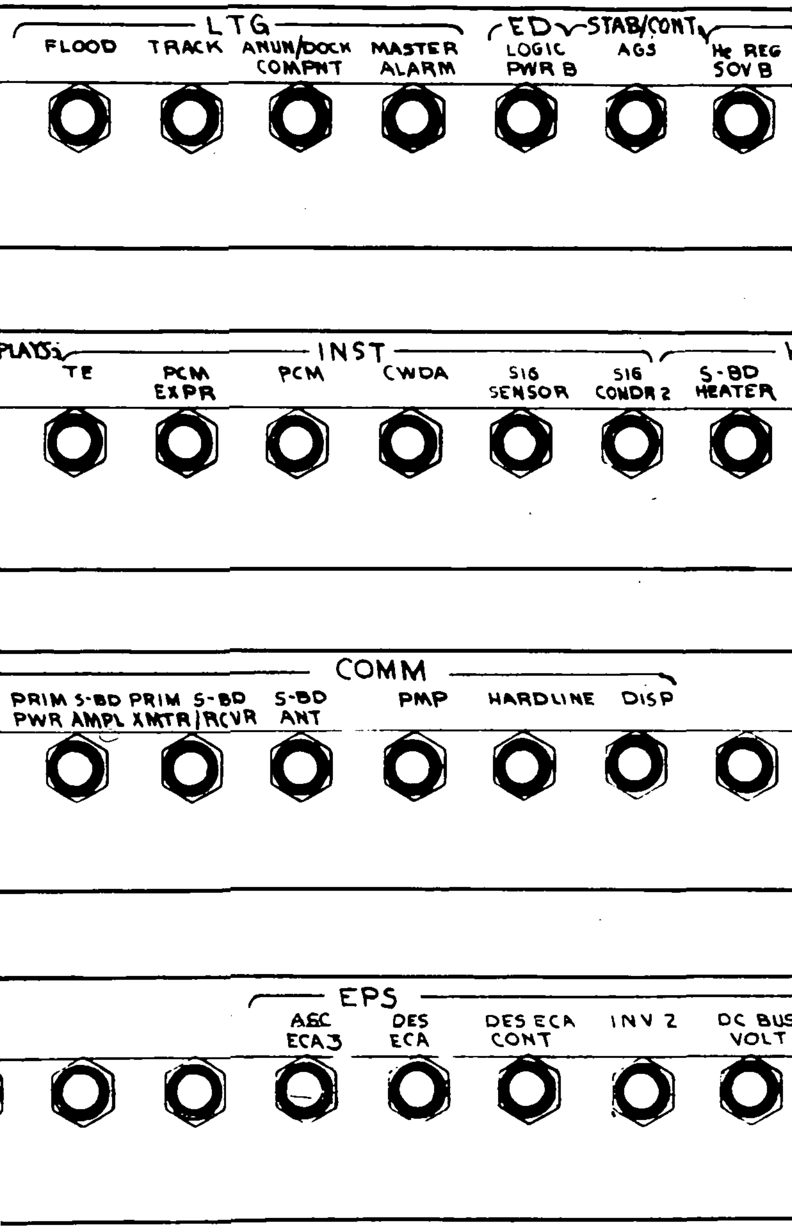
Fig. 5.7-6 Panel II

PANEL II

265



IX


LTG
FLOOD
TRACK
ANUN/DOCK COMPNT
MASTER ALARM
ED
LOGIC PWR B
STAB/CONT
AGS
He REG SOV B
INST
TE
PCM EXPR
PCM
CWDA
SIG SENSOR
SIG CONDR 2
S-BD HEATER
COMM
PRIM S-BD PWR AMPL
PRIM S-BD XMTR/RCVR
S-BD ANT
PMP
HARDLINE
DISP
EPS
ASC ECA 3
DES ECA
DES ECA CONT
INV 2
DC BUS VOLT

2

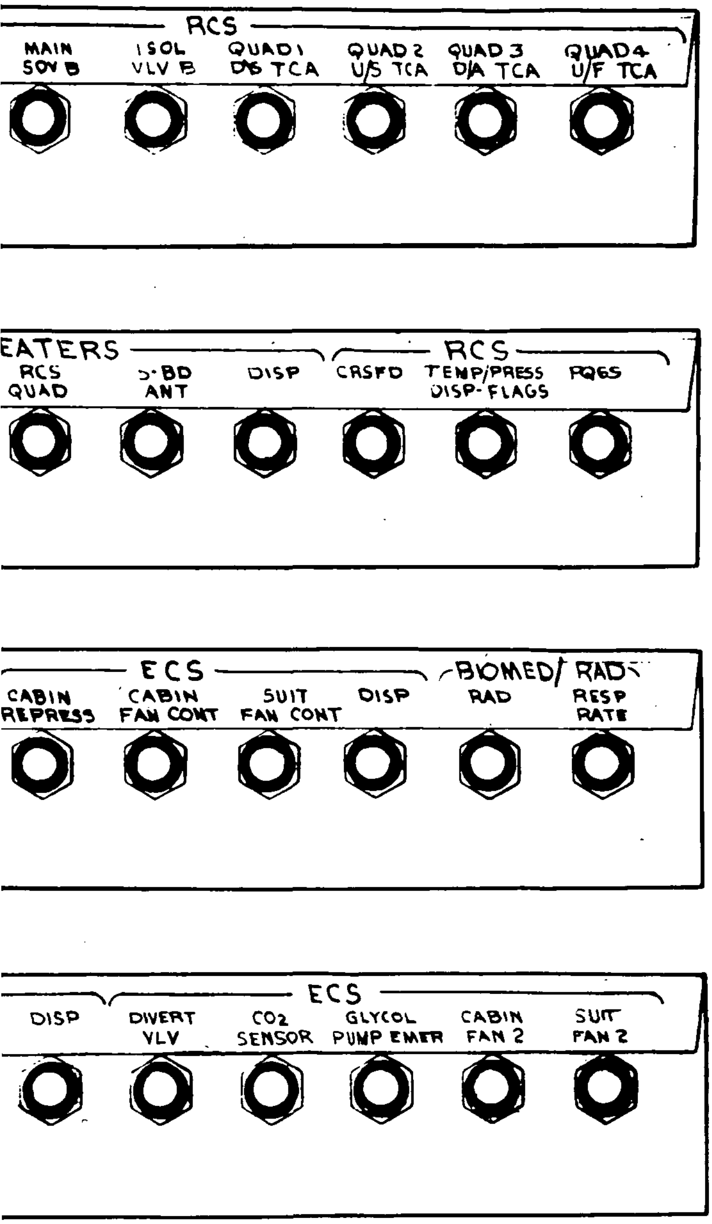
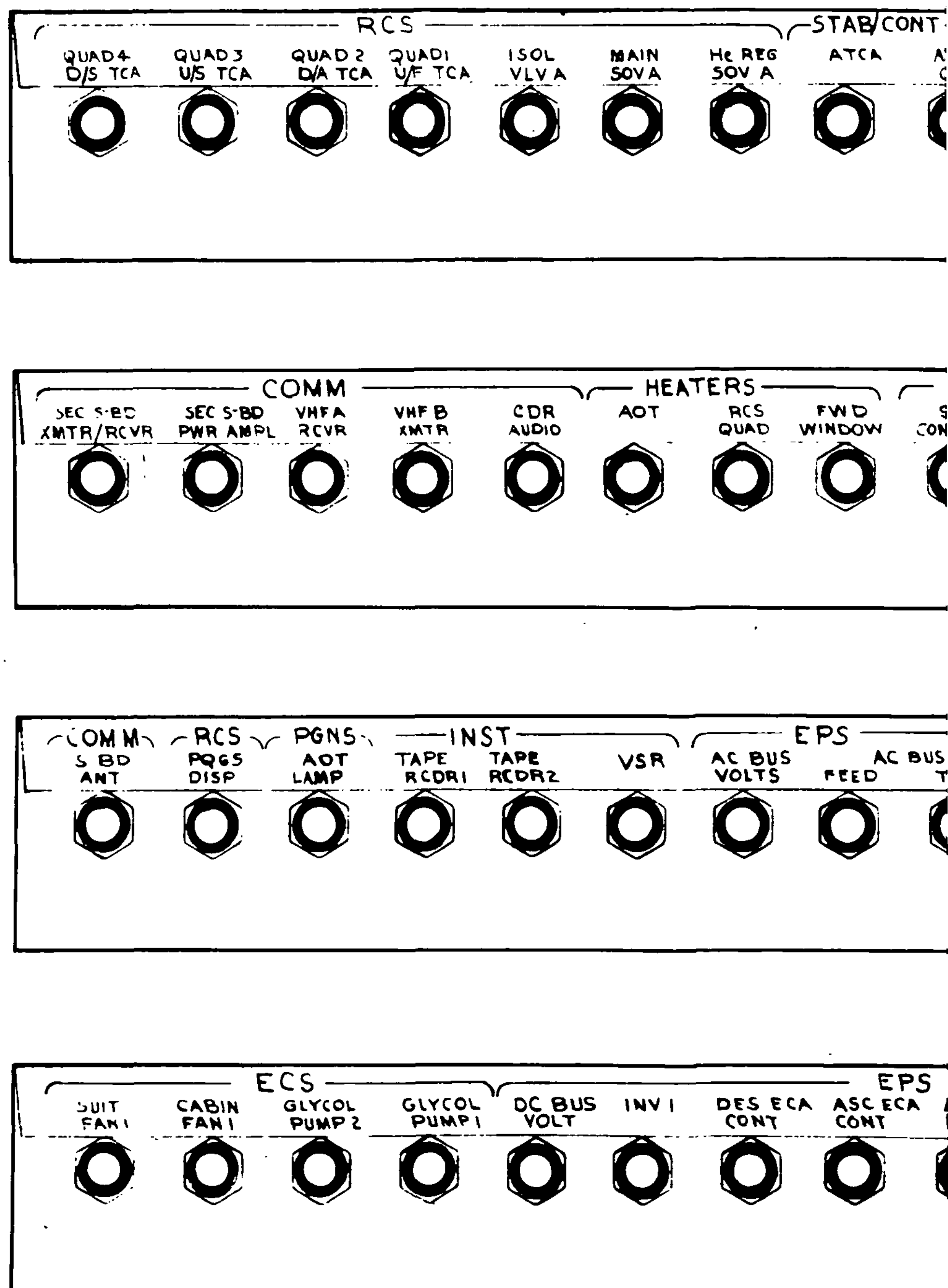


Fig. 5.7-7 Panel IX

3


RCS
STAB/CONT
QUAD 4 D/S TCA
QUAD 3 U/S TCA
QUAD 2 D/A TCA
QUAD 1 U/F TCA
ISOL VLV A
MAIN SOV A
He REG SOV A
ATCA
COMM
HEATERS
SEC S-BD XMTR/RCVR
SEC S-BD PWR AMPL
VHF A RCVR
VHF B XMTR
CDR AUDIO
AOT
RCS QUAD
FWD WINDOW
COMM
RCS
PGNS
INST
EPS
S BD ANT
PQGS DISP
AOT LAMP
TAPE RCDR 1
TAPE RCDR 2
VSR
AC BUS VOLTS
FEED
AC BUS
ECS
EPS
SUIT FAN 1
CABIN FAN 1
GLYCOL PUMP 2
GLYCOL PUMP 1
DC BUS VOLT
INV 1
DES ECA CONT
ASC ECA CONT

IV

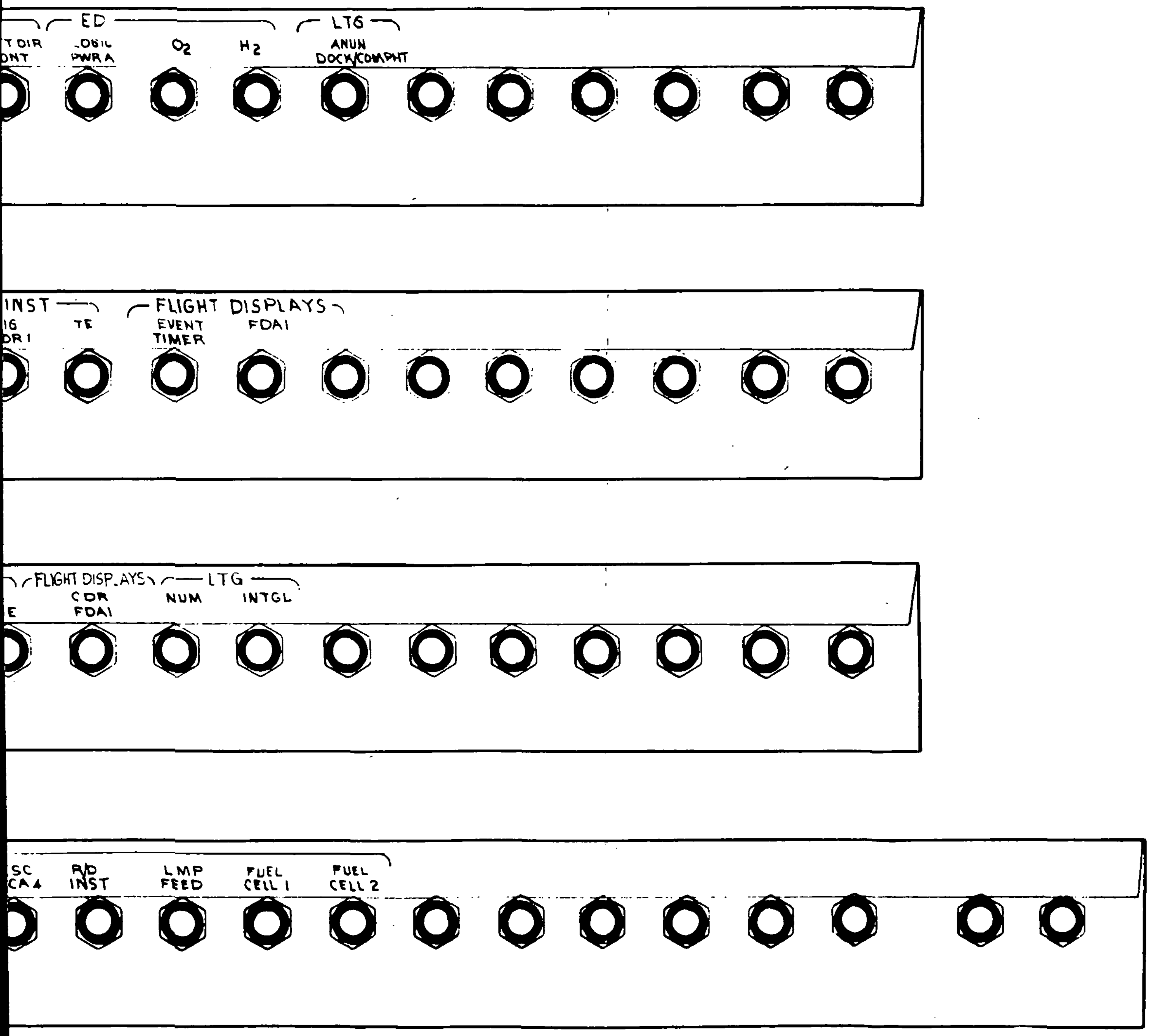


Fig. 5.7-8 Panel IV

6. VEHICLE DESIGN AND INTEGRATION

6.1 INTRODUCTION

6.1.1 Ground Rules and Assumptions

The philosophy for developing the vehicle design is to keep the present LEM intact to the maximum extent possible, satisfying increased subsystem requirements by modifications which have the least influence upon the present LEM design.

The following ground rules have been used during the Phase B study:

- No holes in the pressure shell
- No modification to Ascent and Descent primary structure
- The retention of existing piping and wiring
- Maintain commonality of subsystems between all vehicles
- No changes to the Spacecraft LEM Adapter (SLA)
- Location of subsystem additions to retain many of the GSE Servicing Requirements in the SLA
- Where possible subsystems are to be located in the descent stage to reduce the complexity that modifications to the Ascent Stage would require.
- Crew provisions in the crew compartment that may be different from the LEM are to be as additions to the vehicle, preserving the location of as many Controls and Displays and Crew Requirements as possible.
- Experiments will be mounted to the vehicle at existing hardpoints

6.1.2 Background Data

A set of Apollo LEM drawings are provided to be used for comparison with the AES vehicles. For details not shown on the AES configuration drawings, the attached drawings 6.1-1, 6.1-2, 6.1-3, 6.1-4, 6.1-5 and 6.1-6, clearly define the structure. Also included are drawings of the volumes and hard points available for experiments. These drawings have been updated from the Phase "A" study and are shown in Figures 6.1-7 and 6.1-8.

6.1.3 Configuration Definition

The baseline vehicle, is the first pass at describing a configuration that is a complete and integrated spacecraft design, capable of providing a specified experiment support capability at its interface with experiment payloads.

The recommended configuration is a refined definition of the baseline vehicle selected from the group of alternate designs.

The alternates are a group of designs showing the different locations and installation of a variety of subsystem configurations. These alternates have been analyzed for the feasibility of methods of manufacturing and structurally attaching them.

6.2 SPACECRAFT DESIGN

6.2.1 Assumptions

In defining the Phase II Laboratory, it is assumed that the spacecraft is a basic LEM vehicle with certain changes incorporated during manufacture, and is built without the following LEM components:

- Ascent Propulsion Section
- Descent Propulsion Section
- Landing Gear
- Right Hand Flight Control Station
- Water Tanks
- Electrical Power Subsystem Batteries
- Base Heat Shield
- Landing Radar
- Rendezvous Radar
- Other Unused LEM Equipment.

It is also assumed that experiment accommodation requirements will be available during the detail design phase, so that provisions may be incorporated during manufacture.

6.2.2 Recommended Configuration

The recommended configuration for the Phase II Lab is shown in Fig. 6.2-1. This configuration is identical to the existing LEM vehicle except as shown on the drawing and described in the following sections. Although an airlock is recommended for the Phase II Lab, none is shown on the configuration since no specific design has as yet been selected. Candidate airlock configurations are shown and described in Paragraph 6.2-4.

6.2.2.1 Ascent Stage

The interior of the Ascent Stage is designed to serve as the work area of the laboratory. Experiment control consoles and display panels are installed and stowage for experiments and expendables is provided. The interior arrangement is completely described in Paragraph 6.3, Crew Provisions.

Additional RCS Propellant to meet the Phase II Lab requirements is mounted on the rear face of the -Z27 bulkhead in the aft equipment bay. Two each of LEM RCS Fuel, Oxidizer, and Pressurization Tanks, with supporting brackets are installed as shown in Fig. 6.2-2.

Also in the Aft Equipment Bay, two Allis-Chalmers Fuel Cell Assemblies, a CSM Water Management Tank, and a LEM GOX Accumulator are mounted on the forward face of the Electronic Replaceable Assembly Cold Plate Structure. This installation is shown in Fig. 6.2-3. The Fuel Cell Assembly Installation is common to the recommended configuration for the Shelter vehicle.

External stowage for the required quantity of Portable Life Support System Lithium Hydroxide Canisters and constant wear garments is provided on either side of the Ascent Stage below the RCS Propellant Tankage. The expendables are inside the Thermal/Micrometeoroid Shielding for thermal control. Access is through a hinged door in the shielding, making the expendables readily available to a crew member during extra vehicular activity.

One additional connector is added to the LEM-CSM interface to provide a hardline communications link as shown in Fig. 6.2-4.

The LEM Thermal/Micrometeoroid Shielding is retained and redesigned locally where required. In the area vacated by removal of the Ascent Propulsion Tanks, the shielding is redesigned to provide protection for the expendables stowed in that area. Other changes are required where experiment components pierce the shielding.

6.2.2.2 Descent Stage

The cryogenic storage section for the Electrical Power Subsystem consists of two AES tanks, one oxygen tank with a usable fluid weight of 1375 lbs. and one hydrogen tank with a usable fluid weight of 144 lbs. Both tanks are located in the descent stage propellant tank bays, the oxygen in the -Y bay and the hydrogen in the +Y bay.

These tanks are supported in a manner similar to the LEM Descent Propellant Tanks. The diagonal tank support beams of the LEM are retained. A conical shaped adapter is mounted to the support beams which provides a skirt type support for the tank. This installation is shown in Fig. 6.2-5.

Radiators to satisfy the heat dissipation requirements of both the Environmental Control Subsystem (ECS) and Electrical Power Subsystem (EPS) are shown in Fig. 6.2-6. The total radiator area is made up of eight identical rectangular panels measuring 3 feet by 5 feet. These modular panels are mounted on the sides of the Descent Stage, two each in the +Z, +Y and -Z, -Y Quadrants, and one on each end bulkhead. With this arrangement, each half of the radiator area is located on opposite sides of the spacecraft, allowing optimum operation for random spacecraft orientation.

The LEM Thermal/Micrometeoroid Shielding on the Descent Stage is redesigned in some areas. A flat panel covers the bottom and replaces the LEM Base Heat Shield and Support Beams. The radiator panels replace the thermal shielding where they exist.

6.2.3 Baseline Configuration

The Baseline Configuration (shown in Fig. 6.2-7), used for costing differs from the recommended configuration as noted below:

- The EPS Fuel Cell Assembly and Cryogenic Storage installation was mounted above the Descent Stage. This was necessary due to the requirement of designing around the LEM Descent Propulsion Section. Two CSM "Housekeeping" size hydrogen tanks were mounted on the Descent Stage structure below the aft equipment bay, necessitating a relocation of the electronic replaceable assembly cold plate. Two CSM Housekeeping size oxygen tanks were mounted in the ascent propulsion fuel bays. Two Pratt and Whitney Aircraft Fuel Cell Assemblies were mounted on top of the Descent Stage over the aft quadrants. Locating the recommended EPS Cryogenic Tankage inside the Descent Stage and the smaller Allis-Chalmers Fuel Cell Assemblies in the Aft Equipment Bay requires less structural redesign, and allows more area for mounting external experiment equipment.

- A 30 sq ft ECS radiator was mounted on each side of the Ascent Stage, and a 25 sq ft EPS radiator was mounted on the +Y and -Y end bulkheads of the Descent Stage. This was changed to the modular concept shown in the recommended configuration for design simplicity and to achieve greater flexibility to meet varying requirements.

- The extra RCS propellant was mounted on a shelf at the top of the Ascent Stage. It appeared to be more conservative to retain the vertical orientation of the LEM tanks while filling and therefore they were relocated on the Aft Equipment Bay.

- No airlock provisions were considered in the Baseline Configuration.

6.2.4 Candidate Airlock Configurations

The recommended Phase II Lab configuration incorporates an airlock. However, no specific airlock design can be described as the recommended design at this time. A number of airlock configurations were investigated for application to the Phase II Lab. An "In Depth Study" was made for:

- A deployable/retractable design located on the front hatch as shown in Fig. 6.2-8.
- A rigid design located in the center bay of the Descent Stage as shown in Fig. 6.2-9.
- A deployable/retractable design common to the Shelter vehicle installed at the Front Hatch as shown in Fig. 6.2-10.

The Forward Hatch Airlock as shown in Fig. 6.2-8 uses a foldable material for construction of the cylindrical wall. Retracted, the airlock fits within the launch envelope and does not interfere with experiments or view from the windows. Extended, the airlock provides a space 40 in. in diameter and 80 in. long which appears to afford adequate mobility for a pressure-suited Astronaut with a Back Pack. The 40 in. diameter negates the possibility of one Astronaut performing all airlock functions. Final sizing requires further substantiation. Also, the SLA-Lab GSE Tunnel must be inserted through the retracted airlock requiring installation of the airlock hatch after tunnel removal.

An example of the type of material that might be used for the foldable wall has been developed by NASA - Langley. (Ref: "Development of an Expandable Airlock Utilizing the Elastic Recovery Principle" by J. G. Williams, NASA - Langley Research Center, Langley Station, Hampton, Va.) Further development is required to explore the broad spectrum of materials and methods of construction to finalize an airlock design. An adapter structure is used to attach and seal the airlock to the periphery of the forward hatch. The adapter performs the transition from a rectangular shape conforming to the hatch to a circular ring to which the flexible airlock is sealed. This adapter is identical to that used on the Shelter vehicle.

The airlock in the Descent Stage Center Bay as shown in Fig. 6.2-9 represents fabrication within the present "State of the Art". A cylindrical pressure vessel is mounted in the Descent Stage utilizing existing Descent Engine Mount Fittings. It is then coupled to the cabin floor through a metal bellows to restrict applied loads, other than pressure, to the Descent Stage. The 47 in. diameter of the chamber allows for possible donning and/or storage of a Hard Suit, and a Suit Checkout Station can also be incorporated. This design is compatible with the Docking Tunnel concept which may be used on some Phase II missions. A constraint imposed by this design is the necessity for donning the Back Pack within the airlock due to the 20.5 in diameter access from the Ascent Stage. By redesigning the Aft Cabin Deck Structure, this access can be increased to a 32 in. diameter opening. A change such as this, however, would require structural requalification of the Ascent Stage.

An airlock as shown in Fig. 6.2-10 is used on the Shelter vehicle, and may be adapted to the Phase II Lab by the addition of a retraction mechanism. Two advantages of this design over the cylindrical forward hatch airlock is that both hatches can be operated by the occupant and commonality with the Shelter is achieved. An added constraint would be the extreme difficulty of retraction due to its geometry.

6.2.5 Alternate Config.-Alternate EPS Cell Arrangements

Several alternate power supply arrangements were studied which included the use of General Electric, Pratt and Whitney, and Allis-Chalmers Fuel Cell Assemblies, and CSM-AES Cryogenic Tankage. All of the General Electric and Allis-Chalmers Fuel Cell Assembly installation alternates noted herein are common with the Shelter vehicle. These are summarized in Fig. 6.2-11. No compatible installation could be found utilizing the Pratt and Whitney Fuel Cell Assemblies. The recommended Allis-Chalmers Fuel Cell Configuration is shown in Fig. 6.2-1, and is shown in detail in Fig. 6.2-3. Accessibility for replacement in this location is through the top of the Aft Equipment Bay. In this location, the heat dissipated is used to maintain Ascent Stage temperature. Other installations of two Allis-Chalmers Fuel Cell Assemblies are as shown in Fig. 6.2-12 and 6.2-13. Both installations are on the Descent Stage structure, one external on the Aft End Bulkhead, the other internal in the +Y, -Z Quadrant. Accessibility for removal is good in both cases. The external installation will require a more complicated radiator installation, i.e., folding panels, while the internal installation will require relocation of the LEM GOX Tank.

The recommended installation, if General Electric Fuel Cell Assemblies are used, is shown in Fig. 6.2-14. Four Fuel Cell Assemblies are mounted to the forward face of the cold plate structure in the Aft Equipment Bay. This installation has the same advantages as the recommended Allis-Chalmers installation. Other General Electric FCA installations are shown in Fig. 6.2-15. One configuration shows two units mounted externally on each Y Axis End Bulkhead. The other installation is internal with four units mounted on a beam in the +Y, -Z Quadrant of the Descent Stage.

The recommended installation for Pratt and Whitney Fuel Cell Assemblies is shown in Fig. 6.2-16. This shows the two units mounted externally on top of the Descent Stage. They are flange-mounted to a bracket structure which is added to the Descent Stage as shown.

Other possible locations for the installation of Pratt and Whitney Fuel Cells are shown in Fig. 6.2-17.

An alternate arrangement of the recommended Cryogenic Storage Configuration using CSM-AES Tanks is shown in Fig. 6.2-5. This shows a stacked arrangement of both tanks in one Descent Stage Bay. This reserves more Descent Stage space for experiments, but requires more structural redesign because the tanks protrude through both upper and lower horizontal panels. Other possible locations for installation of AES size Cryogenic Tanks are shown in Fig. 6.2-18

6.2.6 Alternate Configuration-Alternate Radiator Installations and Variable Radiator Area Designs

6.2.6.1 Radiator Installations

Other locations for mounting 3 ft by 5 ft modular radiator panels are shown in Fig. 6.2-19. A fold-out configuration is shown on the Descent Stage which doubles the area of the Quadrant Radiator installation. Panels in some of the locations shown are hinged for access to items located behind them. Fig. 6.2-20 shows detail construction of a Modular Radiator Panel being constructed under a test program.

6.2.6.2 Variable Radiator Area Exposure Systems - Mechanical Design

The purpose of the variable radiator area control system is to automatically adjust radiator exposure area with variations in coolant loop thermal loading. These variations are produced by operating and shutting-down on-board electrical equipment, by fluctuations in ECS requirements, and by variations in external thermal environment. They reflect themselves as thermal inputs to the radiator loop. Fairly constant coolant temperature exiting from the radiator is maintained by increasing or decreasing the effective radiator system exposure area.

Two mechanical systems were studied to achieve variable radiator area exposure. The first, a controllable hinged-door arrangement, and the second, a controllable "window shade". The "window shade" arrangement was, and continues to be investigated on a Grumman, in-house funded, Advanced Development Program. Ground rules for these systems are:

- Coolant exit temperature from the radiator is to be maintained between a fixed temperature range such as 30°F and 50°F.
- Radiator door opening is to be infinitely variable from 0 to 160 deg rotation for the hinged door concept.
- Radiator exposure area is to be infinitely variable from 0 to 100% for the "window shade" concept.

The hinged door arrangement is shown in Fig. 6.2-21. It consists of a linear sensor/actuator, sector and bellcrank assembly, steel drive tapes and tensioning tape guides. Radiator exit coolant fluid is piped from the radiator panels to the drive system actuator which contains a temperature sensitive viscous compound. This compound expands and contracts linearly with fluid coolant temperature changes, thereby imparting a modulating motion to the radiator door panels. The panels rotate to approximately 160 deg when the drive actuator fully strokes. The total actuator travel is obtained within a 20°F temperature band - i.e., from 30°F to 50°F, where the 30°F position is radiator door close and 50°F is radiator door full open.

The radiator doors are synchronized and driven by spring steel drive tapes. These tapes act as timing links since they are fastened to their sectors and experience relatively short travel. Any induced vibrations to the doors feedback directly to the drive actuator via these drive tapes. The viscous compound in the actuator tends to dampen out these vibrations and maintain dynamic stability. Six tensioning guides are used to maintain a preload in the tapes and secure them during vehicle vibrations. The tapes form a continuous system drive loop and therefore are only used as tensile members during extend and retract actuation cycles.

Among the favorable features of this design are simplicity and the possibility of doubling the available radiator area by utilizing the door inner surface as extra radiator area.

The "window shade" system is shown, as used in a test rig, in Fig. 6.2-22. The system consists of an actuator, a gear drive and drive shaft, and a shade drum with its shade. It utilizes the identical sensor/actuator used in the hinged door arrangement. The actuator stroke in response to coolant fluid temperatures, operates the crank on a common shaft with the sector gear.

Rotation of the sector drives the pinion and drive shaft. The shade is wound around the shade drum with two steel tapes connecting the shade draw bar and the drive shaft. A third steel tape connects the drive shaft to the shade drum, but is wrapped opposite to the shade wrap, providing a positive synchronization loop. Testing will be conducted in a vacuum chamber to confirm system operation, as well as the effect of unrolling and re-rolling the shade material on fatigue life, cold welding, etc. Presently, the most promising material appears to be vapor deposited aluminum on a "KAPTON" film.

Among the favorable features of this system are compactness and the fact that there are no large panels suspended from the vehicle. An alternative control and drive for these applications is to use an electrical system. While the system would be more complex, it does not appear to be beyond the state-of-the-art.

Further consideration must be given to the selection of the actuator compound. The configuration shown is based on a hydro-carbon "grease" compound presently being used on the LEM vehicle cabin temperature control (Pyrodyne compound #1014). Freon and other temperature sensitive fluids with relatively high rates of thermal expansion will be investigated. Higher viscosity fluids appear to be desirable since sealing problems are reduced and vibration damping is increased. Further studies and development testing of these compounds are necessary to select the optimum fluid which satisfies all the system requirements. Among these are actuation response time (compound time constant), sealing characteristics, viscous damping properties, weight, and chemical and thermal stability.

6.2.7 Potential Modifications Per Flight

A review of Phase A studies was made to identify per mission modifications which would affect the spacecraft configuration. These were studied further under the Phase B ground rules and are presented as follows.

6.2.7.1 View Finder

An optical viewfinder telescope is required for Lunar orbit and earth surveillance missions. To meet the ground rule of "No Change to the Pressure Shell", an attempt was made to arrive at a scheme which would not require requalification of the pressure shell. One such scheme is shown in Fig. 6.2-23. A Kollsman Viewfinder is installed in a fitting which replaces the right hand cabin window. This fitting is installed and sealed in the same manner as the window. In this location, the optical path is direct to the eye-piece which is readily available to the crewman for viewing or camera changing. Thus, by qualifying the pressure integrity of the viewfinder to the local fitting, and by maintaining an identical structural and seal joint between the fitting and LEM structure (as the existing LEM window has), requalification of the Ascent Stage Pressure Shell will not be required.

6.2.7.2 Additional Pressurized Volume and/or Docking Tunnel

Several configurations for the use of the Descent Engine Bay on a per mission basis are shown in Fig. 6.2-24.

A canister, shown in Fig. 6.2-25, which provides 7.5 cu ft of volume for stowage of experiments or expendables may be used. This canister is sealed to the Ascent Stage Structure in the same manner as the Ascent Engine Cover using a Marmon-type clamp. The installation requires no structural modifications other than removing the engine support lugs from the ring. Auxiliary support members are attached to the top of the Descent Stage.

If more pressurized volume is required for additional Lab work area or experiment stowage, a larger canister may be installed. This is a 47 in diameter, 85 cu ft pressurized container which is supported at the Descent Engine Mount Fittings. It is structurally isolated from, but sealed to the Ascent Engine Cover Ring. If the mission calls for the docking of two Laboratories in orbit, a structure is used in the same location which supports a docking ring and probe mechanism at the external end. This docking tunnel duplicates the mechanism of the CSM and procedures for docking are the same as for LEM to CSM. For this use, a pressure hatch is used at the cabin floor and an additional structural support is added at the bottom of the Descent Stage. After docking, the probe mechanism is removed and stowed. The tunnel provides a pressurized passageway between the two vehicles.

For use as an airlock, the container incorporates a Pressure Hatch at the External End. This application is described in Paragraph 6.2.4

In all these configurations, a 20.5 in diameter access through the Ascent Engine Support Ring is available without modification to the Ascent Stage structure. This is sufficient for a suited but unpressurized crewman. The PLSS Back Pack must be handed through. If a larger passageway is desired, a redesign of the Aft Cabin Floor could increase the opening to 32 in diameter.

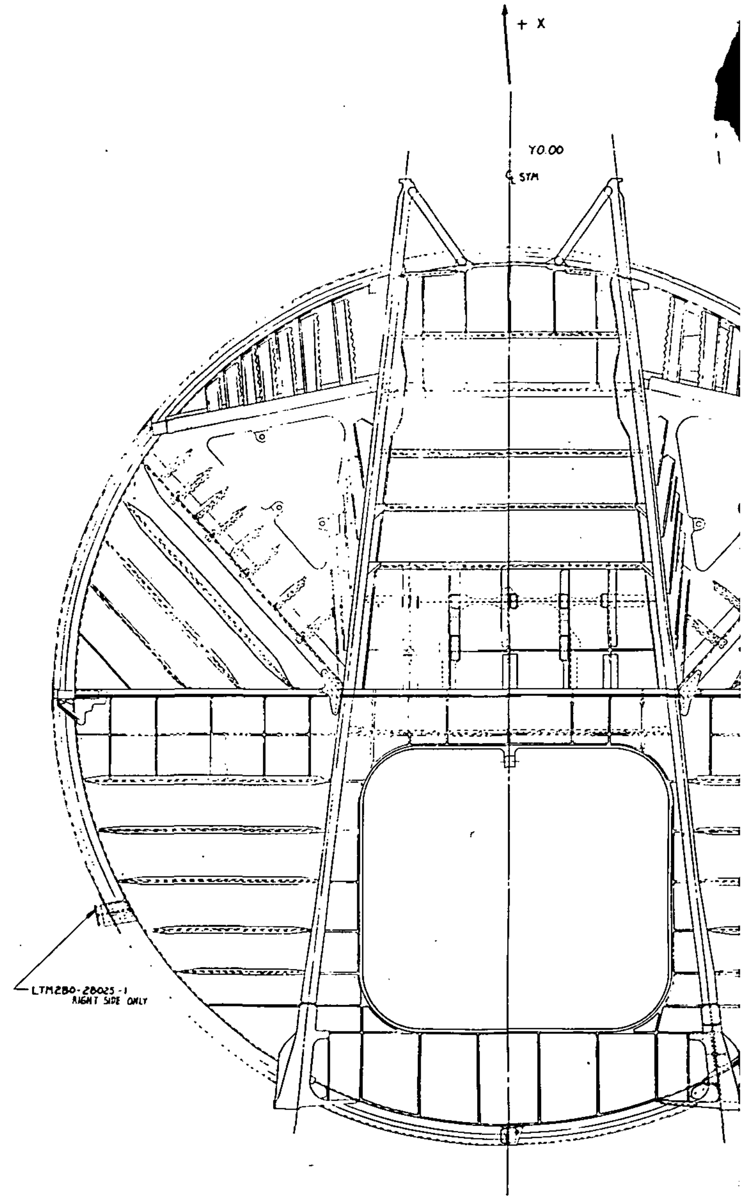
6.2.7.3 Additional RCS Propellant

For missions which require a greater amount of reaction control propellant, modules of LEM RCS Propellant Tanks are installed at locations shown in Fig. 6.2-26. In these locations, access to control valves and filling connections is retained.

6.2.7.4 Low Profile Descent Stage Configuration

For missions which carry large payload items, a configuration as shown in Fig. 6.2-27 can be used. The LEM Descent Stage is replaced by a rack structure which supports the Ascent Stage in the Adapter. By the use of this structure, which has beams of 30 in depth instead of 65 in for the LEM Descent Stage, a dimension of 84 in to the S-1VB clearance envelope is available. This depth, within the confines of the adapter retraction clearance, is available for experiment mounting.

(9)



LDW 280-28010-1 ASSY.
VIEW LOOKING AFT

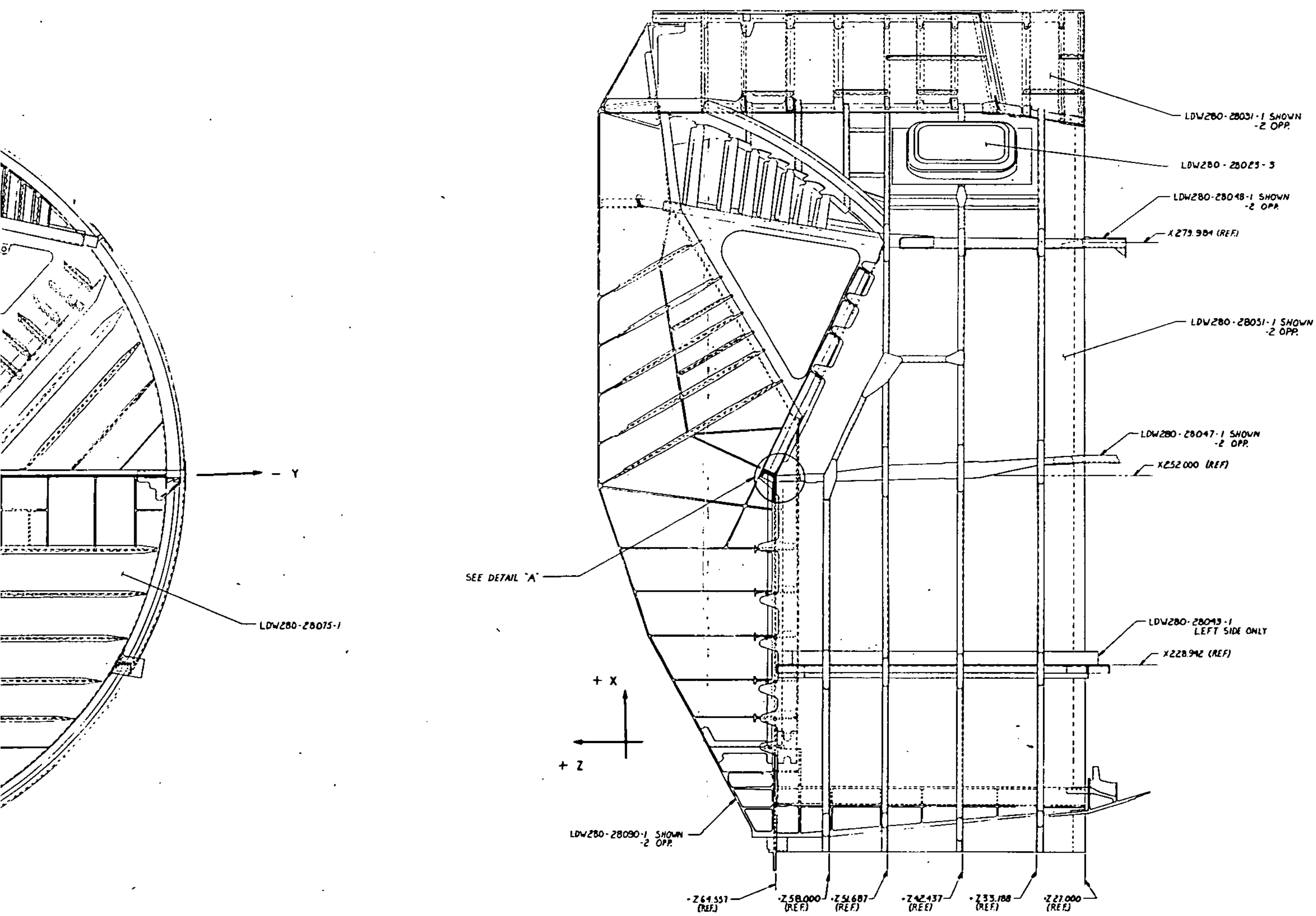
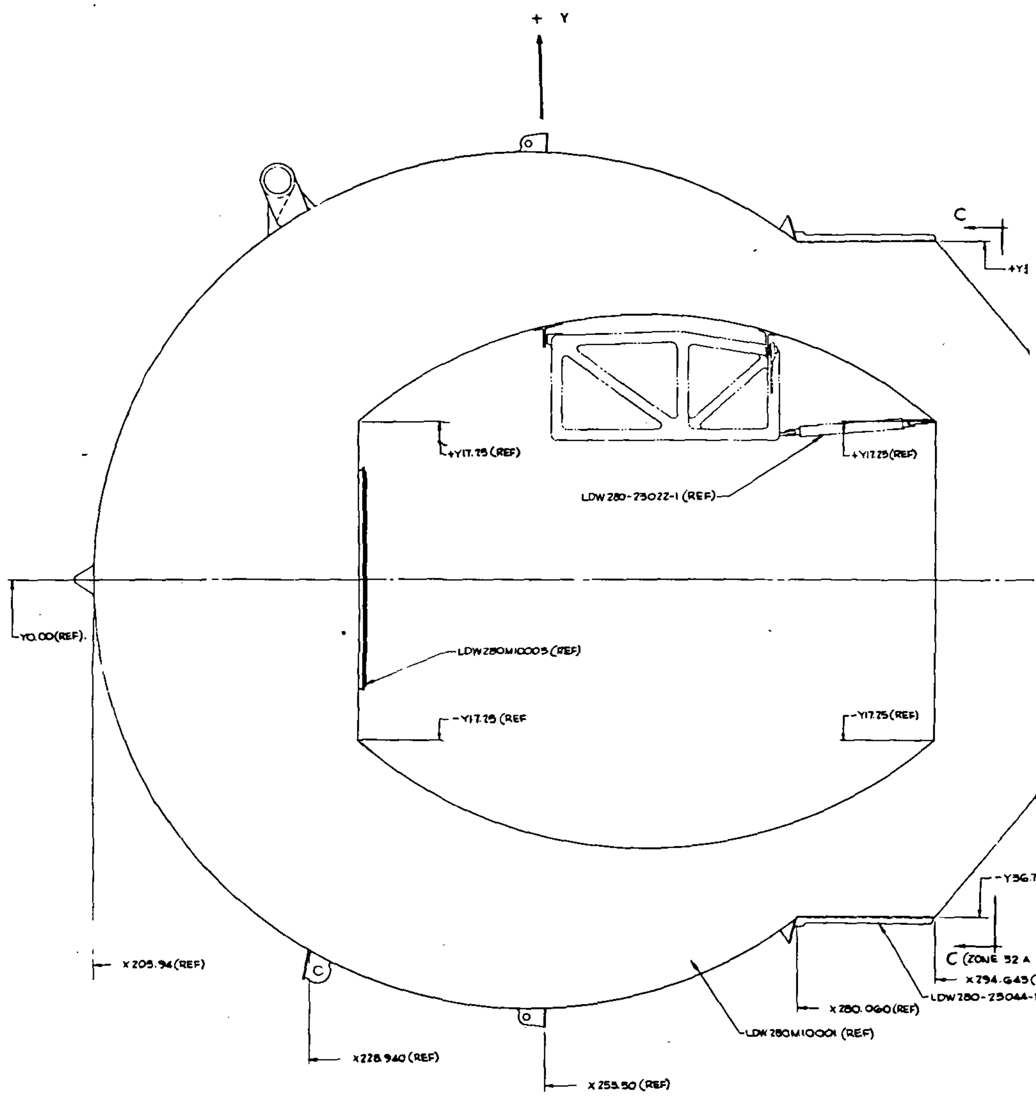


Fig. 6.1-1 LEM Structural Arrangement Ascent Stage Forward Cabin

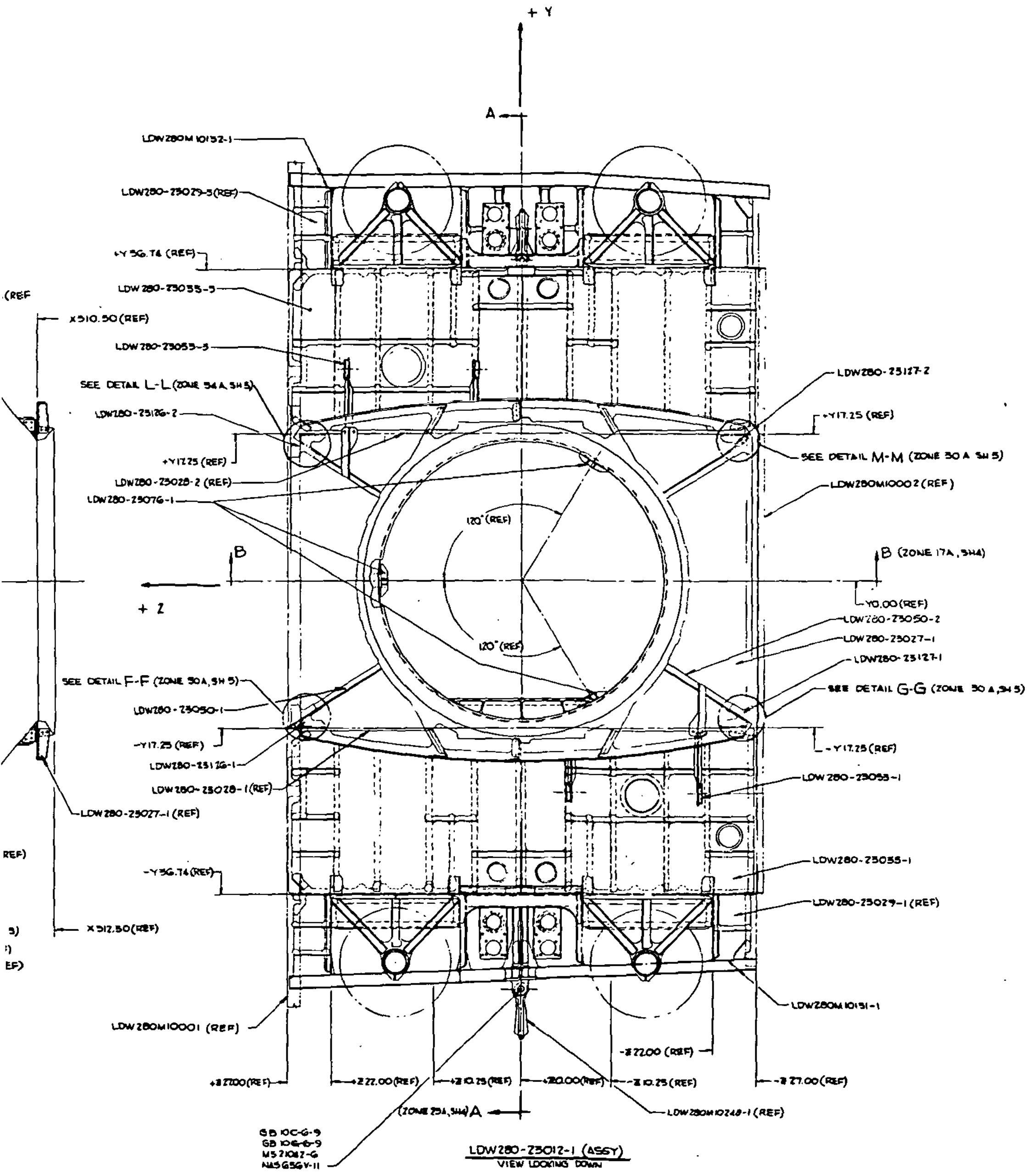
Grumman



VIEW LOOKING AFT

6.1-2

(1)



LDW280-23012-1 (ASSY)
VIEW LOOKING DOWN

FWD

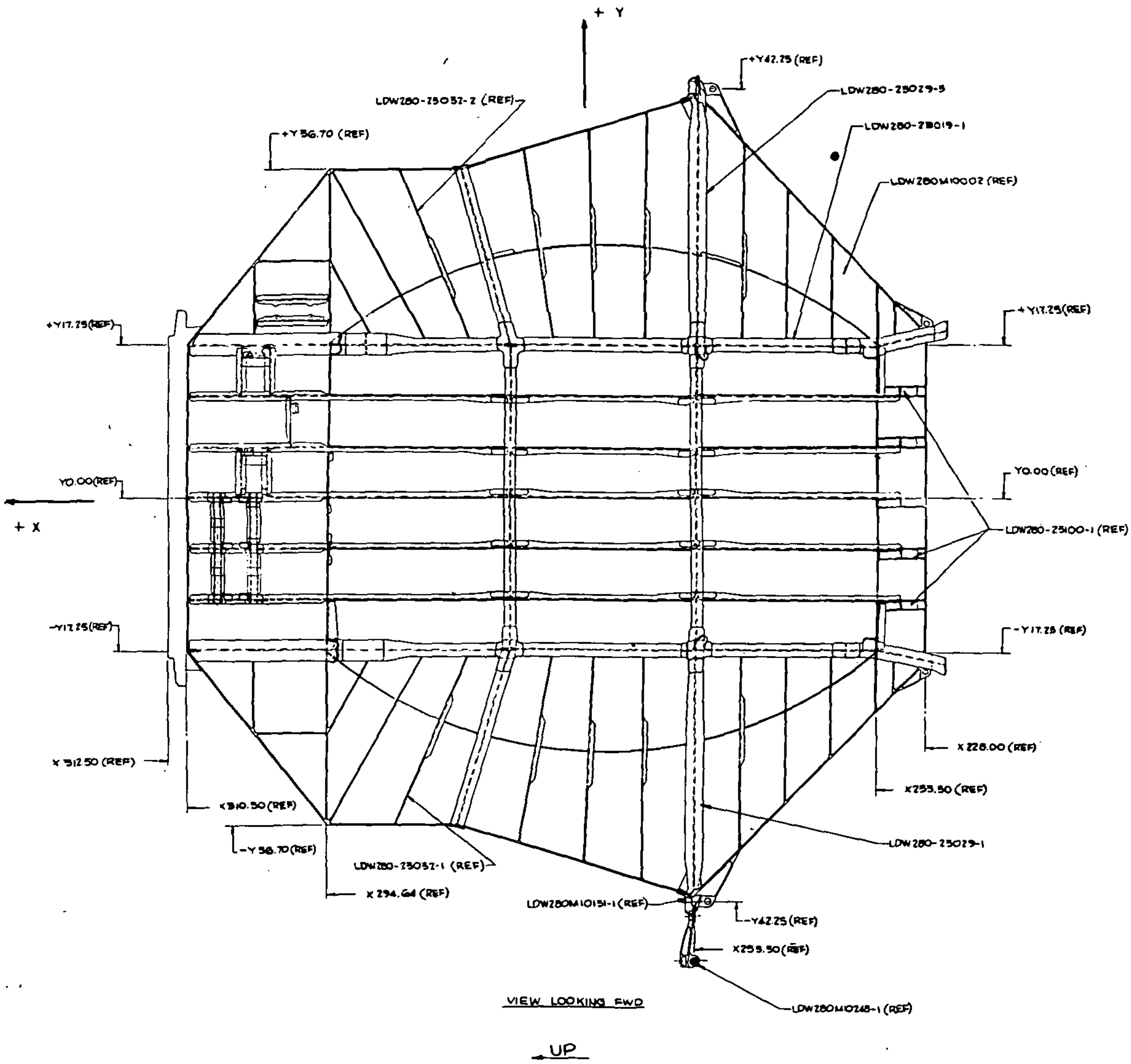
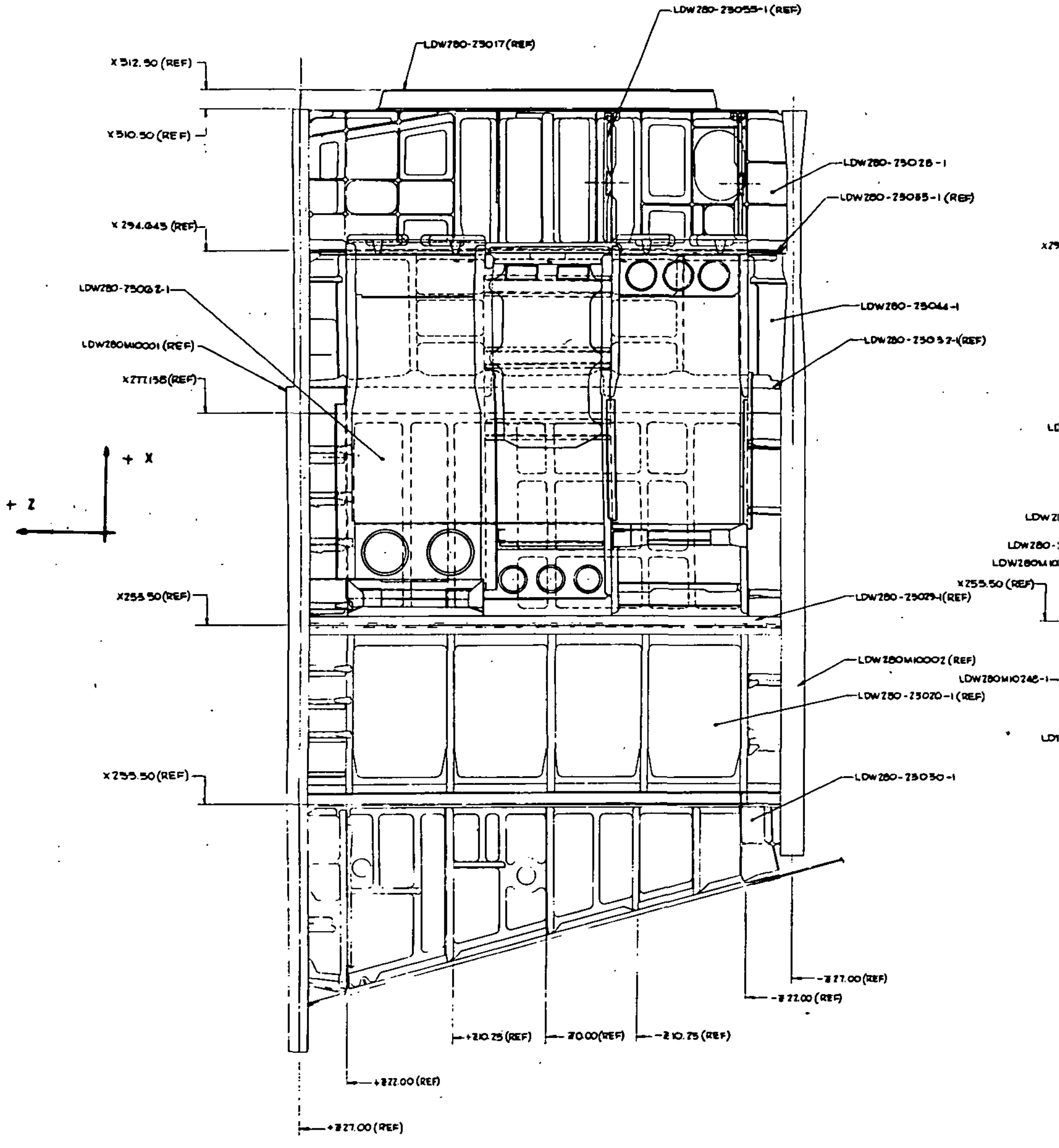


Fig. 6.1-2 LEM Structural Arrangement
Ascent Stage Aft Cabin

(3)

Grumman

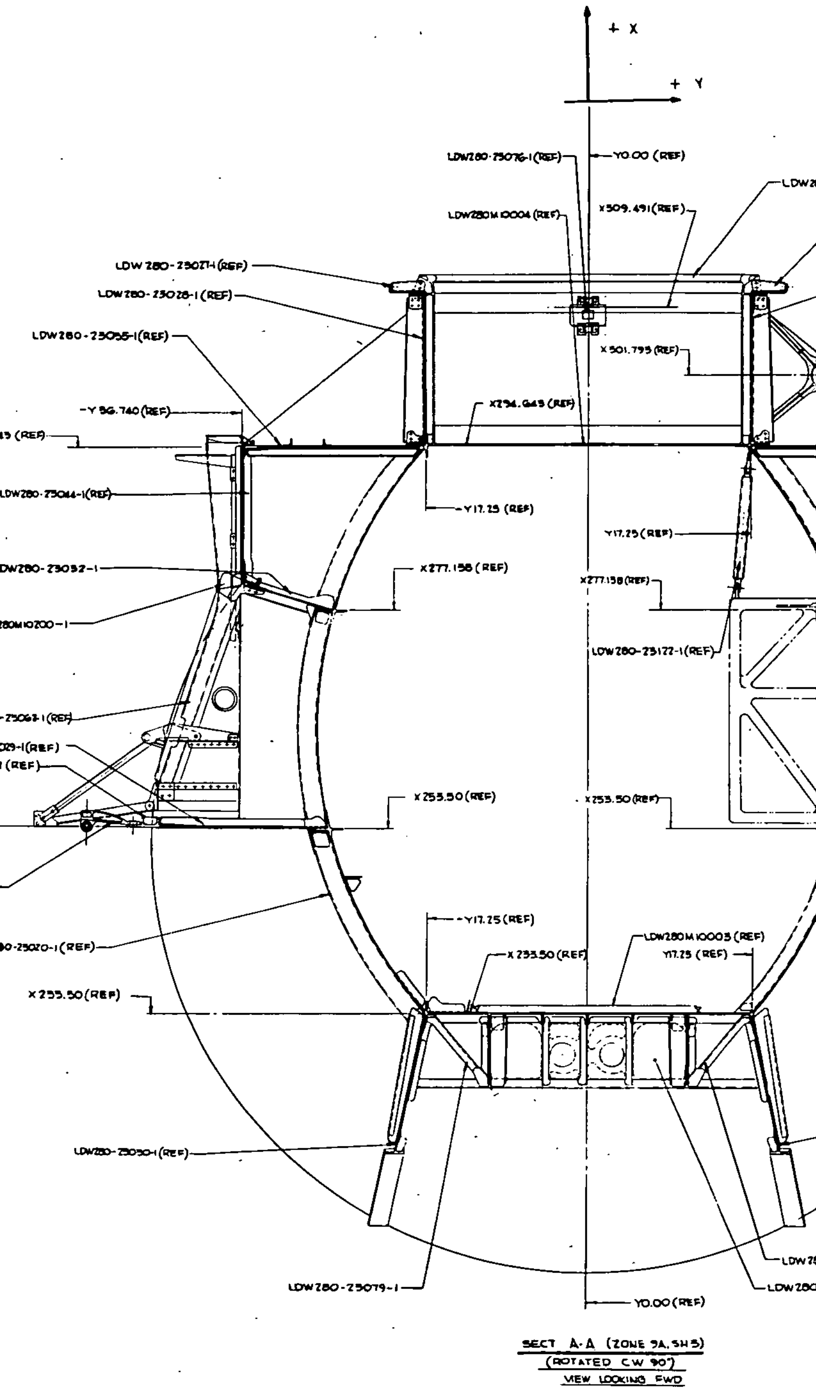


L.H. SIDE LOOKING INBD

← FWD

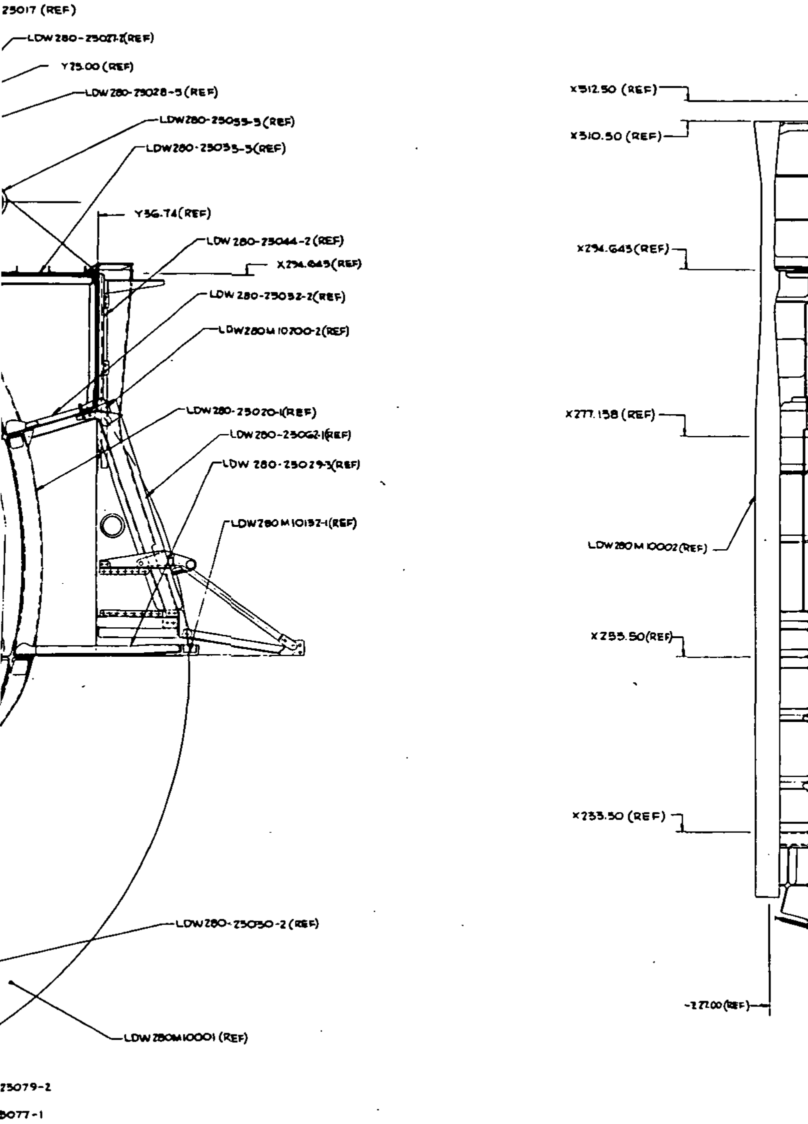
6.1-3

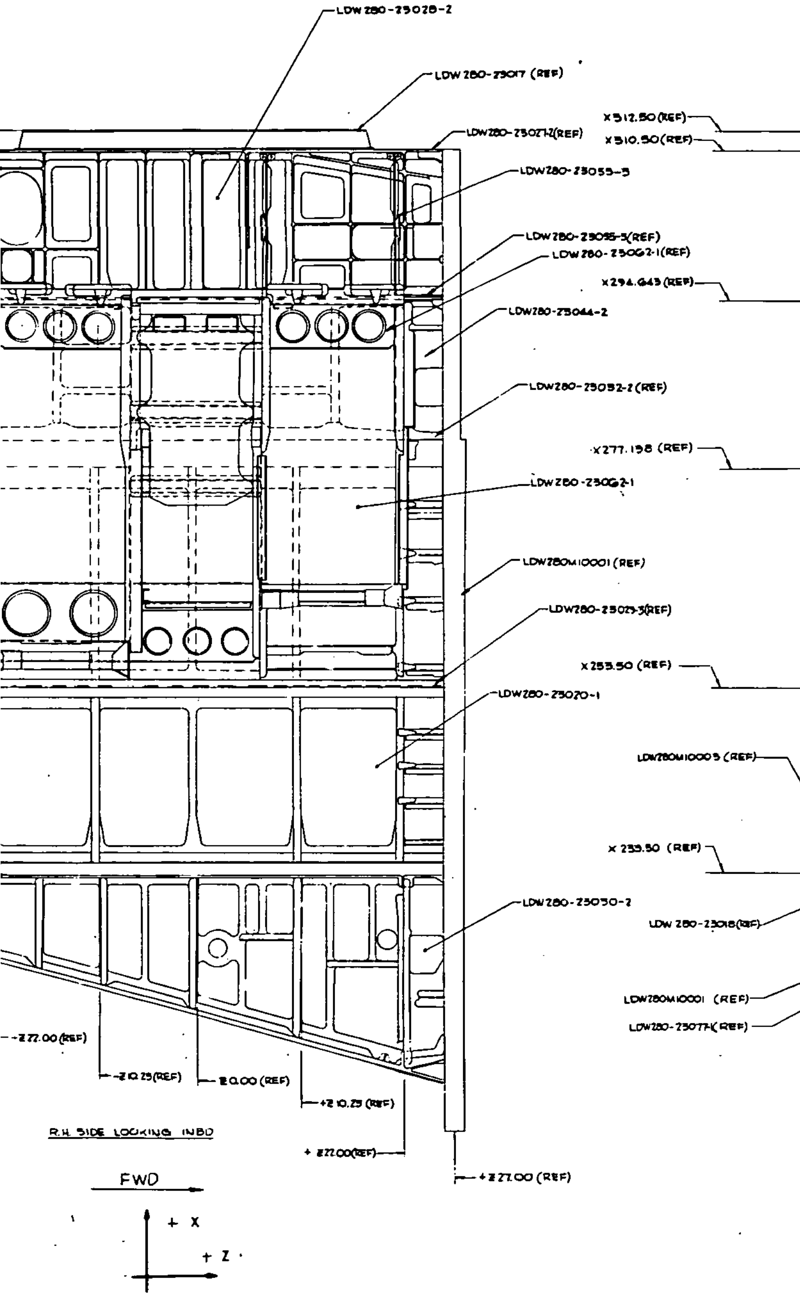
①


+ X
+ Y
LDW280-23076-1(REF)
Y0.00 (REF)
LDW280M10004 (REF)
X509.491(REF)
LDW 280-23027-1(REF)
LDW280-23028-1(REF)
LDW280-23055-1(REF)
X501.795(REF)
-Y 56.740(REF)
X296.649(REF)
LDW280-23044-1(REF)
Y17.25 (REF)
Y17.25(REF)
LDW280-23032-1
X277.158 (REF)
X277.158(REF)
LDW280-23122-1(REF)
X255.50(REF)
X255.50(REF)
Y17.25(REF)
LDW280M10003 (REF)
X255.50(REF)
Y17.25 (REF)
X255.50(REF)
LDW280-23030-1(REF)
LDW280-23079-1
Y0.00(REF)
SECT A-A (ZONE 9A, SH3)
(ROTATED CW 90°)
VIEW LOOKING FWD

6-1-3

(2)


25017 (REF)
LDW 280-25027-2(REF)
Y25.00 (REF)
LDW 280-25028-5 (REF)
LDW280-25055-5 (REF)
LDW280-25035-5(REF)
Y56.74(REF)
LDW 280-25044-2 (REF)
X294.645(REF)
LDW 280-25052-2(REF)
LDW280M10700-2(REF)
LDW280-25020-1(REF)
LDW 280-25062-1(REF)
LDW 280-25029-3(REF)
LDW280M10152-1(REF)
LDW280-25030-2 (REF)
LDW280M10001 (REF)
25079-2
5077-1
X512.50 (REF)
X510.50 (REF)
X294.645(REF)
X277.158 (REF)
LDW280M10002(REF)
X255.50(REF)
X233.50 (REF)
-227.00(REF)



LDW 280-23028-2
LDW 280-23017 (REF)
LDW280-23027-2(REF)
X 512.50 (REF)
X 510.50 (REF)
LDW280-23055-5
LDW 280-23095-5(REF)
LDW 280-23062-1(REF)
X 294.643 (REF)
LDW280-23044-2
LDW280-23052-2(REF)
X 277.158 (REF)
LDW 280-23062-1
LDW280M10001 (REF)
LDW280-23029-5(REF)
X 255.50 (REF)
LDW280-23020-1
LDW280M10005 (REF)
X 235.50 (REF)
LDW280-23050-2
LDW 280-23018(REF)
LDW280M10001 (REF)
LDW280-23077-1(REF)
-Z 27.00 (REF)
-Z 10.25 (REF)
Z 0.00 (REF)
+Z 10.25 (REF)
+Z 27.00(REF)
+Z 27.00 (REF)
R.H. SIDE LOOKING INBD
FWD
+ X
+ Z

6-1-3

(4)

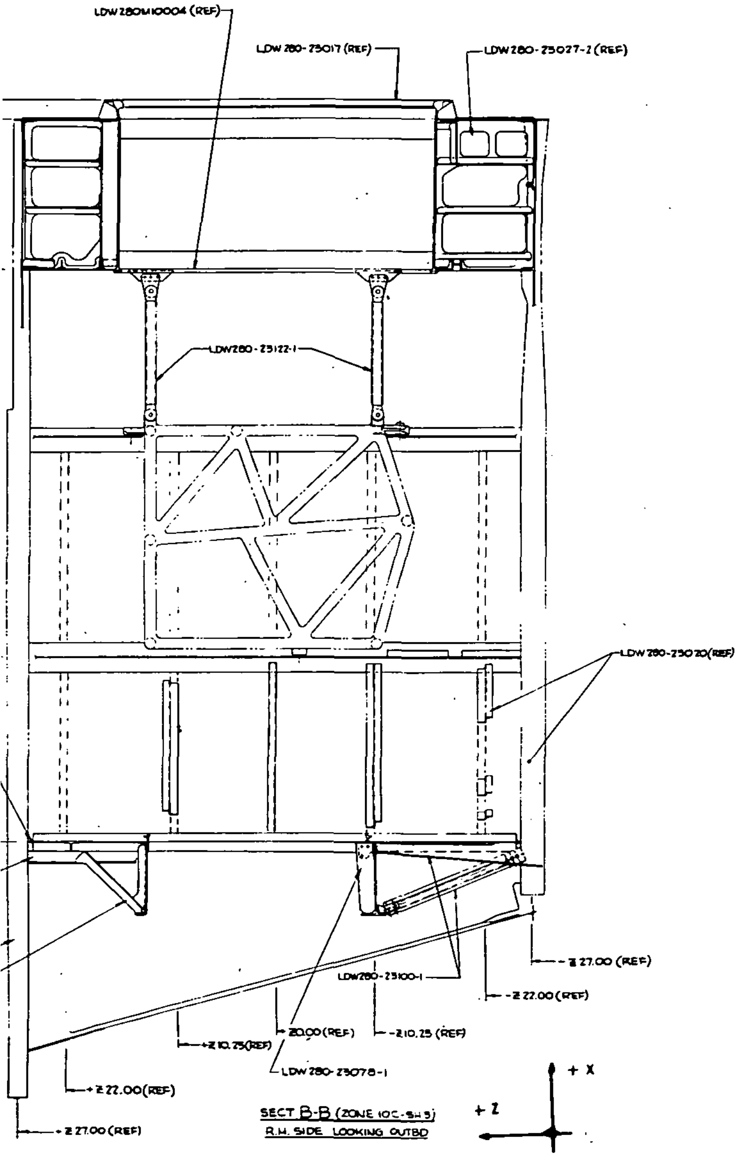


Fig. 6.1-3 LEM Structural Arrangement
Ascent Stage Aft Cabin

5

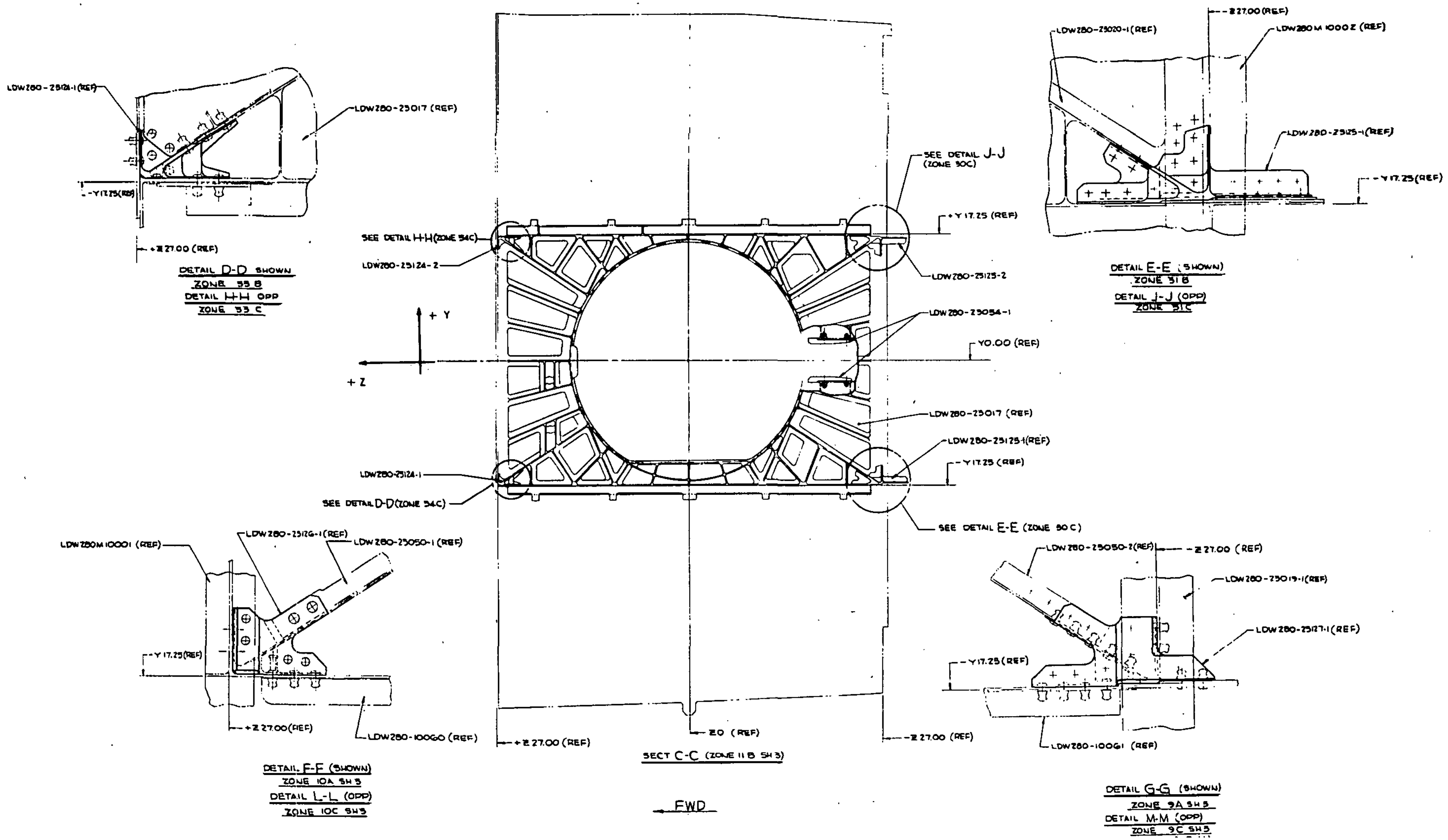
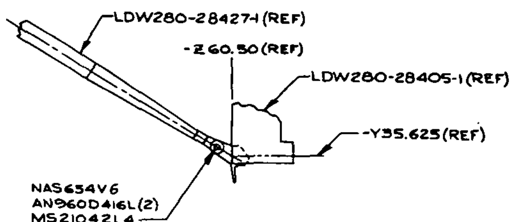
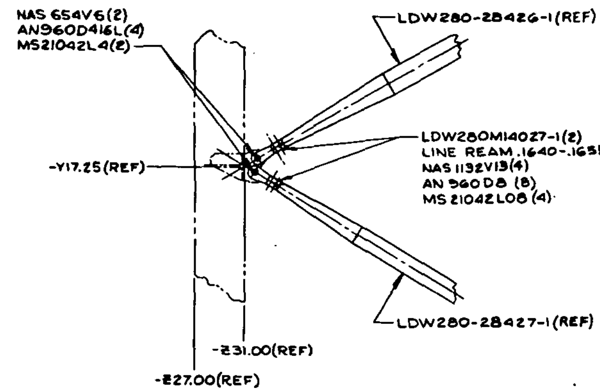


Fig. 6.1-4 LEM Structural Arrangement
Ascent Stage Aft Cabin

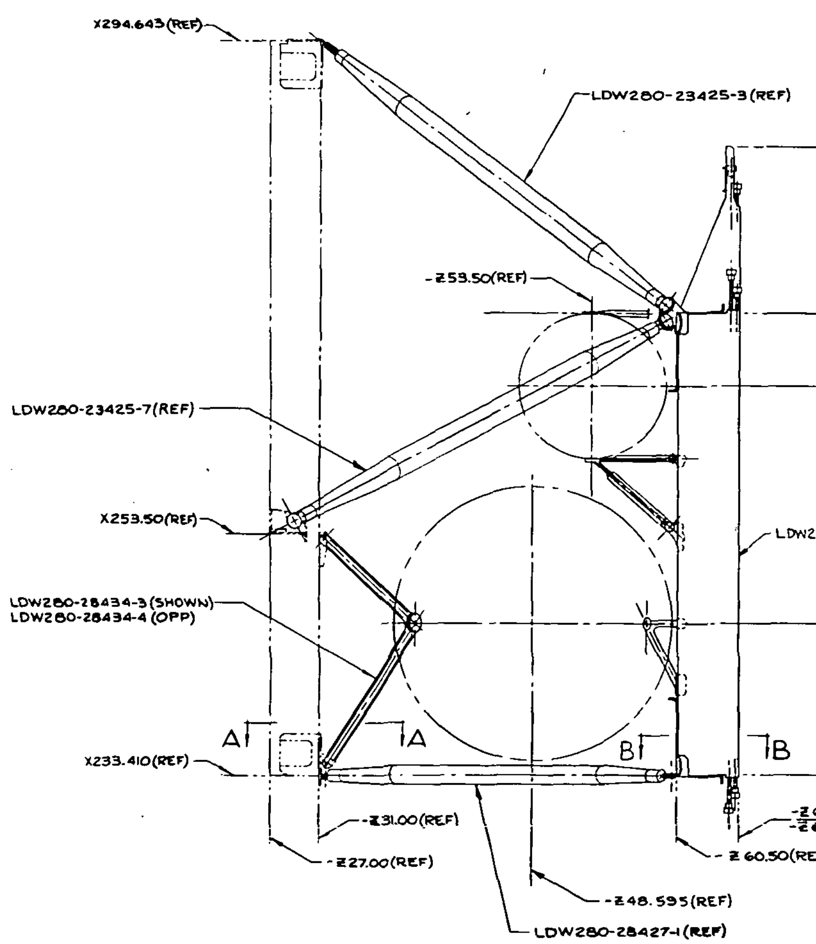
17

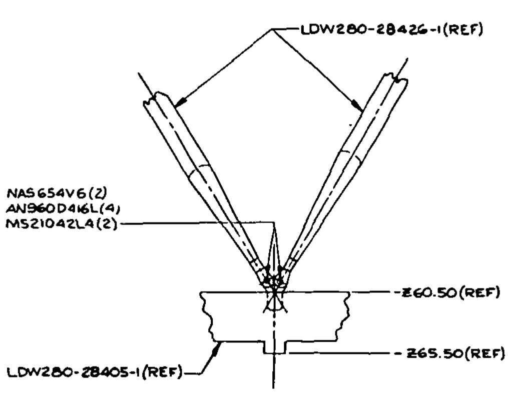


VIEW B-B
LH (SHOWN) RH (OPP)

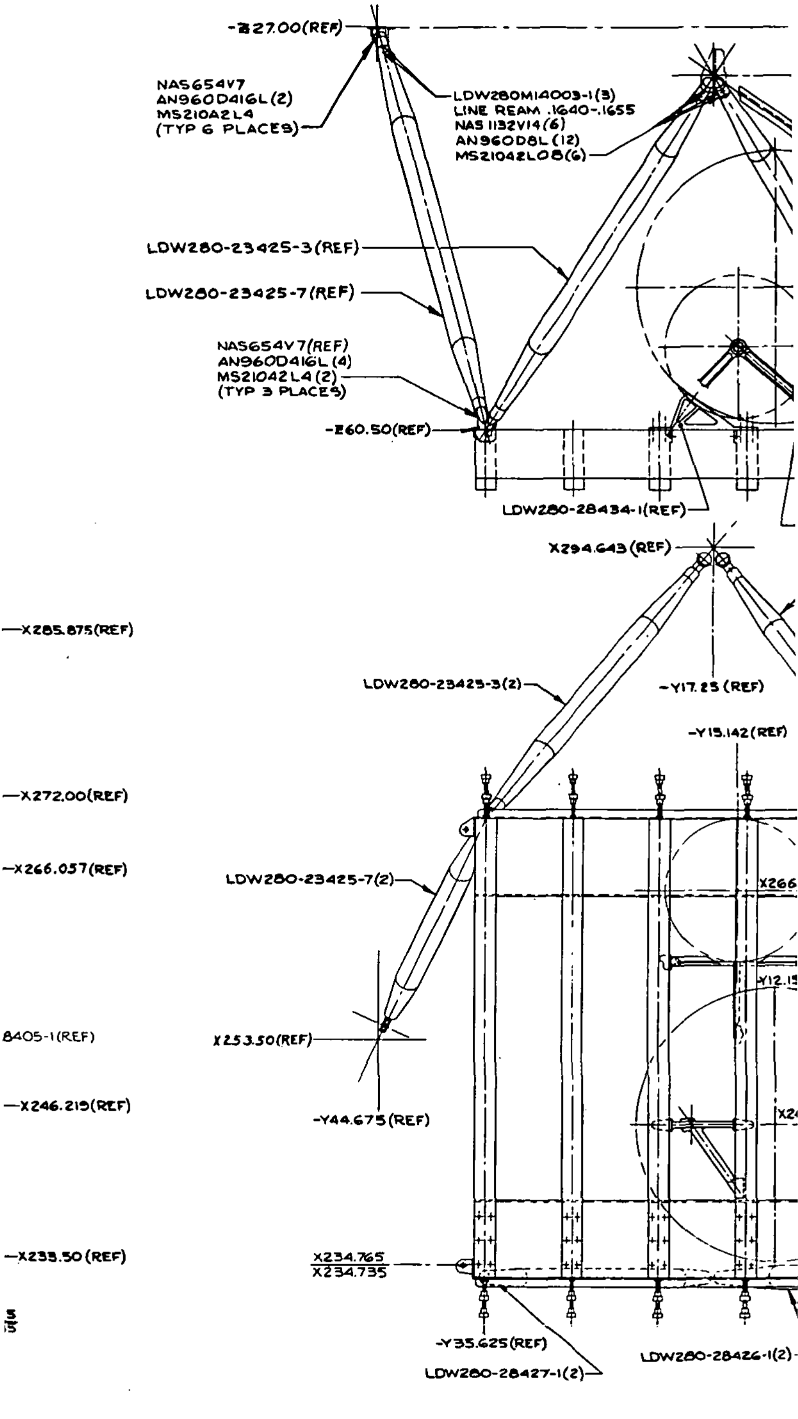


VIEW A-A
LH (SHOWN) RH (OPP)





VIEW C-C



-Z27.00(REF)
NAS654V7
AN960D416L(2)
MS21042L4
(TYP 6 PLACES)
LDW280M14003-1(3)
LINE REAM .1640-.1655
NAS 1132V14(6)
AN960D8L(12)
MS21042L08(6)
LDW280-23425-3(REF)
LDW280-23425-7(REF)
NAS654V7(REF)
AN960D416L(4)
MS21042L4(2)
(TYP 3 PLACES)
-Z60.50(REF)
LDW280-28434-1(REF)
X294.643(REF)
-X285.875(REF)
LDW280-23425-3(2)
-Y17.25(REF)
-Y15.142(REF)
-X272.00(REF)
-X266.057(REF)
LDW280-23425-7(2)
8405-1(REF)
X253.50(REF)
-X246.219(REF)
-Y44.675(REF)
-X233.50(REF)
X234.765
X234.735
-Y35.625(REF)
LDW280-28426-1(2)
LDW280-28427-1(2)

2

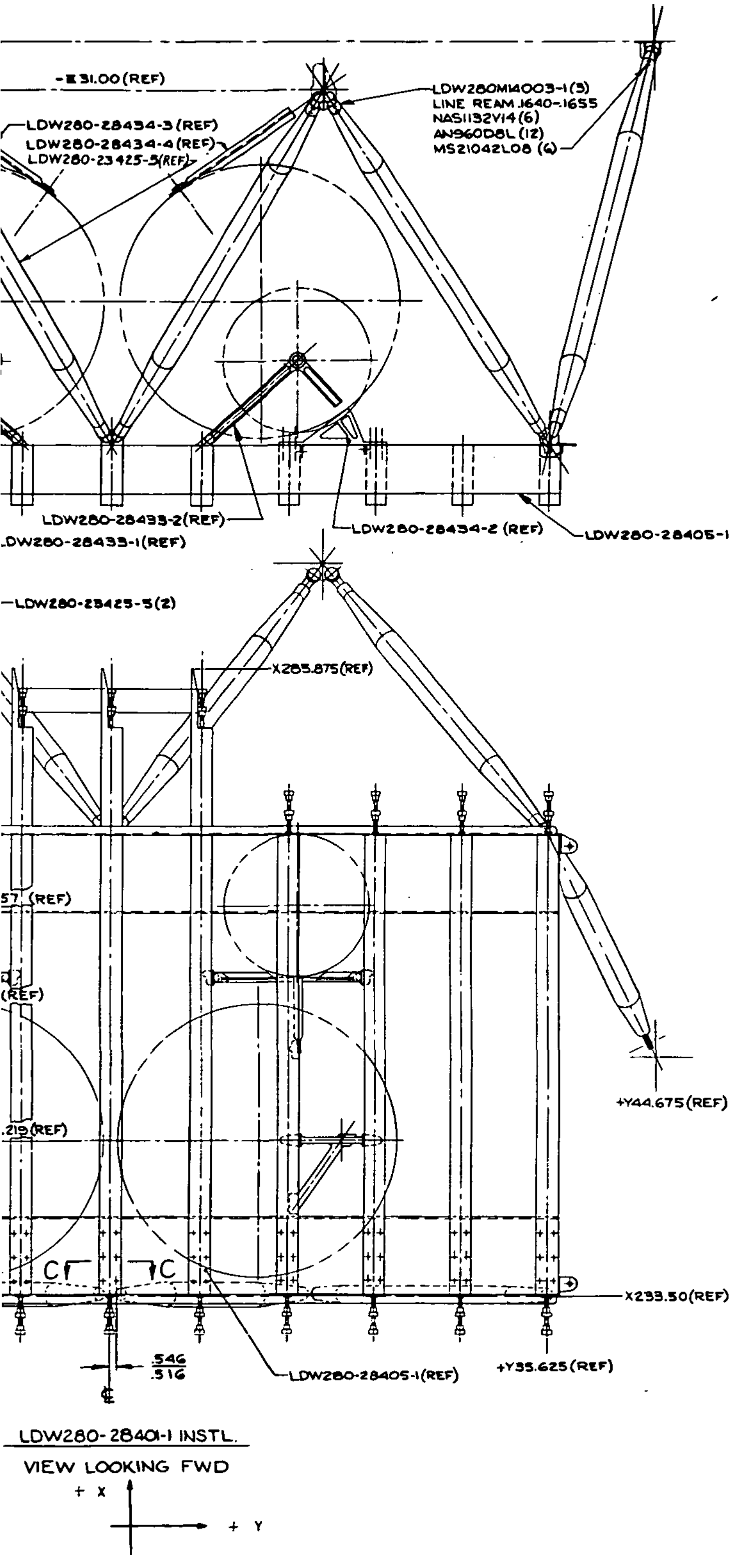
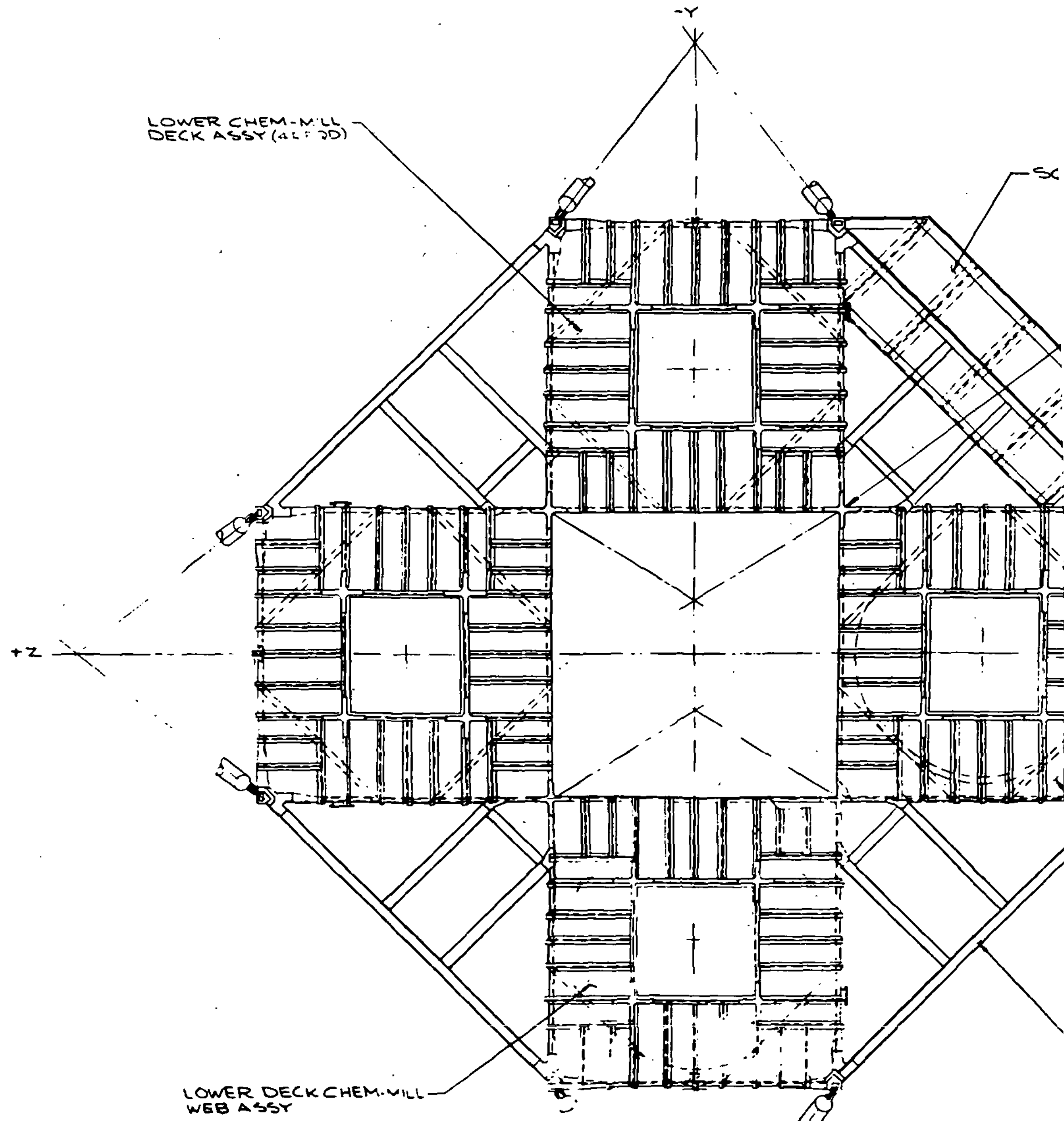
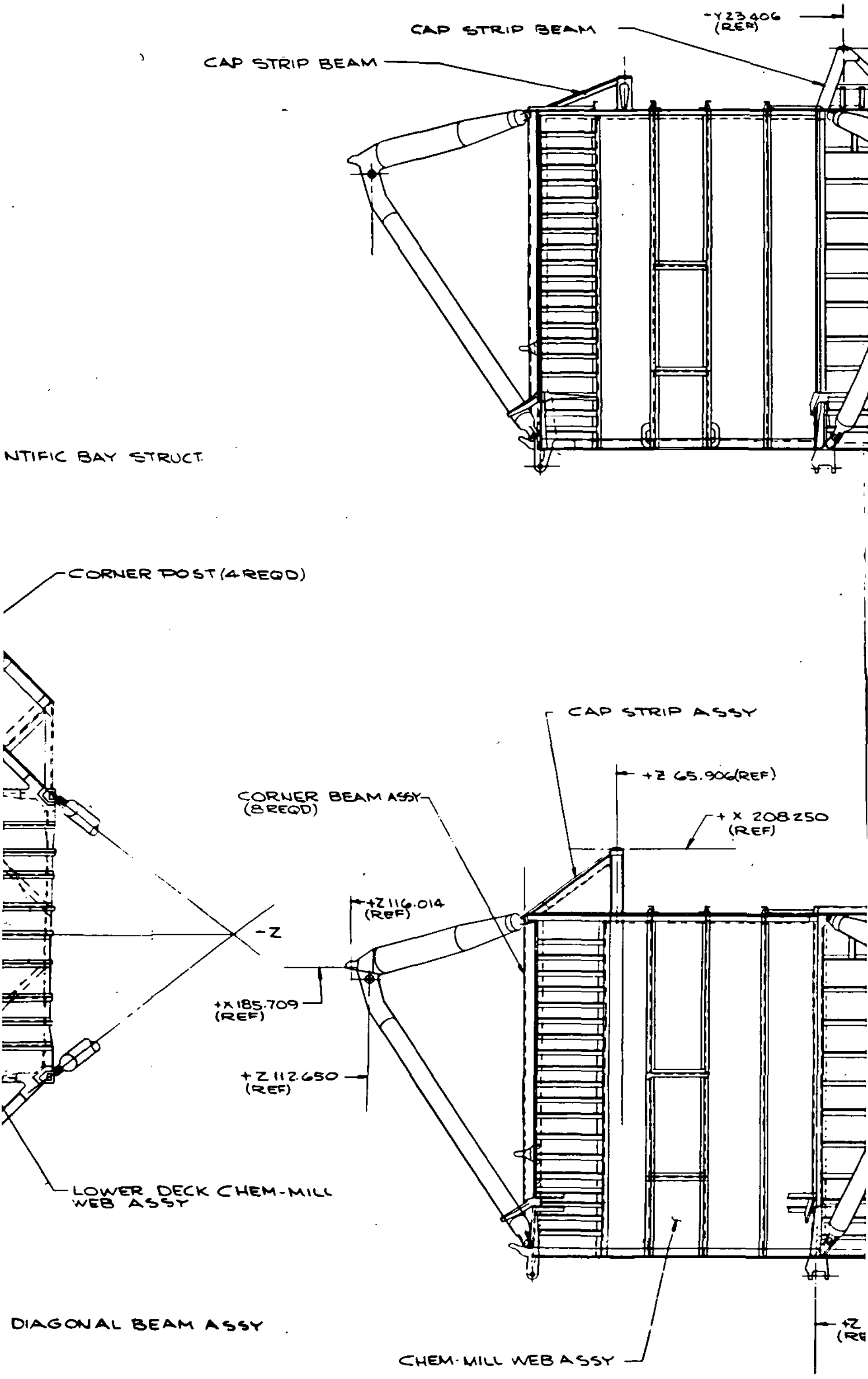


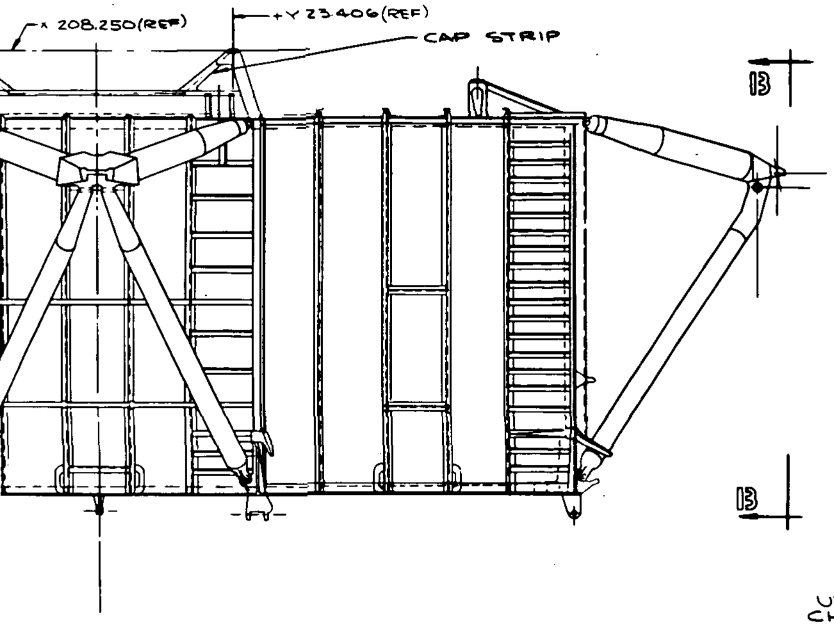
Fig. 6.1-5 LEM Structural Arrangement Ascent Stage Aft Equipment Compartment



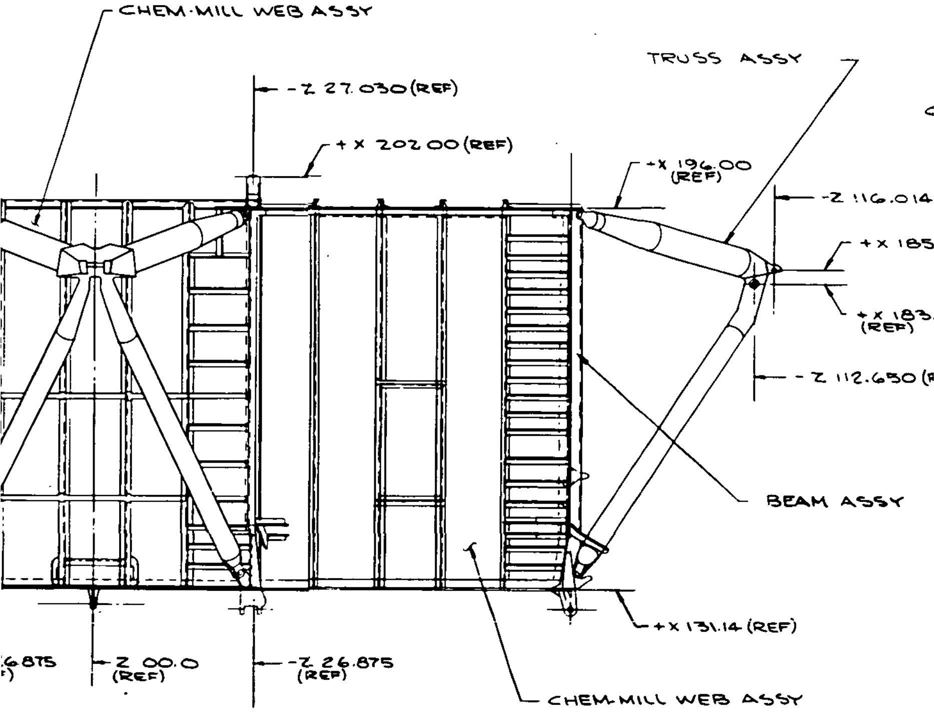
/IEW LOOKING UP
LOWER DECK

6 1-6
(1)


-Y 23.406
(REF)
CAP STRIP BEAM
CAP STRIP BEAM
NTIFIC BAY STRUCT.
CORNER POST (4 REQD)
CAP STRIP ASSY
+Z 65.906 (REF)
CORNER BEAM ASSY
(8 REQD)
+X 208.250
(REF)
+Z 116.014
(REF)
-Z
+X 185.709
(REF)
+Z 112.650
(REF)
LOWER DECK CHEM-MILL
WEB ASSY
DIAGONAL BEAM ASSY
CHEM-MILL WEB ASSY



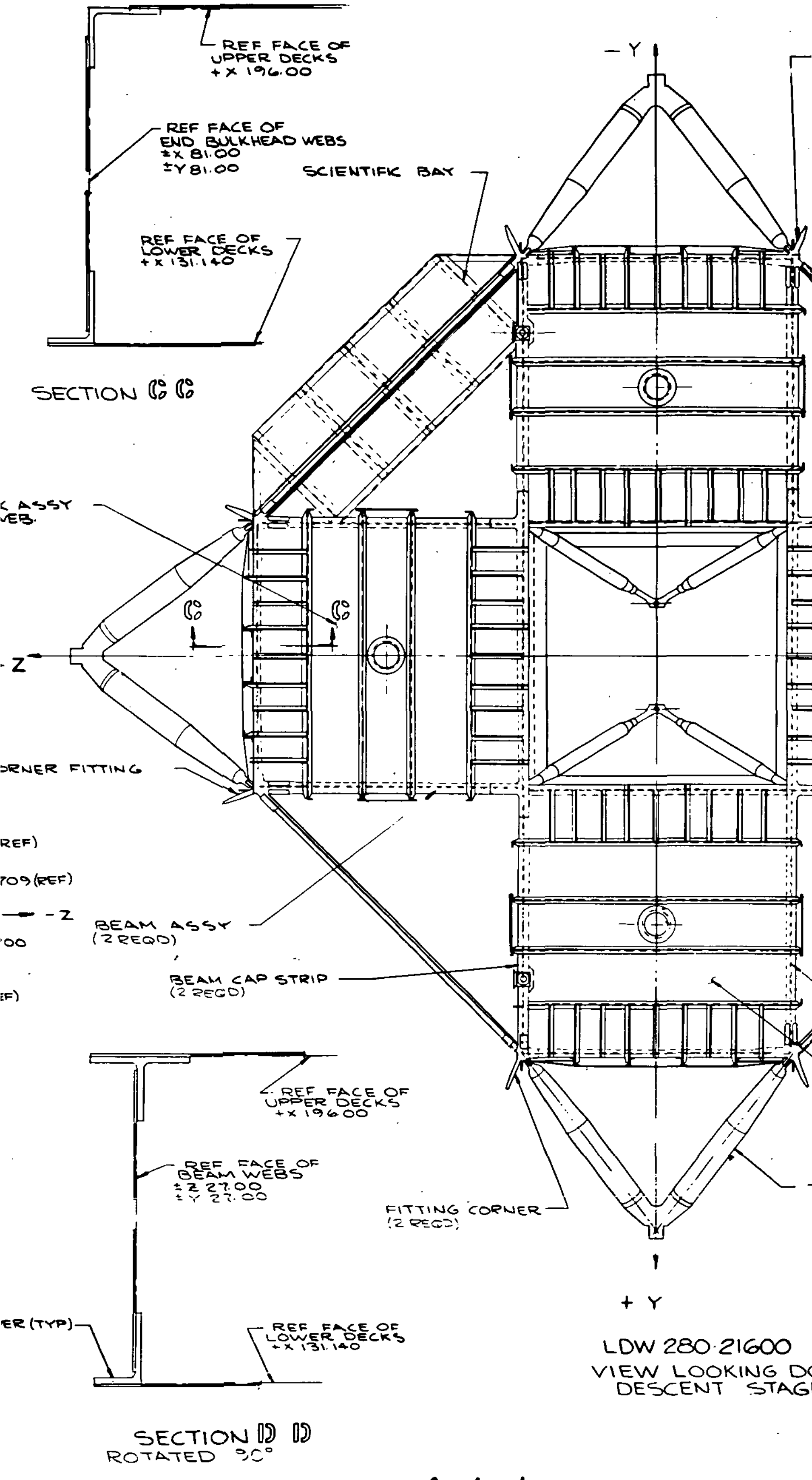
VIEW A-A
ROTATED 90°



B-B
VIEW LOOKING INBD
-Y 81.00 / -Y 27.00

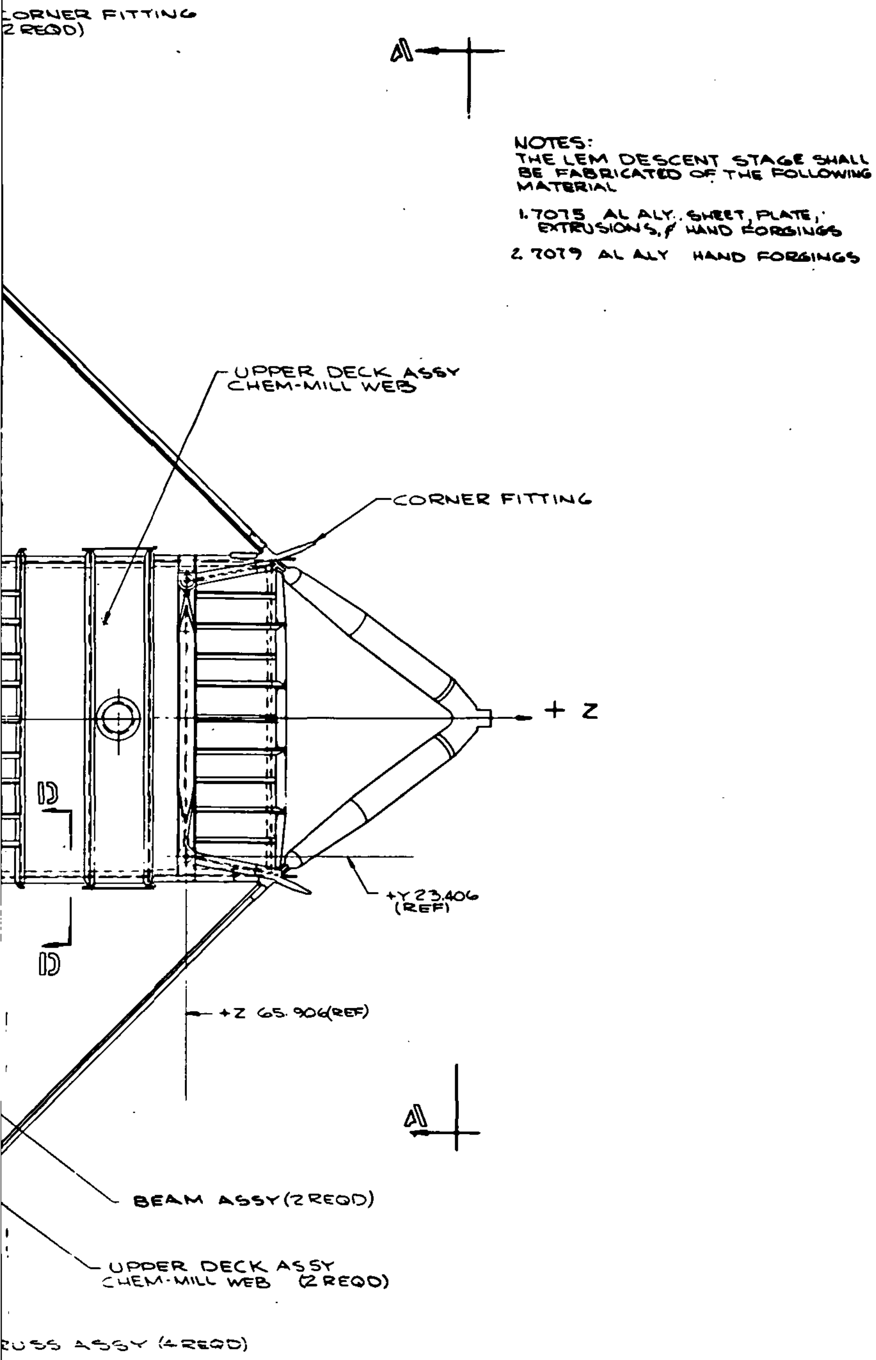
BEAM LO

6.1-6
(3)


REF FACE OF UPPER DECKS +X 196.00
REF FACE OF END BULKHEAD WEBS ±X 81.00 ±Y 81.00
SCIENTIFIC BAY
REF FACE OF LOWER DECKS +X 131.140
SECTION C C
-Y
-Z
ORNER FITTING
REF)
709 (REF)
-Z
BEAM ASSY (2 REQD)
BEAM CAP STRIP (2 REQD)
REF FACE OF UPPER DECKS +X 196.00
REF FACE OF BEAM WEBS ±Z 27.00 ±Y 27.00
FITTING CORNER (2 REQD)
ER (TYP)
REF FACE OF LOWER DECKS +X 131.140
SECTION D D ROTATED 90°
+Y
LDW 280-21600
VIEW LOOKING DO
DESCENT STAG

6.1-6

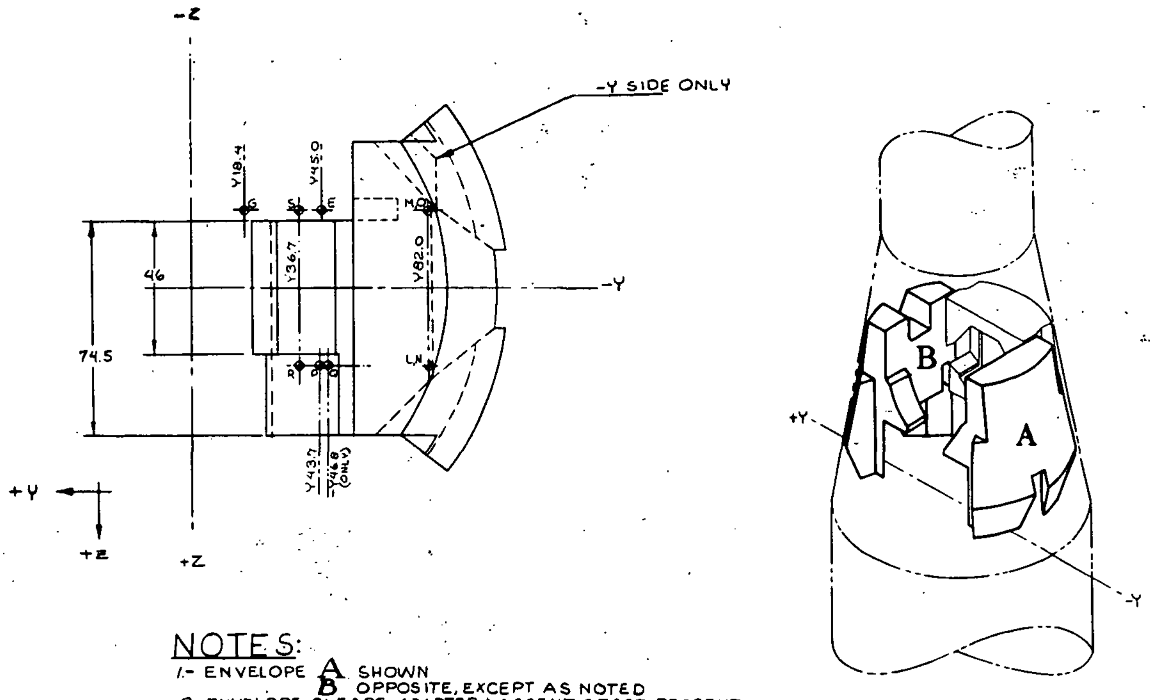
(4)



WN

Fig. 6.1-6. LEM Descent Stage Structural Arrangement

(5)



NOTES:

1.- ENVELOPE **A** SHOWN
B OPPOSITE, EXCEPT AS NOTED
2.- ENVELOPE CLEARS ADAPTER & ASCENT STAGE, DESCENT STAGE STRUCTURE BY 7 IN. AND IS TANGENT TO THE 1180° F ISOTHERM OF THE RCS THRUSTER PLUME
3.- LOCAL PROTRUSIONS CAN BE ALLOWED IN SOME AREAS.
4.- LETTERS 'A' THRU 'S' INDICATE LOCATIONS OF EQUIPMENT ATTACHMENT HARDPOINTS.

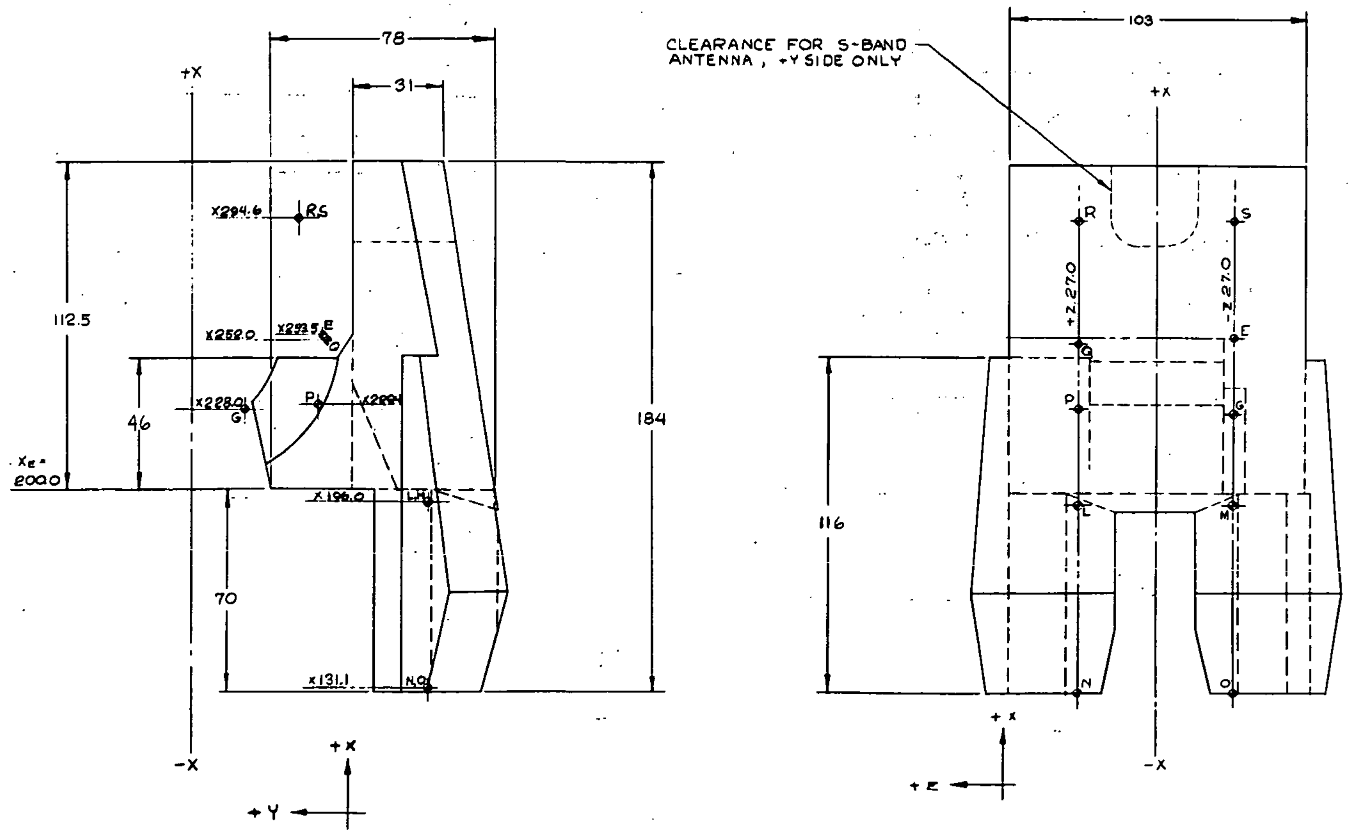


Fig. 6.1-7 Lab Payload Envelope

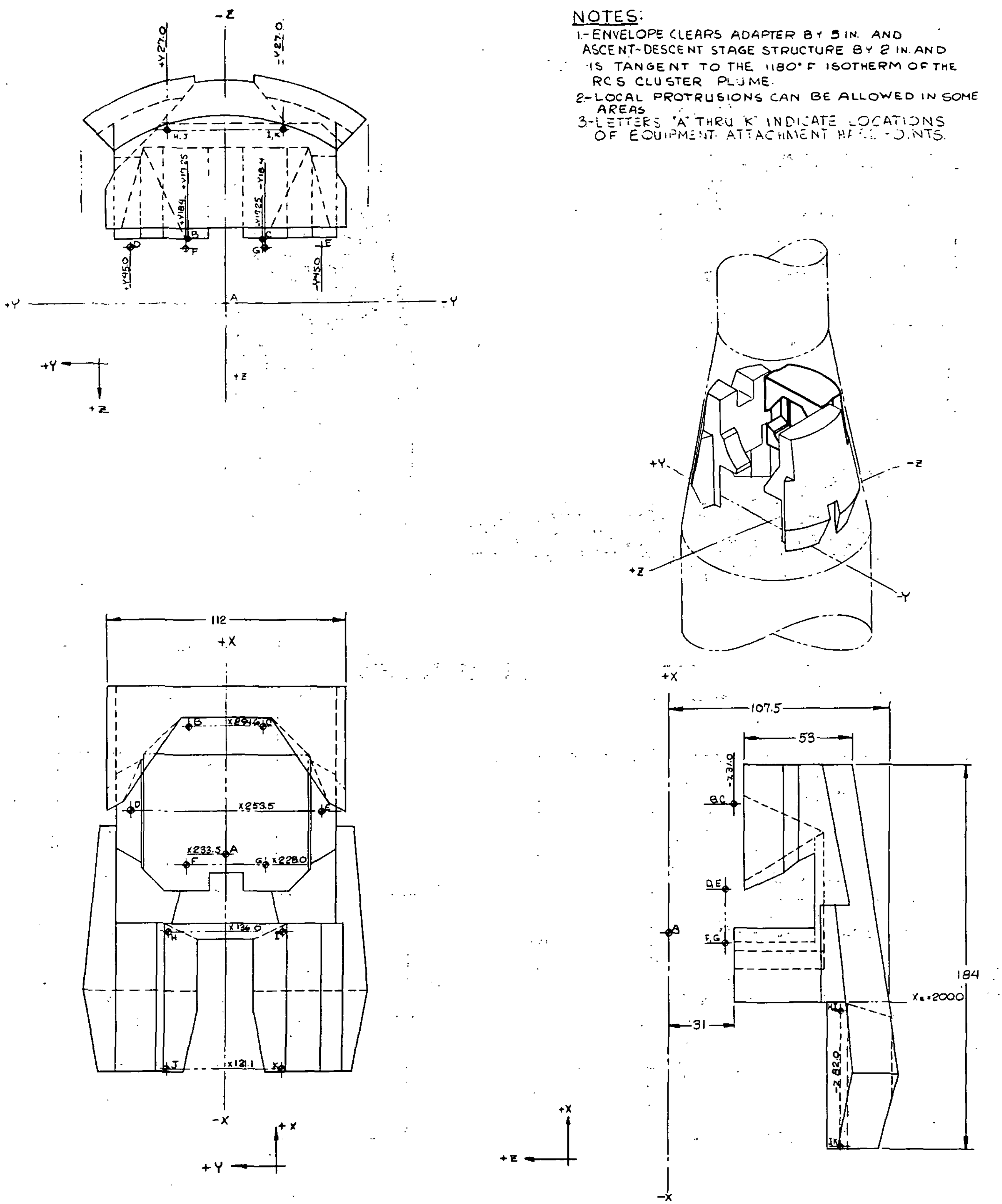
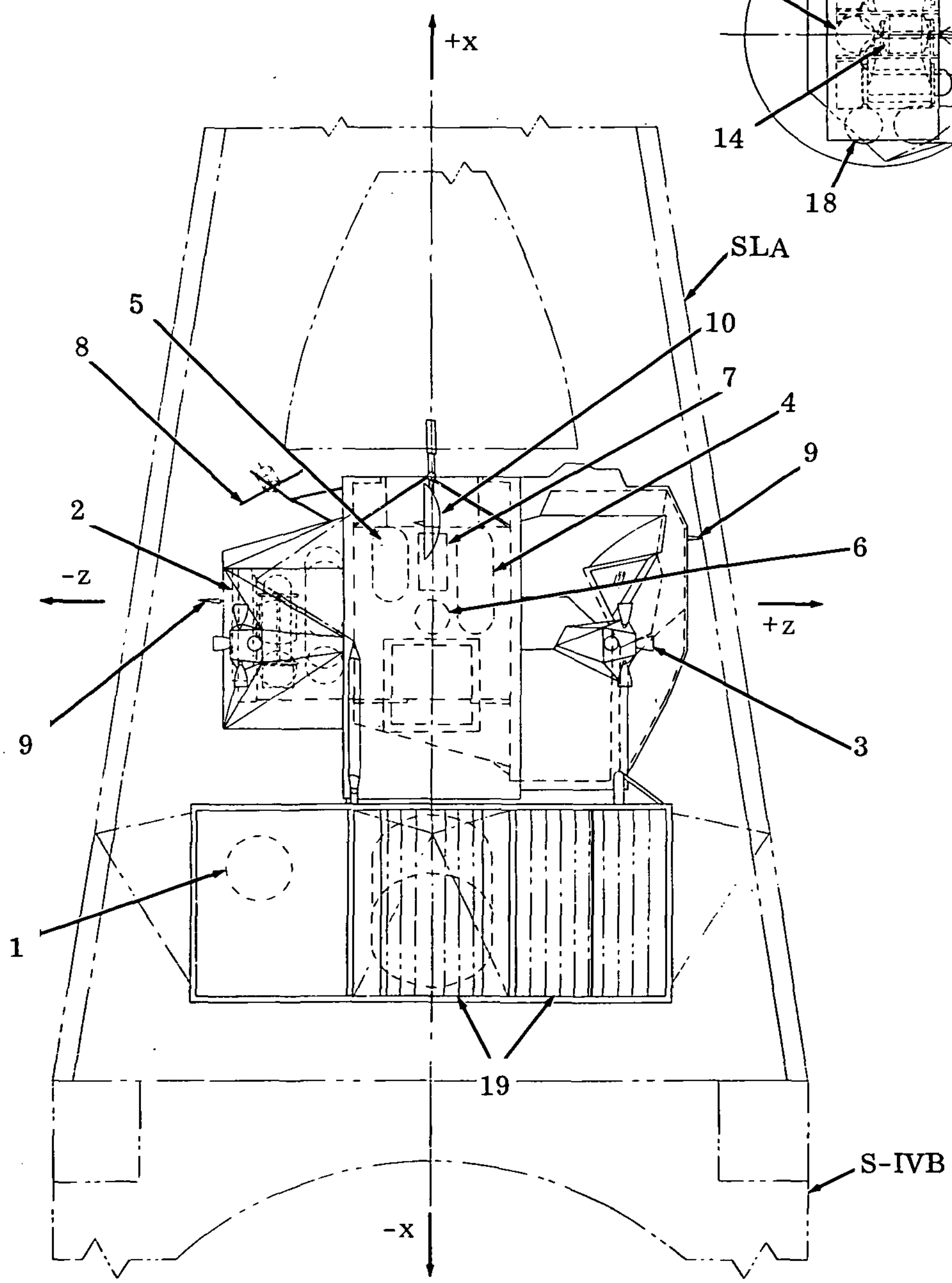
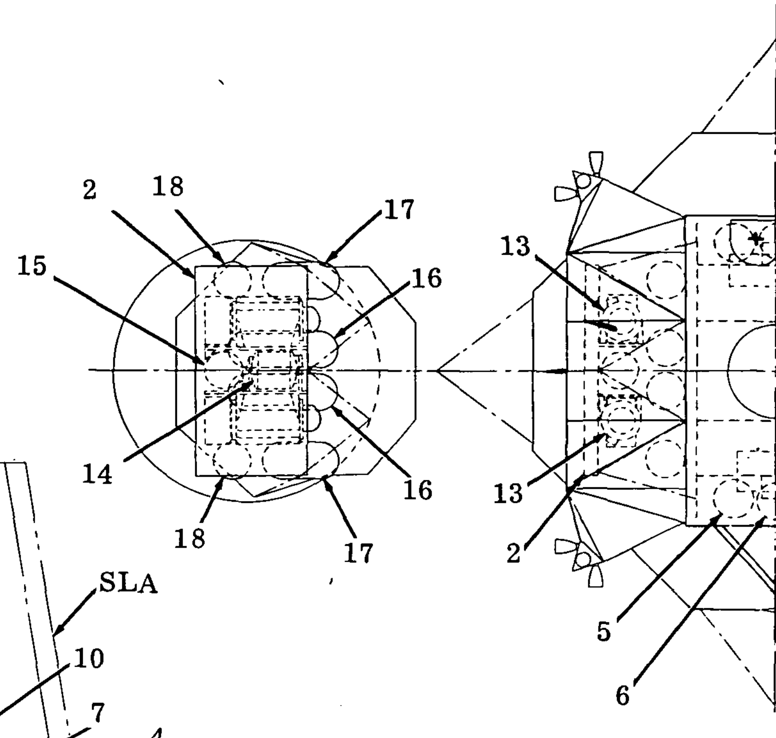


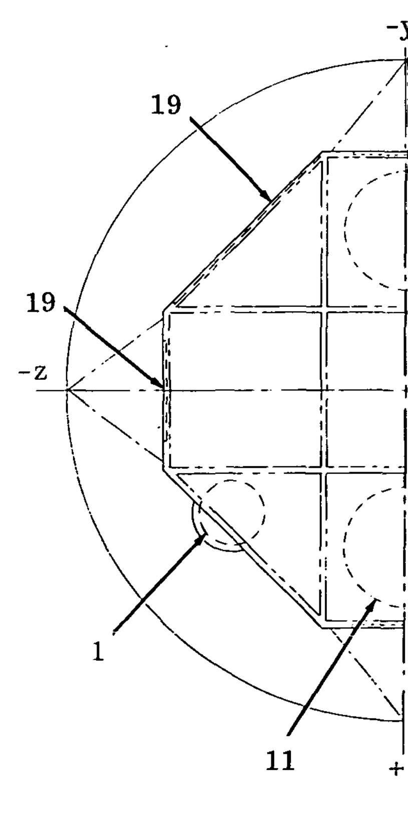
Fig. 6.1-8 Lab Payload Envelope



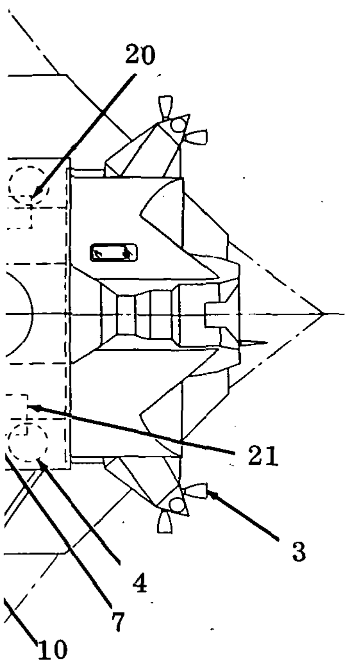
Launch Configuration



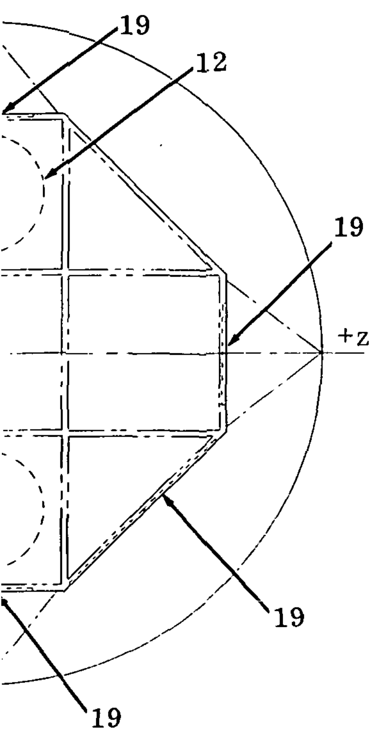
Plan View of



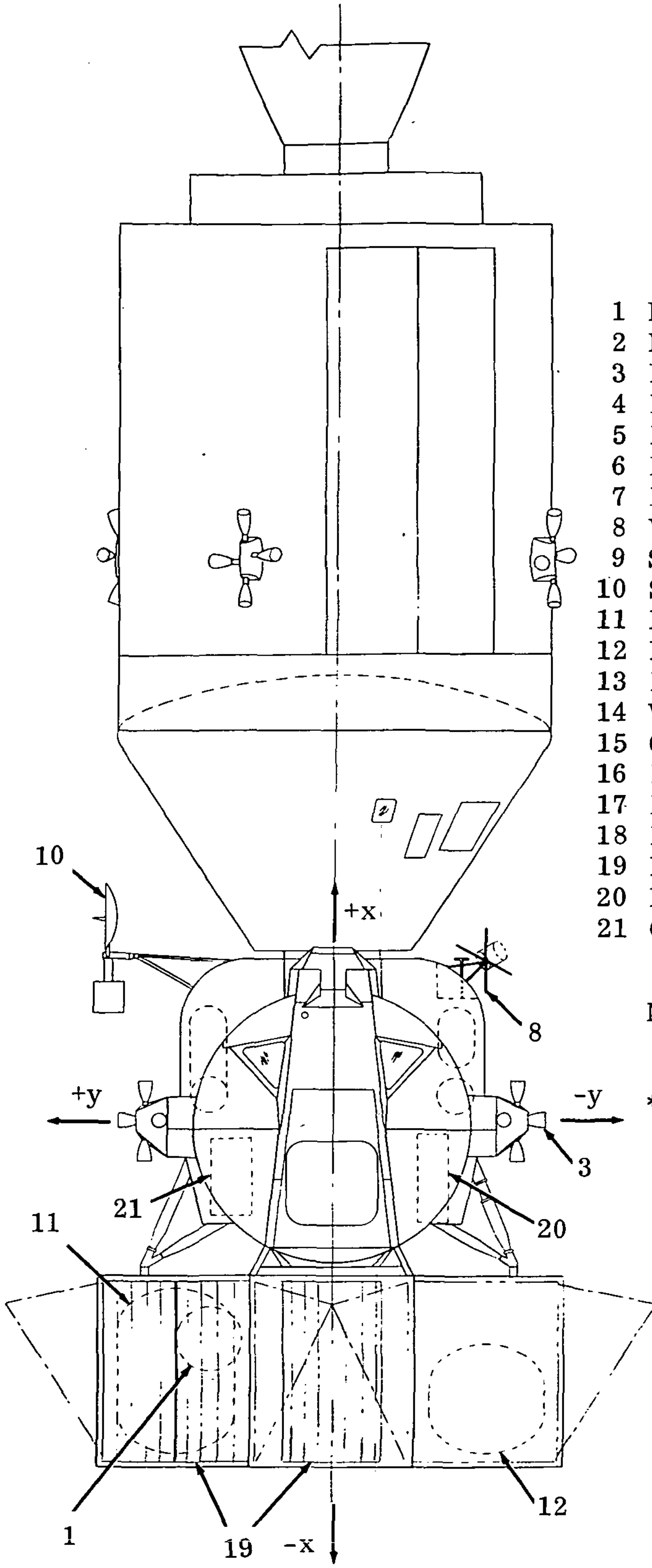
Plan View of I



Ascent Stage



Descent Stage



Orbiting Configuration

0 20 40 60 80 100

Scale – Inches

Key

1 ECS Nitrogen*
2 ERA Cold Plate*
3 RCS Thrusters*
4 RCS Fuel*
5 RCS Oxidizer*
6 RCS Helium*
7 RCS Valves*
8 VHF Antenna*
9 S-Band Antenna*
10 S-Band Steerable Antenna*
11 EPS Hydrozen
12 EPS Oxygen
13 Fuel Cell Assembly
14 Water Tank
15 GOX Accumulator**
16 RCS Fuel**
17 RCS Oxidizer**
18 RCS Helium**
19 ECS & EPS Radiators
20 LiOH Storage
21 Constant Wear Garment Storage

NOTE:

* Existing LEM Installation
** Existing LEM Hardware
The Recommended Configuration Includes An Airlock But No Specific Airlock Has Been Chosen At This Time, Various Airlock Designs Are Shown In Figures 6.2-8, 6.2-9 & 6.2-10

Fig. 6.2-1 Recommended Configuration Phase II LAB

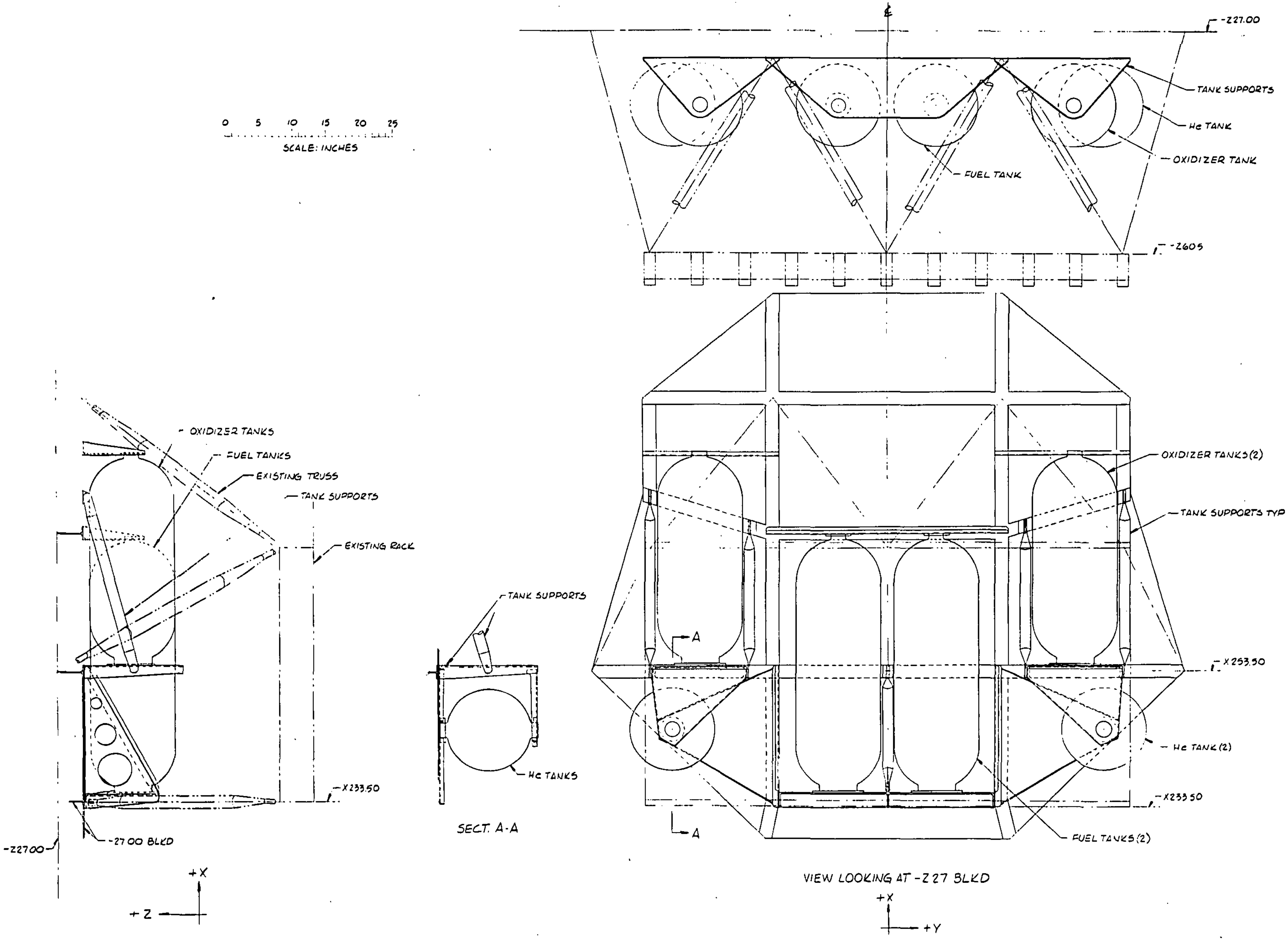
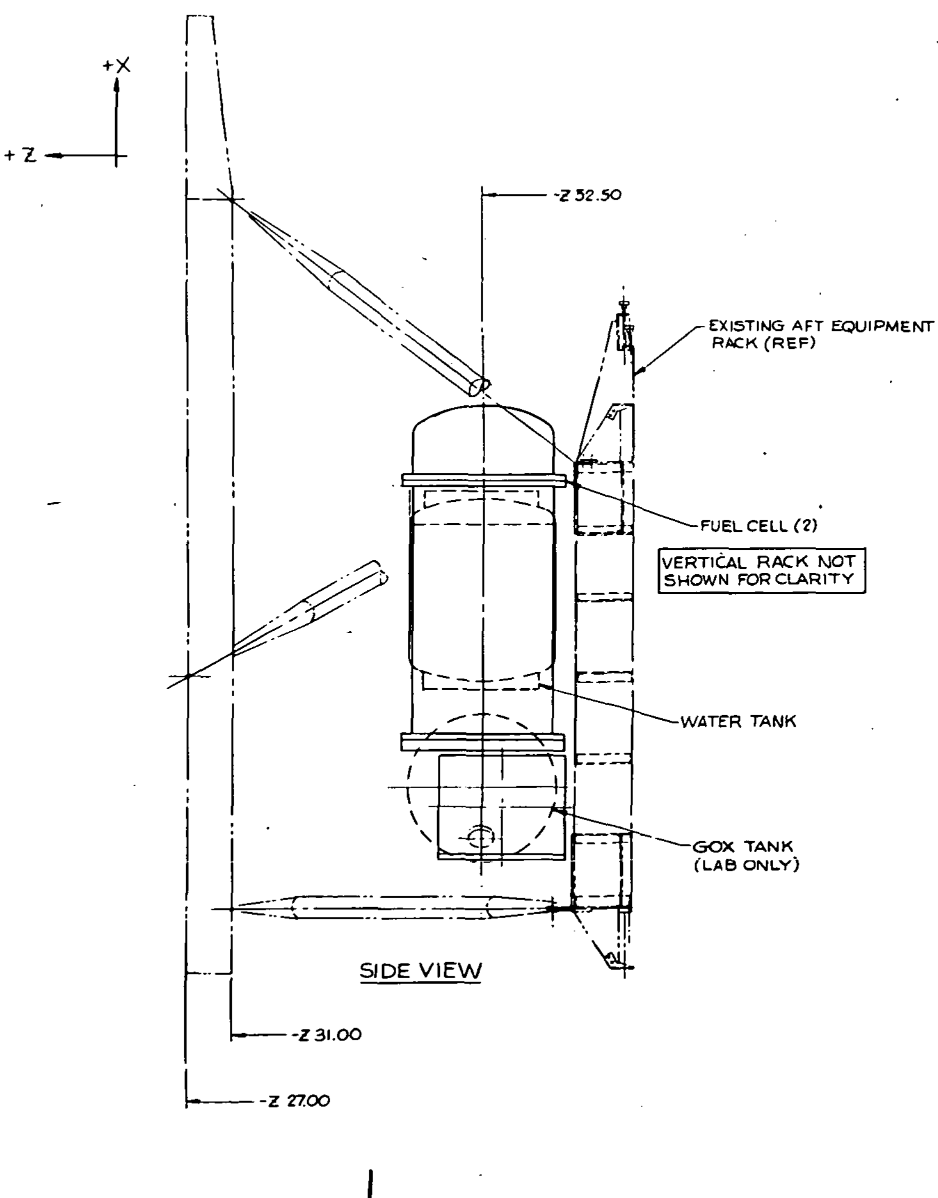


Fig. 6.2-2 Recommended Additional RCS Propellant Tank Instl

27


+X
+Z
-Z 52.50
EXISTING AFT EQUIPMENT RACK (REF)
FUEL CELL (2)
VERTICAL RACK NOT SHOWN FOR CLARITY
WATER TANK
GOX TANK (LAB ONLY)
-Z 31.00
-Z 27.00

SIDE VIEW

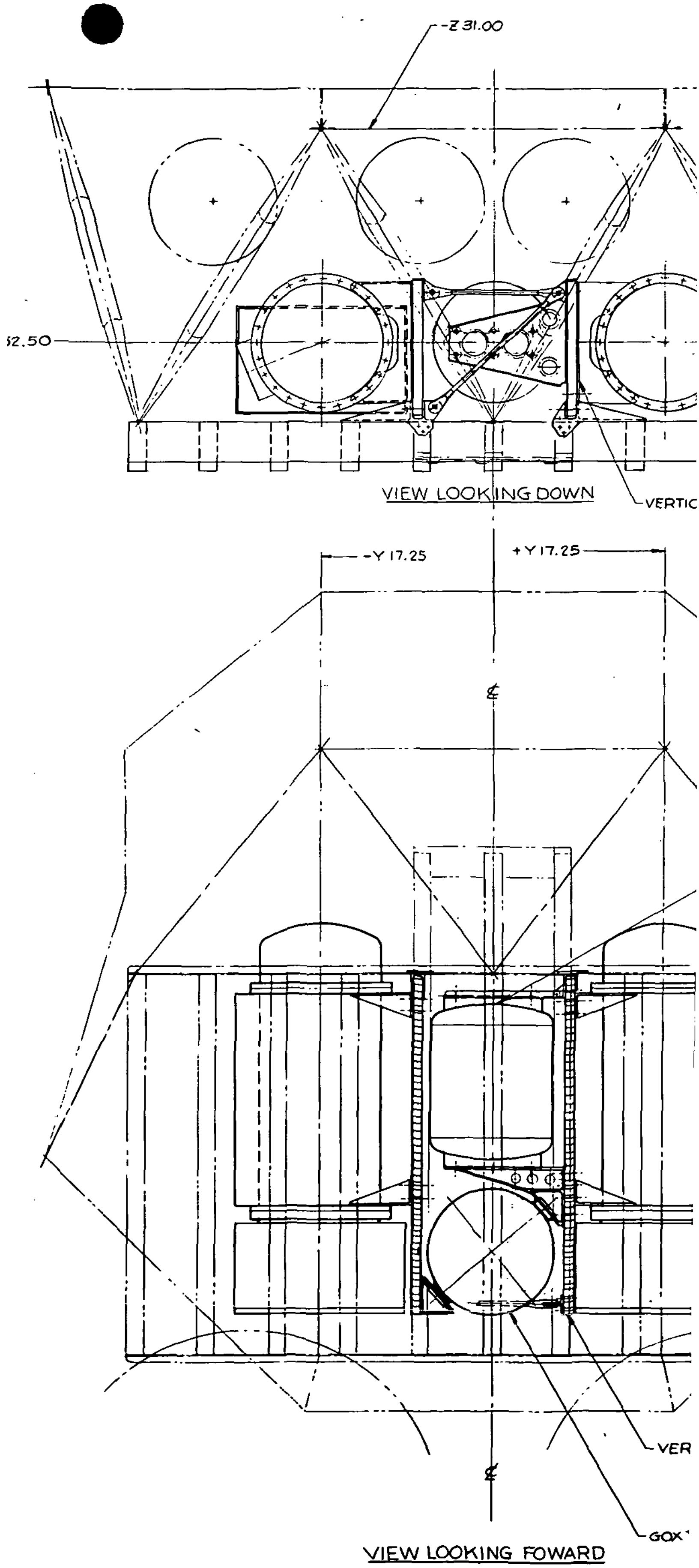
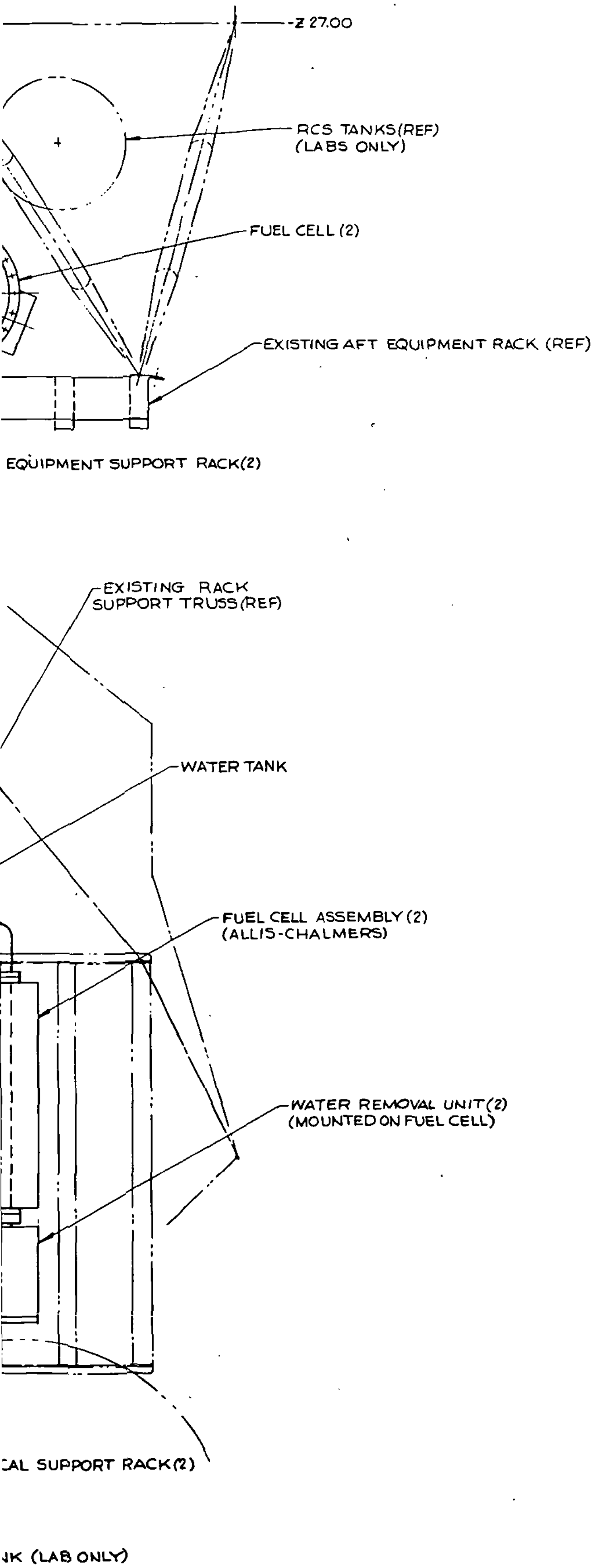


Fig. 6.2-3 Recom

2



ended Allis Chalmers Fuel Cell Installation

Grumman

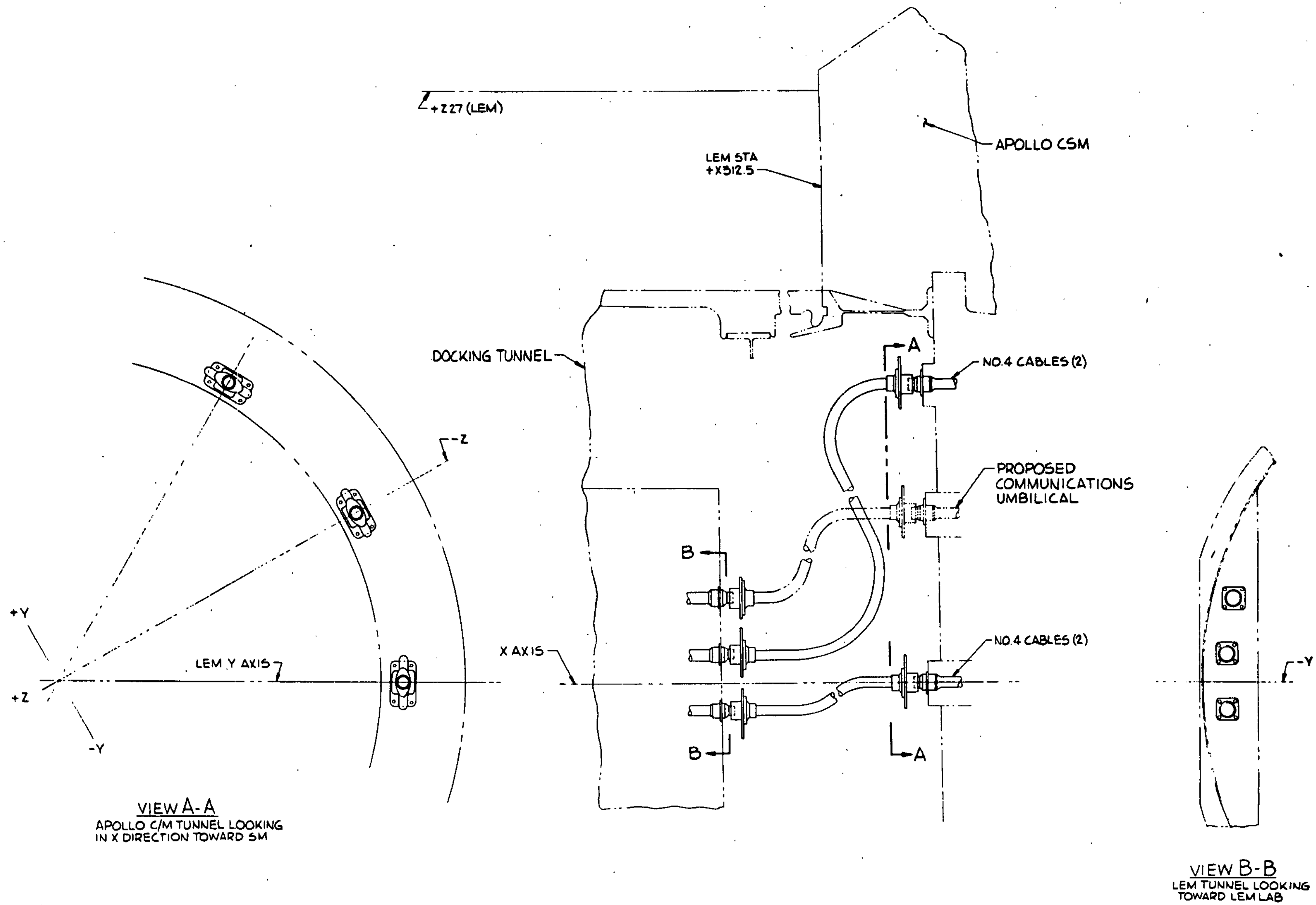
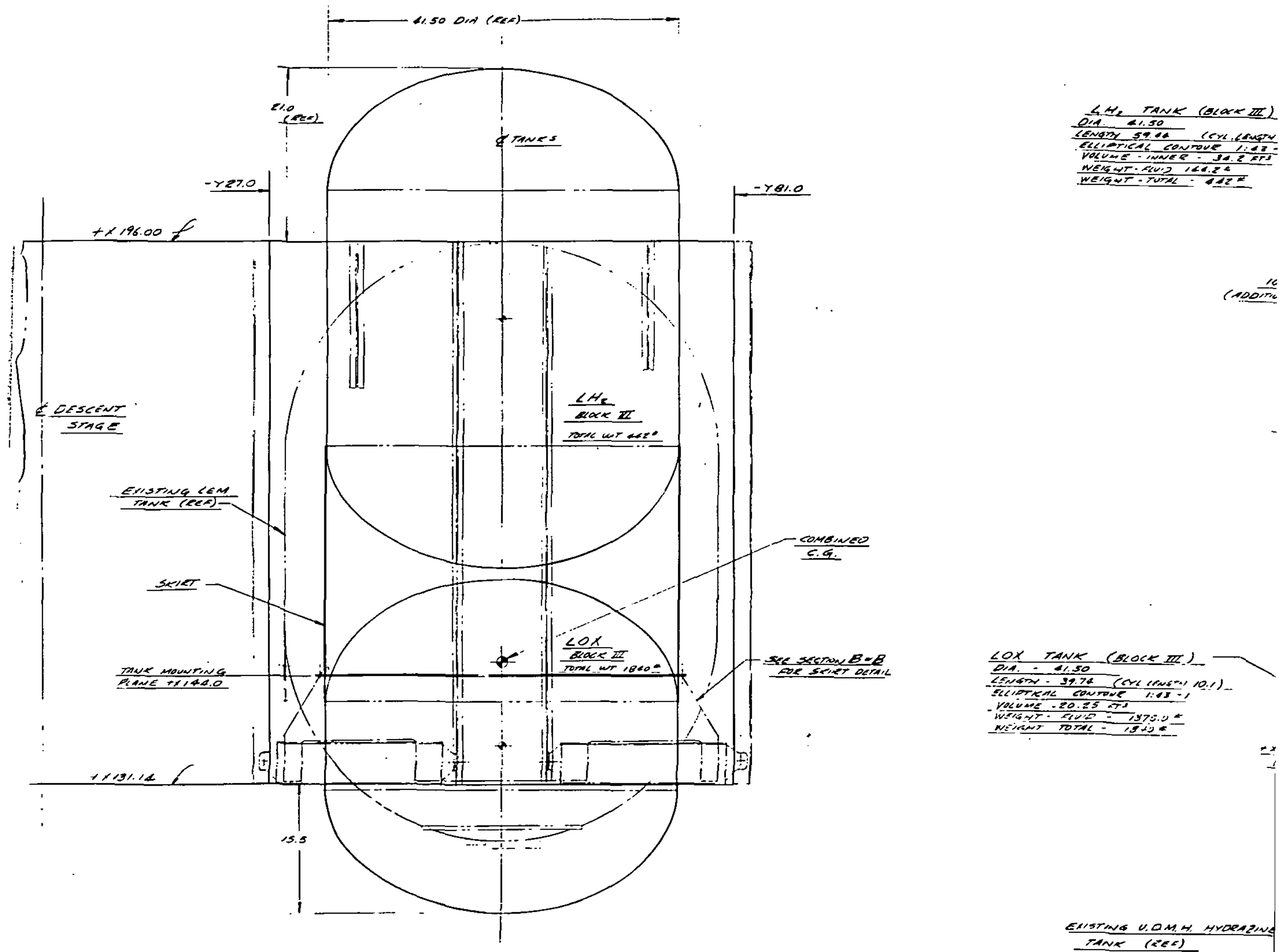
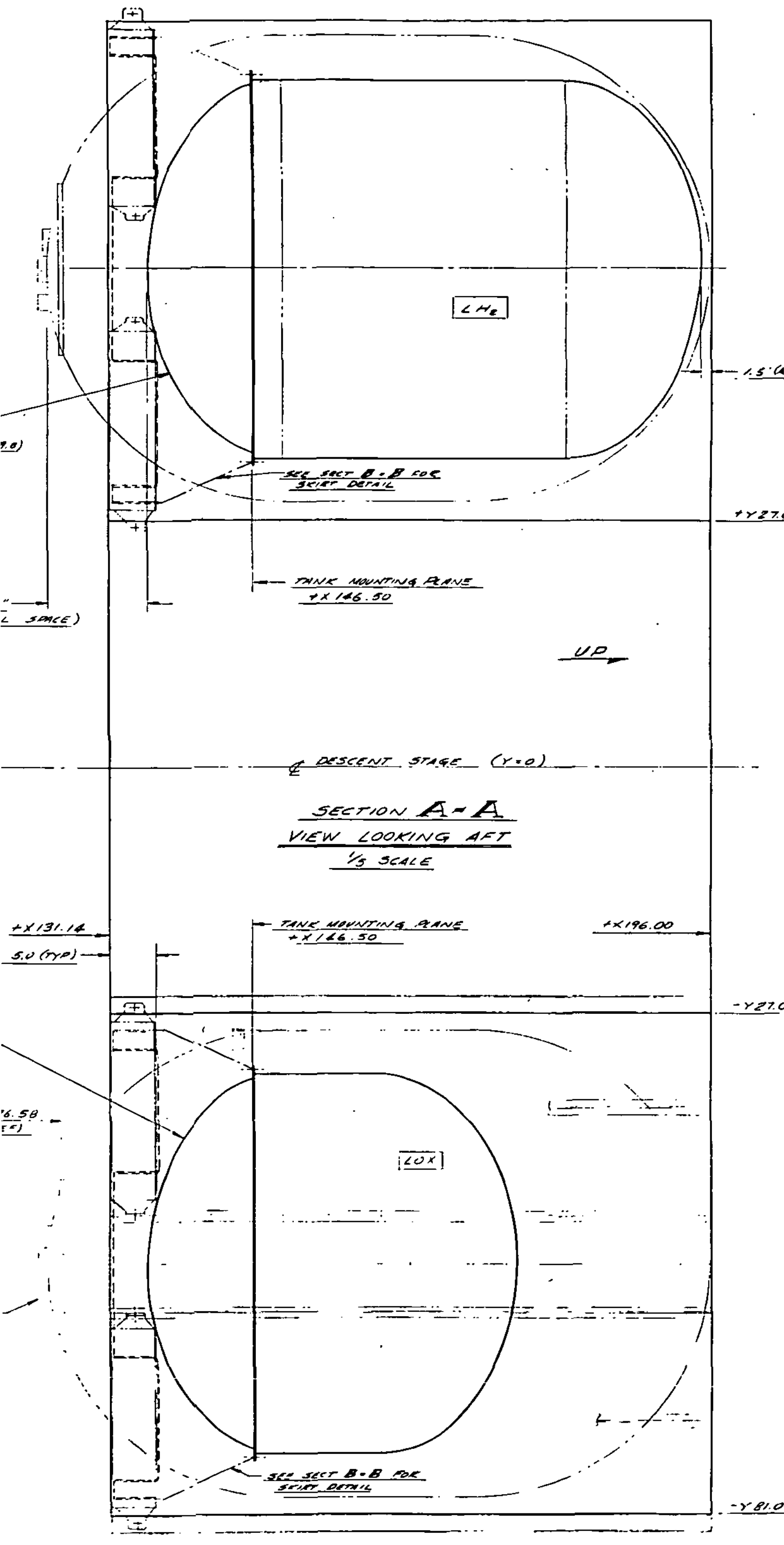


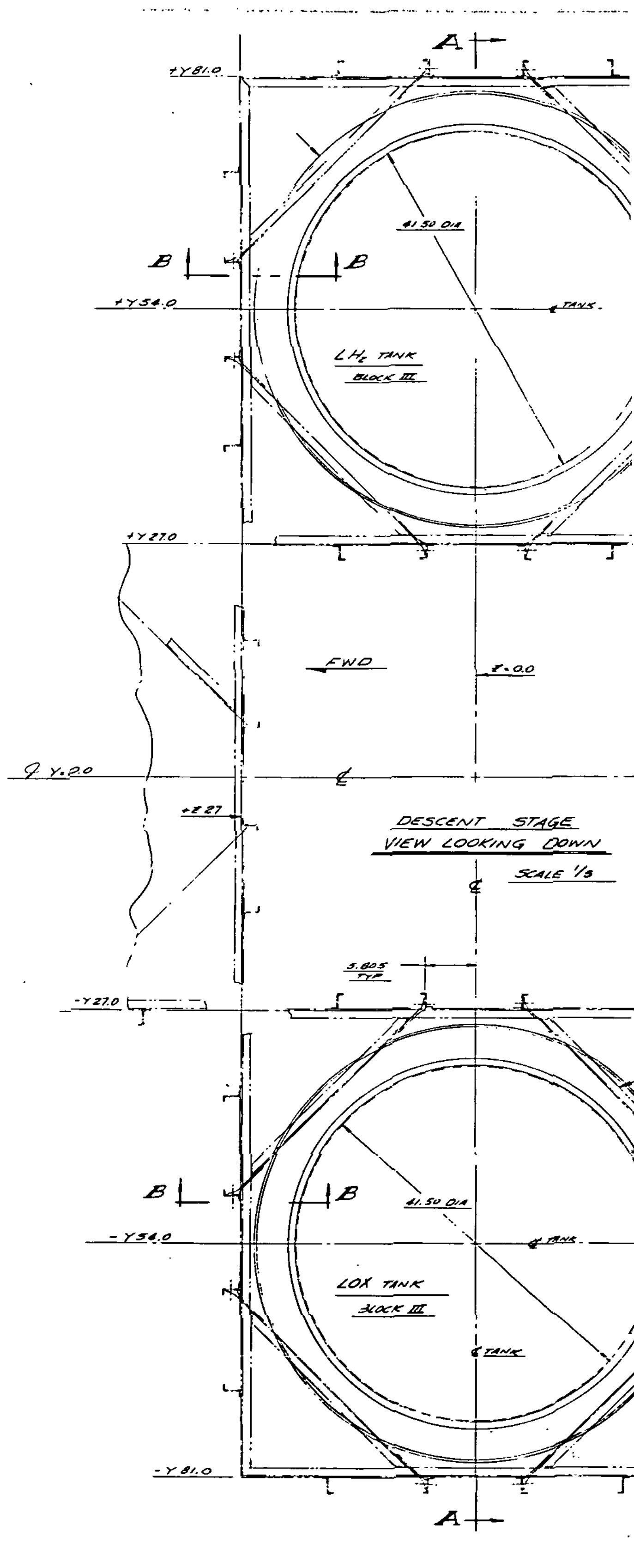
Fig. 6.2-4 Docking Umbilical Lab - CSM Interface

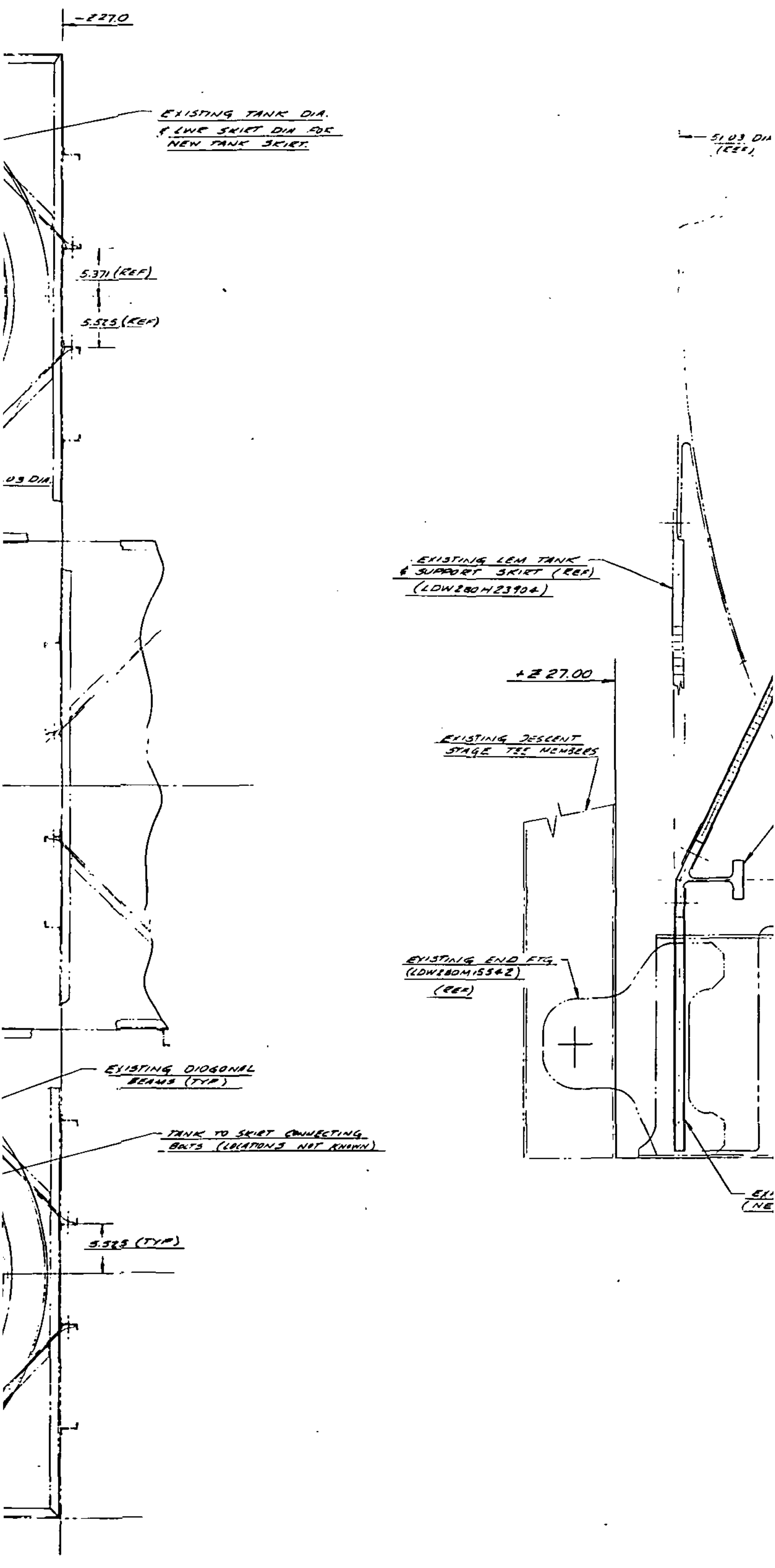


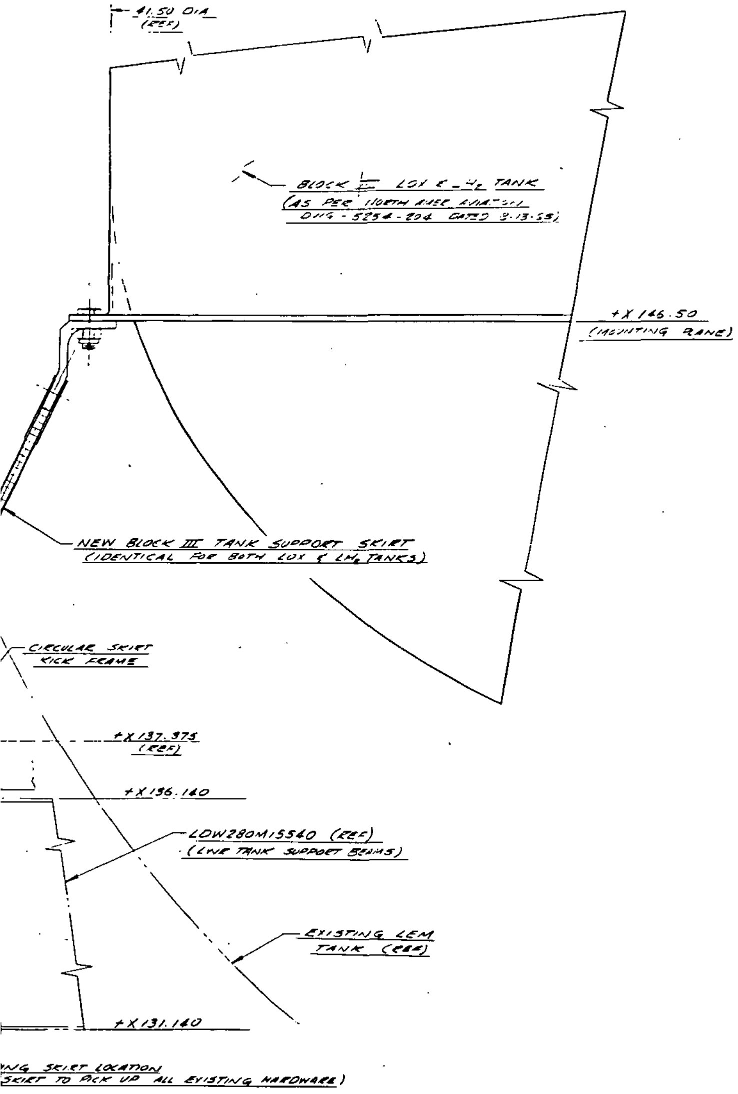
SECTION A-A (ROTATED 90°)
VIEW LOOKING AFT 1/5 SCALE
OPTIONAL TANK ARRANGEMENT

6.2-5 (1)


LH2
SEE SECT B-B FOR SKIRT DETAIL
TANK MOUNTING PLANE
+X 146.50
UP
℄ DESCENT STAGE (Y=0)
SECTION A-A
VIEW LOOKING AFT
1/5 SCALE
+X131.14
5.0 (TYP)
TANK MOUNTING PLANE
+X 146.50
+X196.00
LOX
SEE SECT B-B FOR SKIRT DETAIL


A
+Y81.0
41.50 DIA
B
B
+Y54.0
TANK
LH_2 TANK
BLOCK III
+Y27.0
FWD
Z-0.0
℄ Y-0.0
℄
+Z27
DESCENT STAGE
VIEW LOOKING DOWN
SCALE 1/3
℄
5.805
TYP
-Y27.0
B
B
41.50 DIA
-Y54.0
℄ TANK
LOX TANK
BLOCK III
℄ TANK
-Y81.0
A


-Z 27.0
EXISTING TANK DIA. & LWR SKIRT DIA FOR NEW TANK SKIRT.
5.371 (REF)
5.525 (REF)
51.03 DIA (REF)
EXISTING LEM TANK & SUPPORT SKIRT (REF) (LDW280H23904)
+Z 27.00
EXISTING DESCENT STAGE TEE MEMBERS
EXISTING END FTG. (LDW280M15542) (REF)
EXISTING DIOGONAL BEAMS (TYP)
TANK TO SKIRT CONNECTING BOLTS (LOCATIONS NOT KNOWN)
5.525 (TYP)

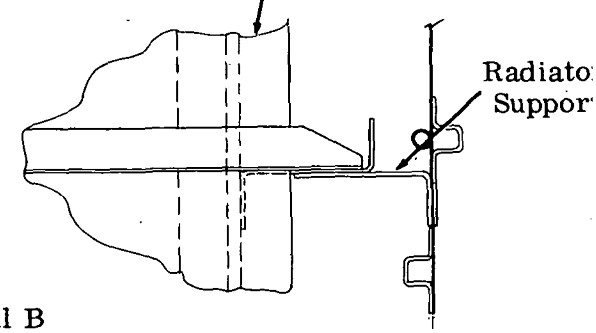


SECTION B-B
TANK SUPPORT DETAIL
FULL SIZE

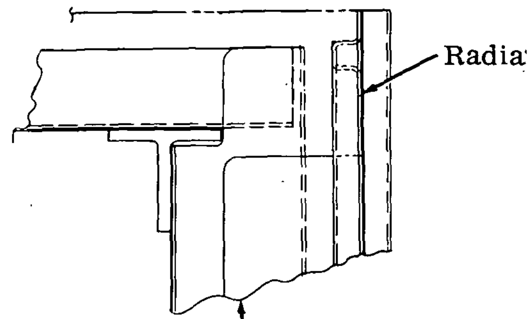
Fig. 6.2-5 Recommended Cryogenic Tank Installation Structural Arrangement Phase II Lab

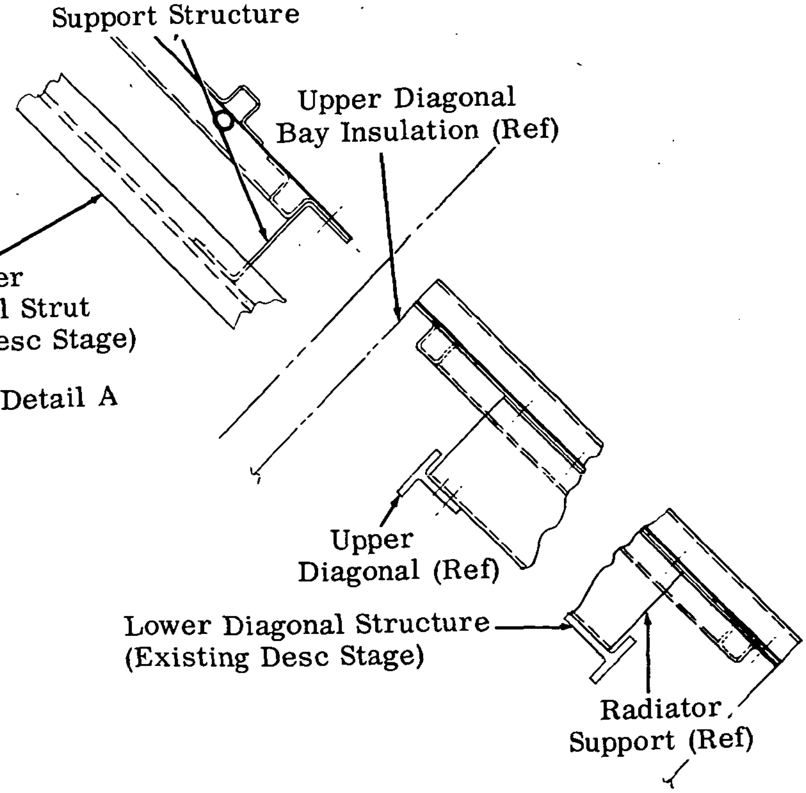
5

Grumman



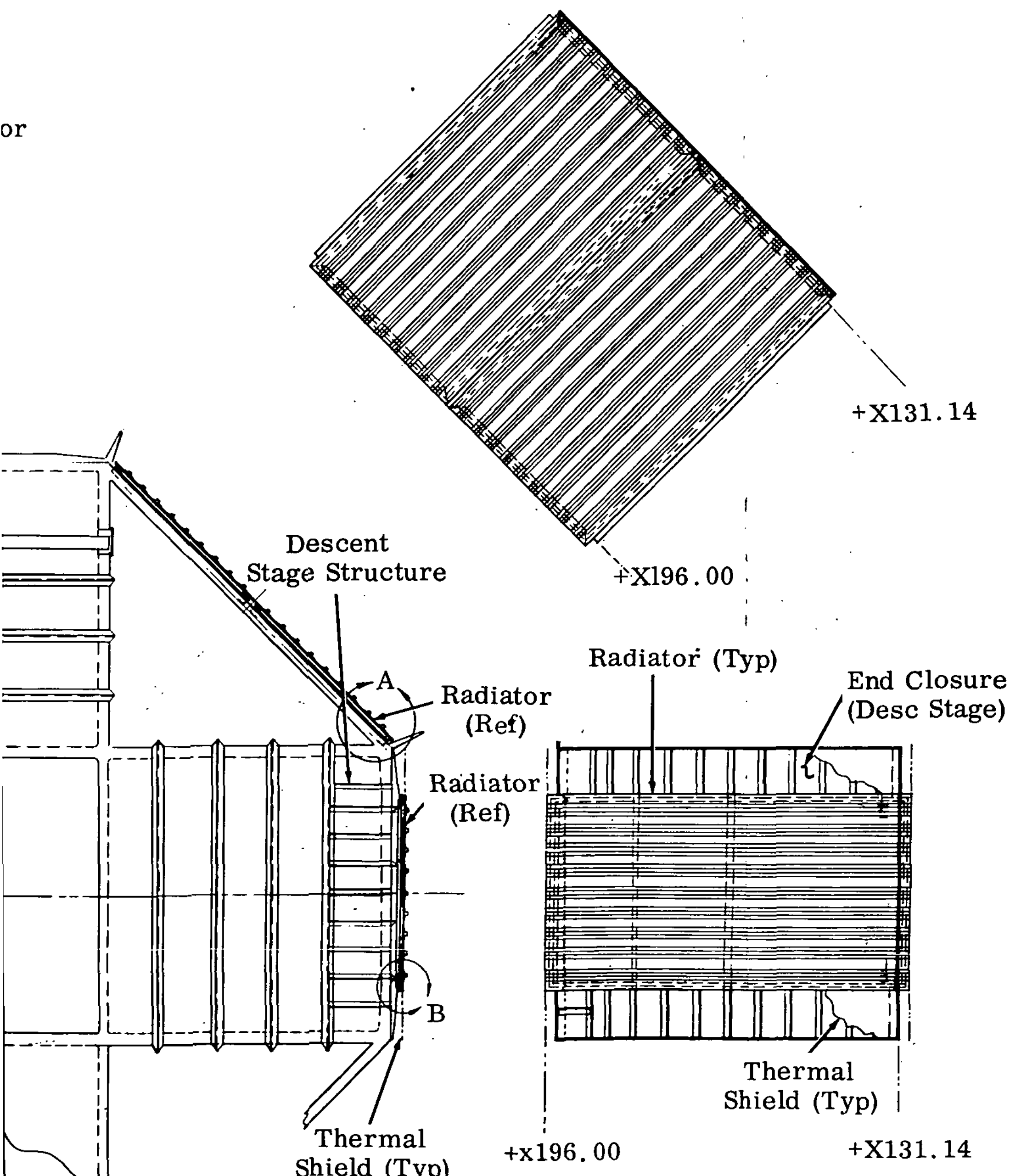
Detail B





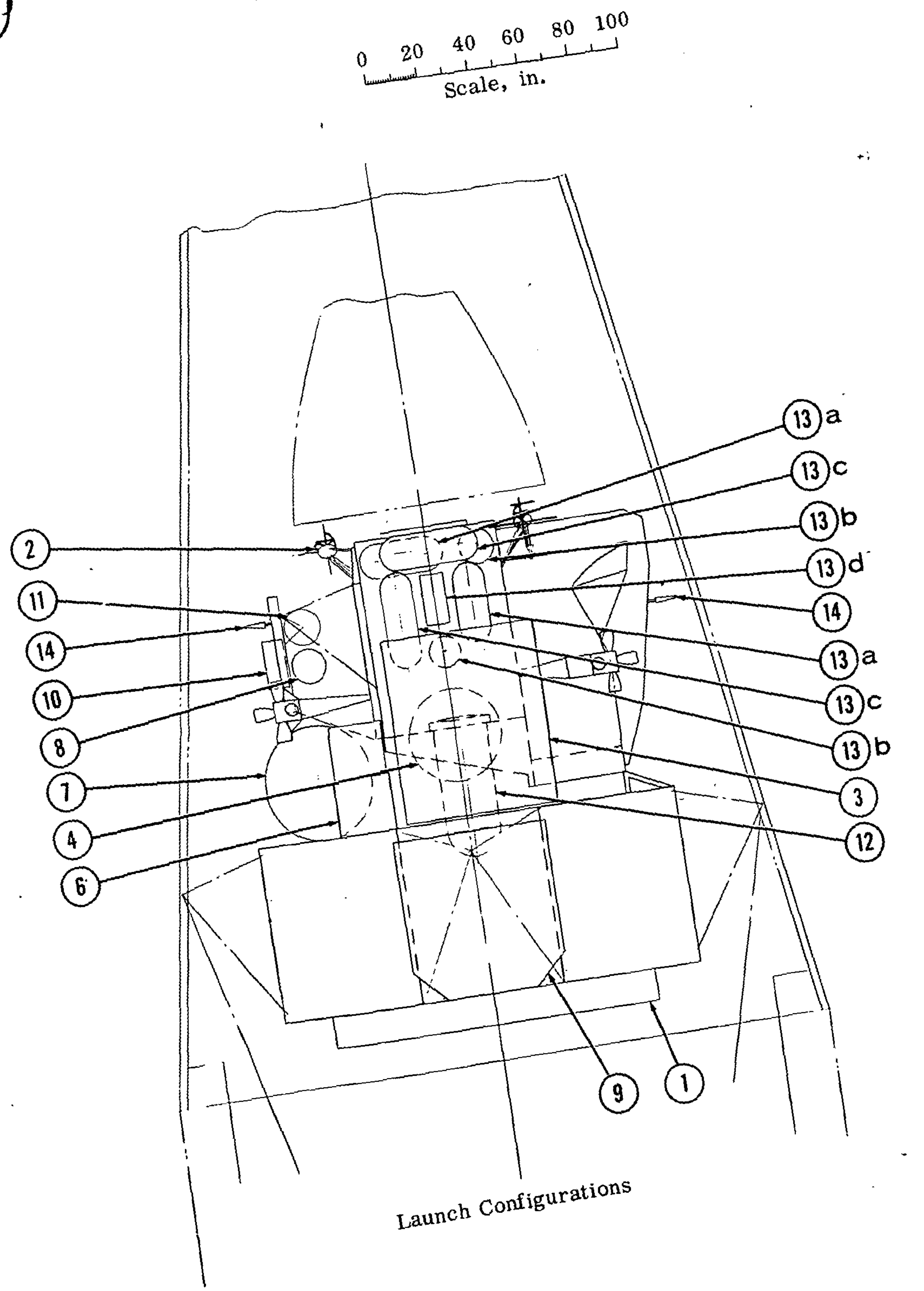
Detail A

D



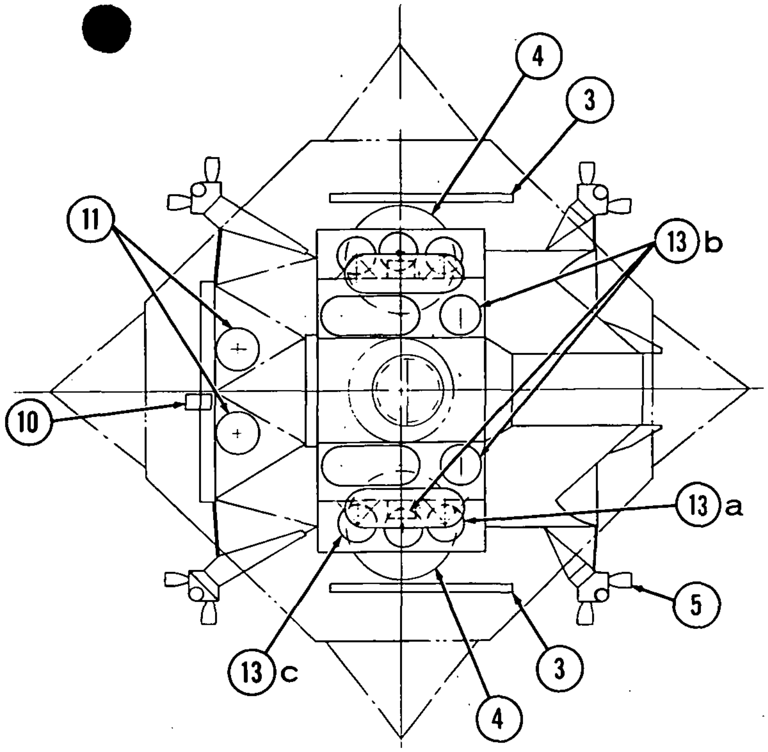
/iew Looking Down
scent Stage (Typ, 4 Places)

Fig. 6.2-6 Radiator Support Structural Arrangement

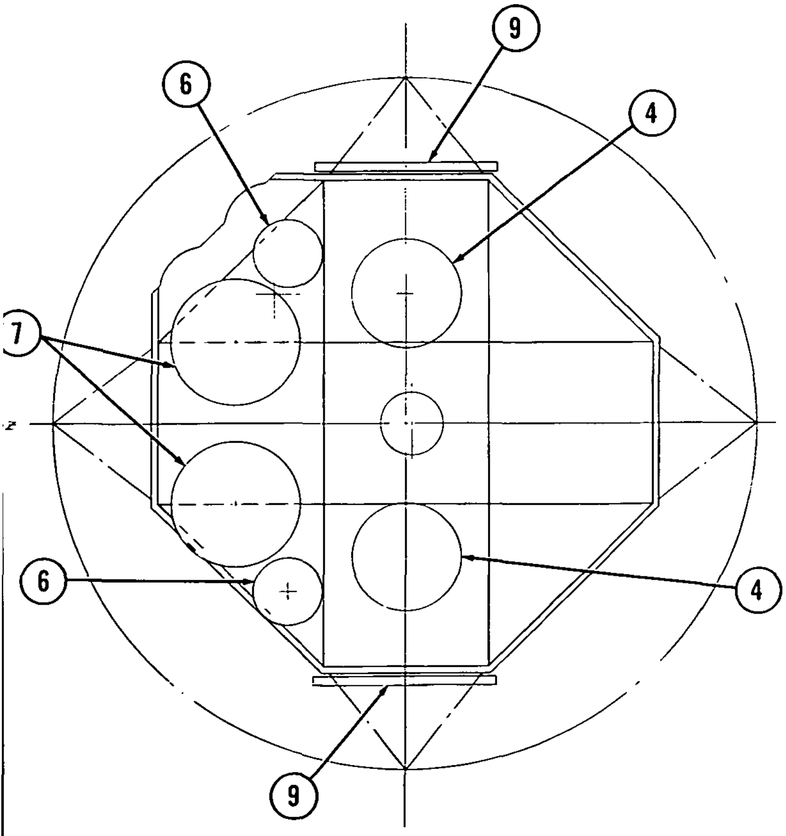


Launch Configurations

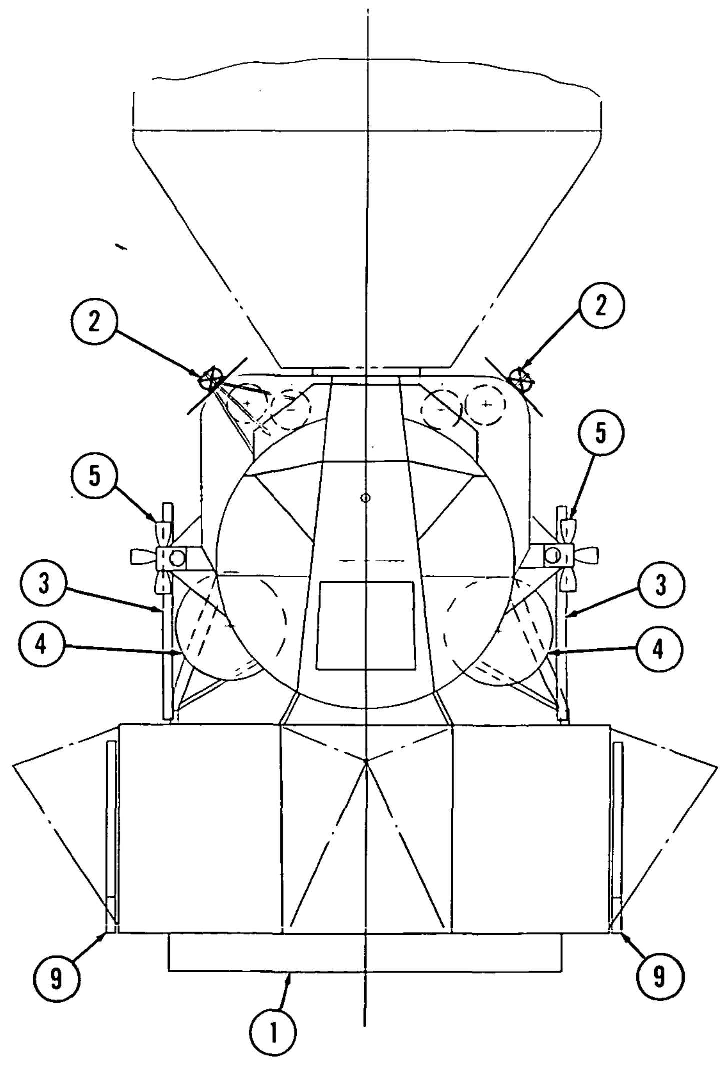
1 Lower Deck Shield
2 VHF In-Flight Ant (2)
3 ECS Radiator Panels (2)
4 O_2 Tanks (2)
5 RCS Thrusters (16)
6 FCA (2)
7 H_2 Tanks (2)
8 H_2O Tanks (2)
9 FCA Radiator Panels (2)
10 7 kw-hr Peaking Batt
11 GOX Tanks (2, Accumulators)
12 Mid-section Canister
13 RCS
  a) Fuel Tanks (4)
  b) He Tanks (4)
  c) O_2 Tanks (4)
  d) Valve Instls (2)
14 S-Band In-Flight Ant (2)



View Looking Down
At Ascent Stage

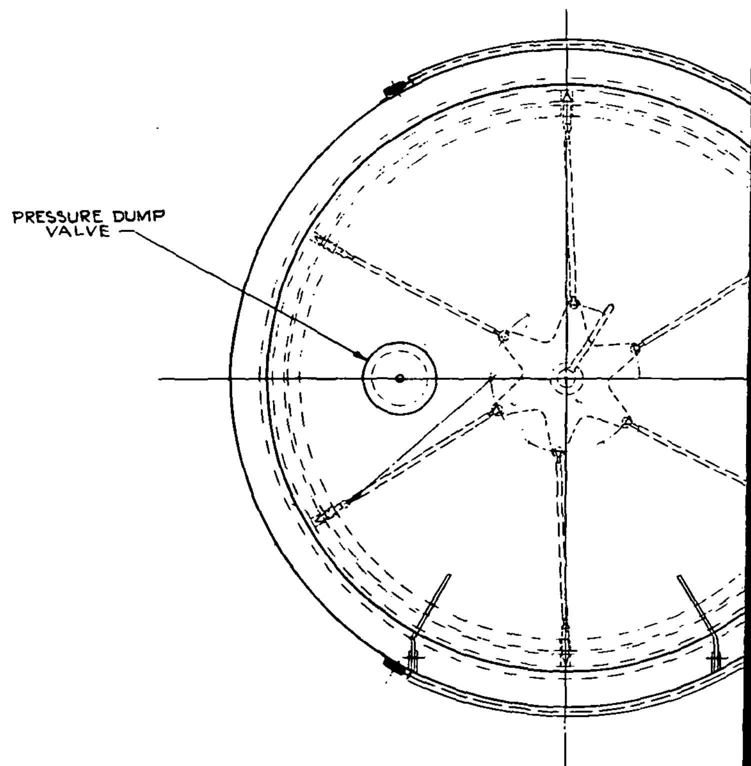


View Looking Down
At Descent Stage

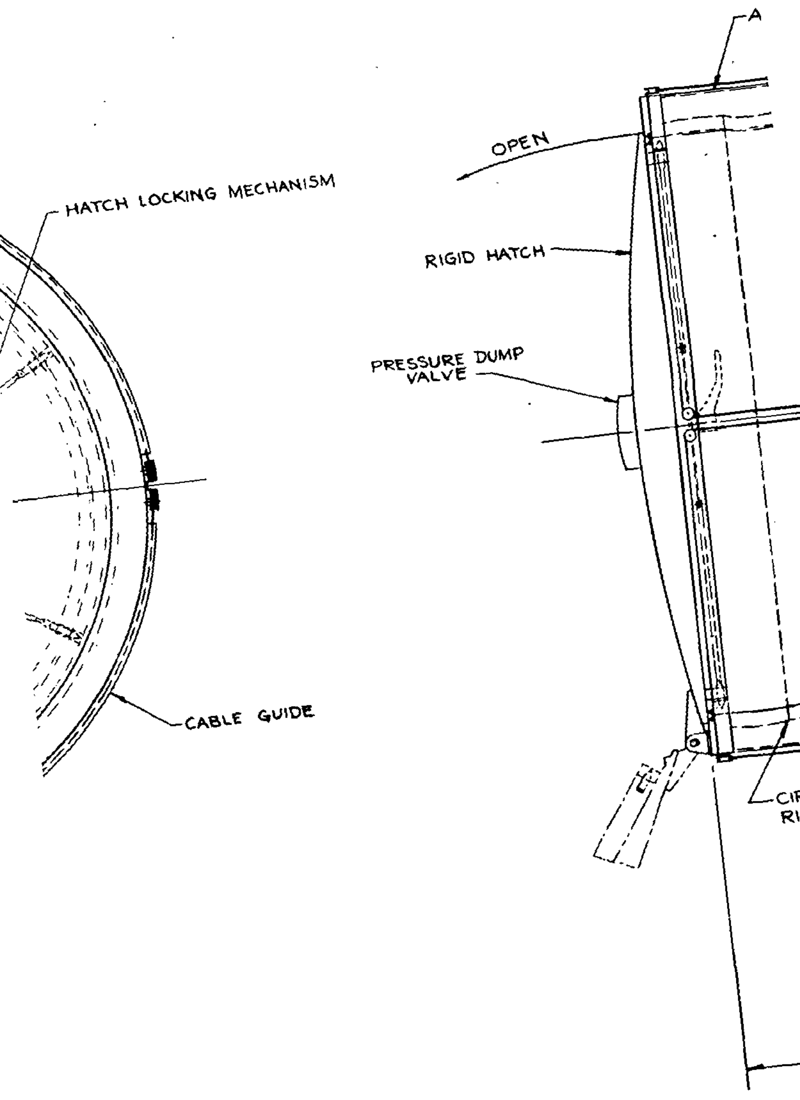


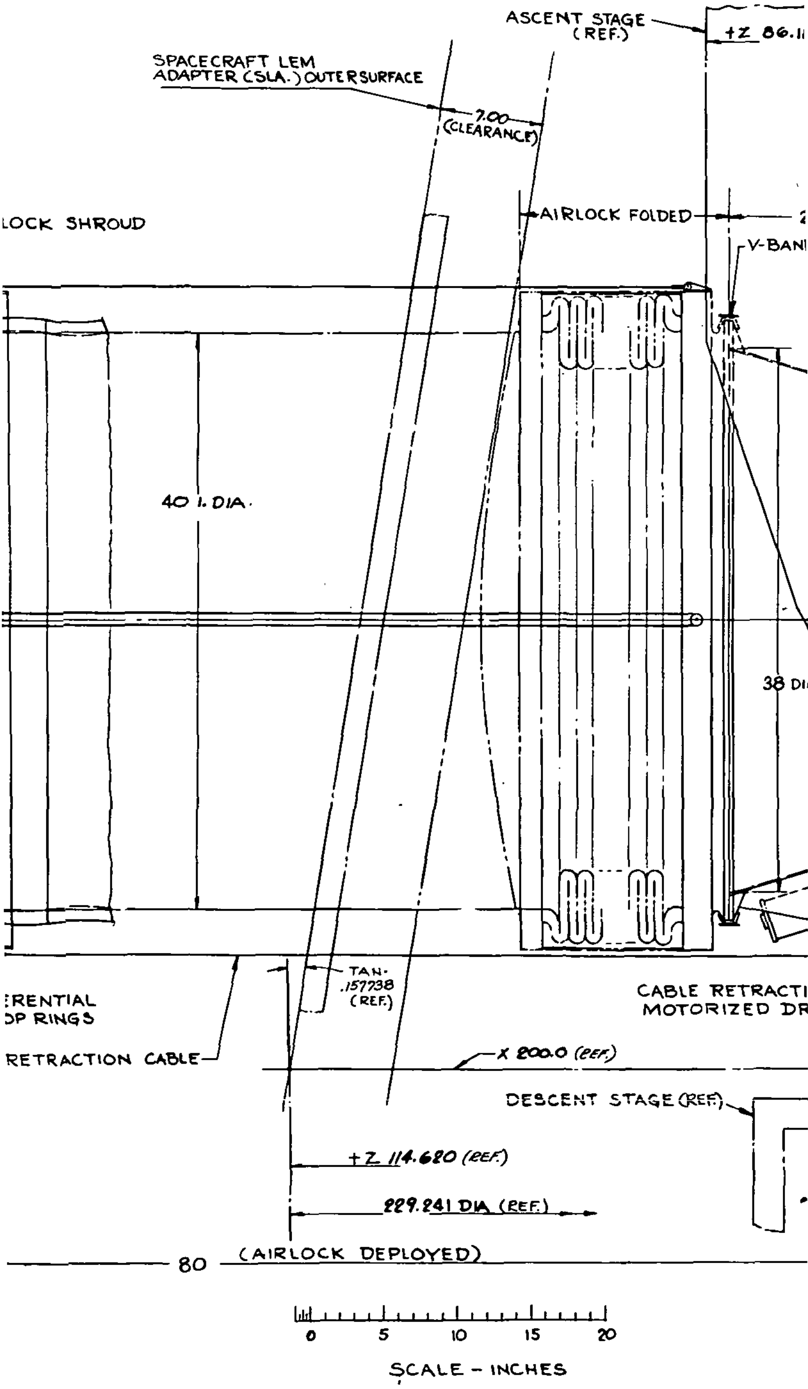
Orbiting Configuration

Fig. 6.2-7 Phase II Lab-Baseline General Arrangement

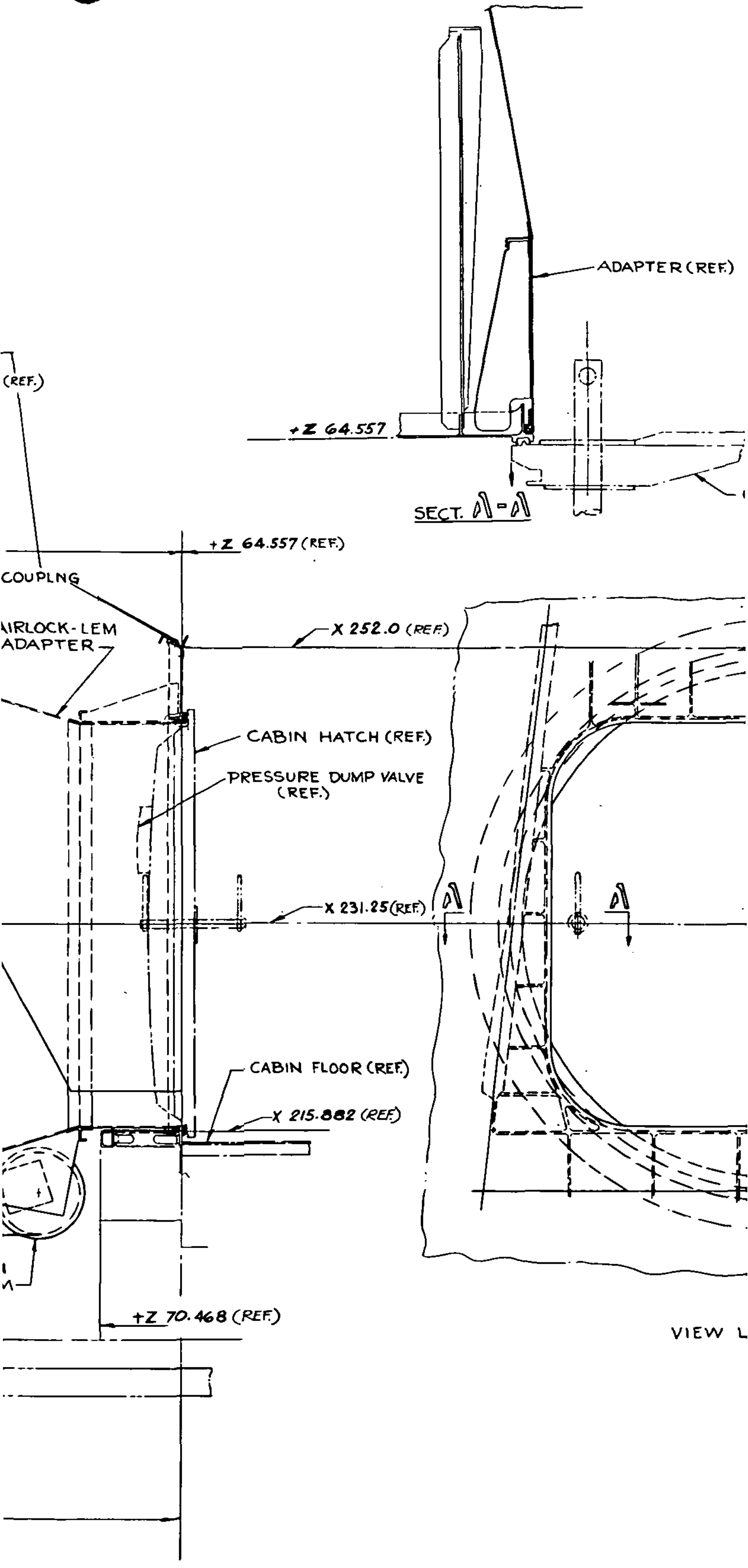


6·2-8 (1)


A
OPEN
HATCH LOCKING MECHANISM
RIGID HATCH
PRESSURE DUMP VALVE
CABLE GUIDE


ASCENT STAGE (REF.)
+Z 86.1
SPACECRAFT LEM ADAPTER (SLA.) OUTER SURFACE
7.00 (CLEARANCE)
LOCK SHROUD
AIRLOCK FOLDED
V-BAN
40 I. DIA.
38 DI
ERENTIAL
OP RINGS
TAN. .157738 (REF.)
CABLE RETRACTI
MOTORIZED DR
RETRACTION CABLE
X 200.0 (REF.)
DESCENT STAGE (REF.)
+Z 114.620 (REF.)
229.241 DIA (REF.)
80
(AIRLOCK DEPLOYED)
0 5 10 15 20
SCALE - INCHES

6.2-8
(3)


ADAPTER (REF.)
+Z 64.557
SECT. A-A
(REF.)
+Z 64.557 (REF.)
COUPLNG
AIRLOCK-LEM ADAPTER
X 252.0 (REF.)
CABIN HATCH (REF.)
PRESSURE DUMP VALVE (REF.)
X 231.25 (REF.)
A
A
CABIN FLOOR (REF.)
X 215.882 (REF.)
+Z 70.468 (REF.)
VIEW L

6.2-8

(4)

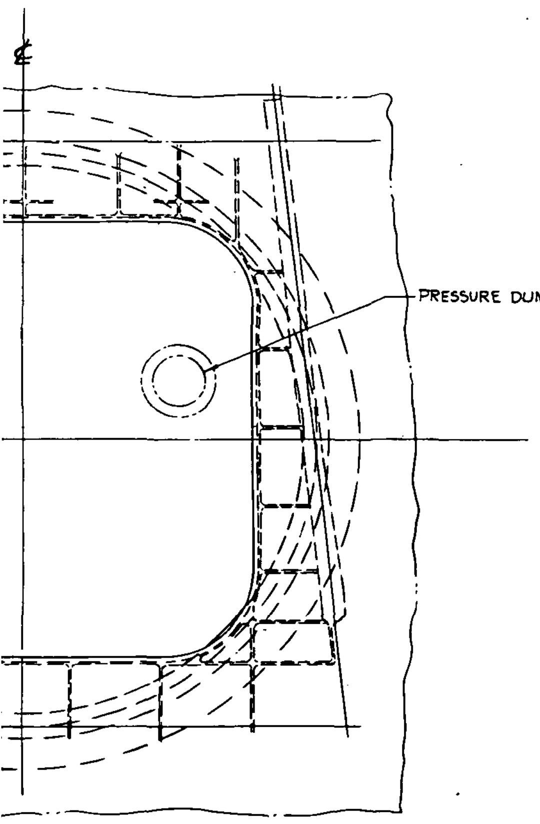
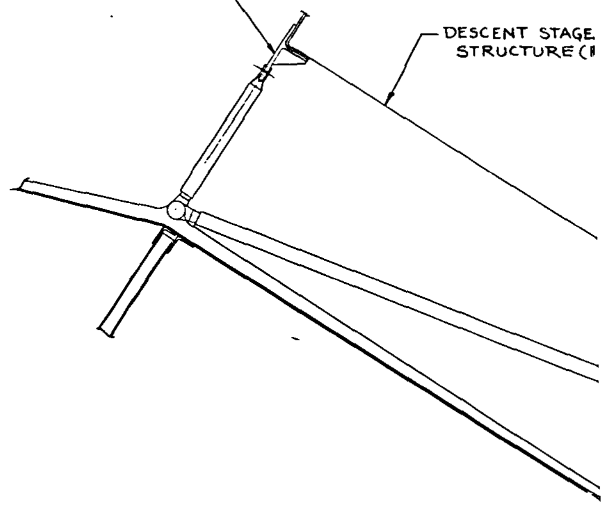


Fig. 6.2-8 Alternate Airlock Configuration Front Hatch Phase II Lab

5

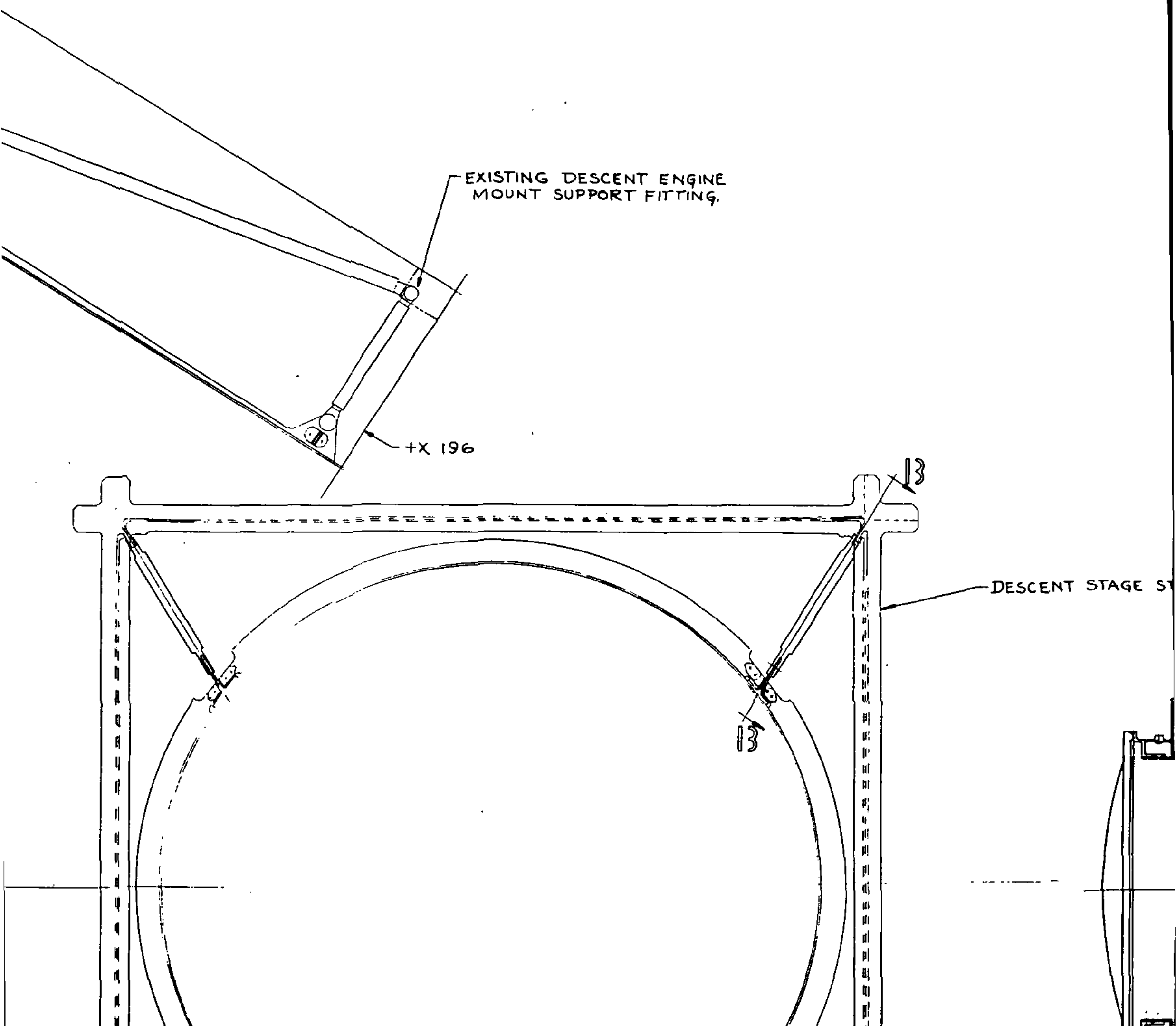
Grumman



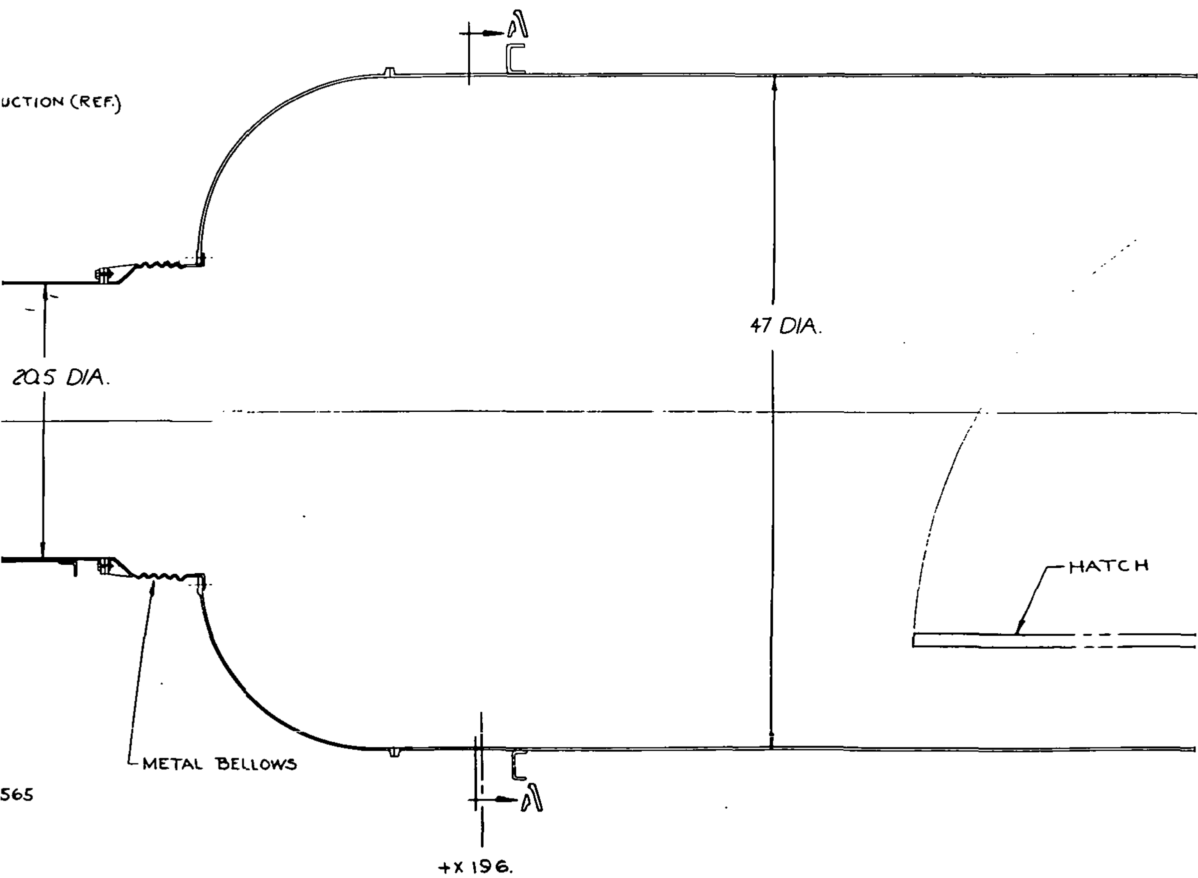
SECTION 13-13
TYP. 4 PLACES

6.2-9 (1)

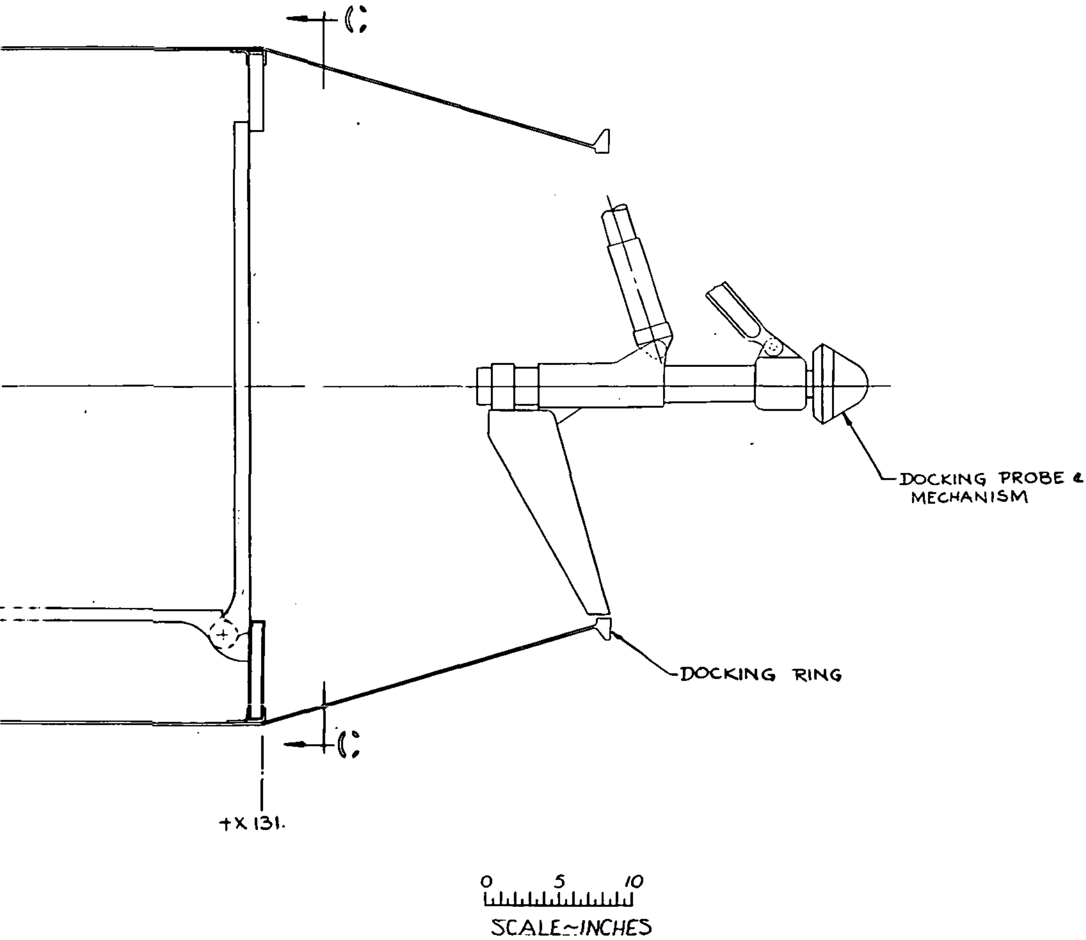
F)


EXISTING DESCENT ENGINE MOUNT SUPPORT FITTING.
+X 196
13
13
DESCENT STAGE ST
ASCENT STAGE CABIN FLOOR
+X 23

VIEW A-A



6.2-9
3


C
DOCKING PROBE & MECHANISM
DOCKING RING
C
+X 131.
0 5 10
SCALE~INCHES

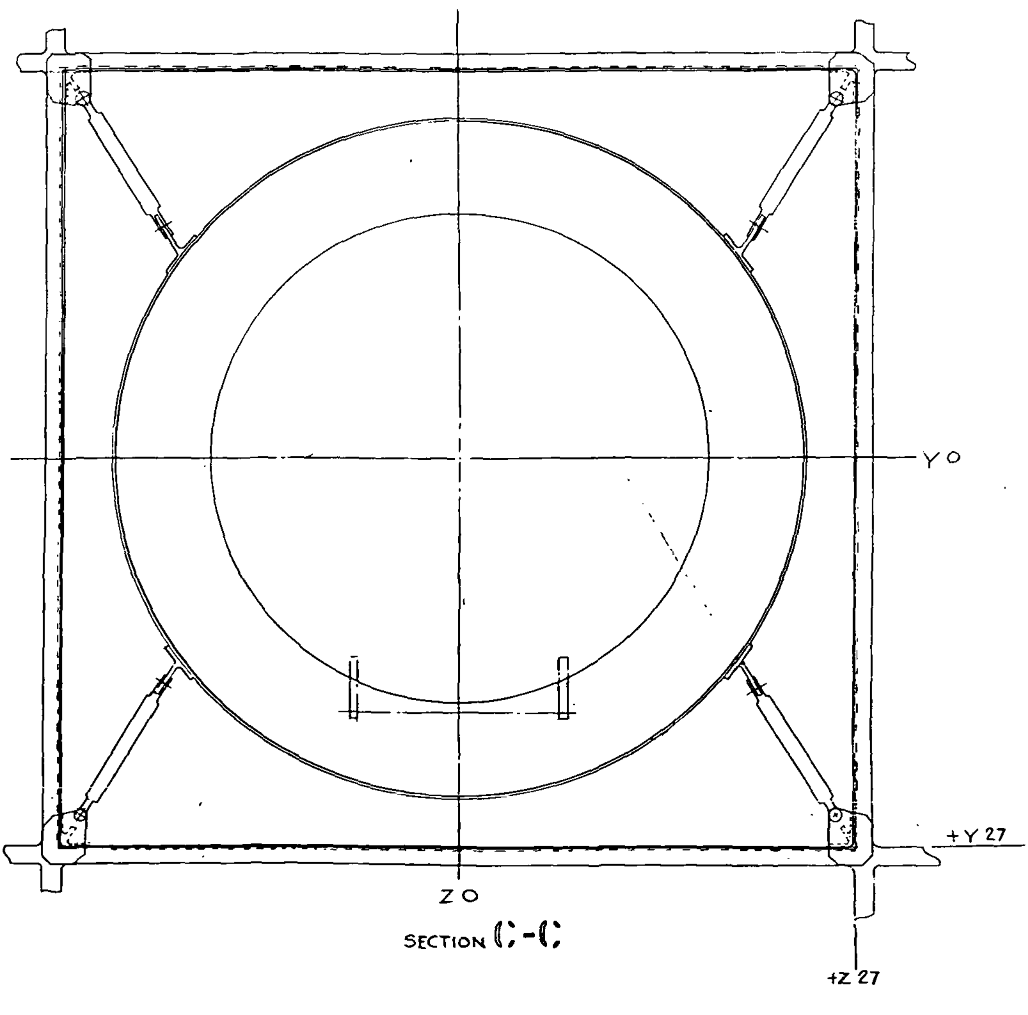
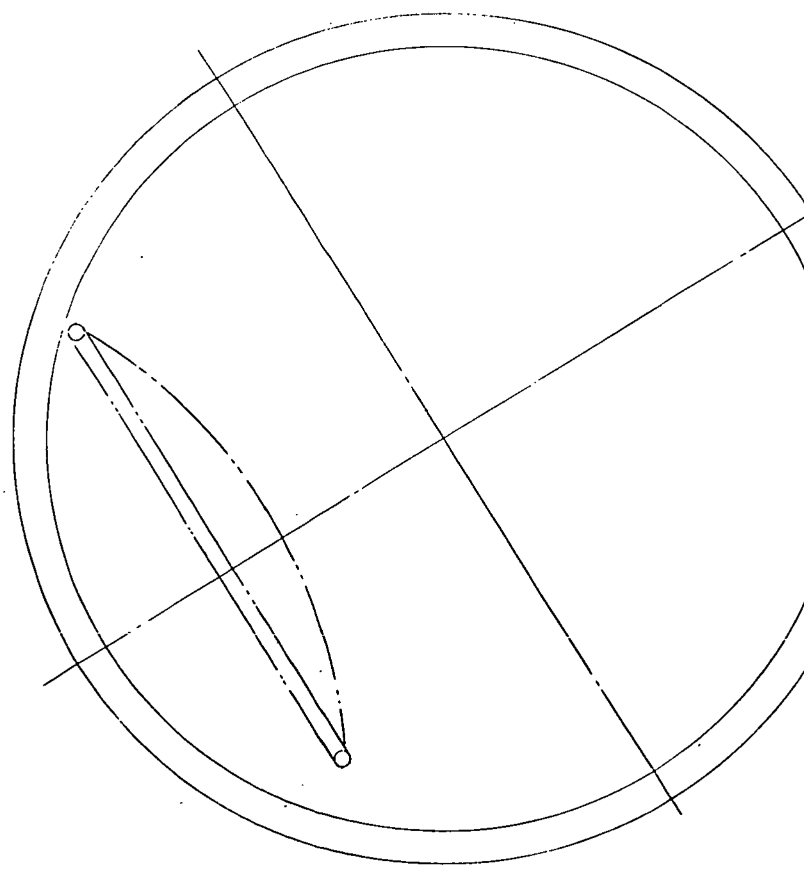


Fig. 6.2-9 Docking Tunnel Alternate Airlock

5

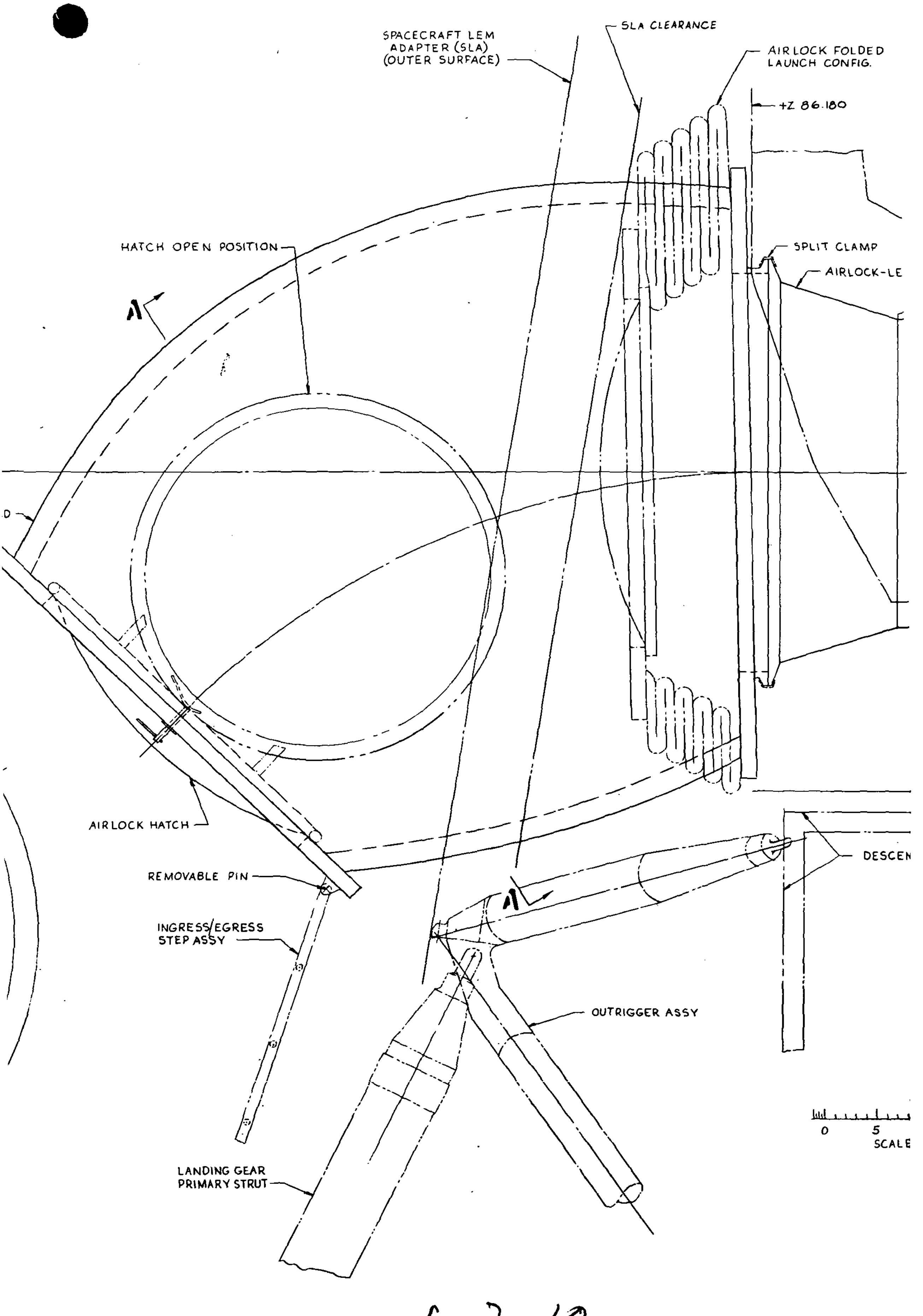
AIRLOCK DEPLO



SECT. A-A

6-2-10

(1)



SPACECRAFT LEM ADAPTER (SLA) (OUTER SURFACE)
SLA CLEARANCE
AIRLOCK FOLDED LAUNCH CONFIG.
+Z 86.180
HATCH OPEN POSITION
A
SPLIT CLAMP
AIRLOCK-LE
AIRLOCK HATCH
REMOVABLE PIN
INGRESS/EGRESS STEP ASSY
DESCEN
OUTRIGGER ASSY
LANDING GEAR PRIMARY STRUT
0
5
SCALE

6.2-10
(2)

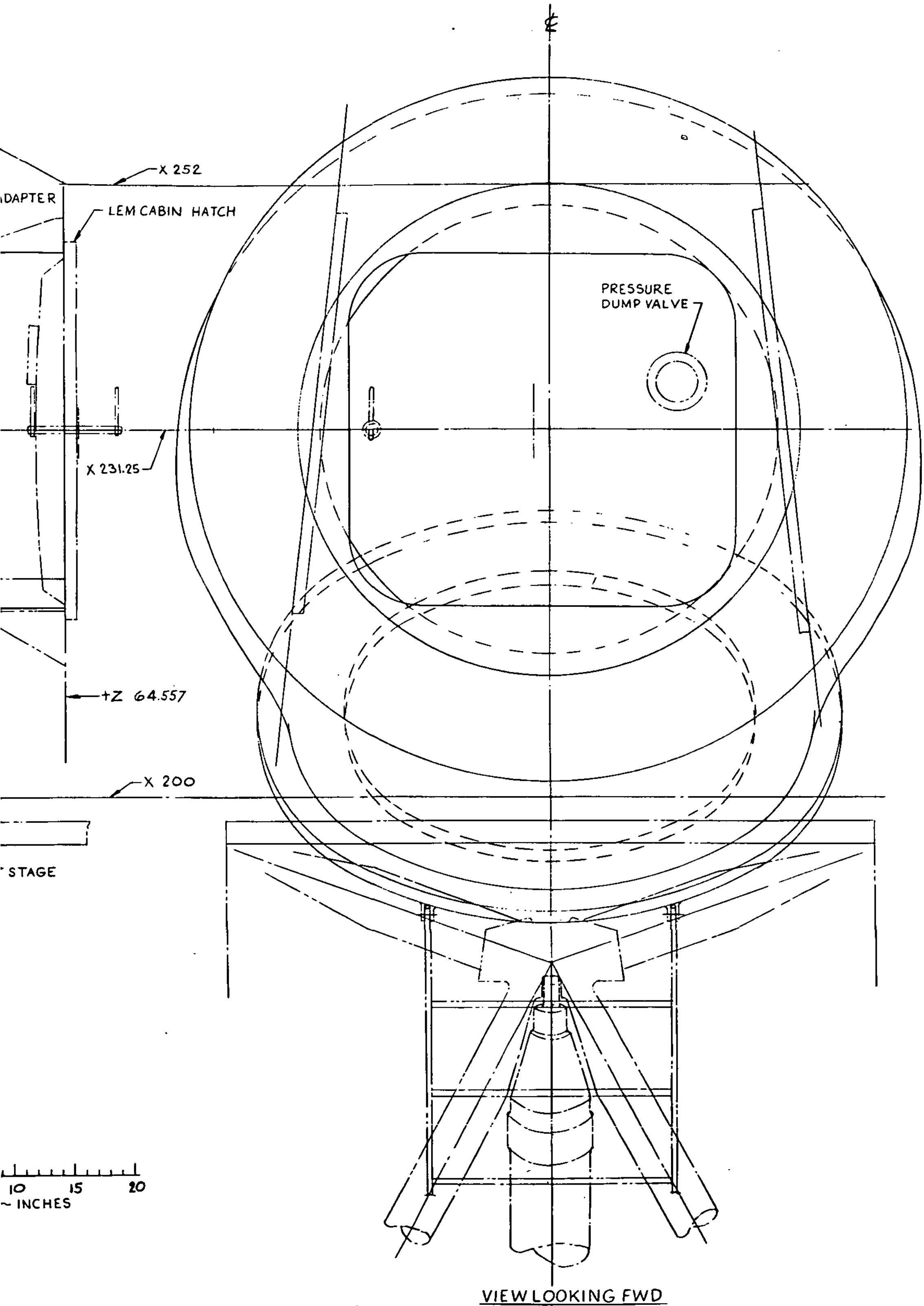
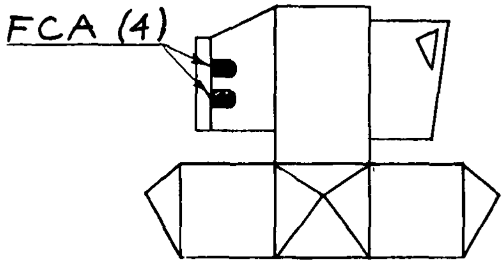
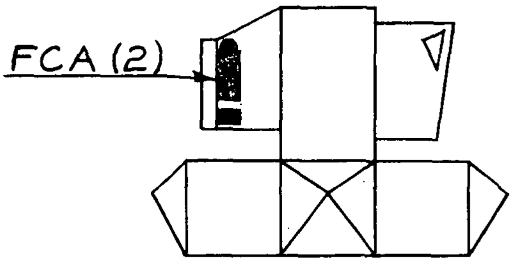
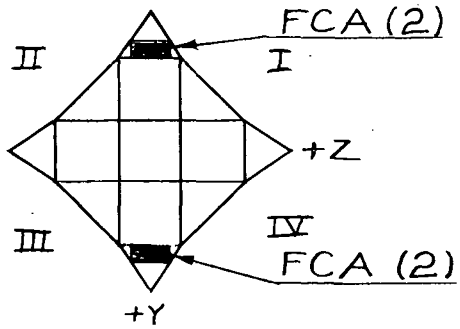


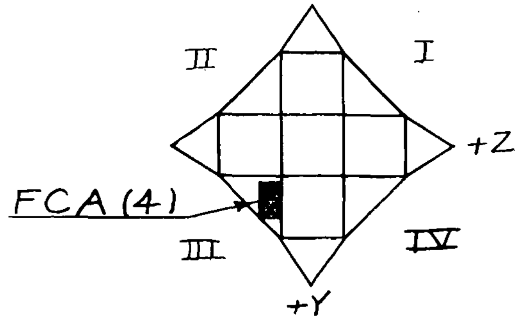
Fig. 6.2-10 Recommended Shelter Airlock Configuration Front Hatch

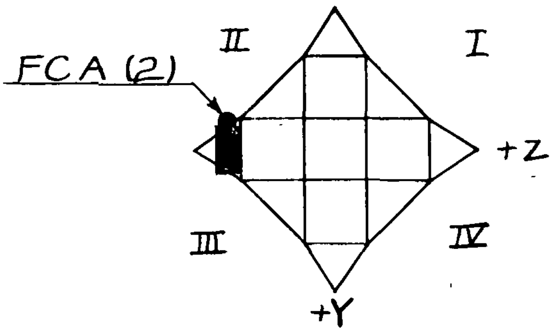
(3)

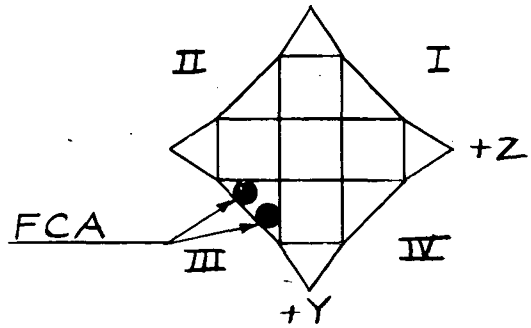
Grumman

General Electric Fuel Cell		
Allis-Chalmers Fuel Cell		
	Phase II Lab	Shelter
• Structural Modification	Minor	Minor
• On-Pad Accessibility	Accessible from top & bottom of equipt bay. Bay is filled with additional RCS tanks.	Accessible from only top of equipt bay. No other equip. is located in bay.
• On-Pad Removal	Removable from top only. Fuel Cell & Water recovery can be removed independently.	Removable from top only. Radiator section must be removed first. Fuel Cell & Water recovery be removed independently.
• Effect on Existing or Recommended Equipment Location.	None	None
• Thermal Considerations	Ascent stage temperatures are maintained.	Ascent stage temperatures maintained.



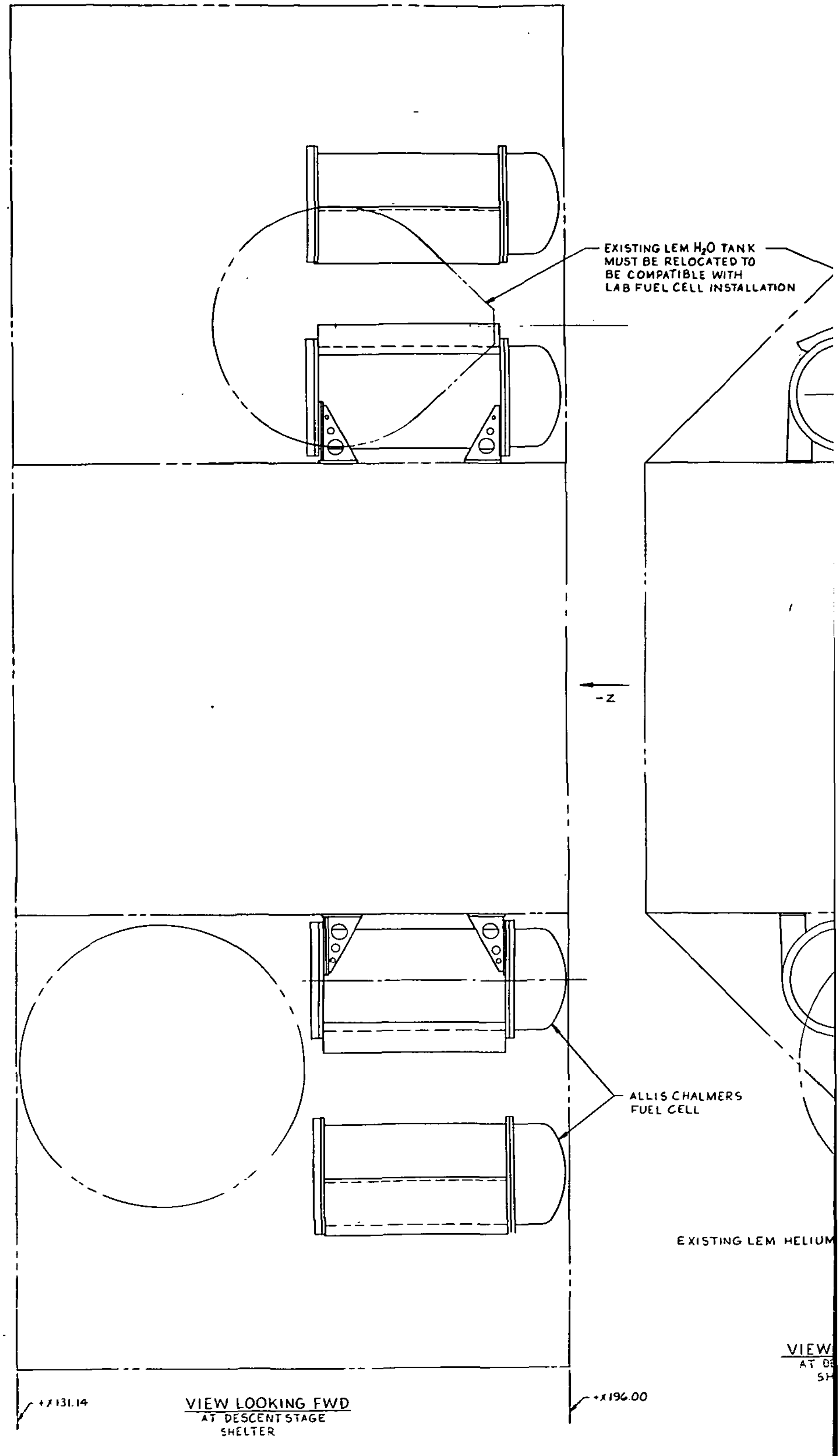






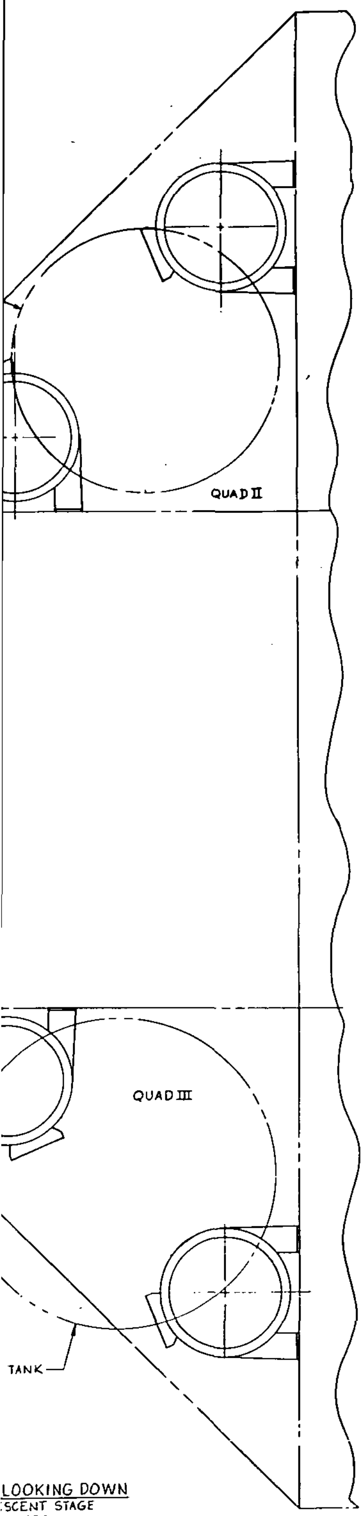
	Phase II Lab	Shelter	Phase II Lab	Shelter
	Minor	Minor	Minor (can be located in Quad II or III)	Minor (can be located in Quad II or II)
	Accessibility Presents no Problems.	Accessibility Presents no Problems.	Accessibility Presents no Problems.	Accessibility Presents no Problems.
an	Removal must be horizontal. Long cantilevered arm presents stability problem.	Removal must be horizontal. Same as lab	Removal presents no problems.	Removal presents no problems.
	Radiators will be located in Quad II & IV & will be extendable.	None	Quad II: None Quad III: Must relocate (lower) GOX tank.	Quad II: Relocate existing H_2O tank (to ascent stage) Quad III: FCA must clear existing He tank.
e	FCA always in use while in orbit. No added heat required.	During stay time, FCA must be provided with heat.	FCA always in use while in orbit. No added heat required.	During stay time, FCA must be provided with heat.

Fig. 6.2-11 Fuel Cell Location Optimization Table



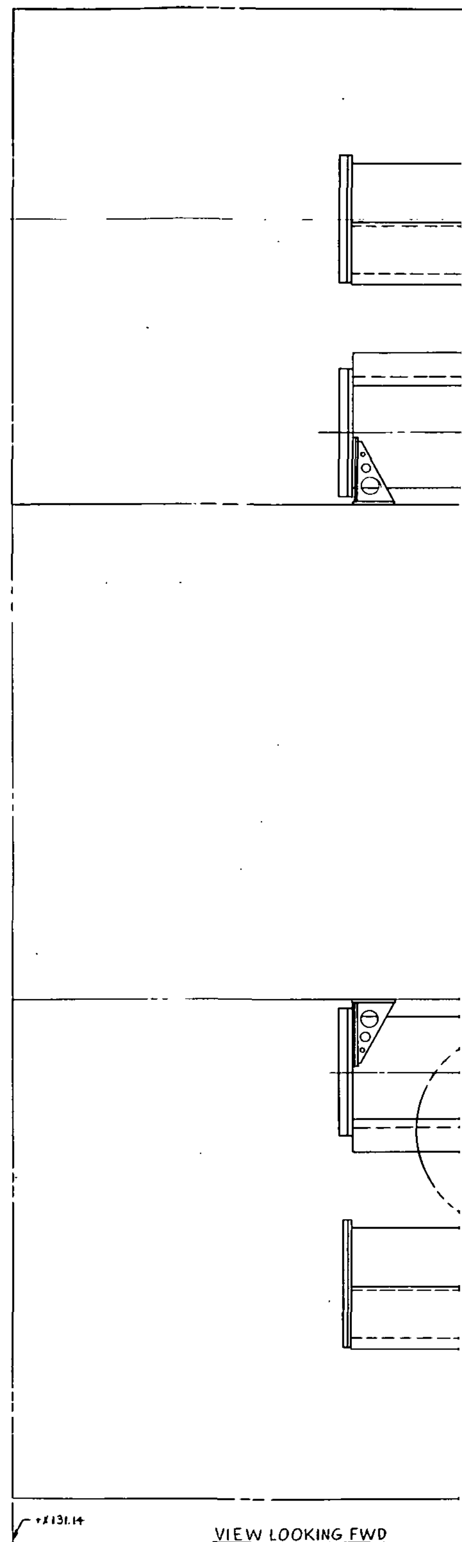
VIEW LOOKING FWD
AT DESCENT STAGE
SHELTER

6.2-12 (1)



LOOKING DOWN
SCENT STAGE
ELTER

0 5 10 15 20 25
SCALE ~ INCHES



VIEW LOOKING FWD
AT DESCENT STAGE
PHASE II LAB

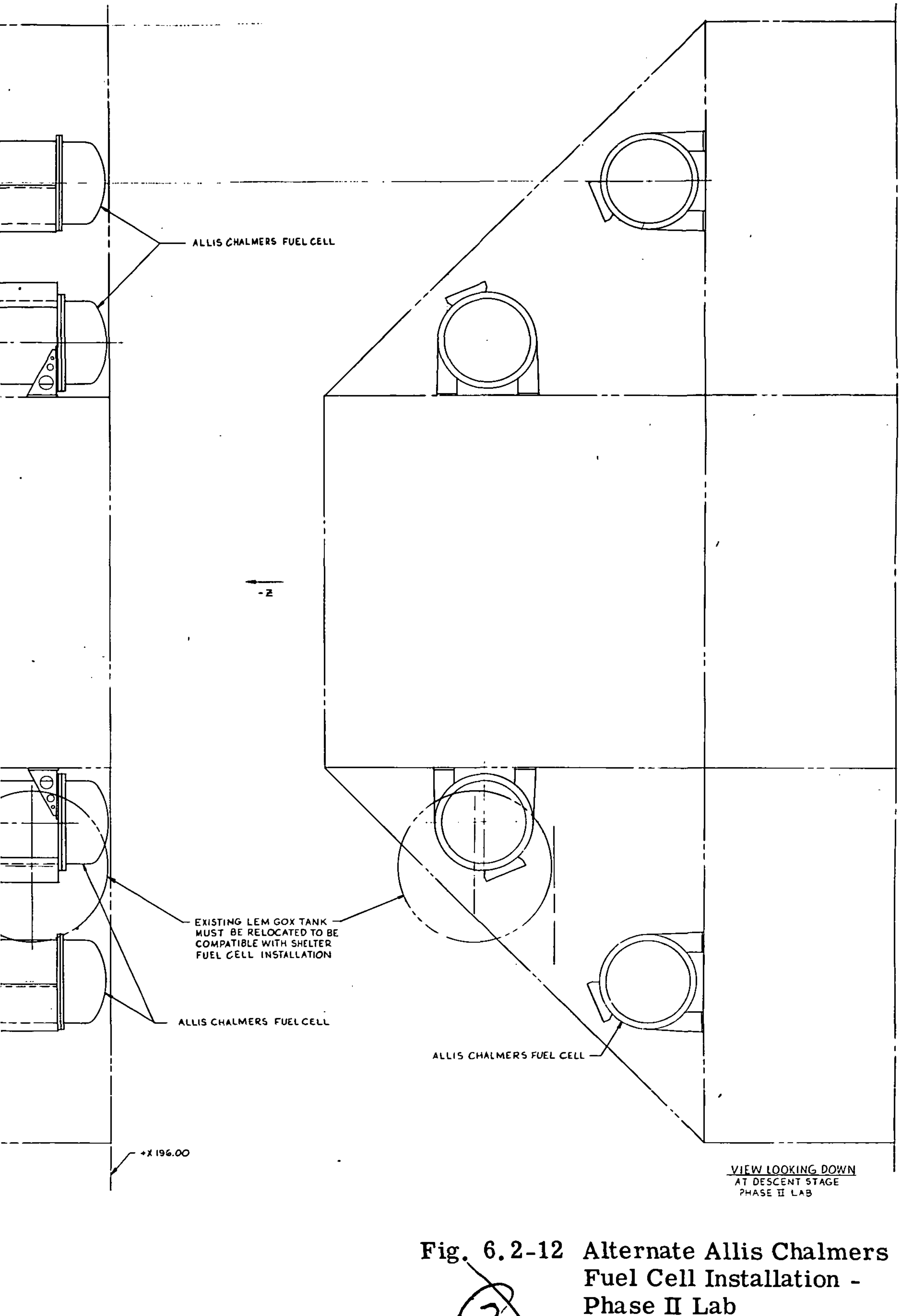


Fig. 6.2-12 Alternate Allis Chalmers Fuel Cell Installation - Phase II Lab

3

Grumman

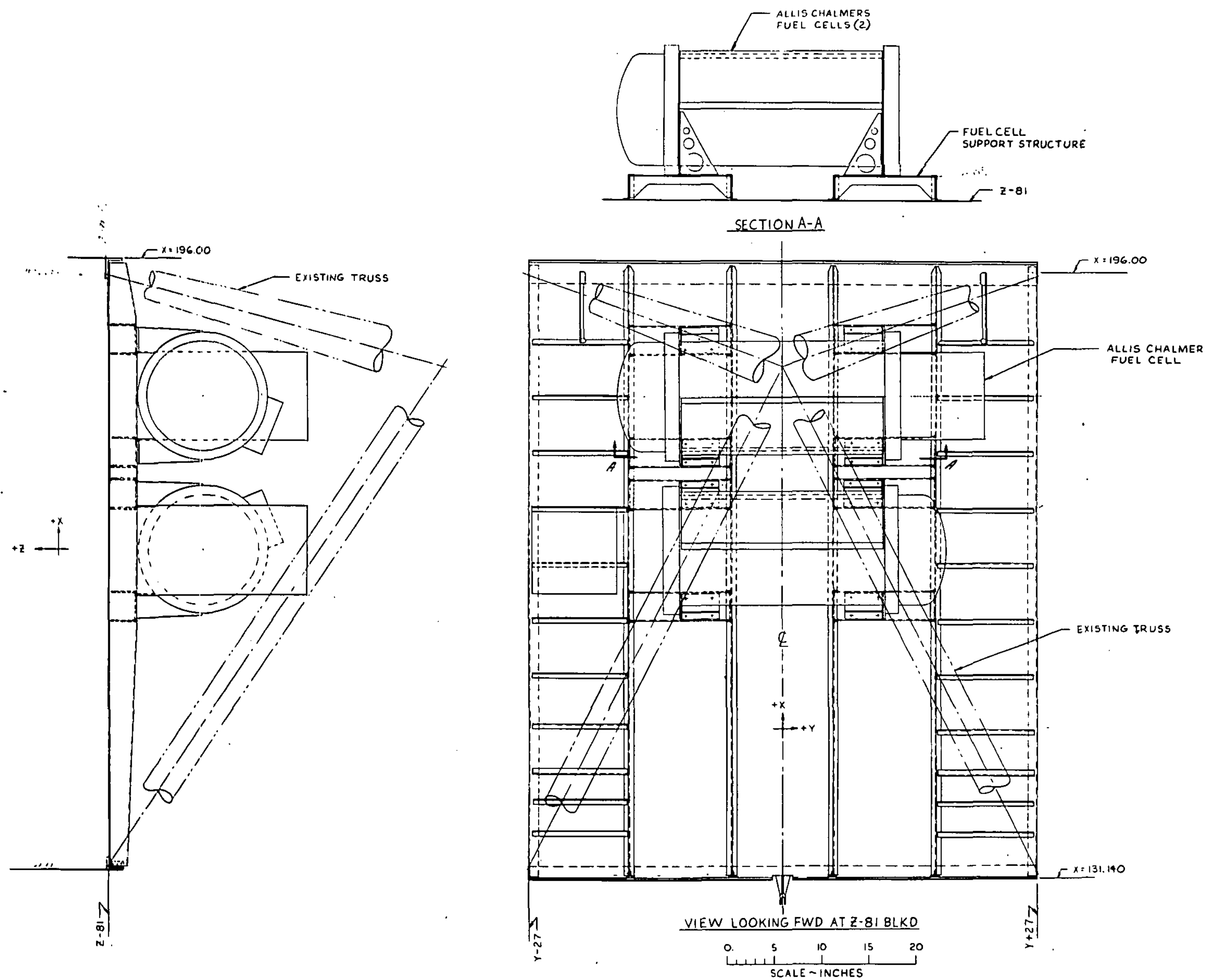


Fig. 6.2-13 Alternate Allis Chalmers Fuel Cell Installation

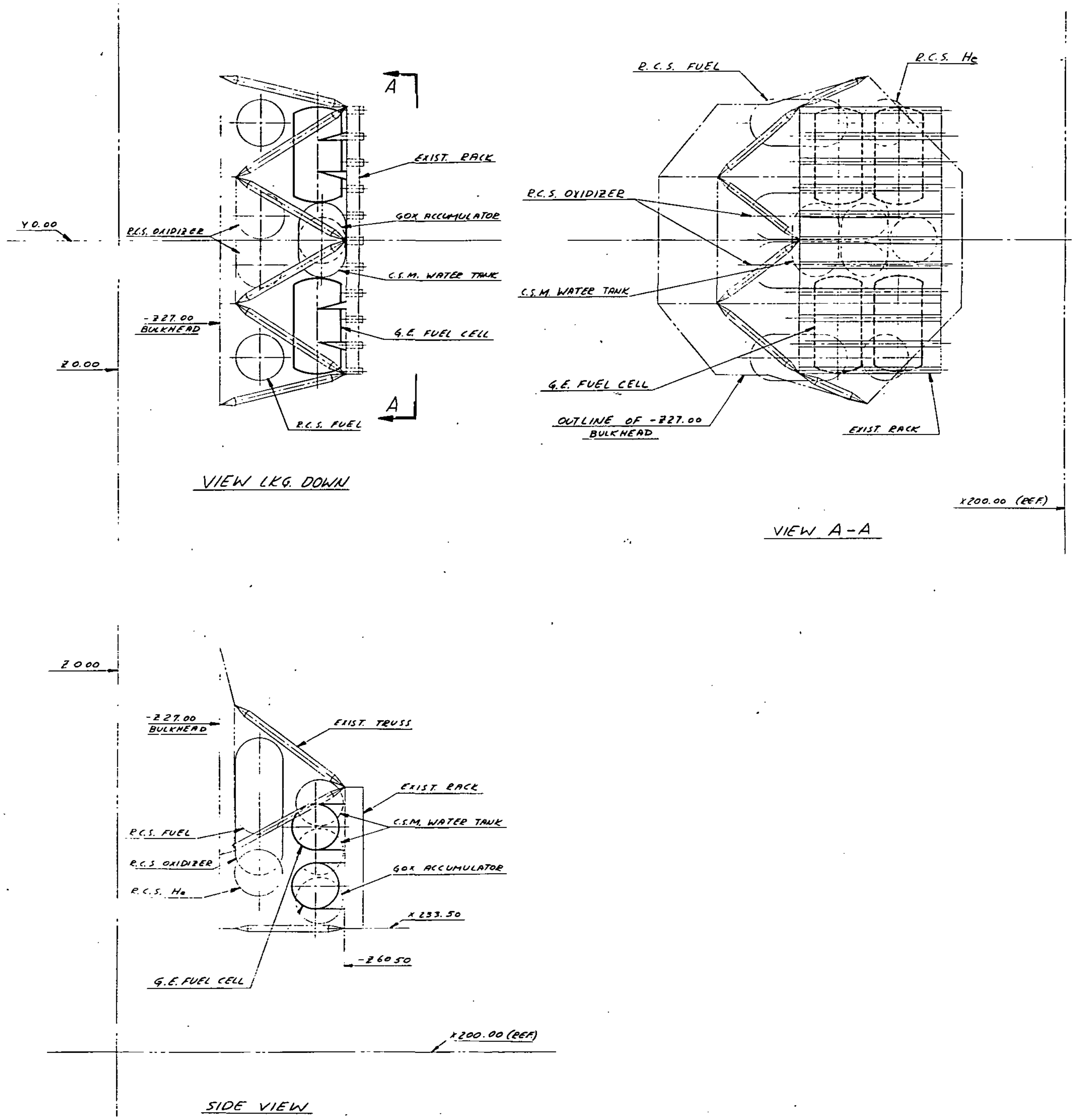
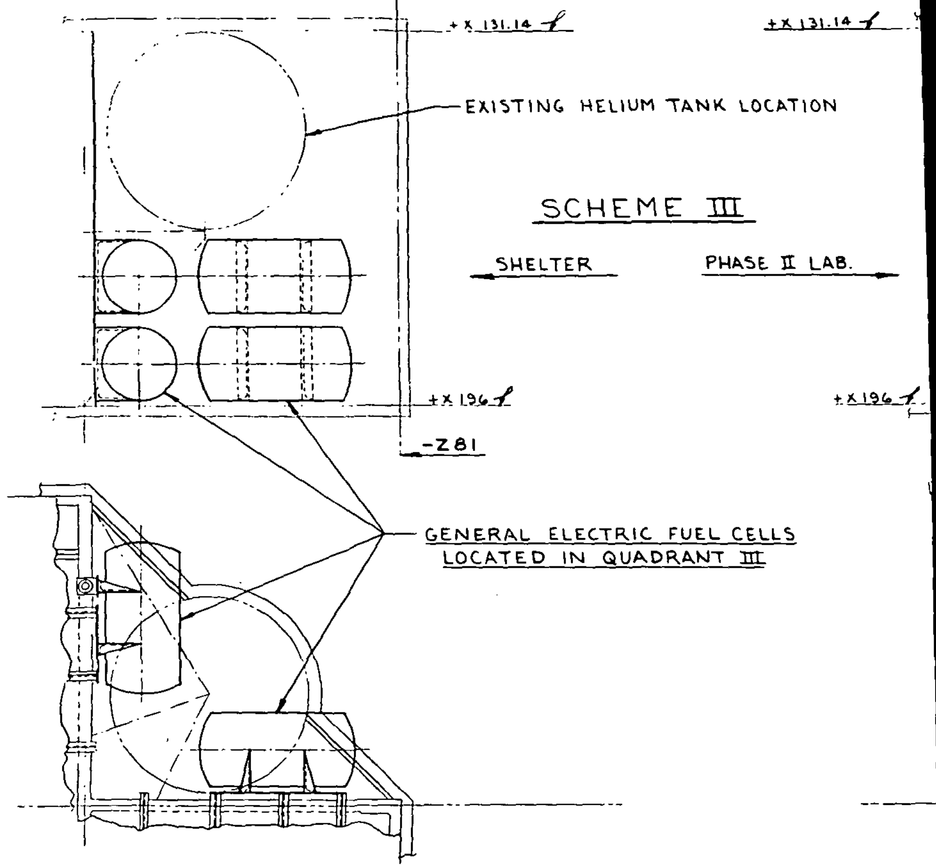
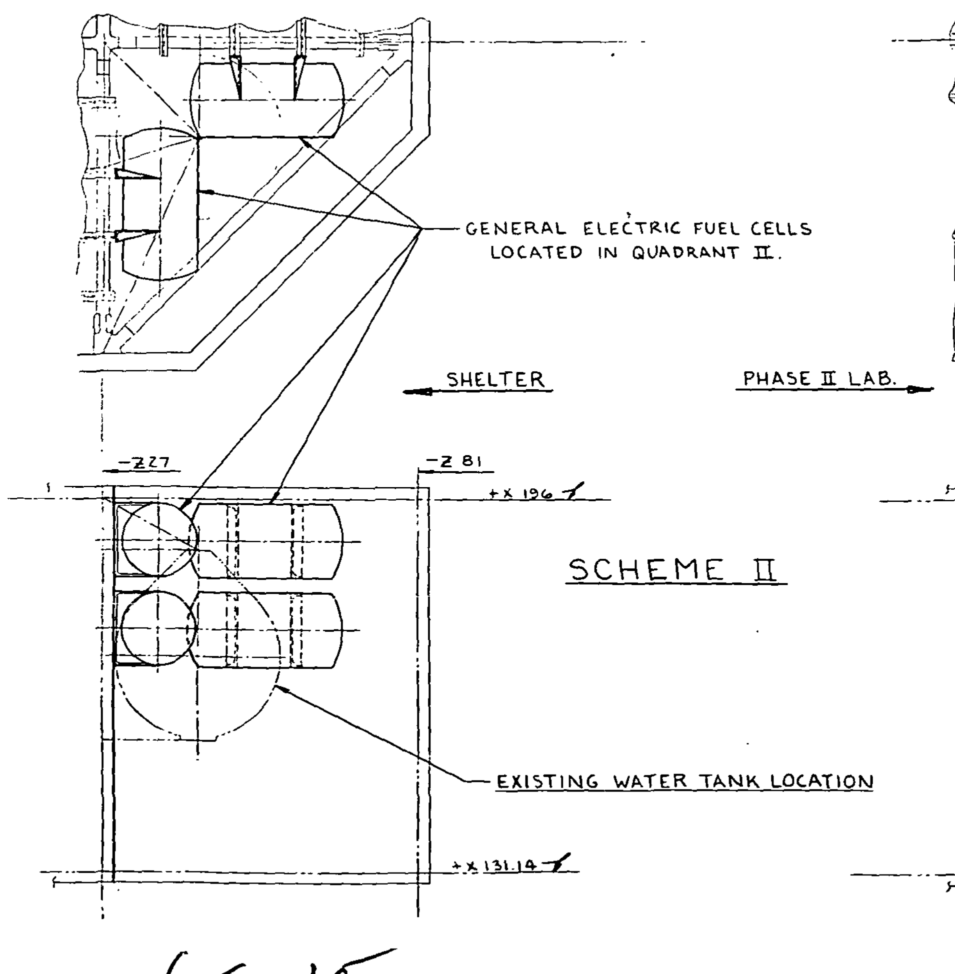
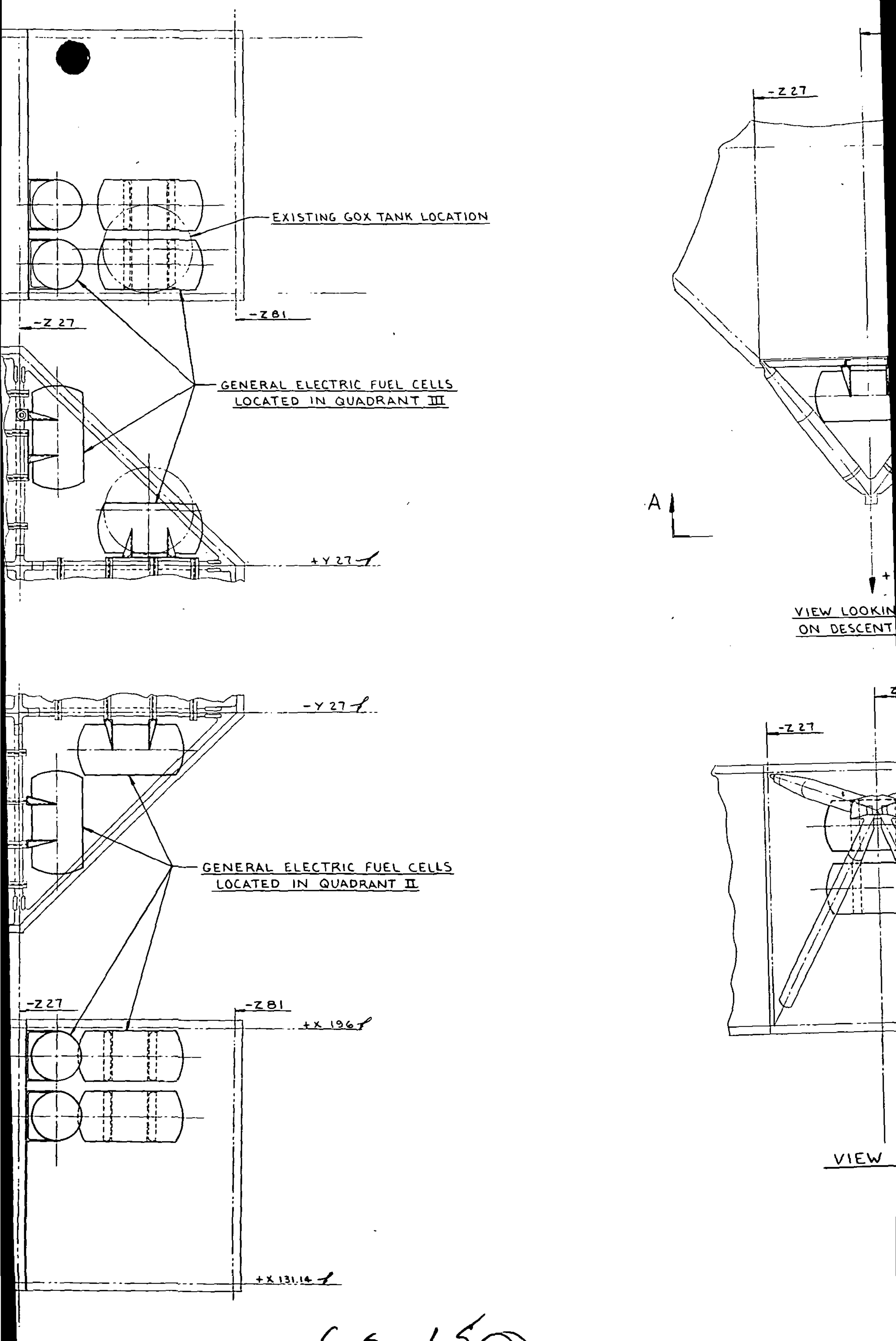


Fig. 6.2-14 Recommended GE Fuel Cell Installation


+X 131.14
+X 131.14
EXISTING HELIUM TANK LOCATION
SCHEME III
SHELTER
PHASE II LAB.
+X 196
+X 196
-Z 81
GENERAL ELECTRIC FUEL CELLS
LOCATED IN QUADRANT III


GENERAL ELECTRIC FUEL CELLS
LOCATED IN QUADRANT II.
SHELTER
PHASE II LAB.
-Z 27
-Z 81
+X 196
SCHEME II
EXISTING WATER TANK LOCATION
+X 131.14

6.5-15 (1)


EXISTING GOX TANK LOCATION
-Z 27
-Z 81
GENERAL ELECTRIC FUEL CELLS
LOCATED IN QUADRANT III
+Y 27 ℄
-Y 27 ℄
GENERAL ELECTRIC FUEL CELLS
LOCATED IN QUADRANT II
-Z27
-Z81
+X 196 ℄
+X 131.14 ℄
-Z 27
-Z 27
A
VIEW

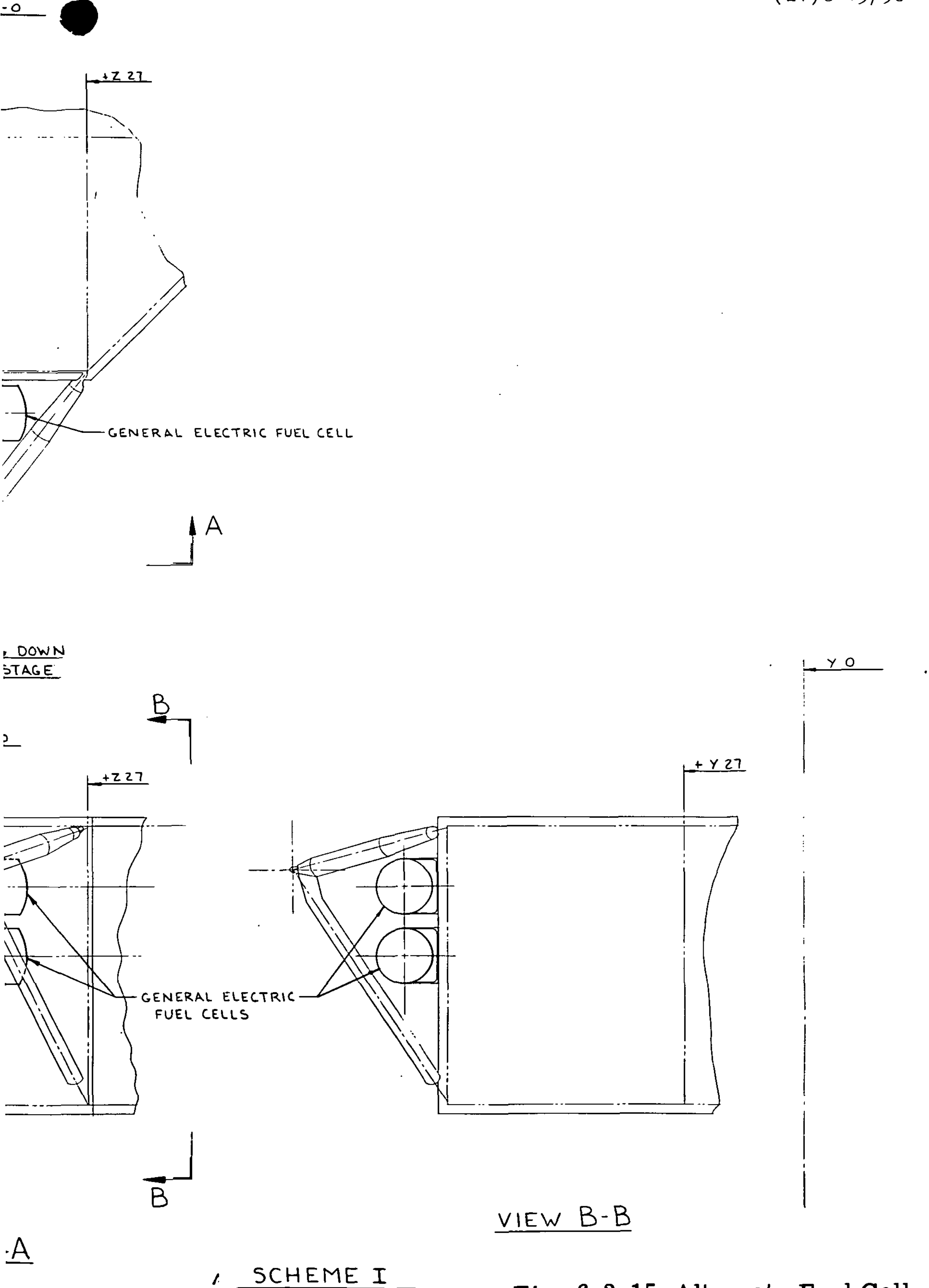
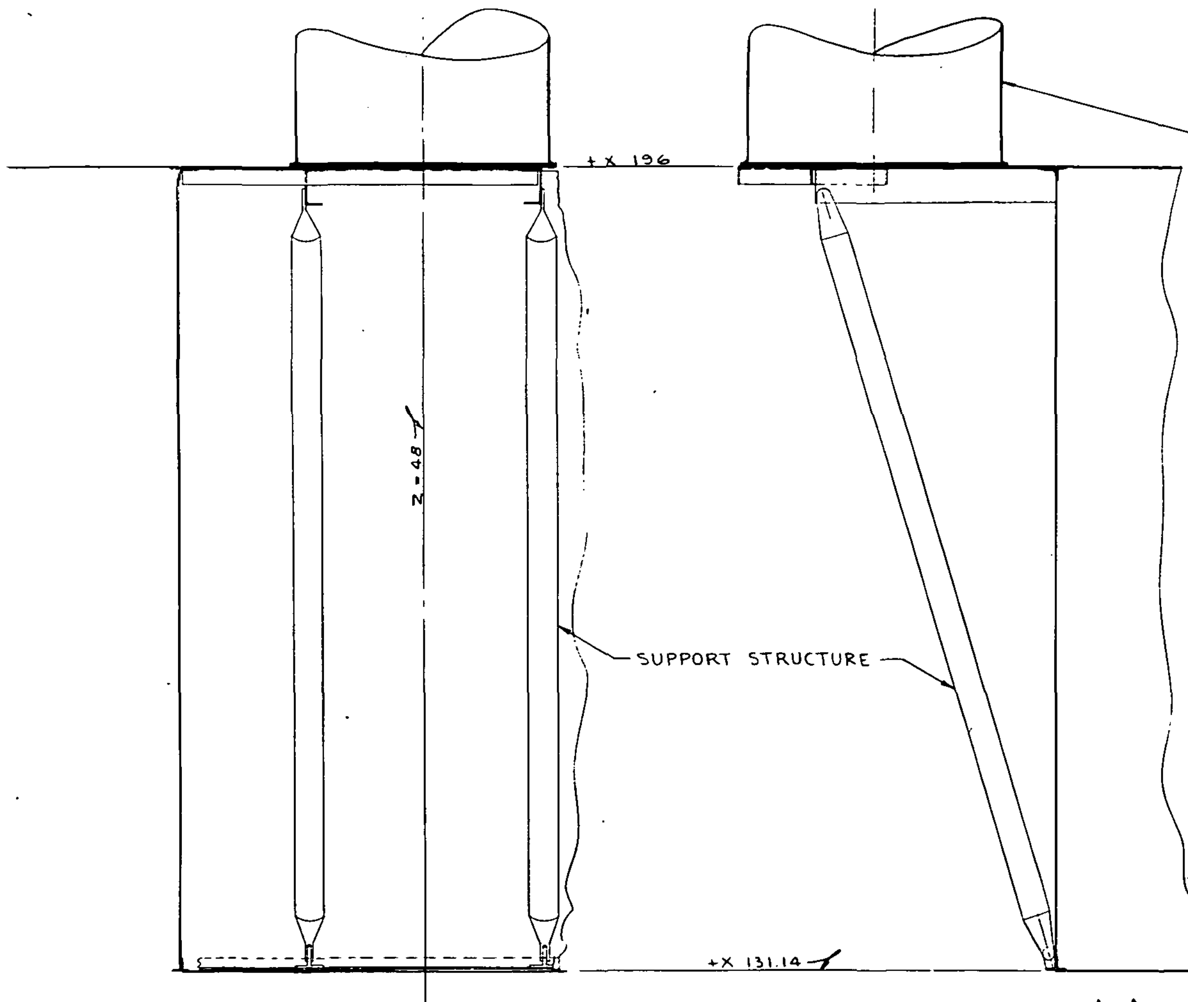


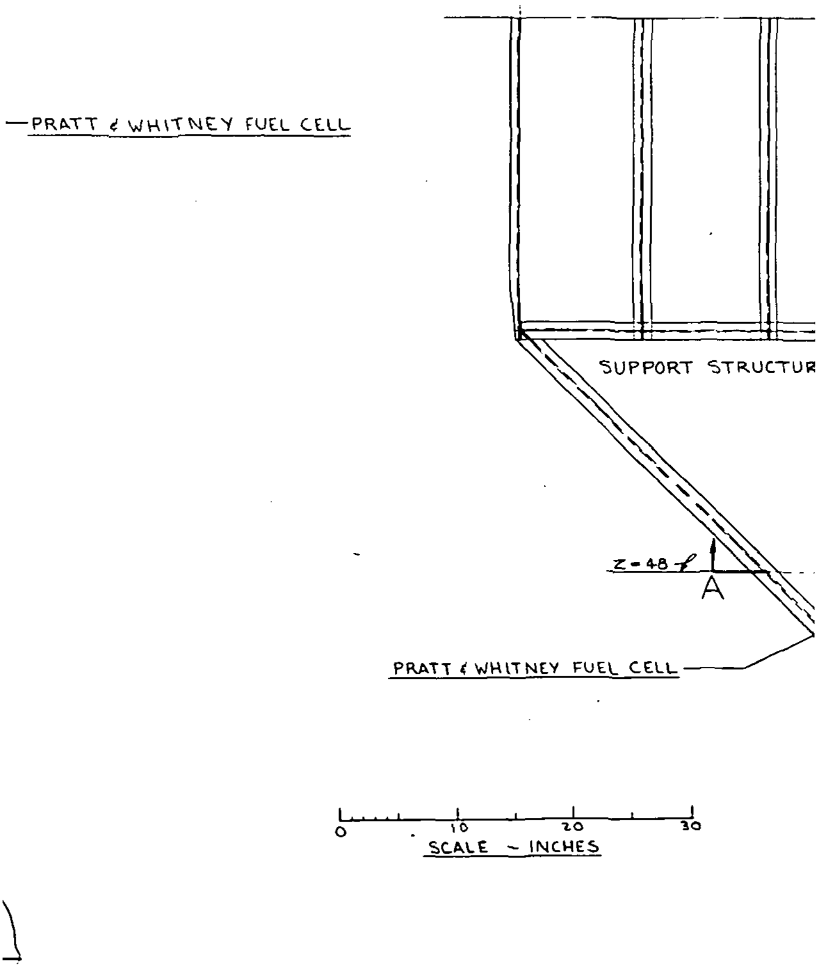
Fig. 6.2-15 Alternate Fuel Cell Installation General Electric Phase II Lab & Shelter

Grumman

51



SECTION A-A


PRATT & WHITNEY FUEL CELL
SUPPORT STRUCTUR
Z=48
A
PRATT & WHITNEY FUEL CELL
0 10 20 30
SCALE ~ INCHES

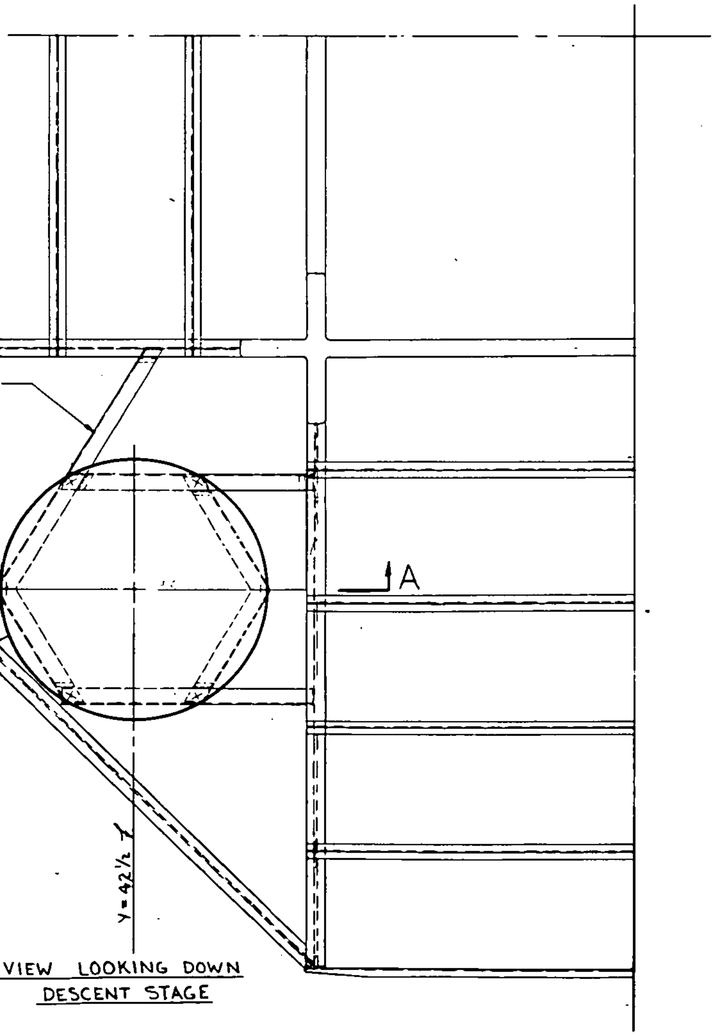
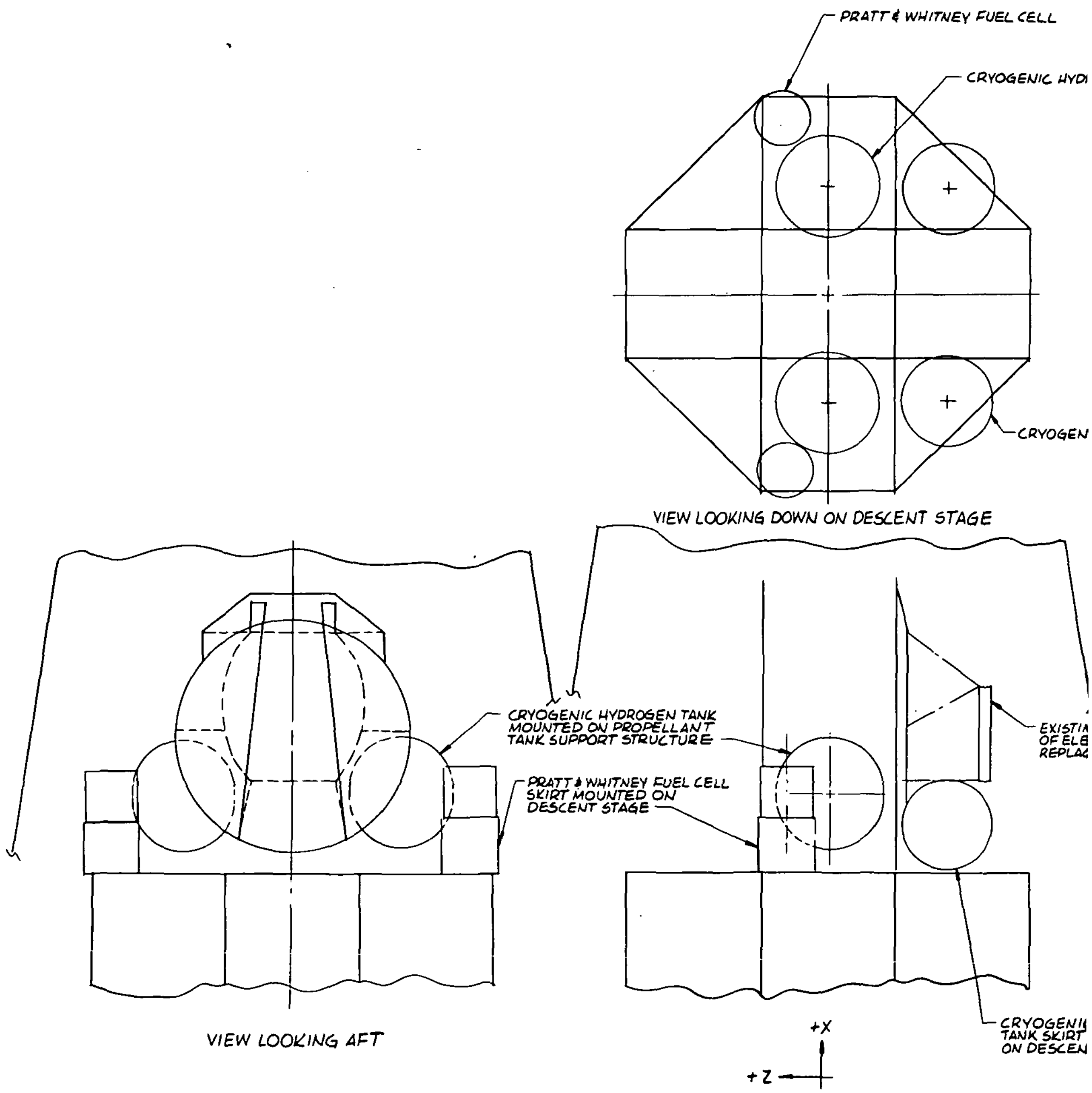


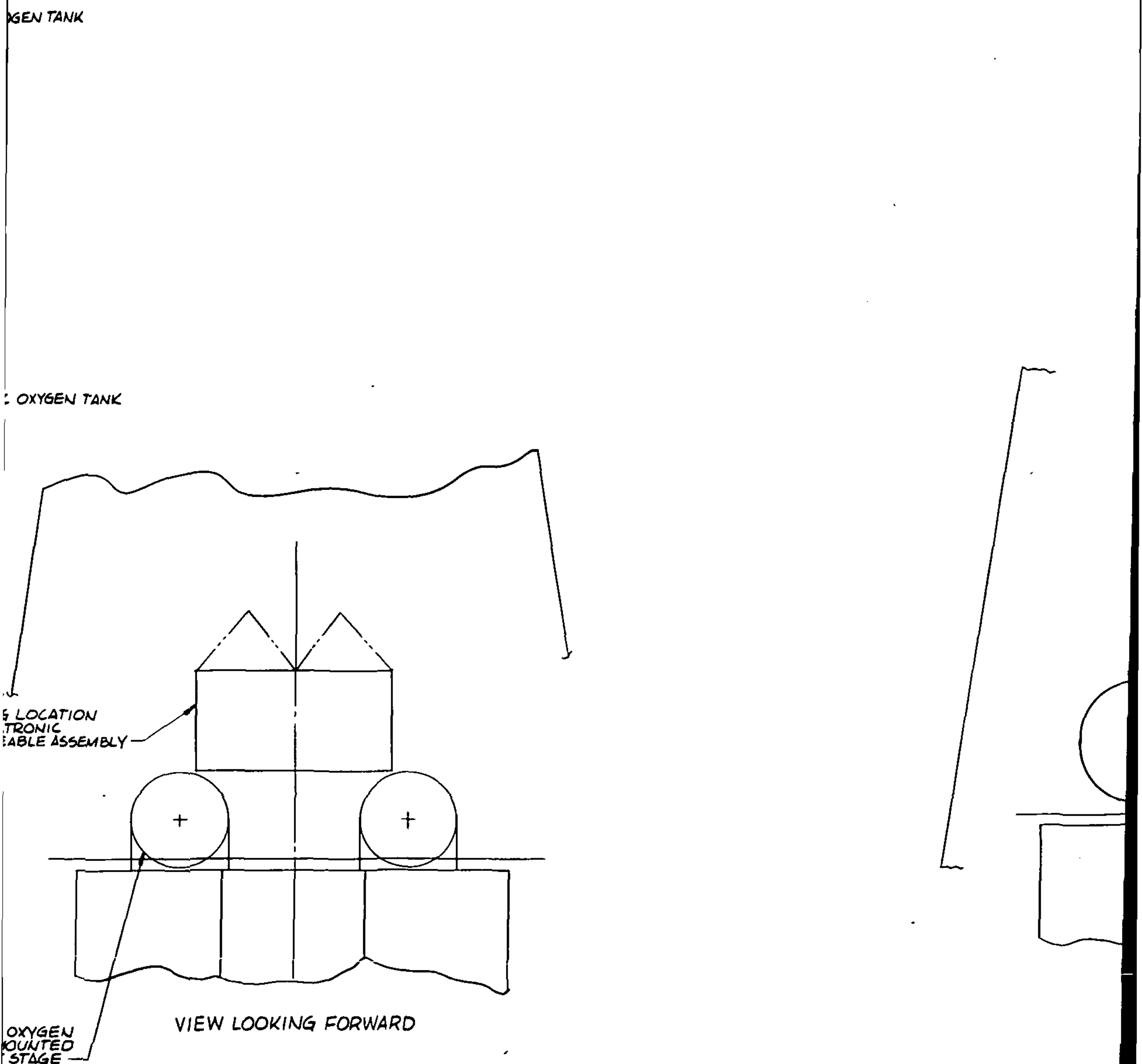
Fig. 6.2-16 Recommended Fuel Cell Install. Pratt & Whitney Phase II Lab

3

Grumman

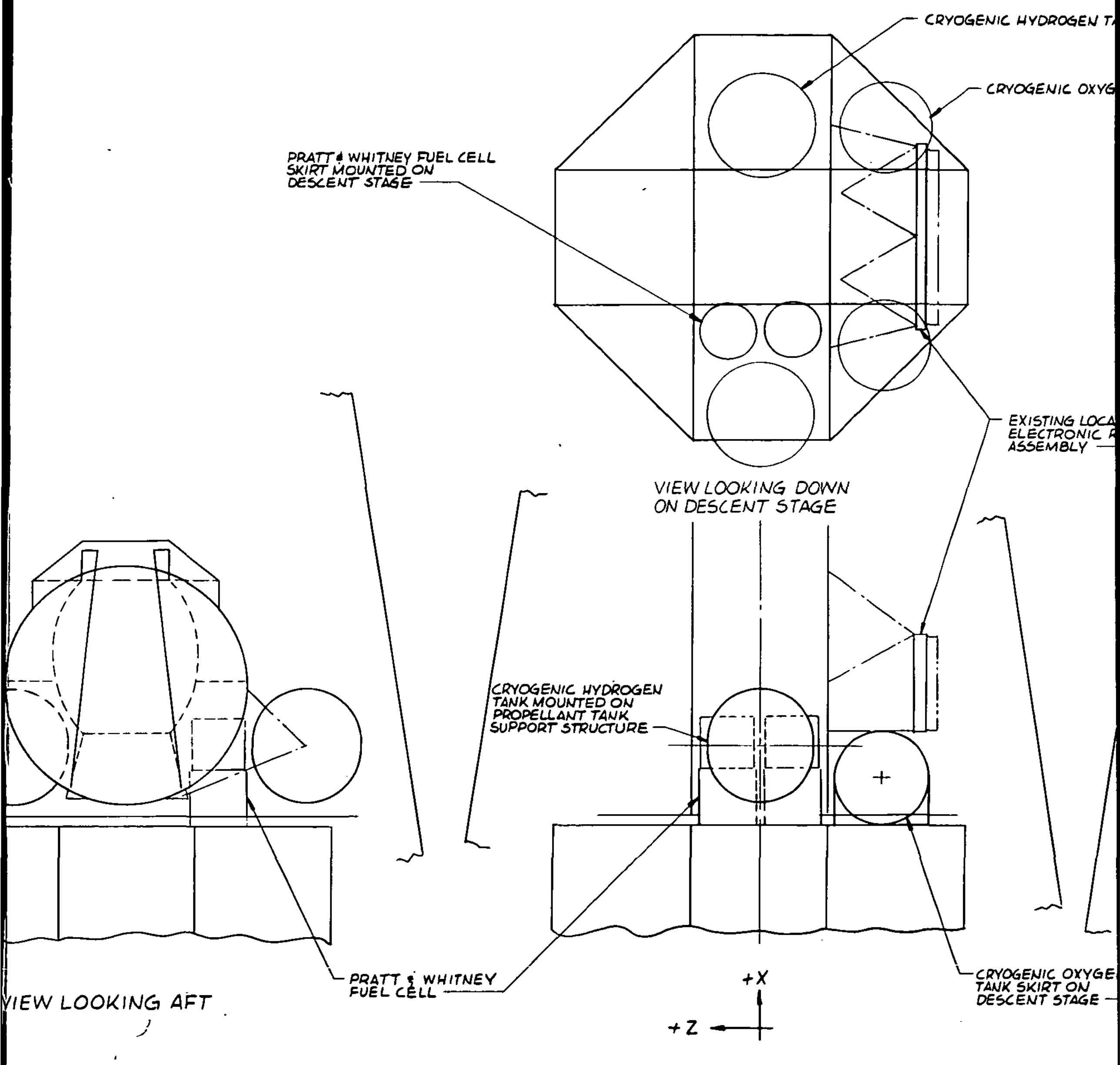


PRATT & WHITNEY FUEL CELL
CRYOGENIC HYD
CRYOGEN
VIEW LOOKING DOWN ON DESCENT STAGE
CRYOGENIC HYDROGEN TANK MOUNTED ON PROPELLANT TANK SUPPORT STRUCTURE
PRATT & WHITNEY FUEL CELL SKIRT MOUNTED ON DESCENT STAGE
EXISTIN OF ELE REPLAC
CRYOGENI TANK SKIRT ON DESCEN
VIEW LOOKING AFT
+X
+Z



VIEW LOOKING FORWARD

6.2.17 ②

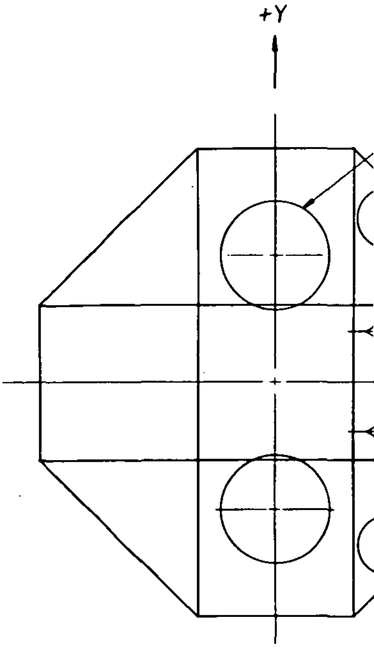


CRYOGENIC HYDROGEN T
CRYOGENIC OXYG
PRATT & WHITNEY FUEL CELL SKIRT MOUNTED ON DESCENT STAGE
EXISTING LOCA
ELECTRONIC
ASSEMBLY
VIEW LOOKING DOWN ON DESCENT STAGE
CRYOGENIC HYDROGEN TANK MOUNTED ON PROPELLANT TANK SUPPORT STRUCTURE
PRATT & WHITNEY FUEL CELL
IEW LOOKING AFT
CRYOGENIC OXYGE
TANK SKIRT ON
DESCENT STAGE
+X
+Z

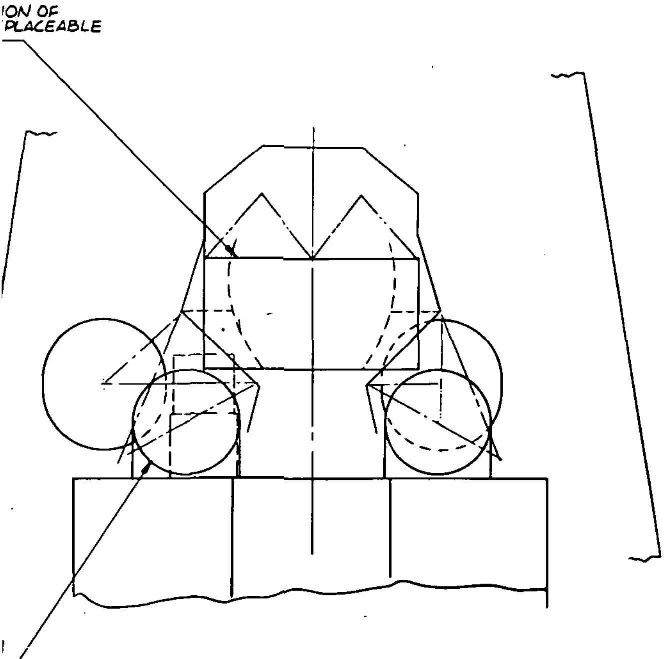
SCHEME II

IK

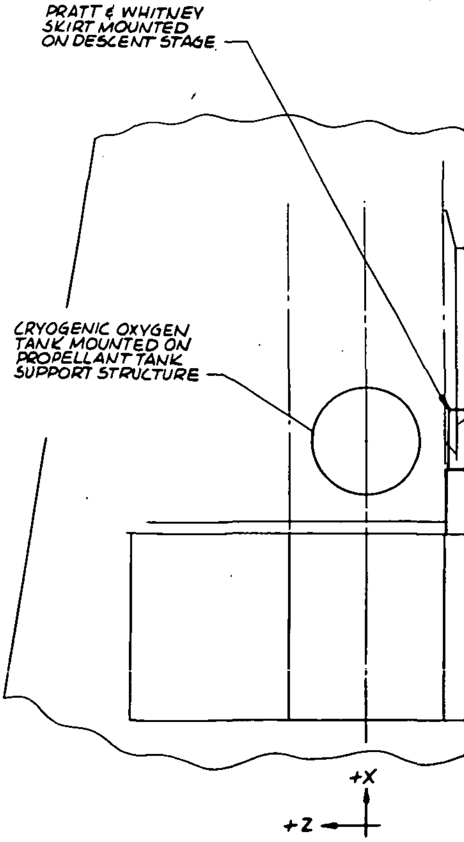
N TANK



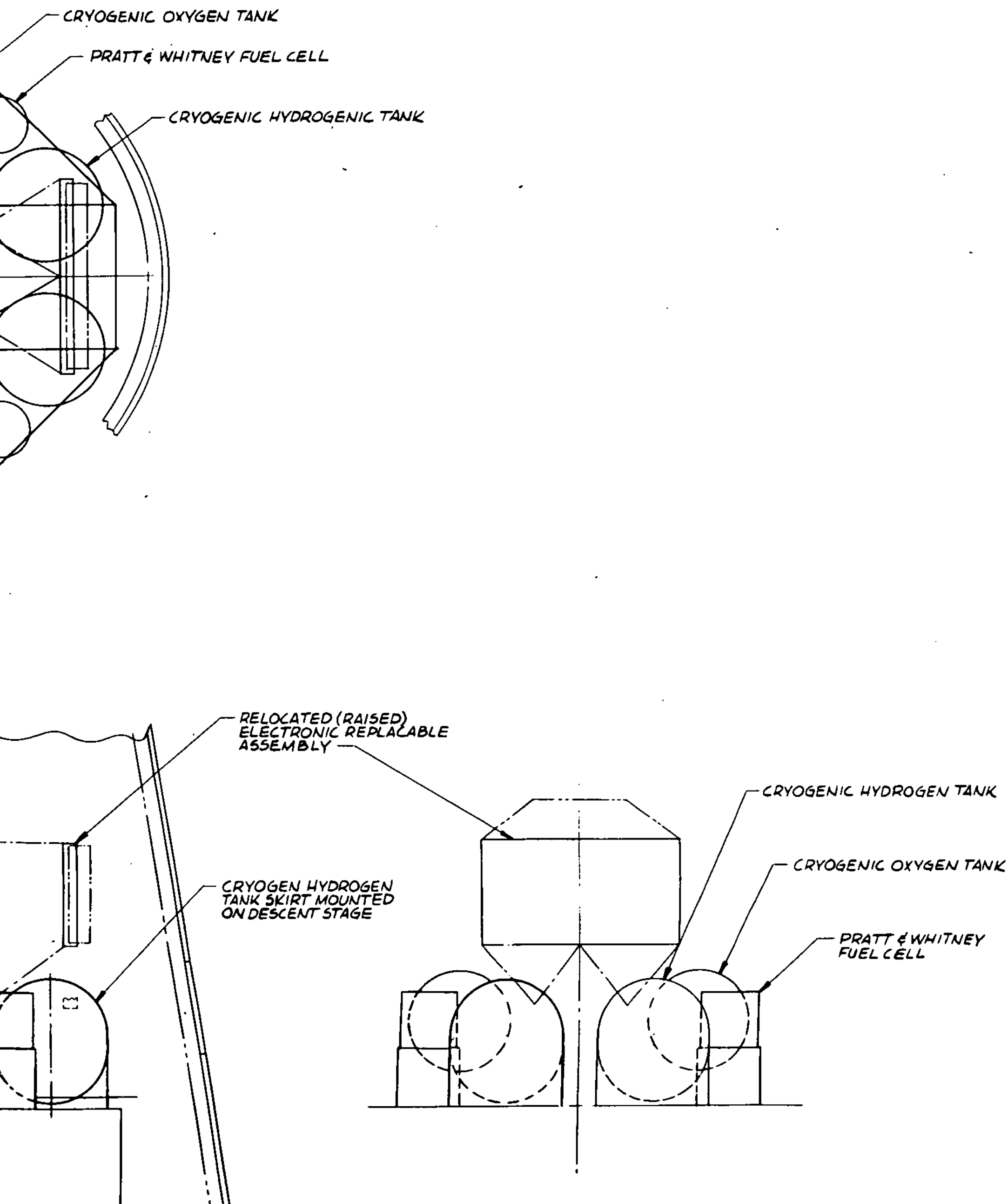
VIEW LOOKING DOWN
AT DESCENT STAGE



VIEW LOOKING FORWARD



SCHEME I
BASELINE CONFIGURATIO

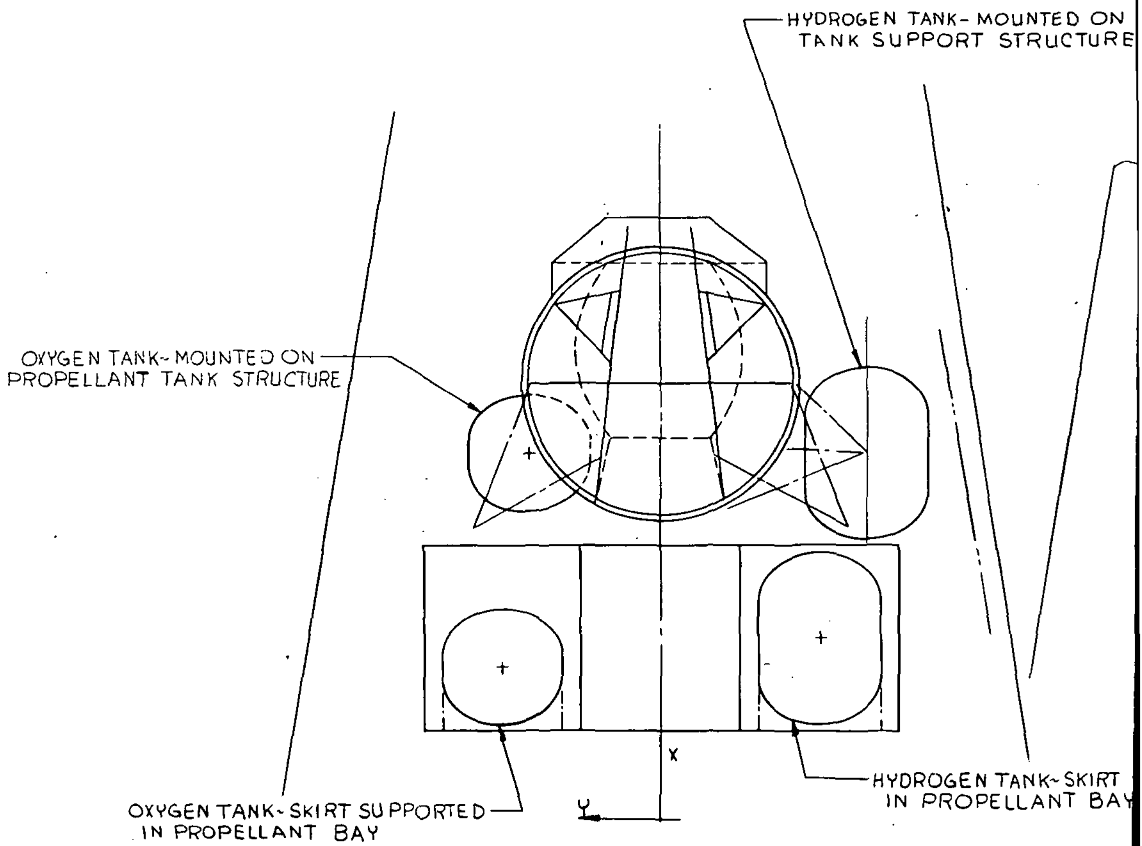


NOTE:
1. TANK CAPACITIES SHOWN ON THIS DRAWING ARE:
OXYGEN — 712 LBS EACH
HYDROGEN- 80 LBS EACH

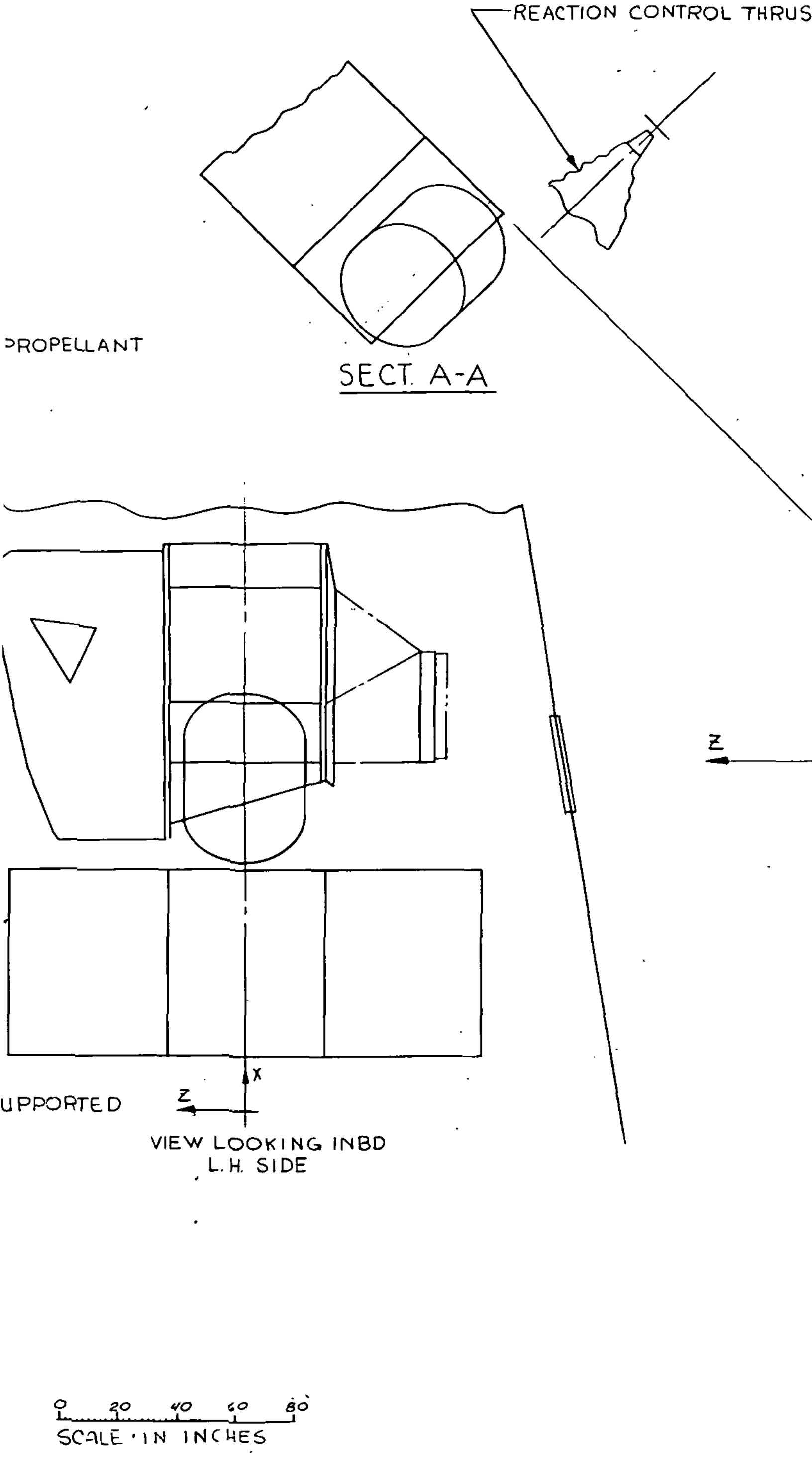
Fig. 6.2-17 Phase II Lab Alternate Locations of Cryogenic Housekeeping Tanks and Pratt & Whitney Cells

Grumman

(58)



VIEW LOOKING AFT


REACTION CONTROL THRUS
PROPELLANT
SECT. A-A
Z
X
UPPORTED
VIEW LOOKING INBD
L.H. SIDE
0 20 40 60 80
SCALE IN INCHES

R PLUME

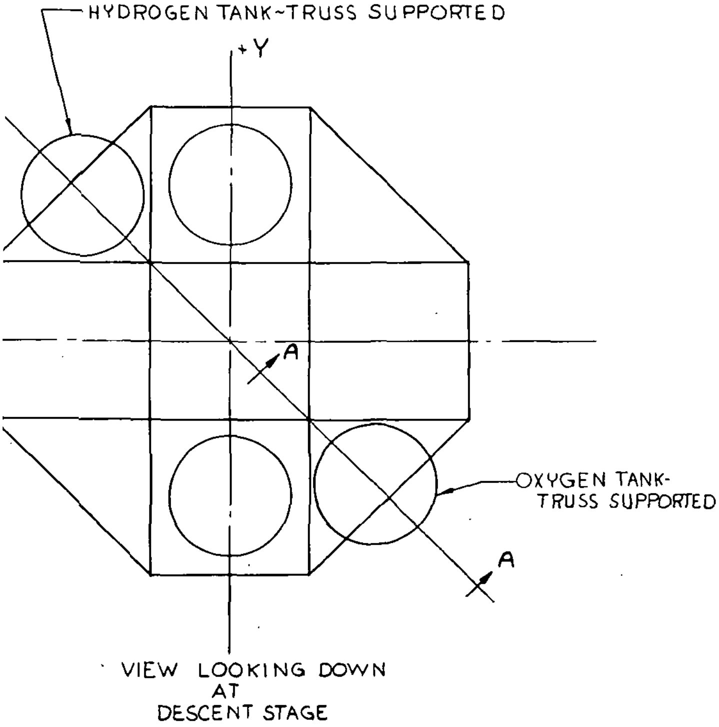
NOTES:

1.- ONE (1) OXYGEN TANK & ONE (1) HYDROGEN TANK REQUIRED PER FLIGHT ARTICLE.

2.- CAPACITY OF TANKS SHOWN ARE:

OXYGEN: 1375 Lbs.

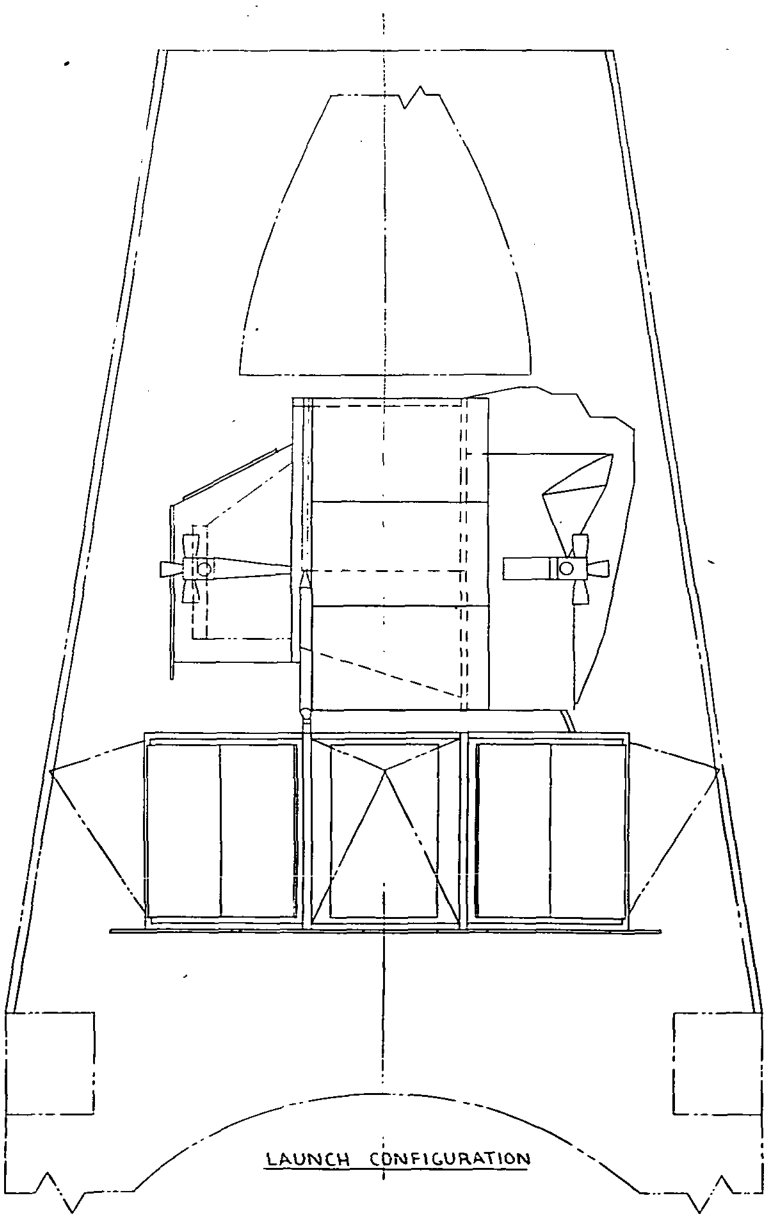
HYDROGEN: 144 Lbs.

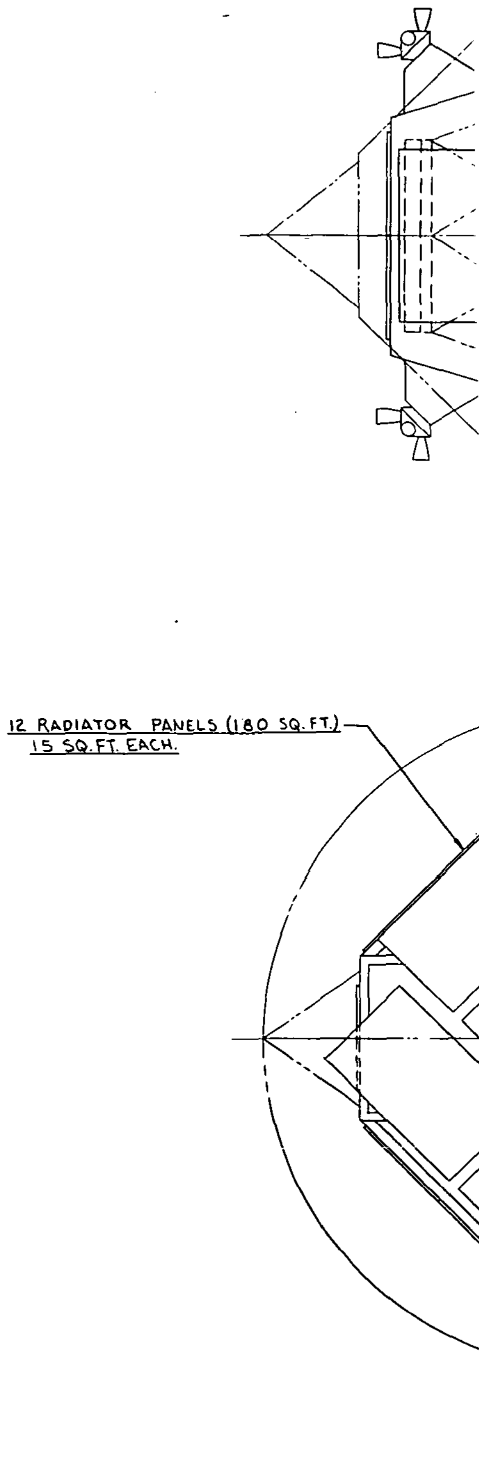


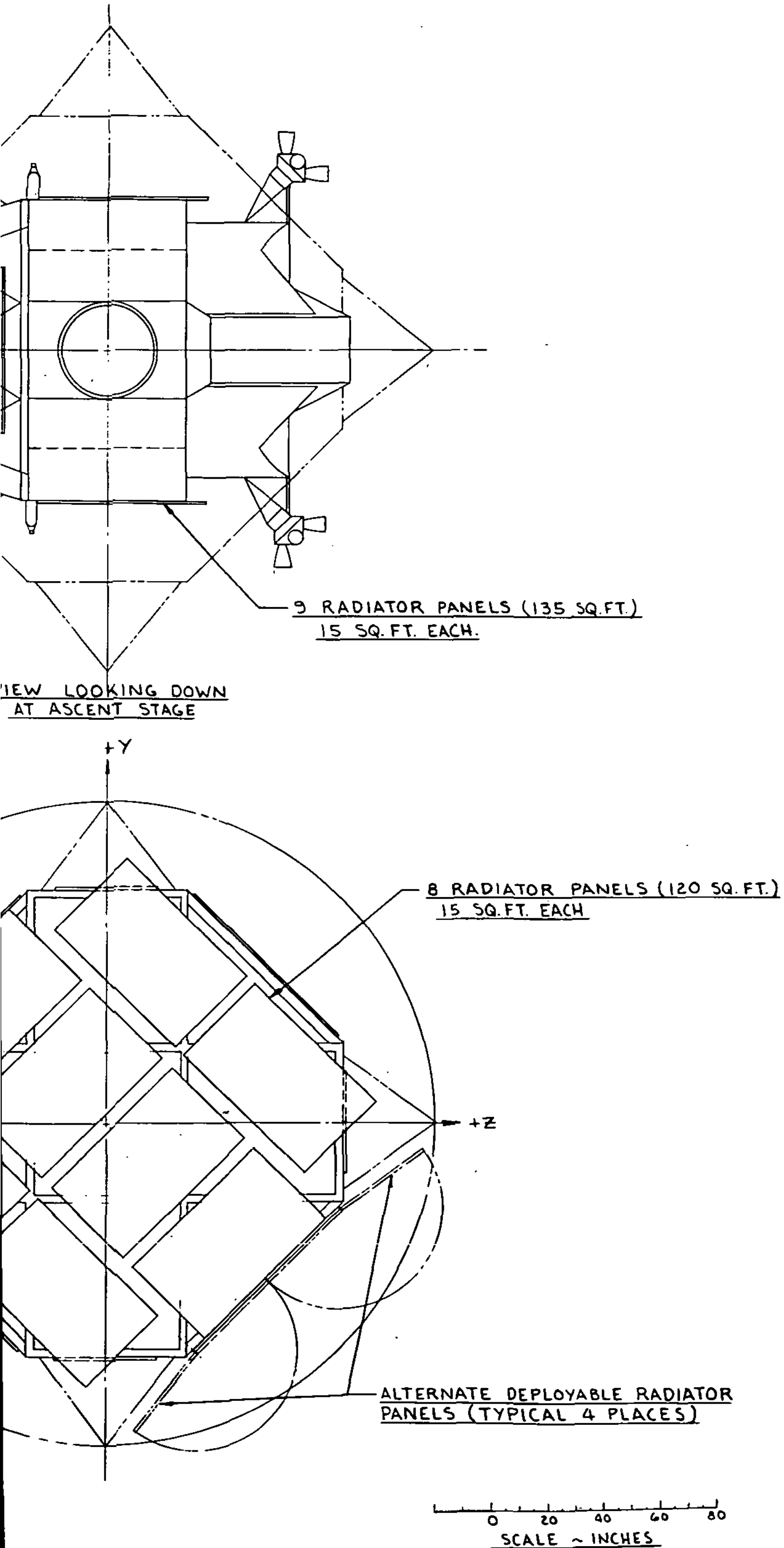
ALTERNATE AES
CRYOGENIC TANKS ARRANGEMENT
PHASE II LAB

Fig. 6.2-18 Alternate AES Cryogenic Tanks Arrangement Phase II Lab

(57)


LAUNCH CONFIGURATION


12 RADIATOR PANELS (180 SQ. FT.)
15 SQ. FT. EACH.



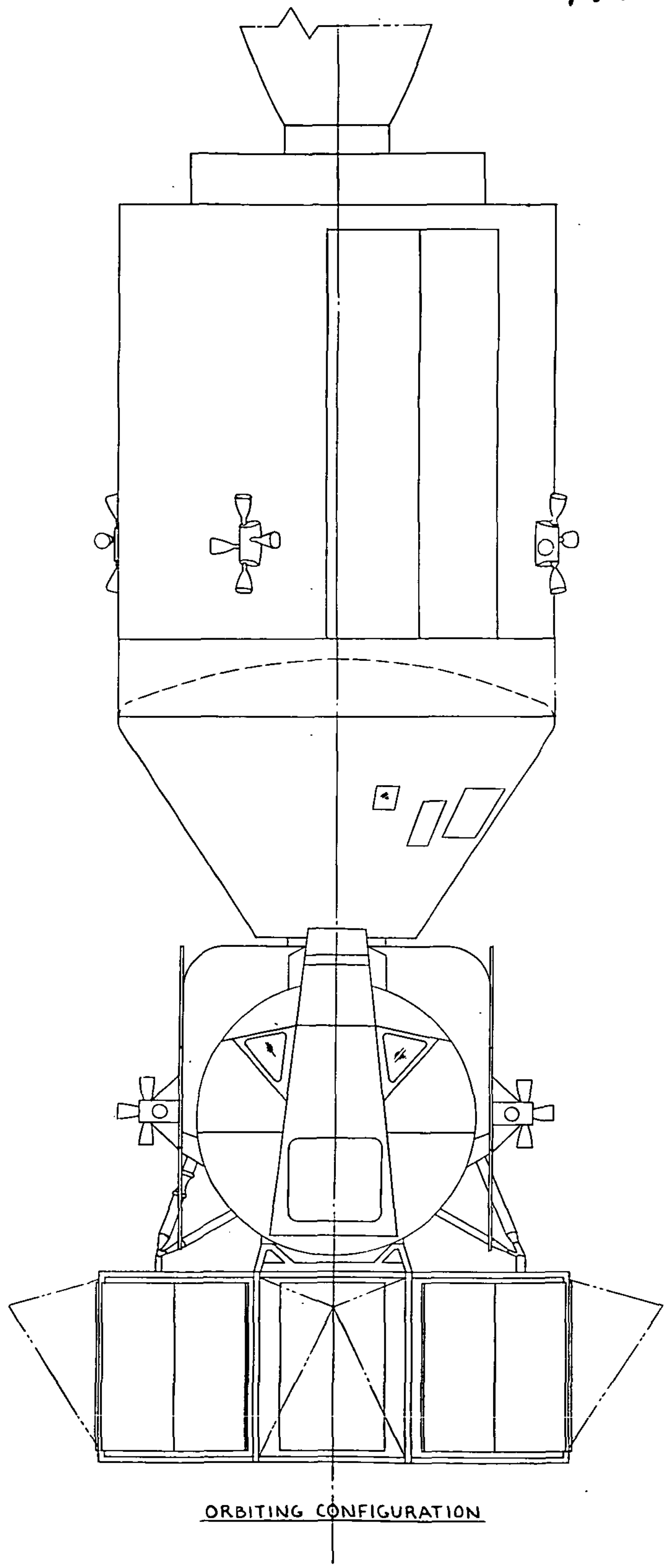
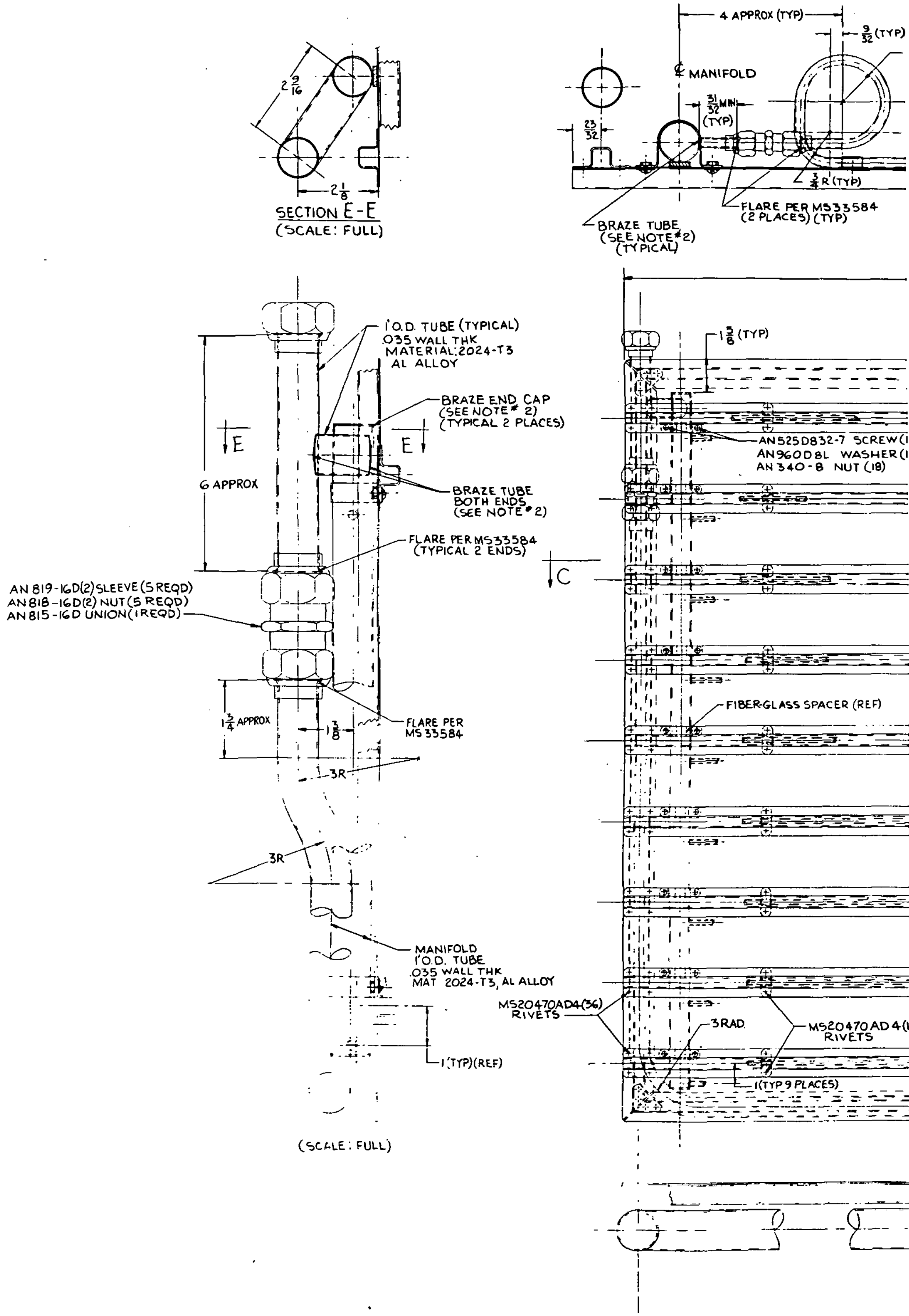
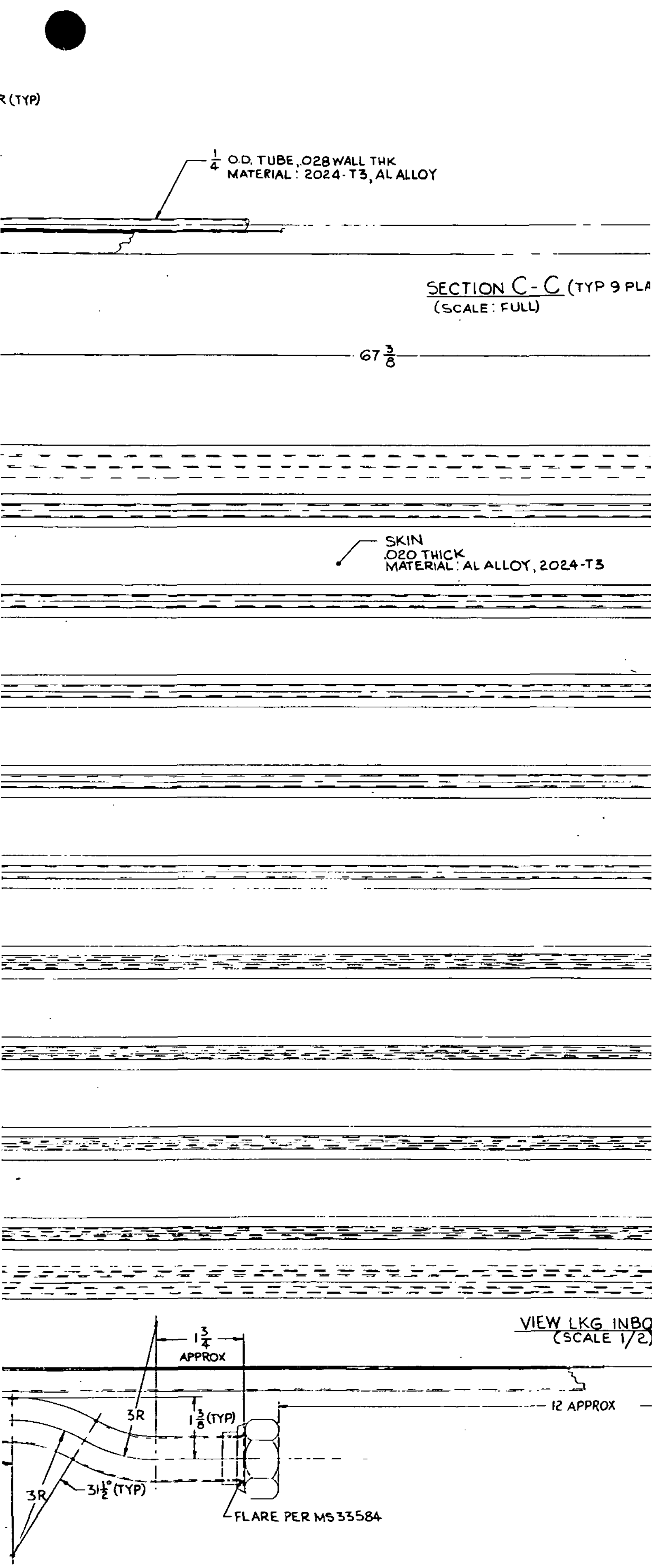


Fig. 6.2-19 Alternate Radiator Locations

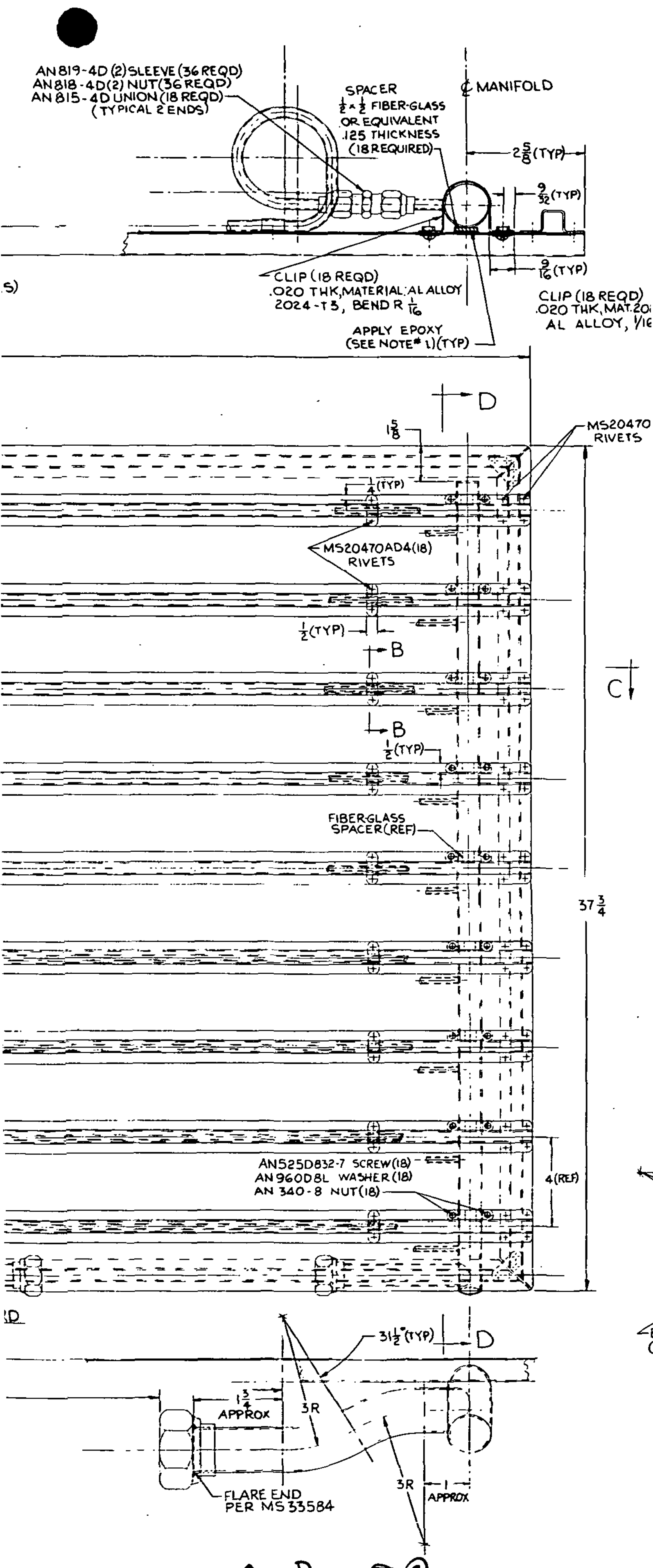

SECTION E-E
(SCALE: FULL)
4 APPROX (TYP)
9/32 (TYP)
℄ MANIFOLD
31/32 MIN (TYP)
23/32
3/4 R (TYP)
FLARE PER MS33584 (2 PLACES) (TYP)
BRAZE TUBE (SEE NOTE #2) (TYPICAL)
1" O.D. TUBE (TYPICAL)
.035 WALL THK
MATERIAL: 2024-T3
AL ALLOY
BRAZE END CAP (SEE NOTE # 2) (TYPICAL 2 PLACES)
BRAZE TUBE BOTH ENDS (SEE NOTE # 2)
6 APPROX
FLARE PER MS33584 (TYPICAL 2 ENDS)
AN 819-16D(2) SLEEVE (5 REQD)
AN 818-16D(2) NUT (5 REQD)
AN 815-16D UNION (1 REQD)
1 3/4 APPROX
1 3/8
FLARE PER MS 33584
3R
MANIFOLD
1" O.D. TUBE
.035 WALL THK
MAT 2024-T3, AL ALLOY
1 (TYP)(REF)
(SCALE: FULL)
1 5/8 (TYP)
AN525D832-7 SCREW
AN960D8L WASHER
AN 340-8 NUT (18)
C
FIBER-GLASS SPACER (REF)
MS20470AD4 (36) RIVETS
3 RAD.
MS20470AD4
RIVETS
1 (TYP 9 PLACES)

6.2.20
①


R (TYP)
1/4 O.D. TUBE, .028 WALL THK
MATERIAL: 2024-T3, AL ALLOY
SECTION C-C (TYP 9 PLA
(SCALE: FULL)
67 3/8
SKIN
.020 THICK
MATERIAL: AL ALLOY, 2024-T3
VIEW LKG INBO
(SCALE 1/2)
1 3/4
APPROX
12 APPROX
3R
1 3/8 (TYP)
3R
31½° (TYP)
FLARE PER MS33584

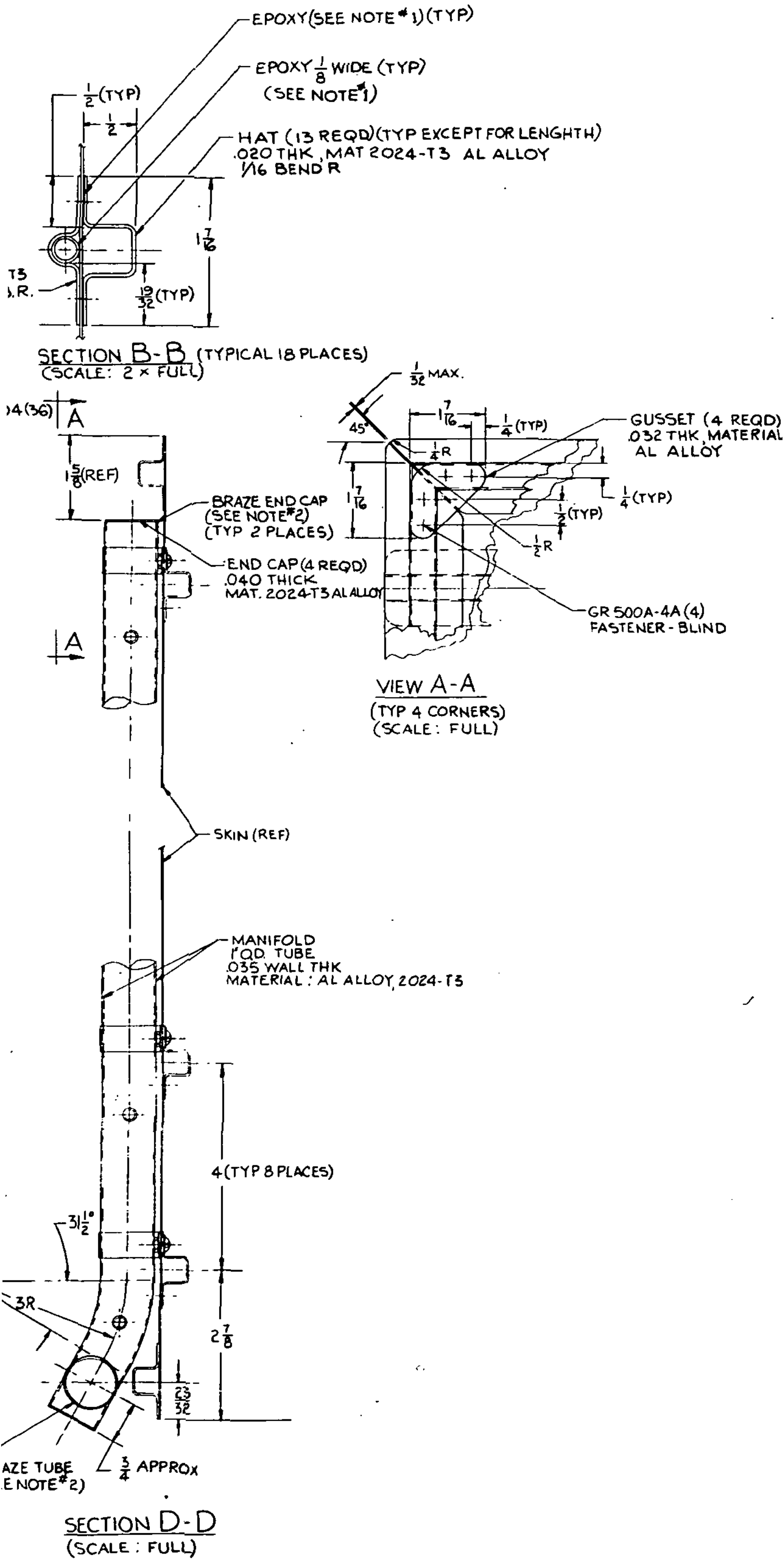
6-2-20

(2)



AN819-4D (2) SLEEVE (36 REQD)
AN818-4D (2) NUT (36 REQD)
AN815-4D UNION (18 REQD)
(TYPICAL 2 ENDS)
SPACER
½ x ½ FIBER-GLASS
OR EQUIVALENT
.125 THICKNESS
(18 REQUIRED)
℄ MANIFOLD
2⅝ (TYP)
9/32 (TYP)
9/16 (TYP)
CLIP (18 REQD)
.020 THK, MATERIAL: AL ALLOY
2024-T3, BEND R 1/16
CLIP (18 REQD)
.020 THK, MAT.20
AL ALLOY, 1/16
APPLY EPOXY
(SEE NOTE# 1)(TYP)
D
1⅝
MS20470
RIVETS
¼ (TYP)
MS20470AD4 (18)
RIVETS
½ (TYP)
B
C
FIBER-GLASS
SPACER (REF)
37¾
AN525D832-7 SCREW (18)
AN960D8L WASHER (18)
AN 340-8 NUT (18)
4 (REF)
31½° (TYP)
1¾
APPROX
3R
FLARE END
PER MS33584
1
APPROX

6, 2-20
③


EPOXY (SEE NOTE #1) (TYP)
EPOXY 1/8 WIDE (TYP) (SEE NOTE #1)
1/2 (TYP)
1/2
HAT (13 REQD) (TYP EXCEPT FOR LENGHTH) .020 THK, MAT 2024-T3 AL ALLOY 1/16 BEND R
1 7/16
T3
.R.
19/32 (TYP)
SECTION B-B (TYPICAL 18 PLACES)
(SCALE: 2 × FULL)
)4(36)
A
1 5/8 (REF)
BRAZE END CAP (SEE NOTE #2) (TYP 2 PLACES)
END CAP (4 REQD) .040 THICK MAT. 2024-T3 AL ALLOY
A
1/32 MAX.
45°
1 7/16
1/4 (TYP)
1/4 R
1 7/16
GUSSET (4 REQD) .032 THK, MATERIAL AL ALLOY
1/4 (TYP)
1/2 (TYP)
1/2 R
GR 500A-4A (4) FASTENER - BLIND
VIEW A-A
(TYP 4 CORNERS)
(SCALE: FULL)
SKIN (REF)
MANIFOLD 1" O.D. TUBE .035 WALL THK MATERIAL: AL ALLOY, 2024-T3
4 (TYP 8 PLACES)
31 1/2°
3R
2 7/8
23/32
AZE TUBE
.E NOTE #2)
3/4 APPROX
SECTION D-D
(SCALE: FULL)

6-2-20
(4)

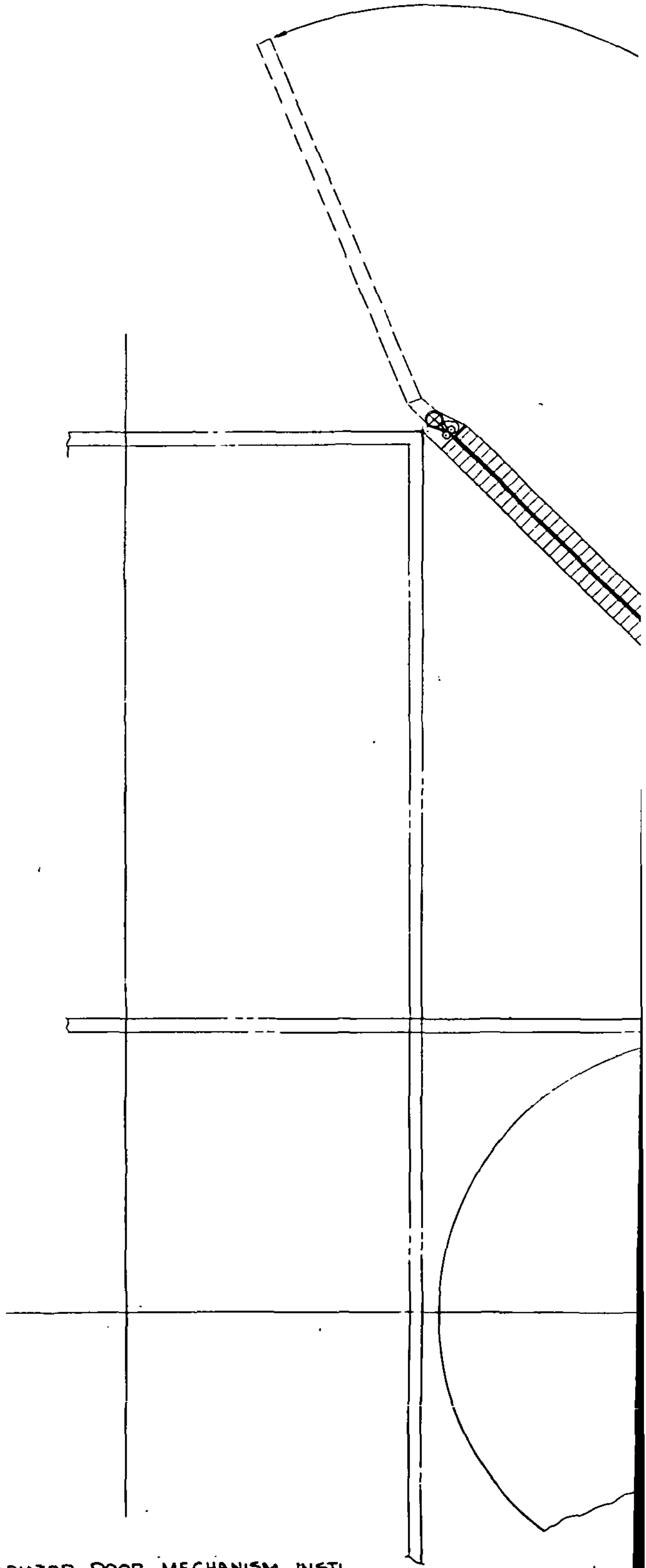
024-T3

NOTES:

1. BONDING INFORMATION FOR RADIATOR:
   MIX BR92 WITH CURING AGENT "A".
   100 PART BR92 TO 8 PART CURING AGENT "A" BY WEIGHT.
   CURE FOR 2 HOURS AT 165°F (MAX 185°F).
   CLEAN PARTS PER G.S.S. 7022.
   PARTS THAT MAY BE IMMERSED USE SODIUM DICHROMATE-SULFURIC ACID. PARTS THAT CAN NOT BE IMMERSED USE PASSAGELL 105.
2. BRAZE WITH QQ-R-566 CLASS FS-RAL-718 ALLOY IN ACCORDANCE WITH GRUMMAN PROCESS SPECIFICATION # 1-4.
3. APPLY LTV-602 SILICONE-BASED WHITE THERMAL COATING TO OUTBOARD FACE PER ENGINEERING INSTRUCTIONS # SD-252-I-70.
4. ALL TUBING MADE FROM 2024-T3 MUST BE ANNEALED BEFORE BENDING.
5. THIS DRAWING MAY BE SCALED.

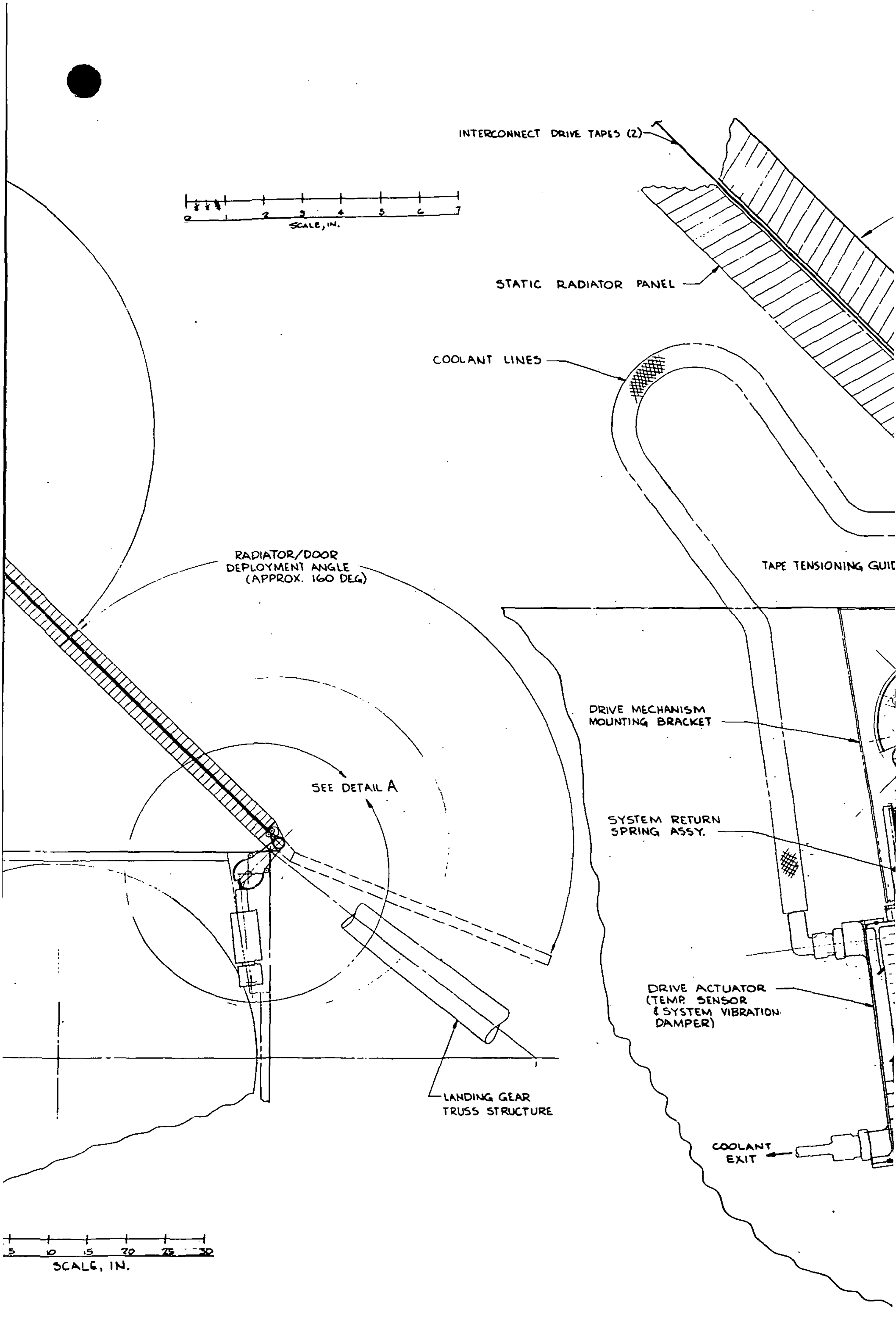
Fig. 6.2-20 Test Radiator Panel
Phase II Lab

5



RADIATOR DOOR MECHANISM INSTL.
VIEW LOOKING DOWN, DESCENT STAGE
(DRIVE MECHANISM & RADIATOR DOORS SHOWN CLOSED)

6.2-21 (1)


INTERCONNECT DRIVE TAPES (2)
SCALE, IN.
STATIC RADIATOR PANEL
COOLANT LINES
RADIATOR/DOOR DEPLOYMENT ANGLE (APPROX. 160 DEG)
TAPE TENSIONING GUID
DRIVE MECHANISM MOUNTING BRACKET
SEE DETAIL A
SYSTEM RETURN SPRING ASSY.
DRIVE ACTUATOR (TEMP. SENSOR & SYSTEM VIBRATION DAMPER)
LANDING GEAR TRUSS STRUCTURE
COOLANT EXIT
SCALE, IN.

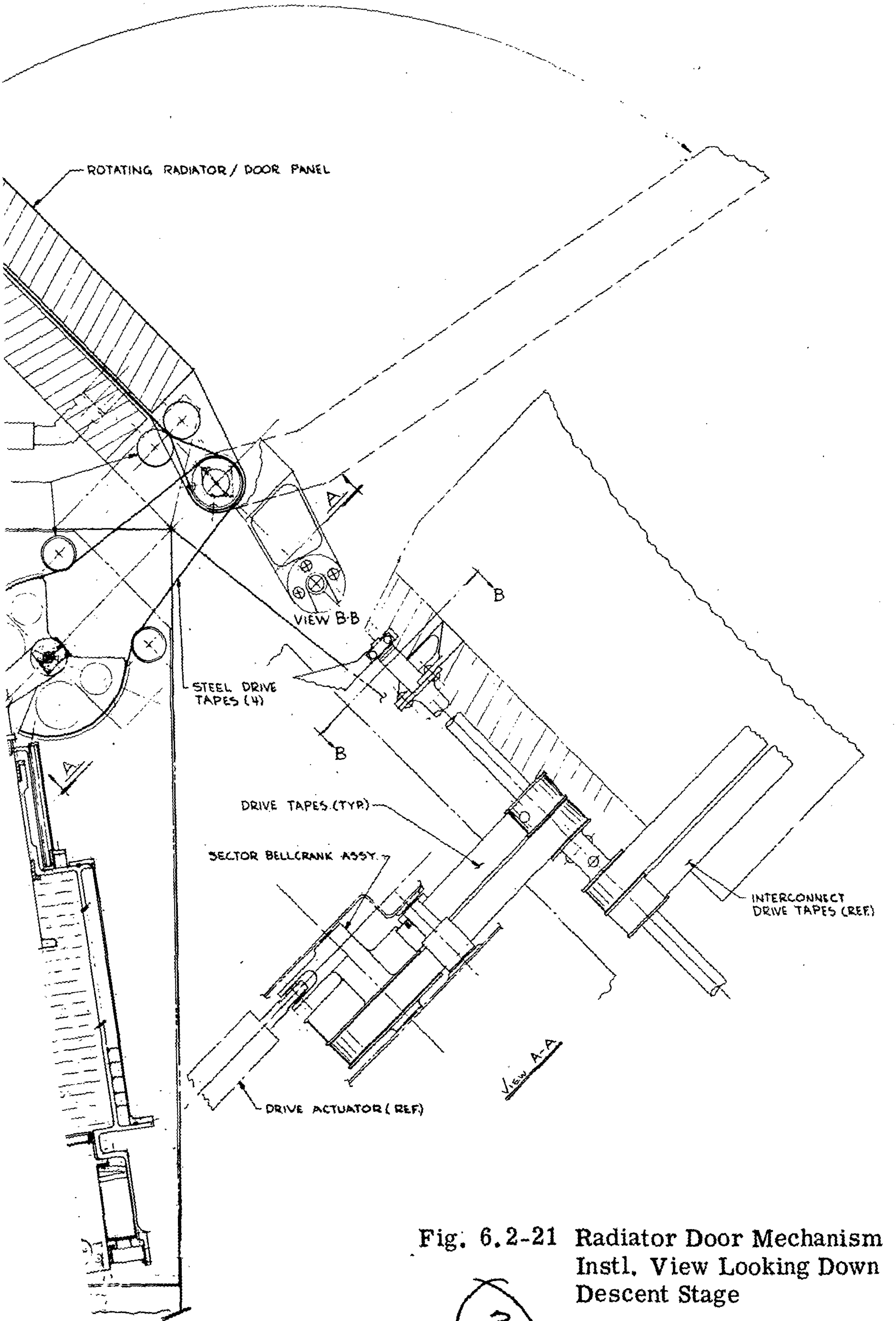
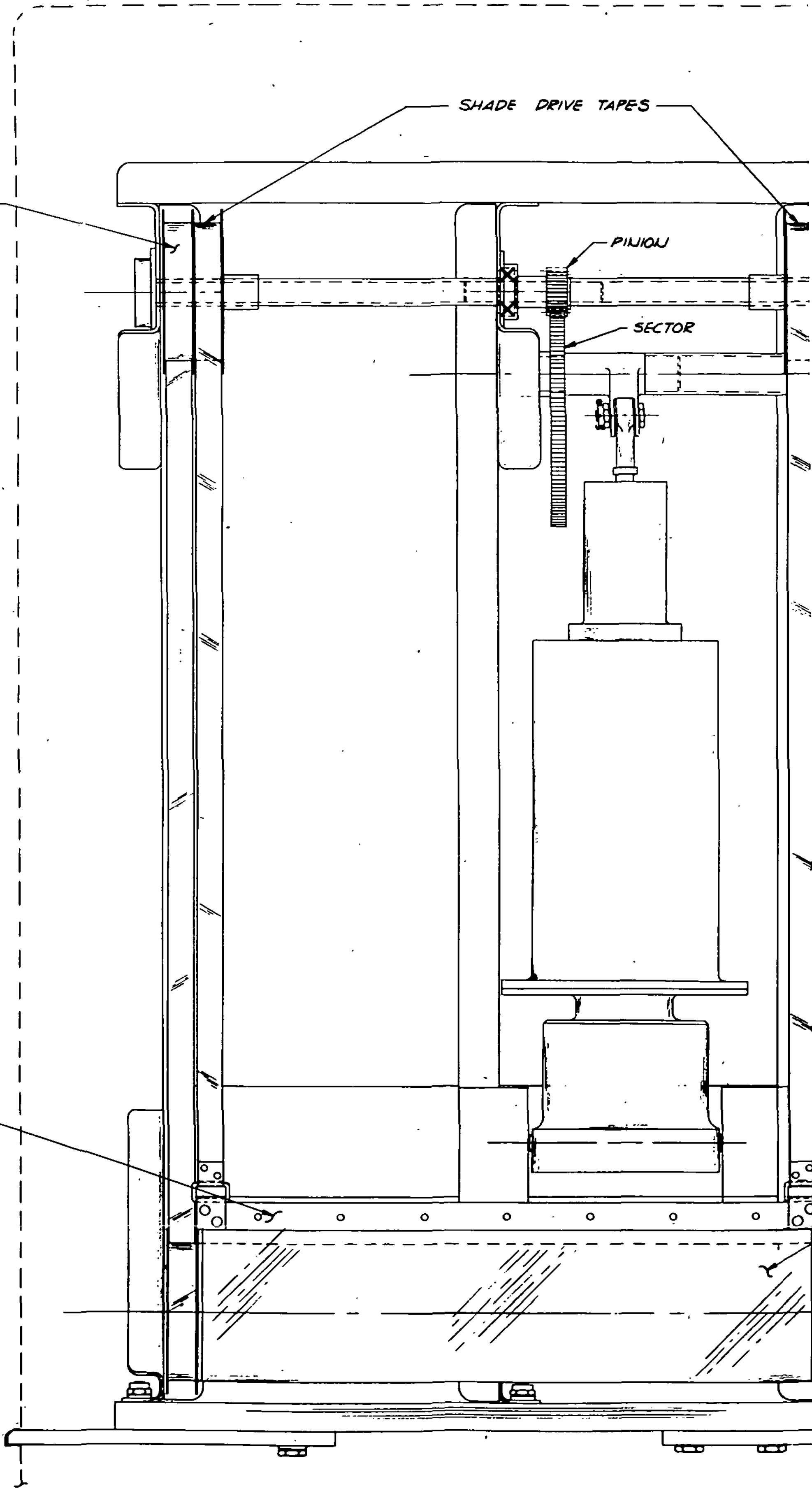


Fig. 6.2-21 Radiator Door Mechanism Instl. View Looking Down Descent Stage

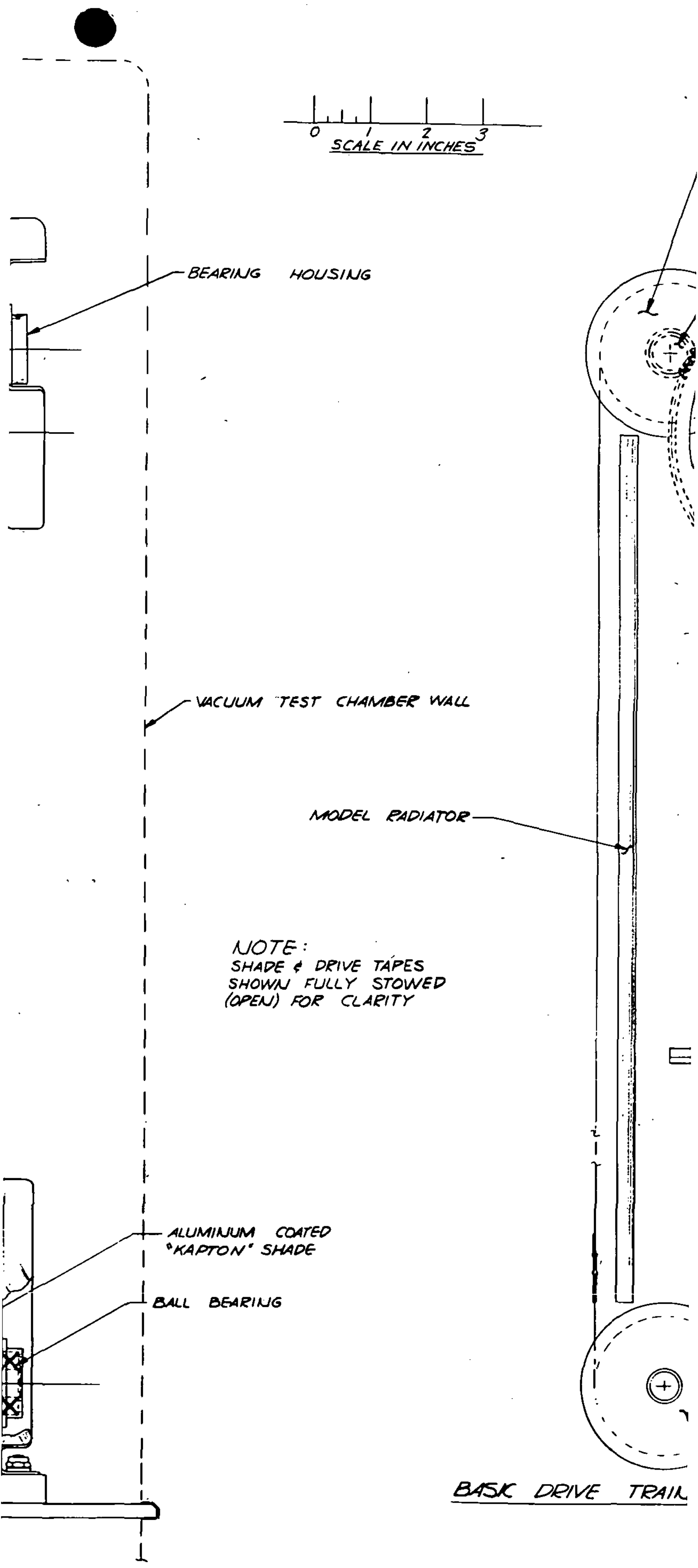
3

Grumman

63



WINDOW SHADE
TEST MODEL



0 1 2 3
SCALE IN INCHES
BEARING HOUSING
VACUUM TEST CHAMBER WALL
MODEL RADIATOR
NOTE:
SHADE & DRIVE TAPES
SHOWN FULLY STOWED
(OPEN) FOR CLARITY
ALUMINUM COATED
"KAPTON" SHADE
BALL BEARING
BASIC DRIVE TRAIN

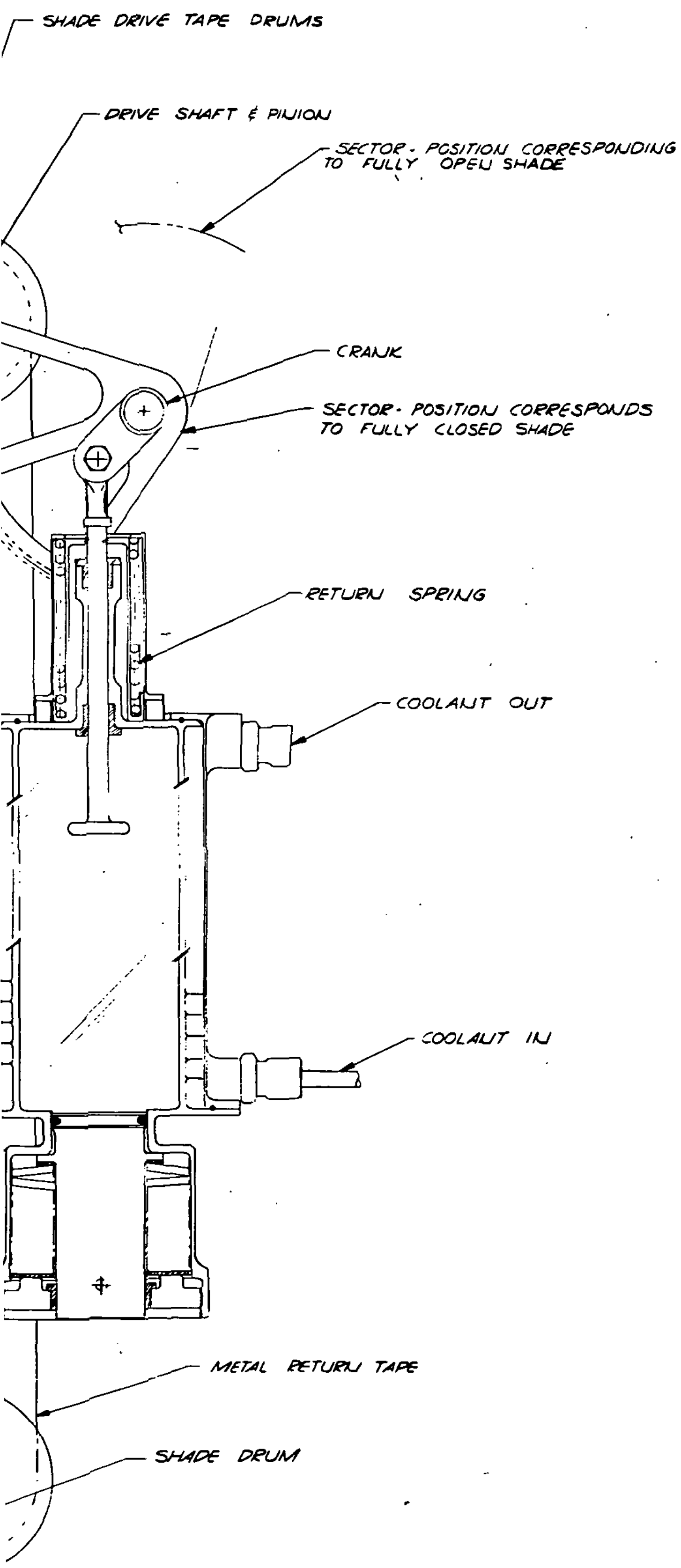
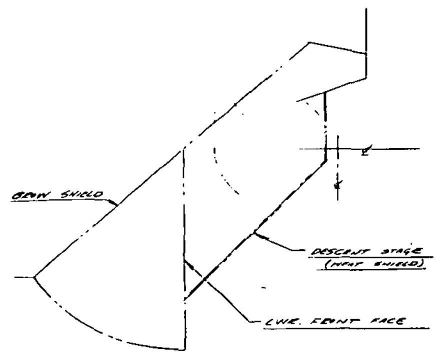
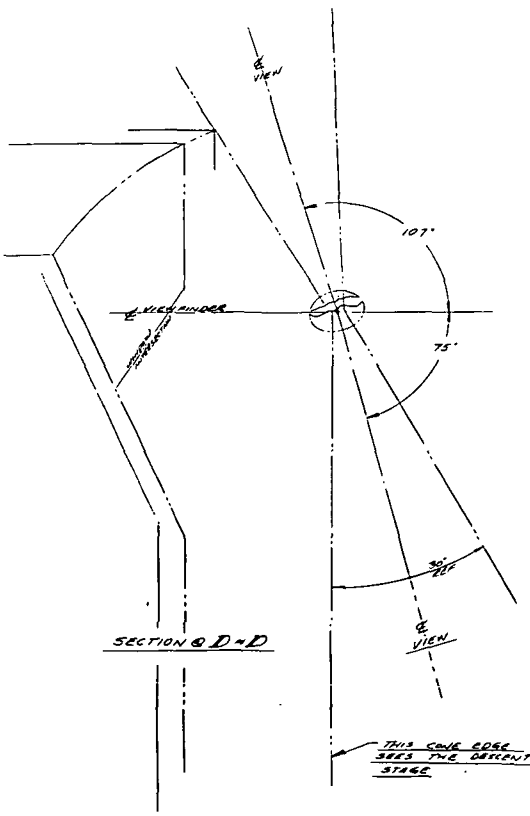
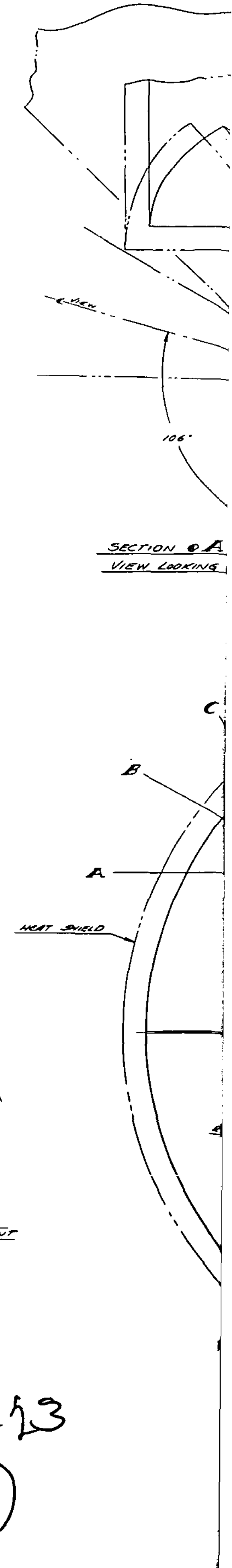


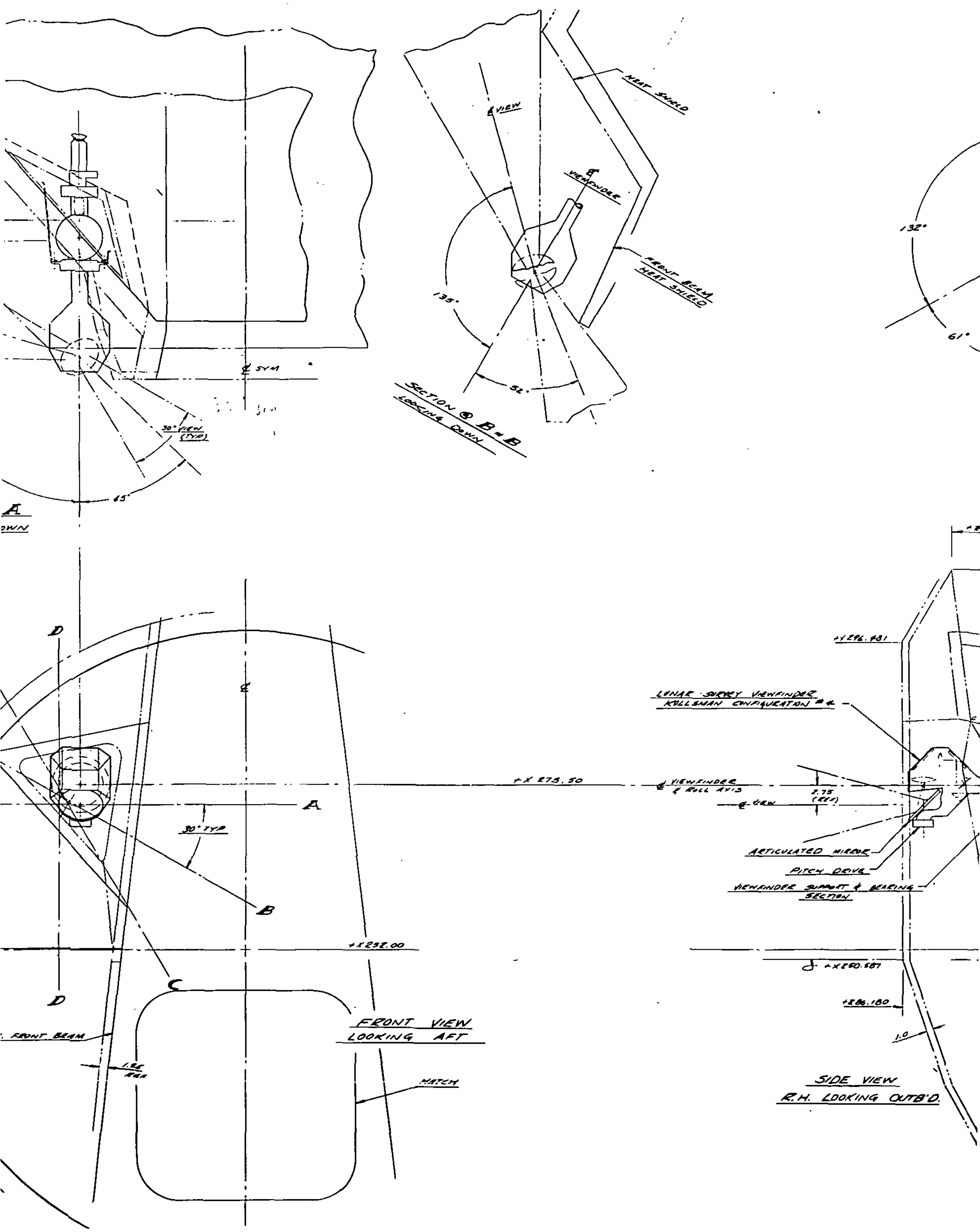
Fig. 6.2-22 Alternate Radiator "Window Shade" Mechanism


CREW SHIELD
DESCENT STAGE (HEAT SHIELD)
LWR. FRONT FACE


VIEW
107°
VIEWFINDER
75°
30° REF
VIEW
SECTION @ D-D
THIS CONE EDGE SEES THE DESCENT STAGE


VIEW
106°
SECTION @ A
VIEW LOOKING
C
B
A
HEAT SHIELD

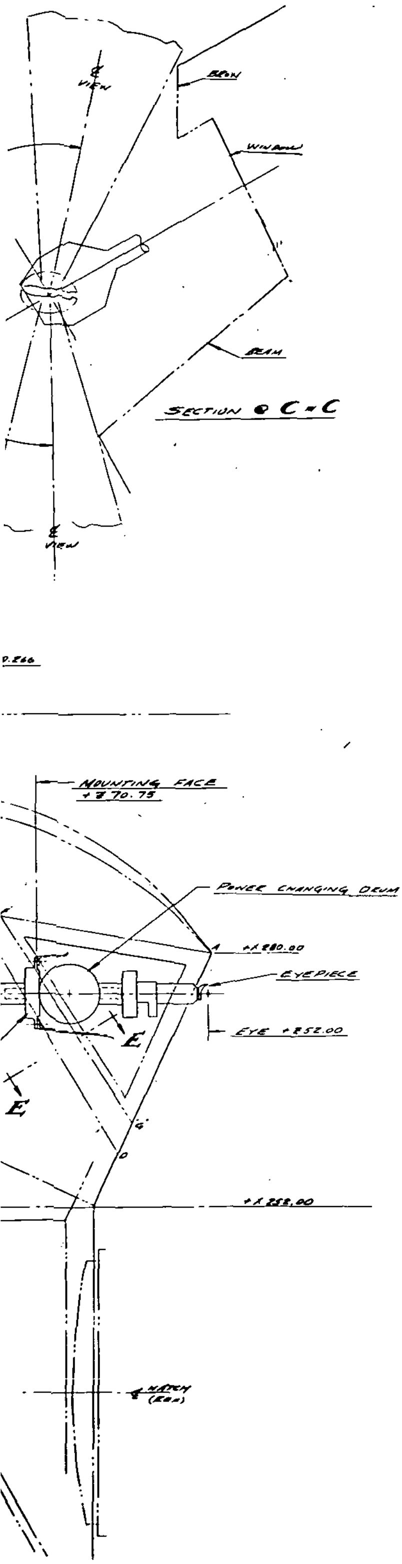
6.5-23
(1)



HEAT SHIELD
℄ VIEW
℄ VIEWFINDER
FRONT BEAM HEAT SHIELD
135°
52°
SECTION @ B-B LOOKING DOWN
132°
61°
℄ SYM
30° VIEW (TYP)
45°
A
D
A
B
C
D
30° TYP
+X 275.50
+X 232.00
FRONT BEAM
1.95 REF
FRONT VIEW LOOKING AFT
HATCH
+X 296.481
LUNAR SURVEY VIEWFINDER KOLLSMAN CONFIGURATION #4
℄ VIEWFINDER & ROLL AXIS
℄ VIEW
2.75 (REF)
ARTICULATED MIRROR
PITCH DRIVE
VIEWFINDER SUPPORT & BEARING SECTION
+X 250.587
+X 246.180
1.0
SIDE VIEW R.H. LOOKING OUTB'D.

6.2-23

(2)



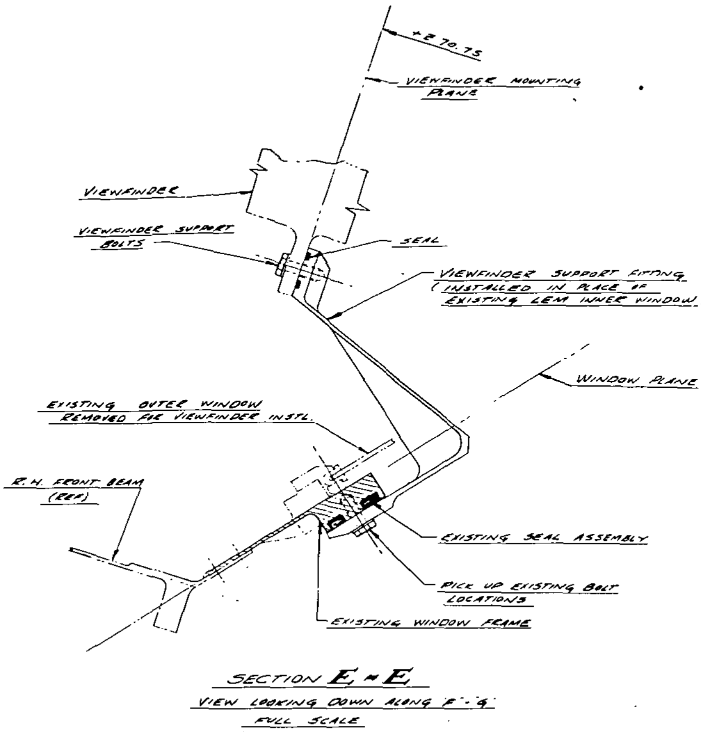
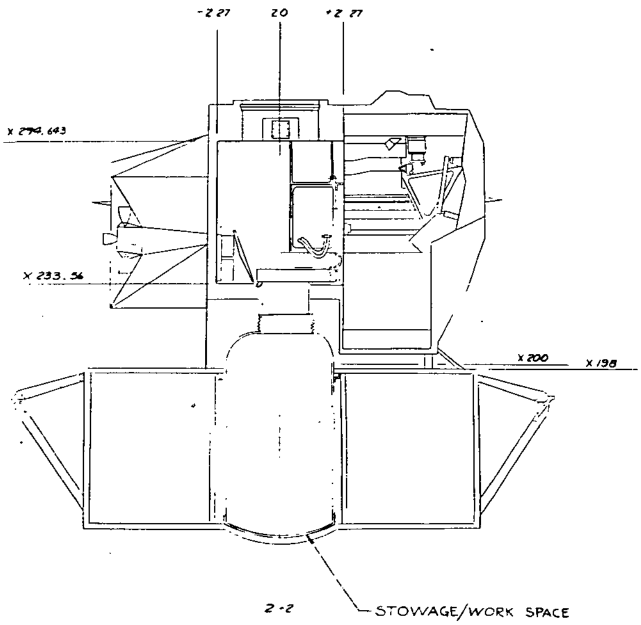
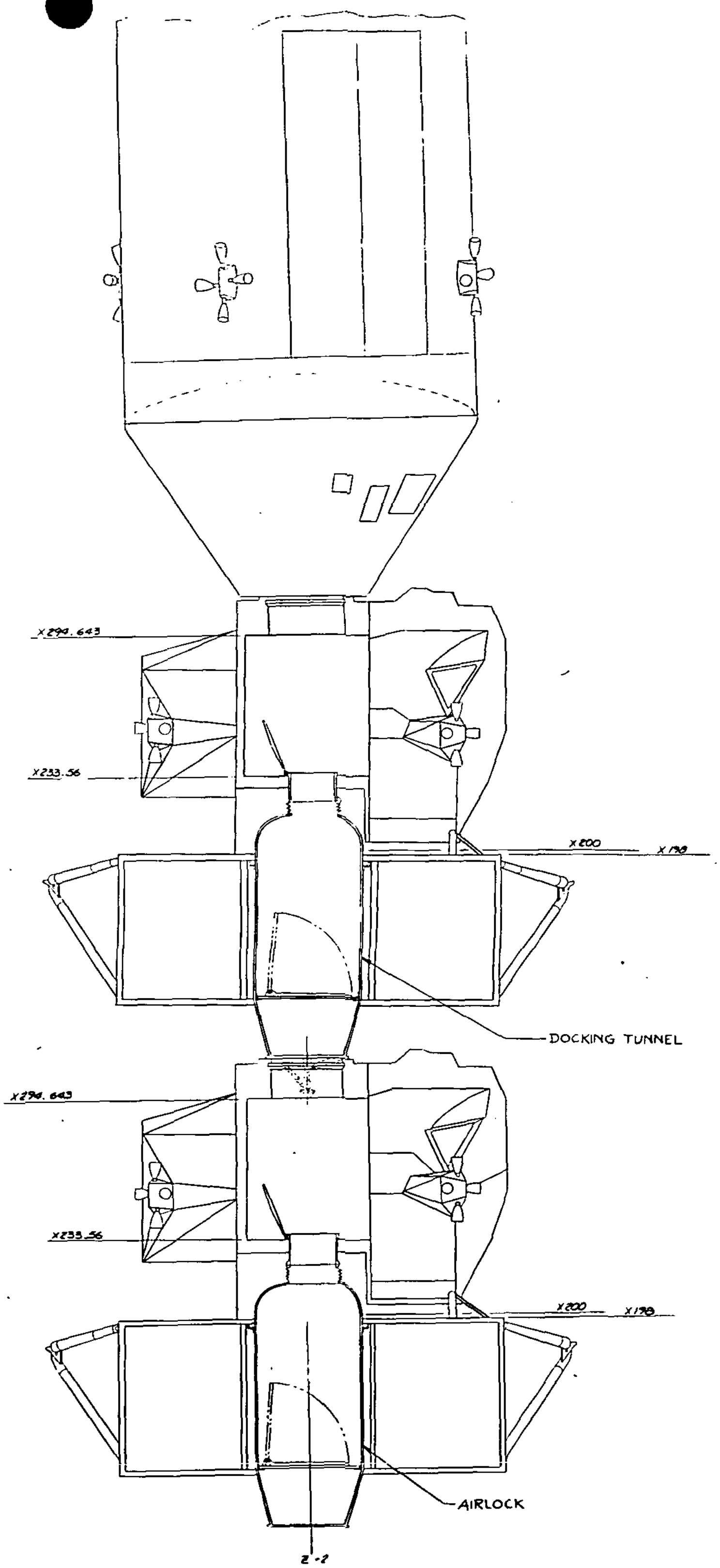


Fig. 6.2-23 Viewfinder Installation

(67)



Z-Z



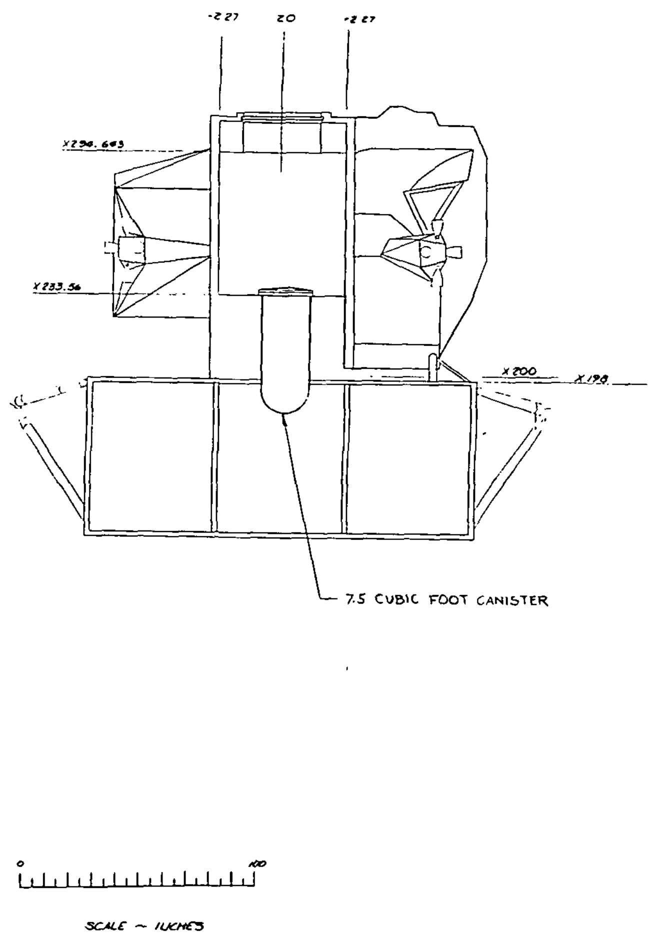
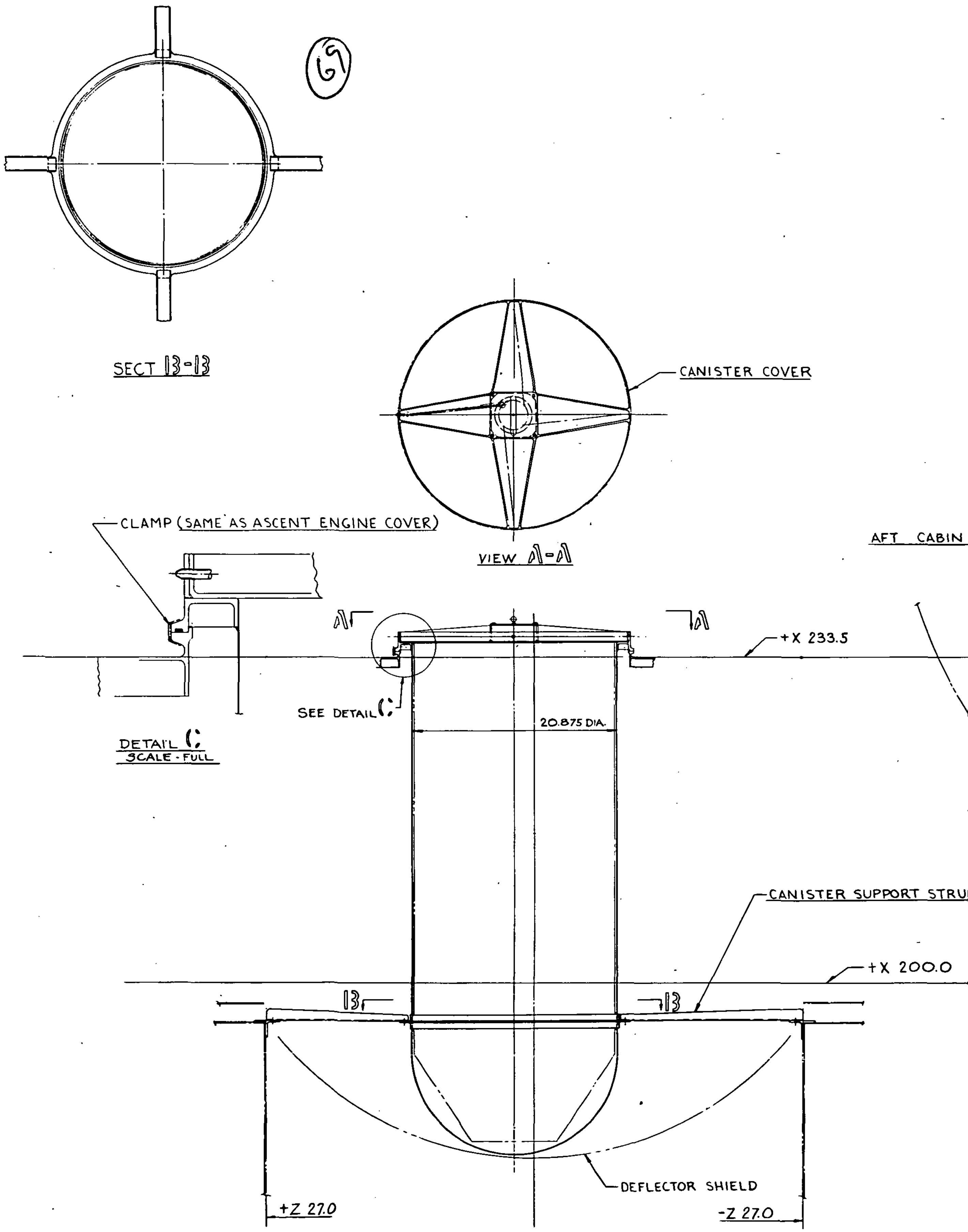


Fig. 6.2-24 Utilization of Descent Engine Bay Phase II Lab


69
SECT 13-13
CANISTER COVER
CLAMP (SAME AS ASCENT ENGINE COVER)
VIEW A-A
AFT CABIN
A
A
+X 233.5
SEE DETAIL C
DETAIL C
SCALE - FULL
20.875 DIA.
CANISTER SUPPORT STRU
+X 200.0
13
13
DEFLECTOR SHIELD
+Z 27.0
-Z 27.0

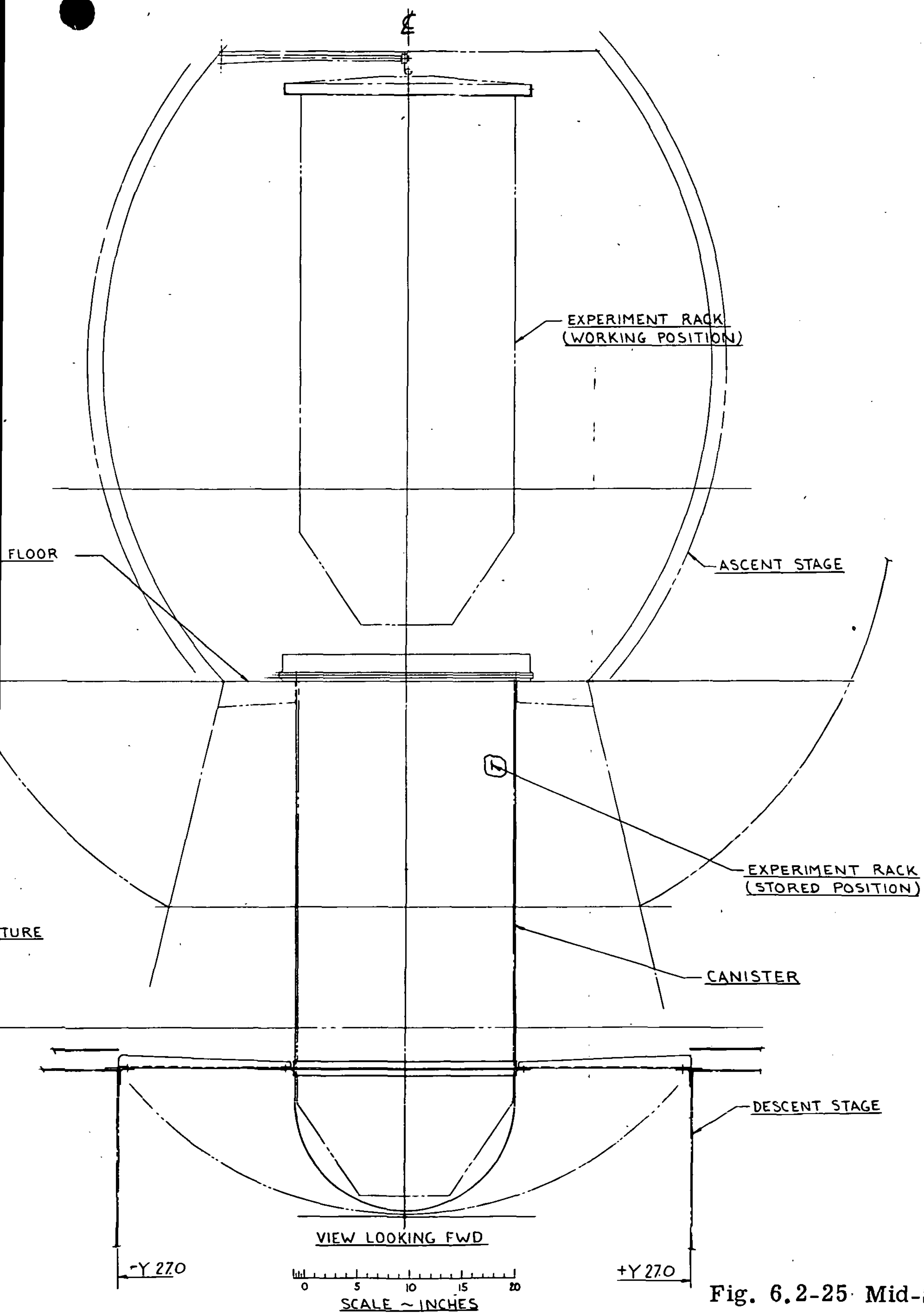


Fig. 6.2-25 Mid-Section Canister

Grumman

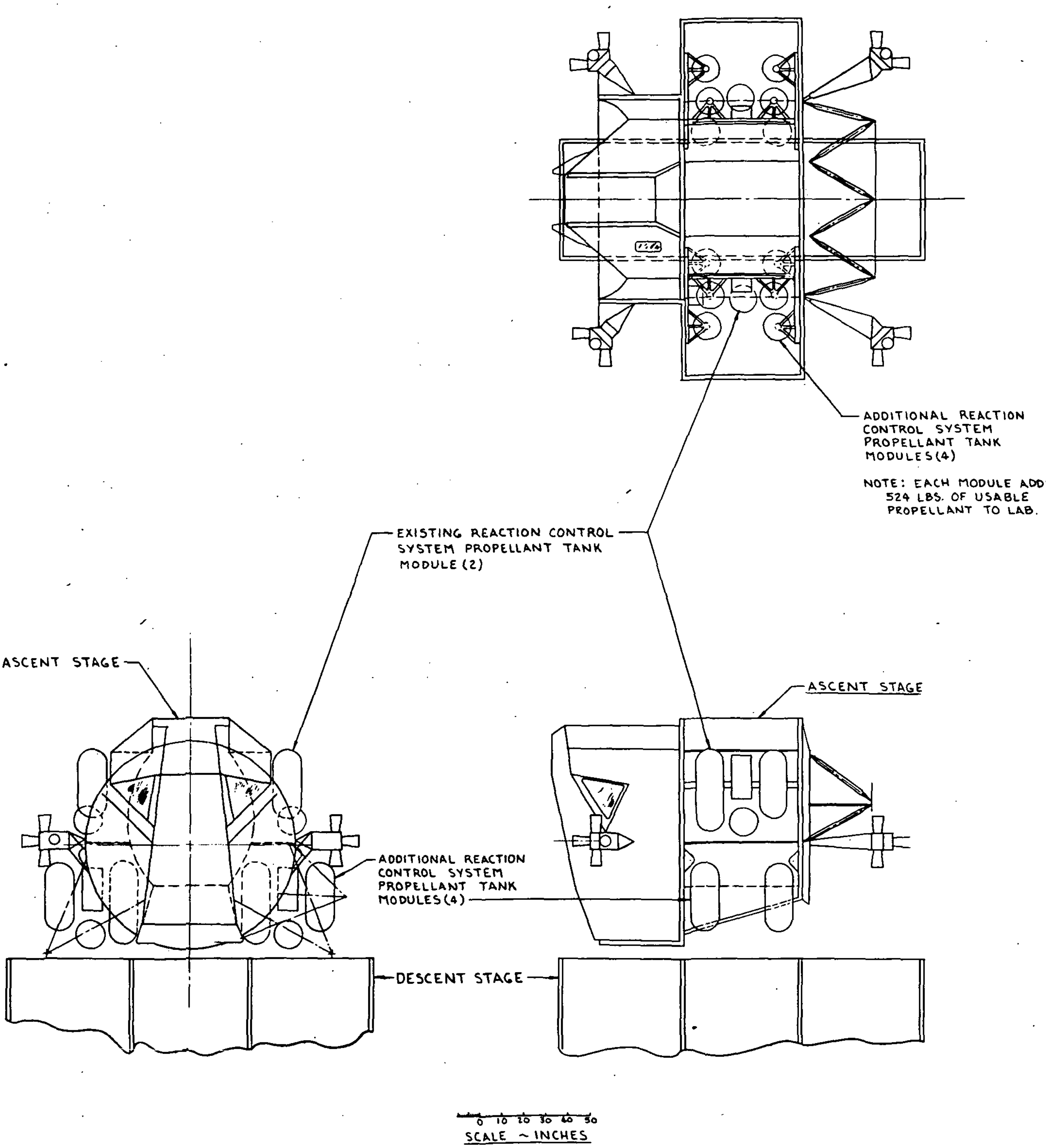
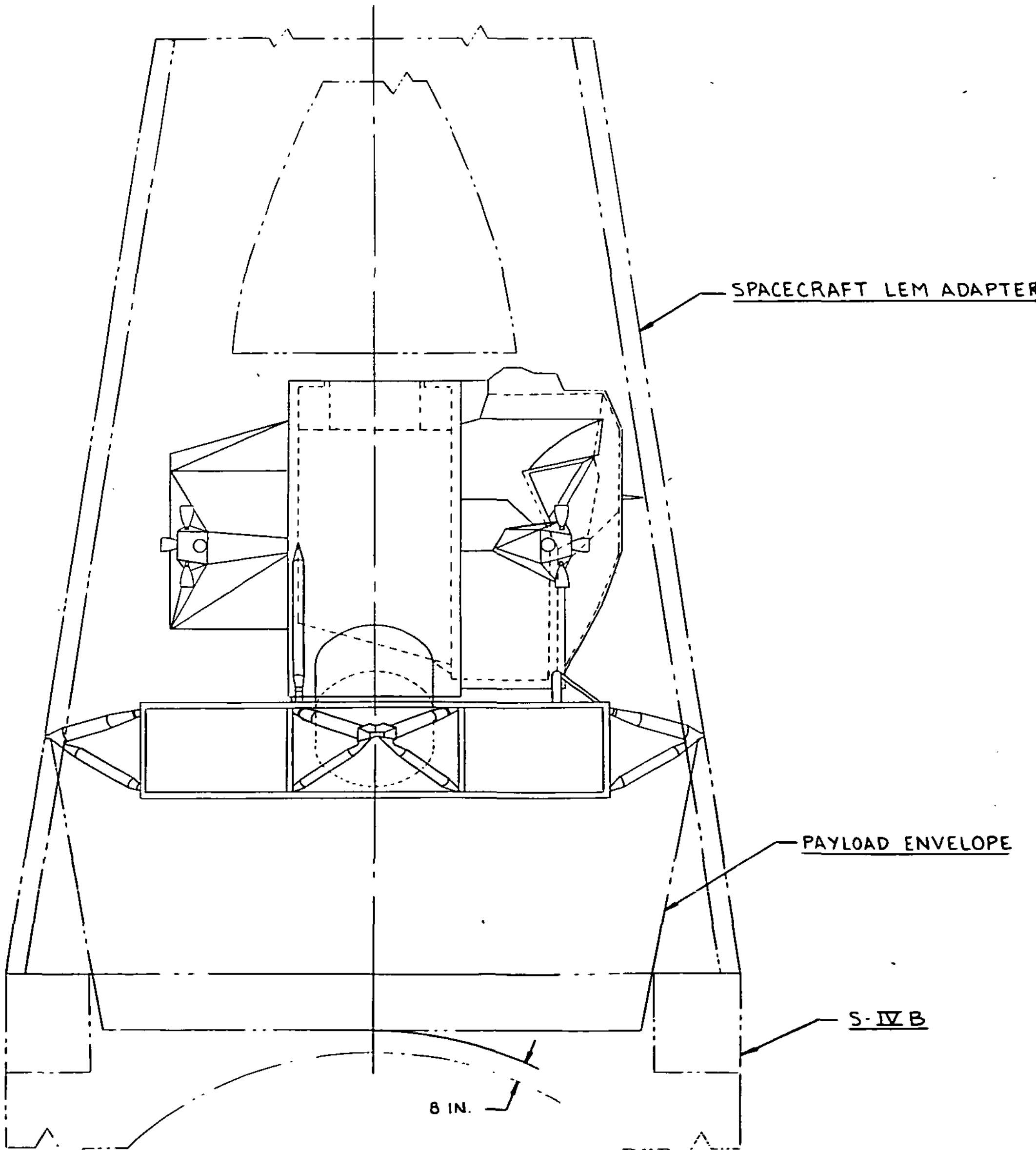
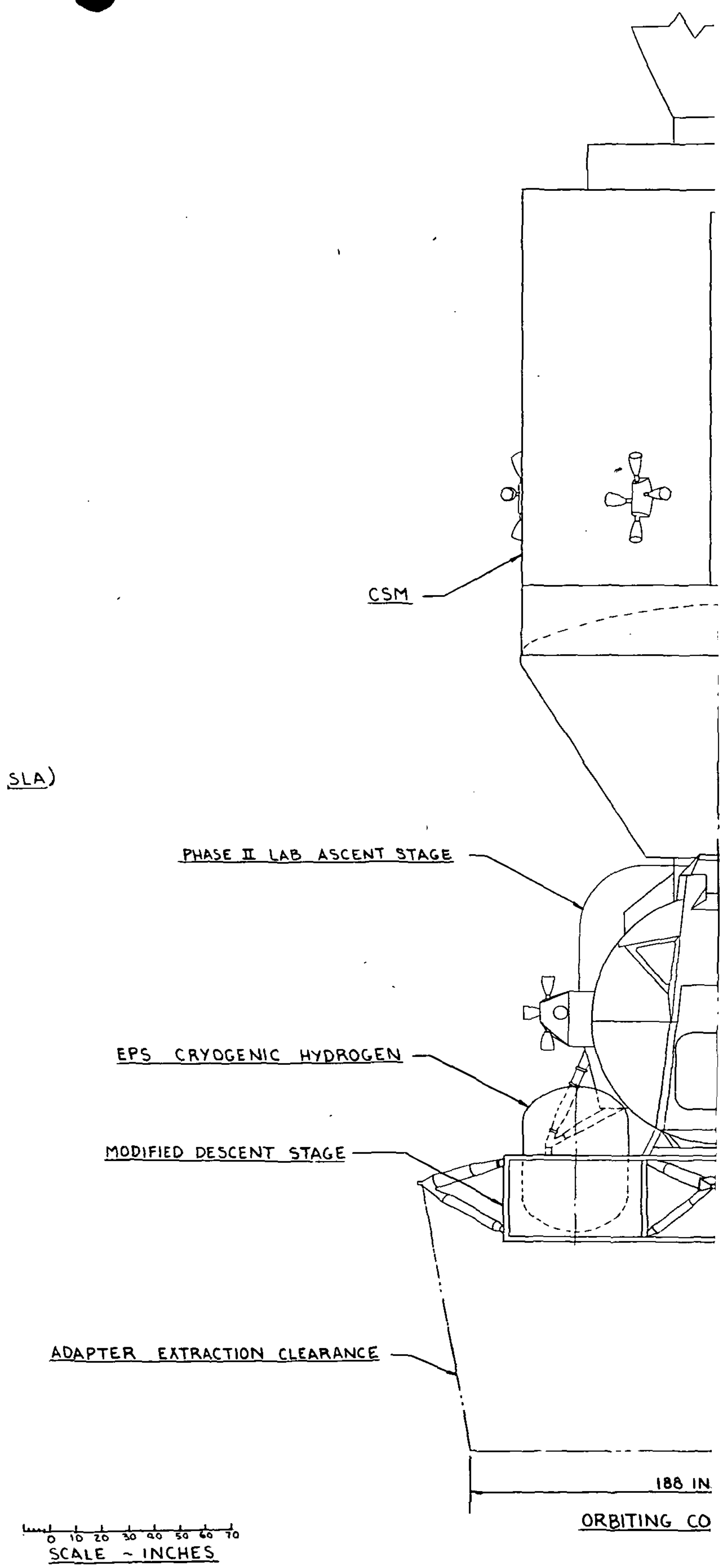


Fig. 6.2-26 Alternate Reaction Control System Propellant Tank Module Locations Phase II Lab



LAUNCH CONFIGURATION



SLA)
CSM
PHASE II LAB ASCENT STAGE
EPS CRYOGENIC HYDROGEN
MODIFIED DESCENT STAGE
ADAPTER EXTRACTION CLEARANCE
188 IN
ORBITING CO
0 10 20 30 40 50 60 70
SCALE ~ INCHES

2

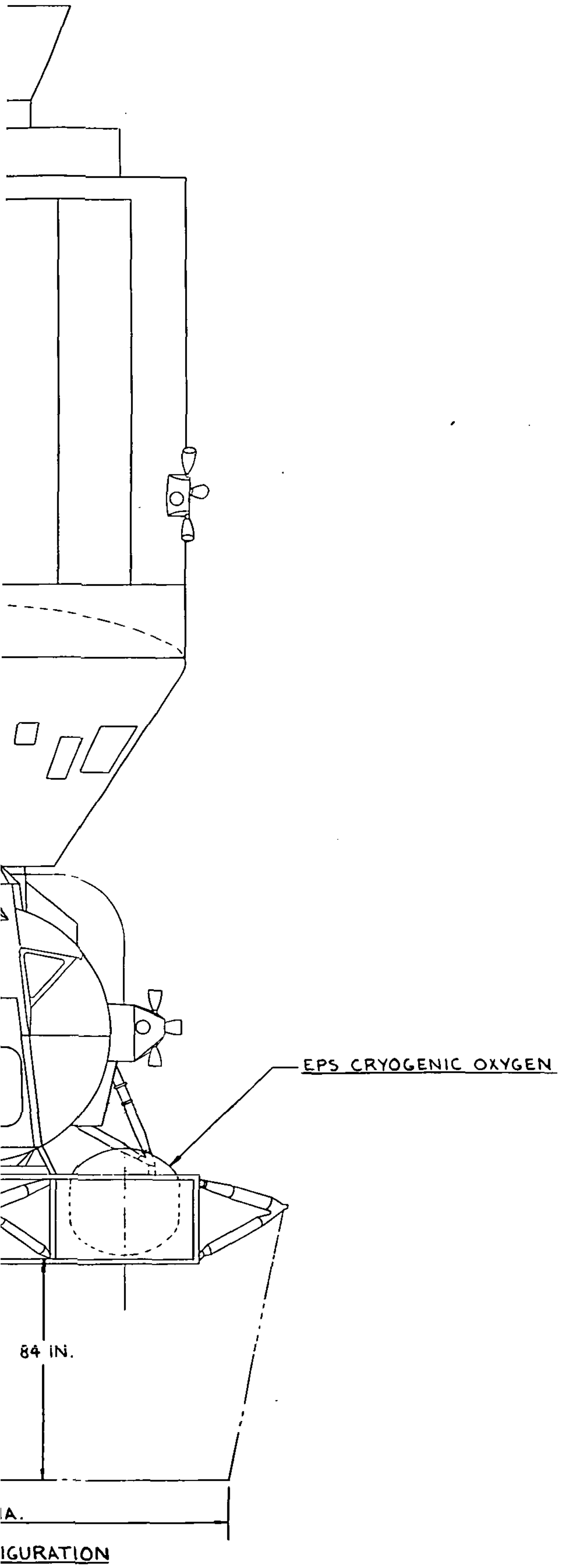


Fig. 6.2-27 Low Profile Descent Stage Configuration per Flight Modification

3

Grumman

6.3 CREW PROVISIONS

6.3.1 Ground Rules

- The CM is to be considered the basic mission and communication center.
- The CM will be the crew living quarters.
- The Phase II Lab will be used mainly as a laboratory.
- The CM will be used as crew shelter during unusual radiation or meteoroid activity.
- CM ECS will incorporate a two-bed thermal swing molecular sieve for CO_2 removal. The present LiOH system shall be retained as a backup for emergencies and for pressure suit operations.
- The CM is required to store three man-days of food and potable water for crew use.
- An airlock will be incorporated.
- The spacecraft will normally carry a three man crew, with no more than two men in the Lab at one time.
- There shall be no requirement that one crew member will be in pressure suit at all times.
- Untreated biological wastes shall not be allowed to become free residue in space.

6.3.2 Assumptions and Background Data

- All Phase II Lab missions shall be 45 day duration with crew members in a shirtsleeve environment.
- The waste management, waste disposal systems, personal hygiene, exercise, rest, medical and recreation equipment is assumed to be located in the CM.
- Crew members will sleep in a soft suit on the CM couches. The space suits will normally be dried, serviced and stowed on the couches.
- Food for the mission in excess of three man-days will be stored in the Lab.
- Water management for food preparation and consumption will be accomplished in the CM.
- Food quantity shall be based on an individual calorie intake of 3000 K calories per man per day.
- Rechargeable batteries will be used for the PLSS.
- Each crew member requires a new constant wear garment (CWG) every two days.
- One pressure garment, one liquid cooled garment, one helmet and one thermo-meteoroid garment are located in the CM storage containers.
- No CM-LiOH cartridges will be carried in the Lab.

6.3.3 Recommended Configuration

Figure 6.3-1 represents the internal arrangement of the Phase II Lab. It shows console arrangements, equipment stowage and work areas.

There is no change in panels or console structures, from the LEM except for addition of folding work tops on both sides and a stowable seat, which can be installed quickly on the left or right hand side of the cabin. Four cu ft of food is located under the cabin floor.

Suit servicing kit, gloves and garment storage areas in the cabin are unchanged. A PLSS is stowed on the inside of the forward hatch.

The view looking outboard, RH side, shows ECS package and related equipment unchanged from the basic LEM, except for the addition of a flexible duct to the blower.

The view looking outboard, LH side, shows the battery charger, 9 PLSS batteries, 5 LiOH containers, recharge station and 9.7 cu ft of food. The PLSS recharging station and LiOH containers remain unchanged.

The aft bulkhead (-Z27) stores 2 CSM type tape recorders, with extra tapes, mounted on cold plates.

The shaded areas indicated available experiment storage volume which totals approximately 6.63 cu ft.

6.3.3.1 Items Removed from the LEM

- CABIN SECTION

  Arm rests (2) RH side
  Translator assembly (1) RH side
  Attitude controller (1) RH side
  T.V. camera and lenses RH side
  Extra film (sequence camera) RH side
  Film and tape (RH side)
  Thermal garment (RH side)
  Restraint system (both sides)
  DSKY and IMU

- MID SECTION

  Waste management system
  Speciment return containers (2) mounted on LH side
  Still camera mounted on LH engine cover
  Water probe and holster LH side
  LiOH container (ECS) engine cover (1)
  EVA life line (1)

- BULKHEAD -Z27

  CDU
  LGC
  PSA
  Signal conditioner
  Part of the cold plate assembly

- EXTERNAL

  Recognition Lights

6.3.3.2 Items Added or Modified

- PLSS Units

  The Lab carries two PLSS units, one at the recharging station in the mid section (as in the basic LEM), and the other stored on the inside of the forward ingress/egress hatch (orbit mode).

- LiOH (PLSS cartridges) (5 1/2 dia x 11 in)

  The 45 day mission requires 44 LiOH PLSS cartridges. Three cartridges are stored in 3 PLSS and an additional 5 units are stored internally in the mid section LH side (Fig. 6.3-1). The remaining 36 cartridges are stored externally (Fig. 6.3-2). Resupply from the external stores can be accomplished on any EVA. All external storage items will have suitable environmental protection.

- PLSS Batteries (3 1/2 x 4 3/4 x 6 1/2) 16.8 v each

  Twelve batteries are recommended for the Phase II Lab. These are rechargeable batteries with a useful discharge expectancy of three hours plus one hour emergency. Batteries can be recharged no more than four times and have a ten hour charge time. Three batteries will be stored within the PLSS units and the remaining nine will be stored in the mid-section LH side, next to the battery charger. (Fig. 6.3.-1).

- Battery charger (3.5 x 5 x 5 x 6.0) weight 5.0 lb Max.

  The battery charger is installed in the mid section LH side at -Z22.

- ECS Duct

  Environmental control of the Lab will be supplied from the CSM by means of the flexible duct feeding through the Lab docking tunnel to the blower assembly. The duct will have a quick disconnect fitting in the tunnel area to provide separation and allow hatch closure for EVA depressurization and for emergencies.

- Food

  Food storage for three men for a 45 day mission requires a volume of 13.7 cu ft based on 3000 K calories per man per day. The CM is required to store three man-days of food.

  It is assumed that light weight food containers will be used. Approximately 179 in^3 (2.3 lb) is allotted for each man per day. Food will be of the freeze-dried variety and will require water for reconstitution. The eating area will be in CM. Four cu ft of food will be stored under the cabin floor and remaining 9.7 cu ft of food will be stored on the LH side in the midsection.

- Voice Recorder (1 3/4 x 4 x 5 7/16)

  Two identical, LEM voice recorders will be carried. They will be located on +Z27 bulkhead, LH side.

- CSM tape recorders (5.5 x 9.5 x 22) 44 lb each

  There are two CSM recorders, each mounted on a cold plate located on the -Z27 bulkhead. One extra tape is stored on the cover of each recorder. Each tape measures 8 in. dia x 1 in deep.

- Garments

  The 45 day orbit mission requires 66 constant wear garments (CWG) allowing for changes every other day. Each crewman will initially be wearing one garment for a total of 3. Six garments will be located in the cabin area (RH side), and remaining 57 (7.5 cu ft) will be stored externally (Fig. 6.3-2). Two liquid cooled garment (LCG) 0.5 cu ft each are stored on the LH side of the cabin section.

  For drying out the LCG can be stored with the soft suits on the unoccupied CM couches.

  One anti-meteoroid/thermal garment is stored on RH side of cabin area. Another is stored in CM.

  Facilities are also included for the hanging of two pressure suits on the -Z27 bulkhead in the mid section, so that they are readily available to the astronauts. They are normally stored on the unoccupied CM couches. In addition the CM stores one pressure garment, and one liquid cooled garment for contingency use by the crew member occupying this section.

- Helmets

  Two helmets are located in mid section LH side as shown on Fig. 6.3-1.

- Work Tables

  Work tables measuring 17 x 24 in. are installed on both sides of the cabin, hinged on the lower side consoles. When stowed, they lie flat against the face of the garment stowage sections (Fig. 6.3-1). A secure latching mechanism is provided in both positions.

- Seats

  One dual-action design seat is included, hinged from +Z27 bulkhead with a 360 deg swivel head. Both joints have a mechanical braking device to hold the seat in any position. The seat head can be folded and locked for stowage against the stowed table top (Fig. 6.3-1).

Two hinge fittings are supplied on +Z27 bulkhead to permit use of the seat on either side of the cabin. The same procedure for stowing is incorporated on both sides of the cabin.

A crew member restrain belt is attached to the seat head.

- Lighting

A dome light is incorporated in the mid section to illuminate the mid cabin.

Individually controlled lighting for both work tables in the cabin section is provided in the middle side consoles.

Two external flood lights are provided on the descent stage. Each light is separately controlled from inside and outside the vehicle.

6.3.3.3 Restraint

The current restraint harness concept is illustrated in Fig. 6.3-3, which shows the vest used for body attachment and the installed harness in a shirtsleeve environment.

The harness consists of a vest, closely fitting the human body to maintain contact with and transmit load to the trunk, through contact with the shoulder, rib and waist. Adjustment is provided in the chest and waist areas. The waist portion of the vest is similar to a belt in that it transmits load to the pelvic area. This part of the vest contains a number of hooks which are designed to pass through holes in an outer garment such as coveralls. An outer adjustable belt would then be attached to the hooks. A semi-rigid strap runs between the legs and fastens to the front and rear of the outer belt. A flexible, quick disconnect cable assembly picks up the strap. Included in the cable assembly is a spring and turnbuckle load cell which attaches through a universal joint to a pickup point in the floor. With the astronaut in an errect standing position, the turnbuckle is adjusted so that the load between the feet and the floor equals full or partial body weight. The applied load can be relieved by use of the quick disconnect or by double knee flexion and the astronaut will find himself tethered but unloaded.

When positioned at a work station, the universal joint attached at the floor will allow for controlled body rotation of 360 deg. The combination of spring and universal joint provides for extended reach actions as well as limited side-to-side motion.

6.3.3.4 Experiment Volume Available

Section	Location	Volume in cu ft
Cabin Section	RH forward console inboard	0.35
	RH forward console outboard	0.25

Section	Location	Volume in cu ft
Cabin Section (Cont.)	LH garment storage comp	1.8
	LH below side console	0.45
	RH below side console	0.28
	-Z27 bulkhead	3.50
	TOTAL	6.63 cu ft

6.3.3.5 Control and Displays

The structural design of the consoles and the shape of the panels has not been changed from the LEM. The panels of the cabin section consoles have been modified to accommodate the Lab subsystem requirements as shown on Fig. 6.3-4. Available area of panels for incorporation of experiment oriented controls and displays is shown in Table 6.3-1.

Table 6.3-1

Available Control and Display Area

Available Panel Area	
Panel or Console Number	Area in Sq in.
I	137
II	44
III	12
V	150
VI	262
TOTAL	605 sq in.

The following additional area is available if the Rendezvous Radar and DSKY are not used.

III Radar	64
VIII DSKY	112
	176 in^2

6.3.4 Baseline Configuration

The baseline configuration is the same as the recommended except that it does not carry an airlock. CSM LiOH containers are also carried.

6.3.5 Alternate Configuration - Airlocks

While an airlock is considered part of the recommended configuration, no specific airlock has been chosen. Various airlock configurations were evaluated during the course of this study. The most promising of which are presented in Fig. 6.3-5 and 6.3-6.

Airlock "A" is mounted off the front hatch, is of the expandable type and cylindrical in form. It measures approximately 80 in. long, 40 in. in diameter and comprises a volume of 65 cu ft. This airlock can be fully compressed to fit inside the shroud envelope for launch and represents an adequate planform when expanded, for an astronaut, with a backpack to perform ingress and egress maneuvers, (Fig. 6.3-5). The difficulty to be considered with this airlock, is that it requires the assistance of a second astronaut to close the Lab hatch prior to the opening of the 36 in diameter airlock hatch during egress and the reverse procedure for ingress. Another disadvantage to be considered is the outward opening hatch which would require an additional effort in terms of the seal design.

Airlock "B" represents the Shelter airlock (Fig. 6.3-6). It is also an expandable type airlock and can be compressed within the shroud envelope at the front hatch. This represents a volume at approximately 89 cu ft and has the advantages of increased volume to allow sufficient astronaut mobility to close the Lab hatch and open the airlock hatch by himself. An inward opening hatch can be incorporated in this design. This airlock does have the disadvantage of presenting an increased volume over airlock "A".

Airlock "C" represents an attempt to utilize volume made available by removal of the Ascent and Descent Engines. Incorporated in this area is a compartment which can be used as an airlock and can also serve other purposes.

It is a rigid pressurized structure approcimately 47 in. in diameter and 88 in. in length with a volume of 85 cu ft. Access to this compartment is gained through a 20.5 in. diameter hole in the floor of the mid section. This hole represents the maximum size that can be obtained without major modification of the basic LEM floor structure. Initial tests have demonstrated the capability of an individual in shirtsleeves and in an unpressurized soft suit to pass thru this diameter.

The compartment would contain an inward opening hatch, a backpack donning station and suit loop connections. Sufficient volume is available to permit opening and closing of both hatches by one astronaut and the donning and doffing of pressure suits and outer garments.

It should be pointed out that the desirability of this concept can be greatly enhanced by increasing the entrance diameter size to allow the astronaut wearing a backpack to enter the airlock. In this manner the man-suit relationship could be fully checked out in the Lab prior to entrance into the airlock.

6.3.6 Alternate Configuration - Descent Stage Compartment

A derivative of the Descent Stage Compartment Airlock previously discussed is illustrated in Fig. 6.3-5 and 6.3-6. Shown here are configurations of this compartment used for:

- Work station and storage volume
- Storage volume
- Docking tunnel

The descent stage compartment attractively lends itself to the incorporation of a sit down work station and storage area. As shown in Fig. 6.3-5, sufficient volume is available for comfortable seating of a man on a swivel stool, a wrap around control and display console containing approximately 7 sq ft of panel area, an 8 cu ft storage volume underneath the console and 30 cu ft storage container located underneath the floor.

Shirtsleeve passage to the descent stage compartment would present no problems and a variety of experiment oriented functions could be conducted in this proposed work station. In addition, the constant wear garments and PLSS LiOH which is normally stored externally, and requires EVA's for replenishment, could be placed in the storage area with 25 cu ft still available.

Another configuration of the descent stage compartment is illustrated in Fig. 6.3-6. In this mode, the compartment is made available for equipment storage and can accommodate 54 cu ft of items with adequate accessibility. Placement of the externally stored consumables, 7.5 cu ft of constant wear garments and 5.5 cu ft of PLSS LiOH, in the compartment would still leave 41 cu ft available for storage of experiment oriented equipment. A maximum storage volume concept is also illustrated and could contain approximately 85 cu ft of storage.

The use of the descent compartment as a docking tunnel to satisfy experiment flight requirements is another consideration for this concept. This is illustrated in Fig. 6.3-6 which shows the docking probe in place and the necessary hatch. Astronaut passage could be accomplished in a shirtsleeve or unpressurized soft suit mode.

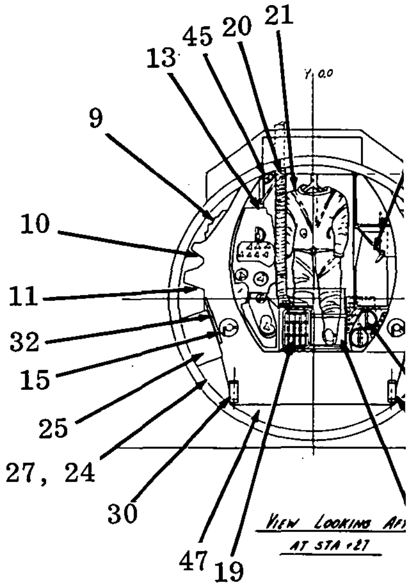
6.3.7 Alternate Configuration - Suit Loop Remove and Addition of a Rear Facing Control & Display Console

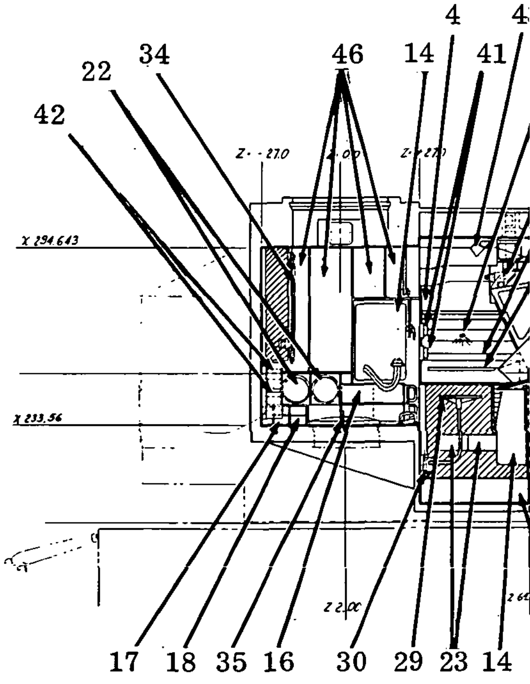
Another proposed concept envisions the removal of the suit loop from the RH side of the mid section. This modification would permit the installation of a rear facing console having an area of 4.4 sq ft and allow for an additional 10 to 12 cu ft of storage volume on the right side of the mid section. This alternate is illustrated in Fig. 6.3-7.

Justification for removal of the suit loop involves the consideration of using the CM suit loop for pressure suit checkout or foregoing the use of the suit loop completely. This is discussed in more detail in Paragraph 4.4.

KEY

1	Front Control Panel - L.H. Side No. 1
2	Front Control Panel - R.H. Side No. 2
3	Front Panel - Center No. 3
4	Circuit Breaker Panels - L.H. Side No. 4
5	Experiment Upper Panel - L.H. Side #5
6	Experiment Lower Panel - L.H. Side #6
7	Front Panel L.H. Side No. 7
8	DSKY Panel Front Center No. 8
9	Circuit Breaker Panels - R.H. Side No. 9
10	Upper Panel - R.H. Side No. 10
11	Lower Panel - R.H. Side No. 11
12	Front Panel - R.H. Side No. 12
13	ECS Unit (Suit & Cabin)
14	PLSS (2) Including Batteries (2) & LiOH Cartridges
15	Emergency Oxygen Supply System (2)
16	LiOH Cartridges (5)
17	Battery Charger
18	Batteries
19	Blower/Heat Exchanger
20	Duct
21	Soft Suits (2)
22	Helmets (2)
23	Suit Servicing Kit & Gloves (2)
24	EVA Boots (2)
25	Anti Meteoroid/Thermal Garment
26	Water Cooled Garment (WCG) (2)
27	Constant Wear Garment (CWG) (6)
28	Windows
29	Adjustable And Stowable Swivel Seat
30	Seat Hinge
31	Arm Rest
32	Work Top
33	Front Hatch
34	Upper Hatch
35	Floor Hatch
36	Cabin Floor
37	Alignment Optical Telescope (AOT)
38	Attitude Controller (R.H.)
39	Translation/Thrust Controller (L.H.)
40	Radiation Survey Meter
41	Voice Storage Recorder (V.S.R.) (2)
42	Experiment Tape Recorder (2)
43	Flood Lights - Cabin (2)
44	Work Top Lights (2)
45	Mid Section Dome Light
46	Food Storage 9.7 cu ft
47	Food Storage 4.0 cu ft

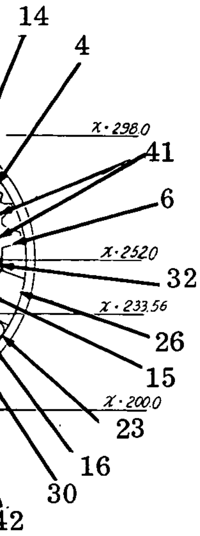


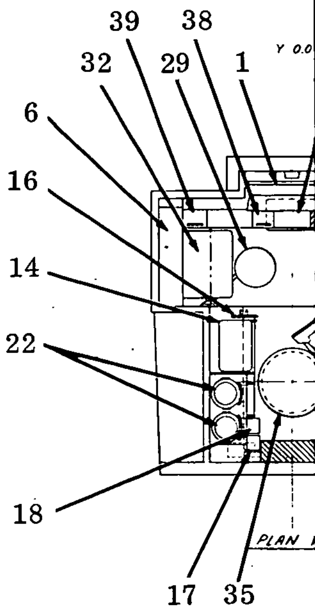


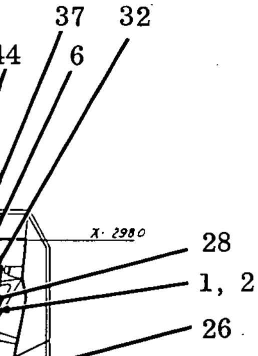
SECTION A-A
VIEW LOOKING OUTB'D L.H. SIDE

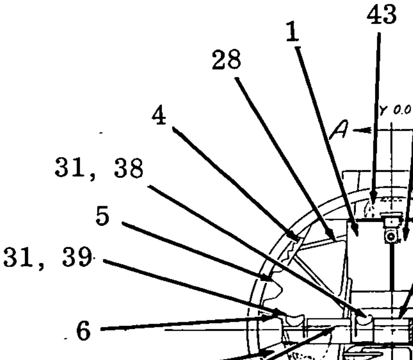
6.34

(2)

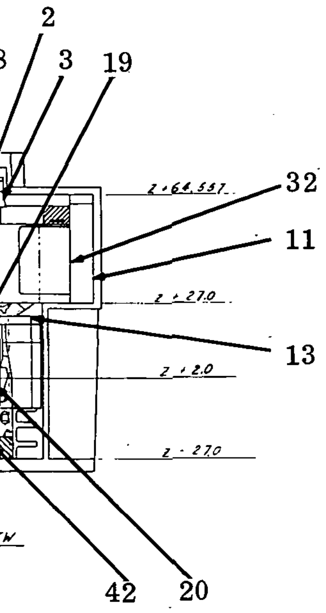

14
4
X-298.0
41
6
X-252.0
32
X-233.56
26
15
X-200.0
23
16
30
42

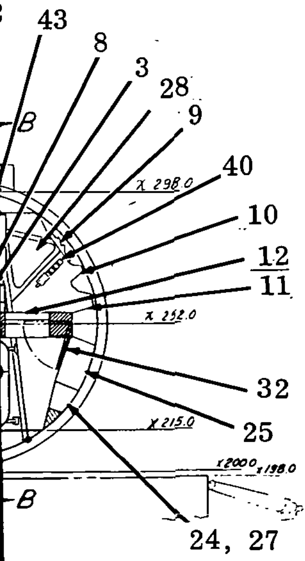

39
38
32
29
1
Y 0.0
6
16
14
22
18
17
35
PLAN

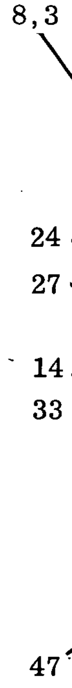

37
32
44
6
X-298.0
28
1, 2
26
X-252.0
33
X-215.0
X200.0
X198.0
47


43
1
28
Y 0.0
4
A
31, 38
5
31, 39
6
26
7
23
29
A
14
33
47
VIEW LOO

6-3-1


2
3
19
Z + 64.557
32
11
Z + 27.0
13
Z + 2.0
Z - 27.0
42
20


43
8
3
28
9
B
X 298.0
40
10
12
11
X 252.0
32
25
X 215.0
X 200.0
X 198.0
B
24, 27


8,3
24
27
14
33
47

6.3-1

(4)

0 10 20 30 40 50 60 70 80 90 100

Scale, in

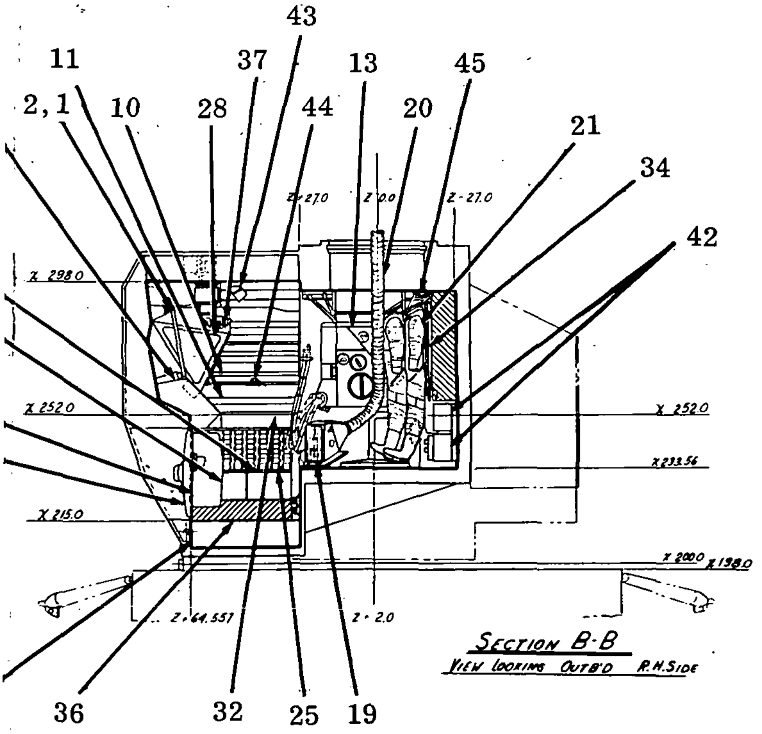
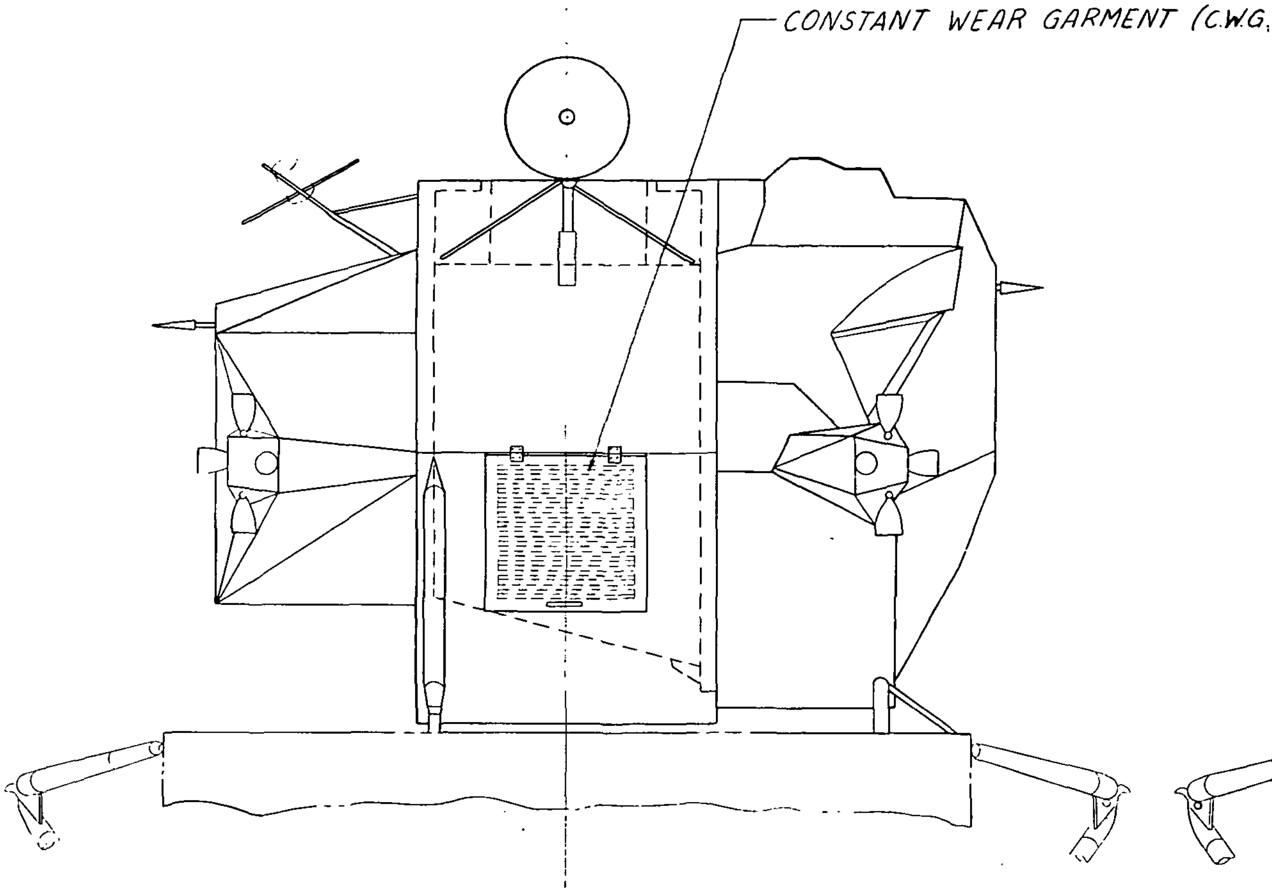


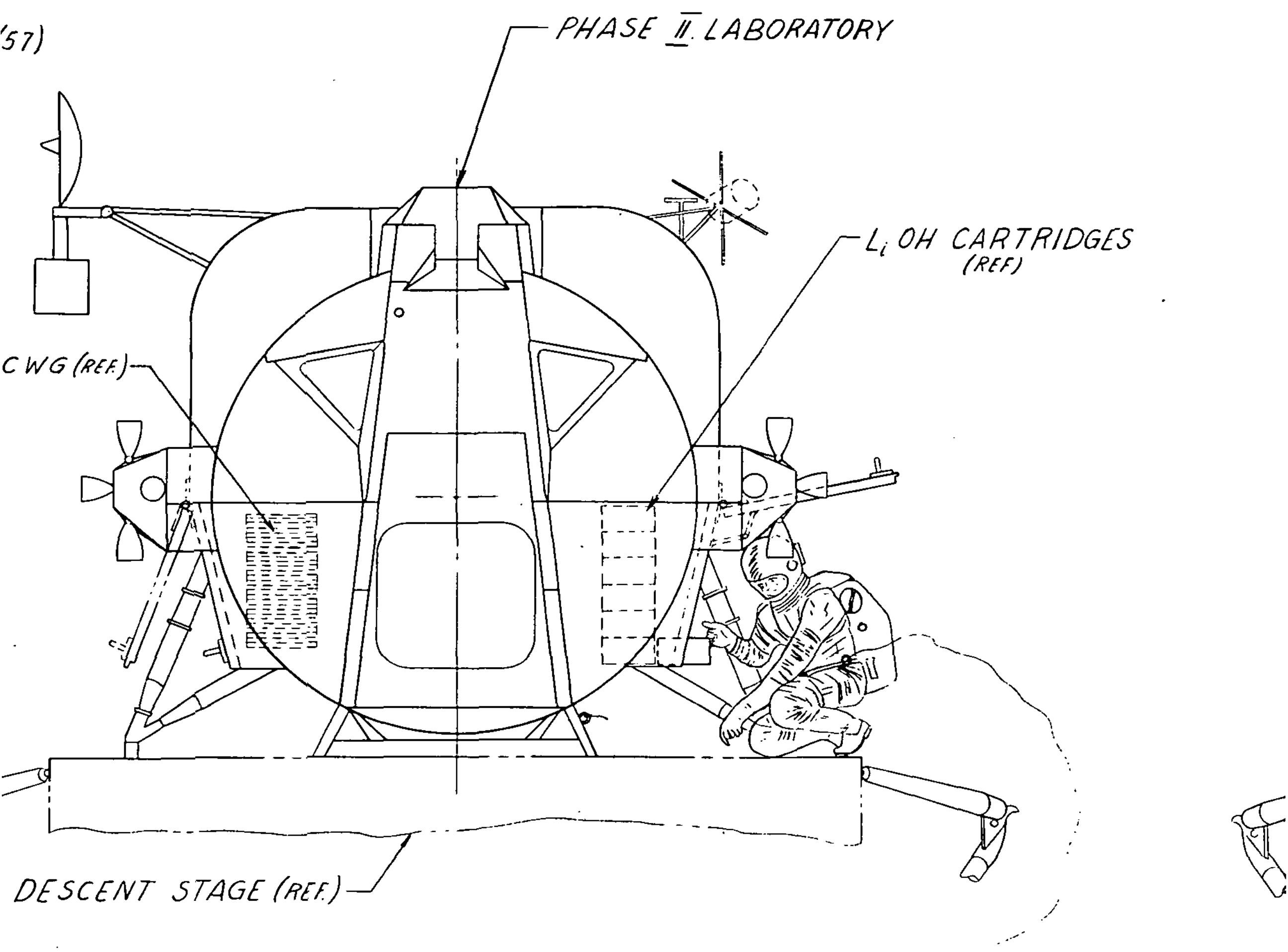
Fig. 6.3-1 Phase II Lab - Recommended Configuration - Inboard Profile

(5)

Grumman

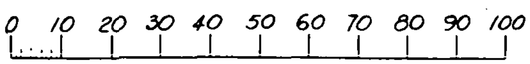


VIEW LOOKING INBOARD
R.H SIDE



EXTERNAL STOWAGE

VIEW LOOKING AFT.



SCALE 1:20

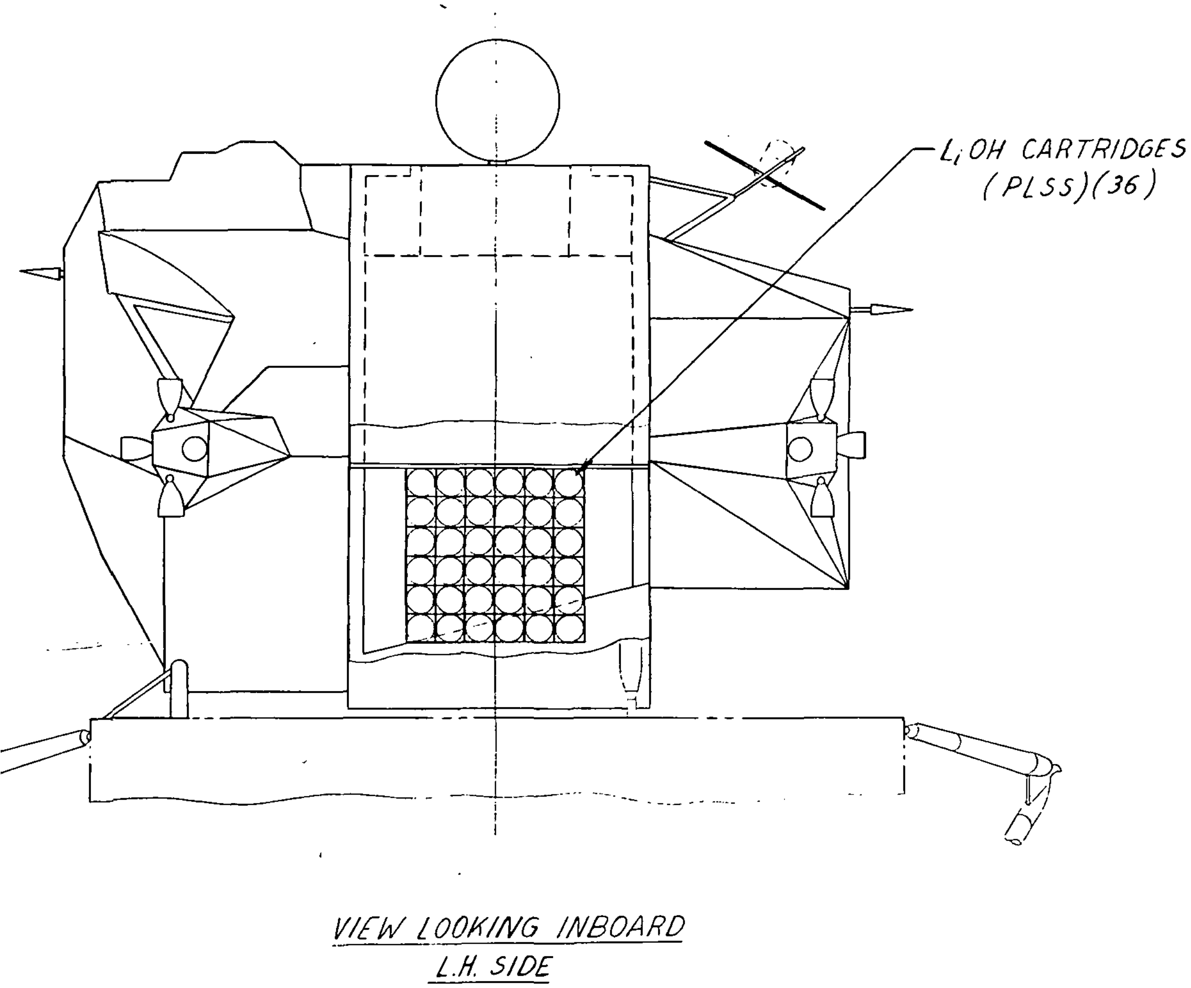


Fig. 6.3-2 External Stowage

(3)

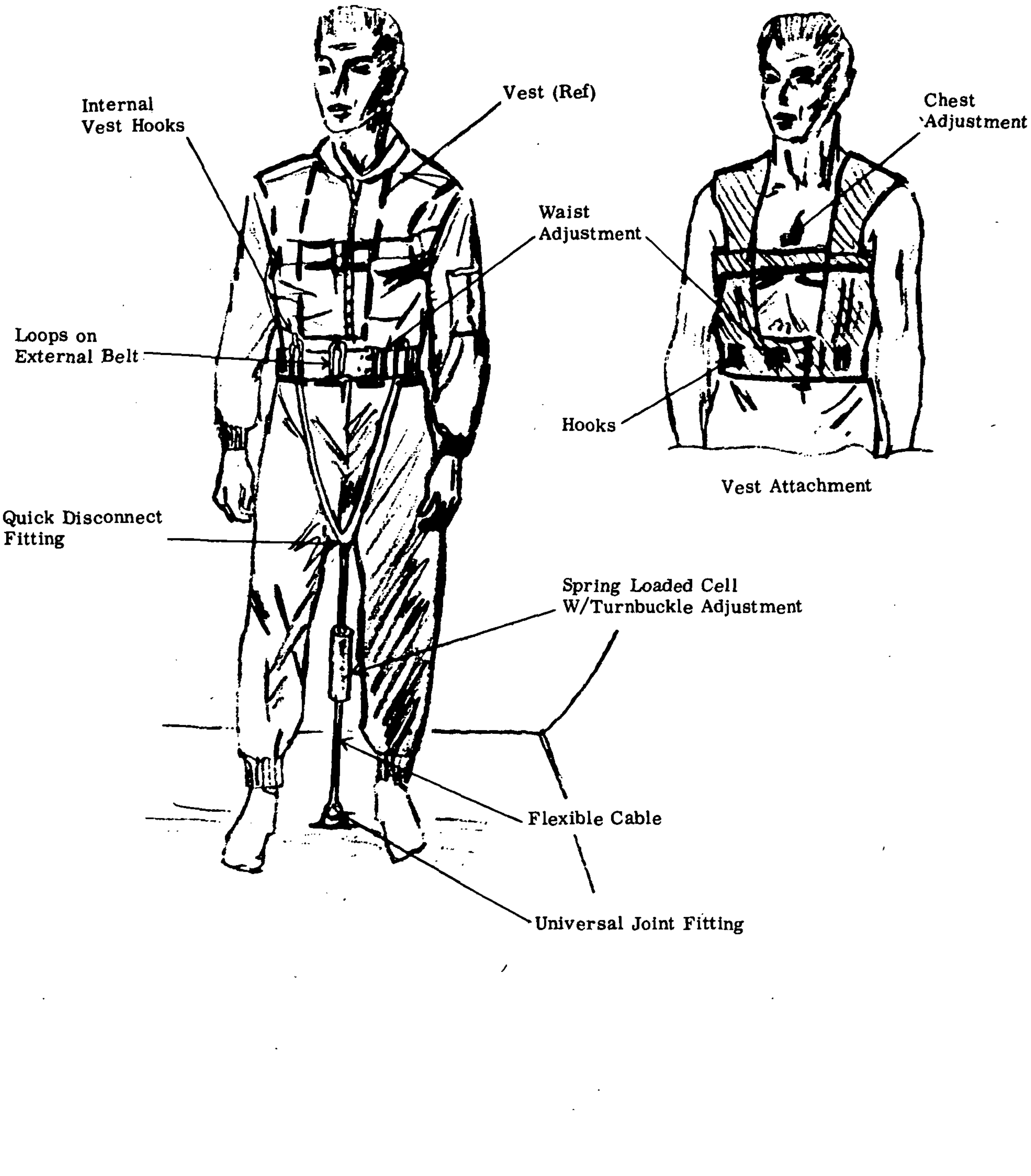
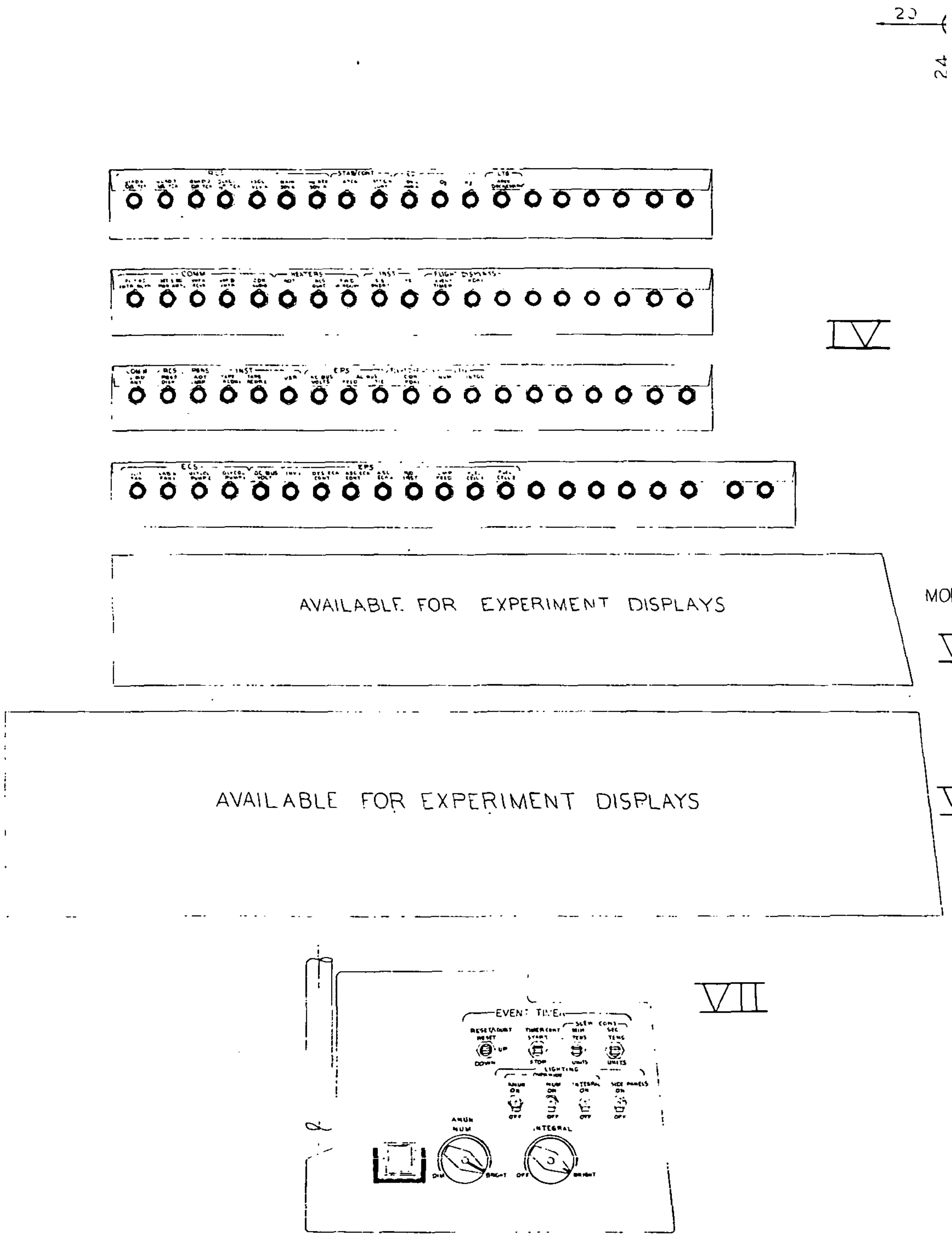
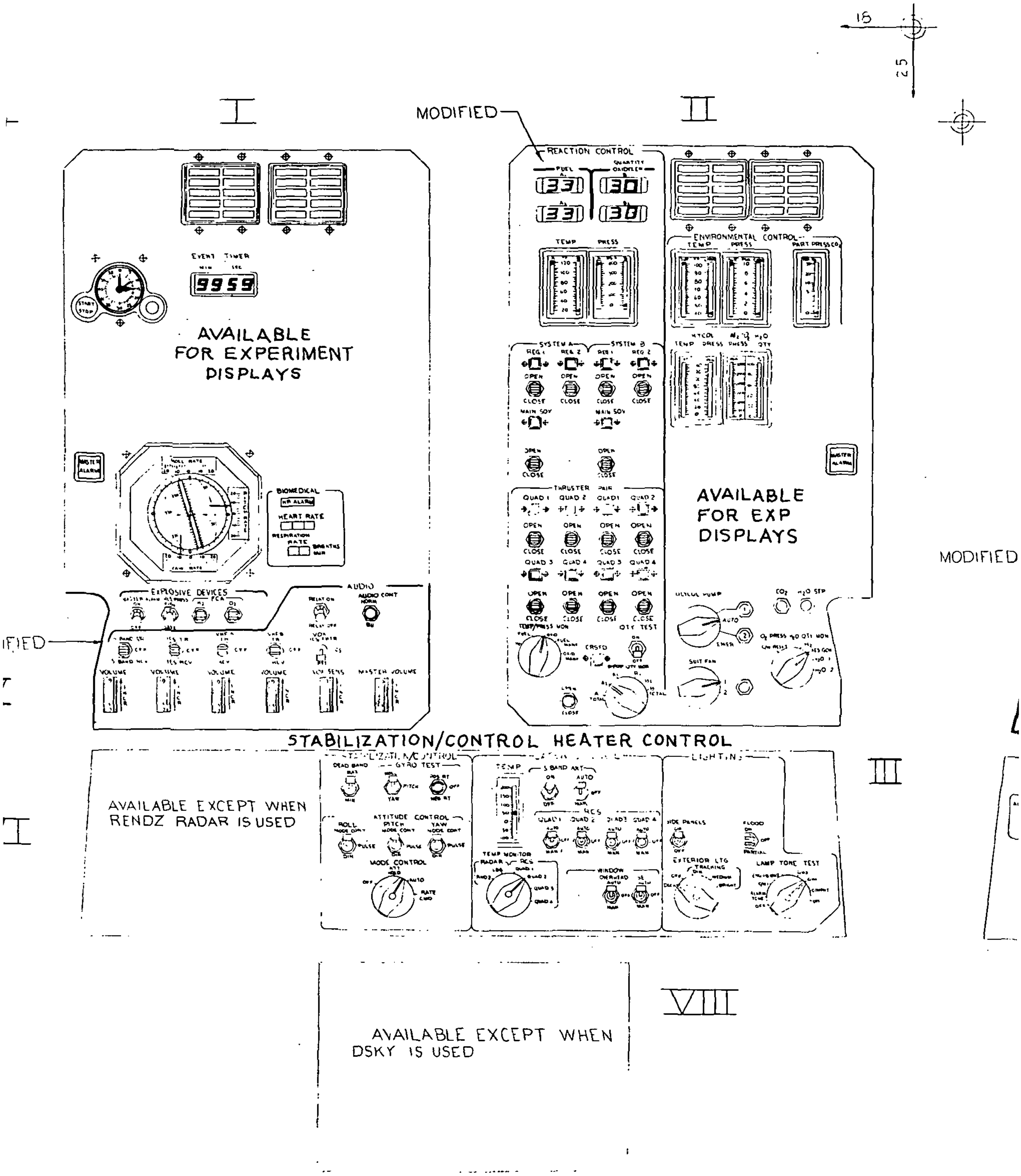


Fig. 6.3-3 Restraint Harness


IV
AVAILABLE FOR EXPERIMENT DISPLAYS
AVAILABLE FOR EXPERIMENT DISPLAYS
VII
EVENT TIMER
LIGHTING
INTEGRAL
BRIGHT

6.3 4 (1)



PHASE II LAB

½ SCALE

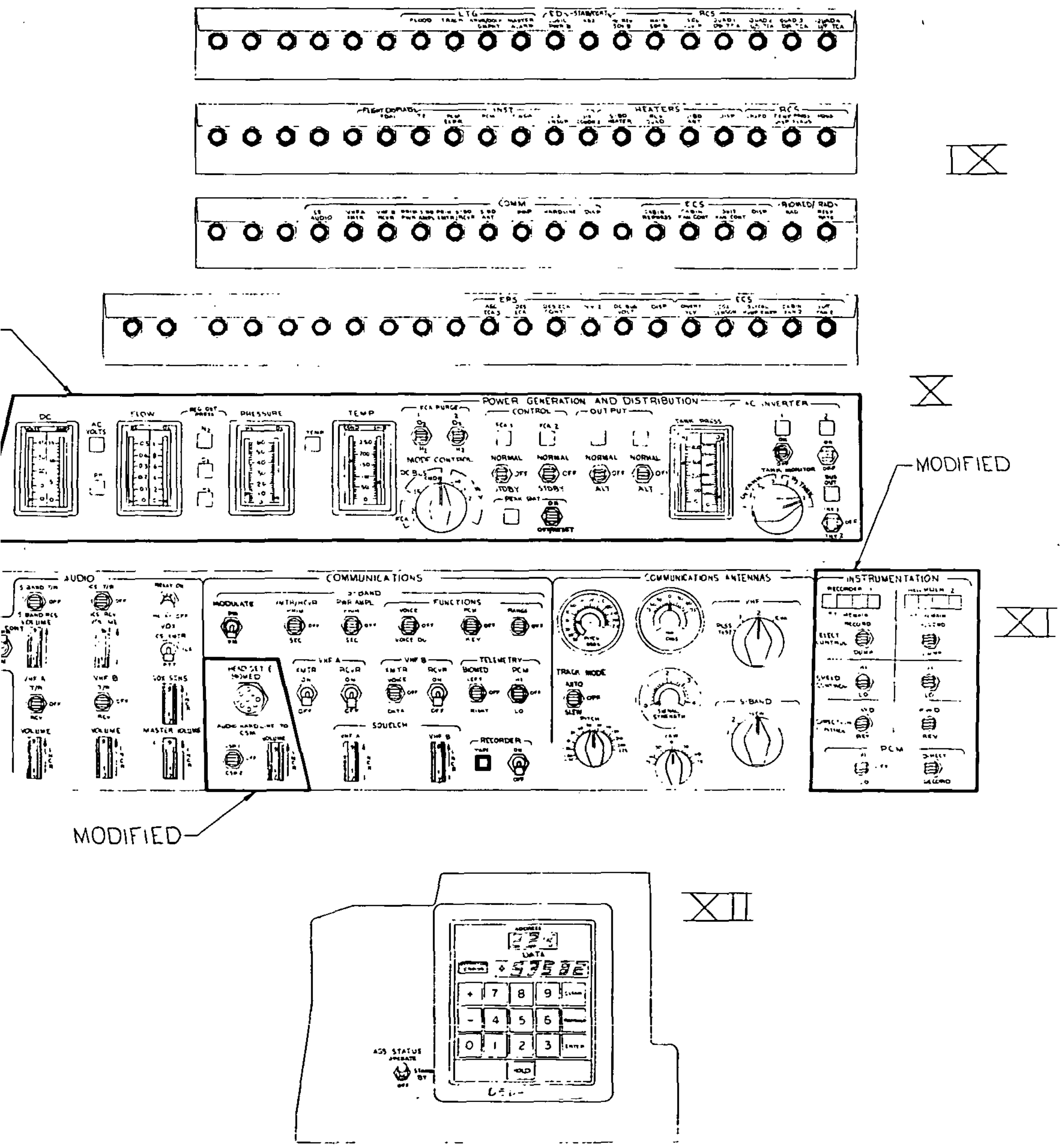
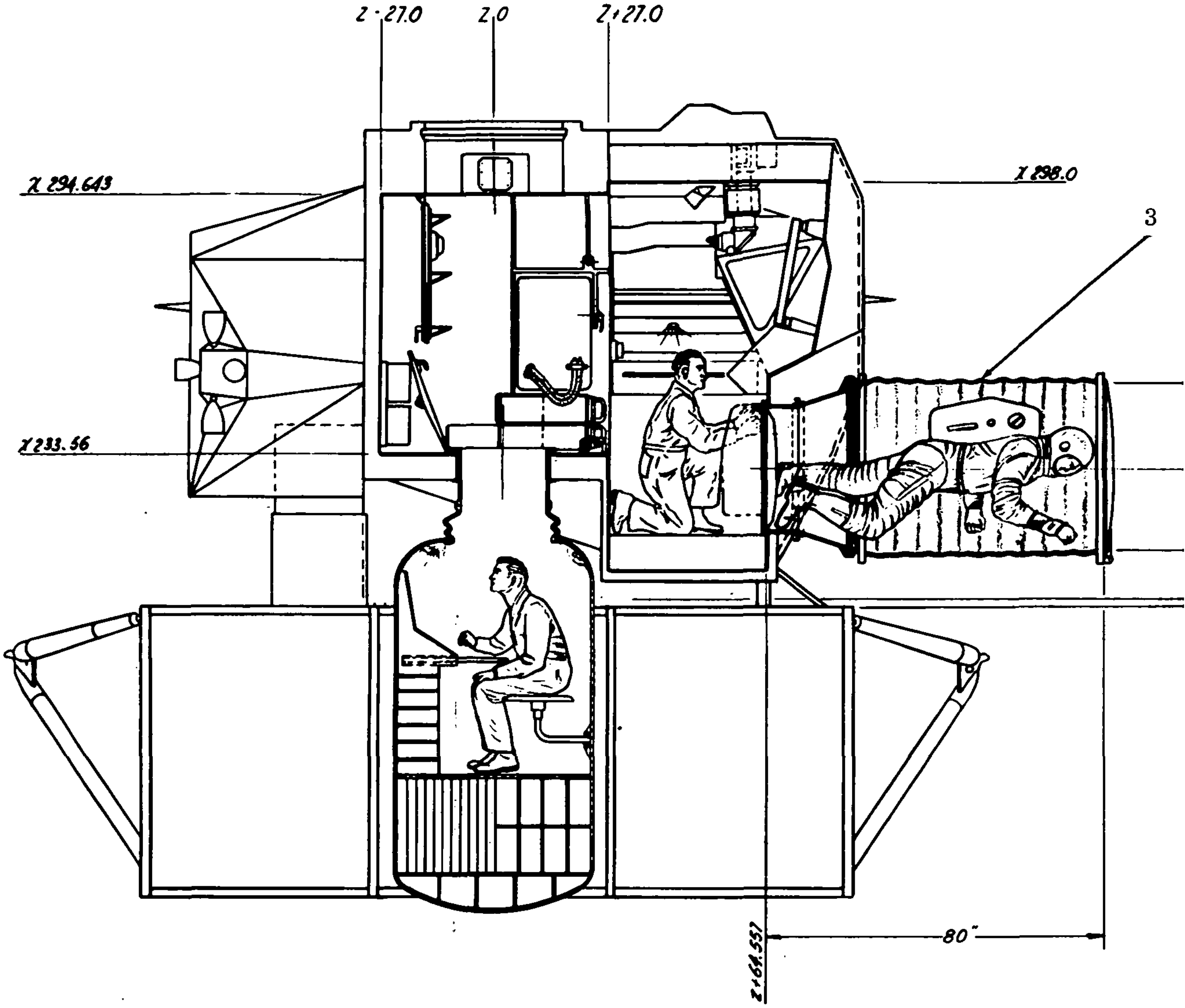
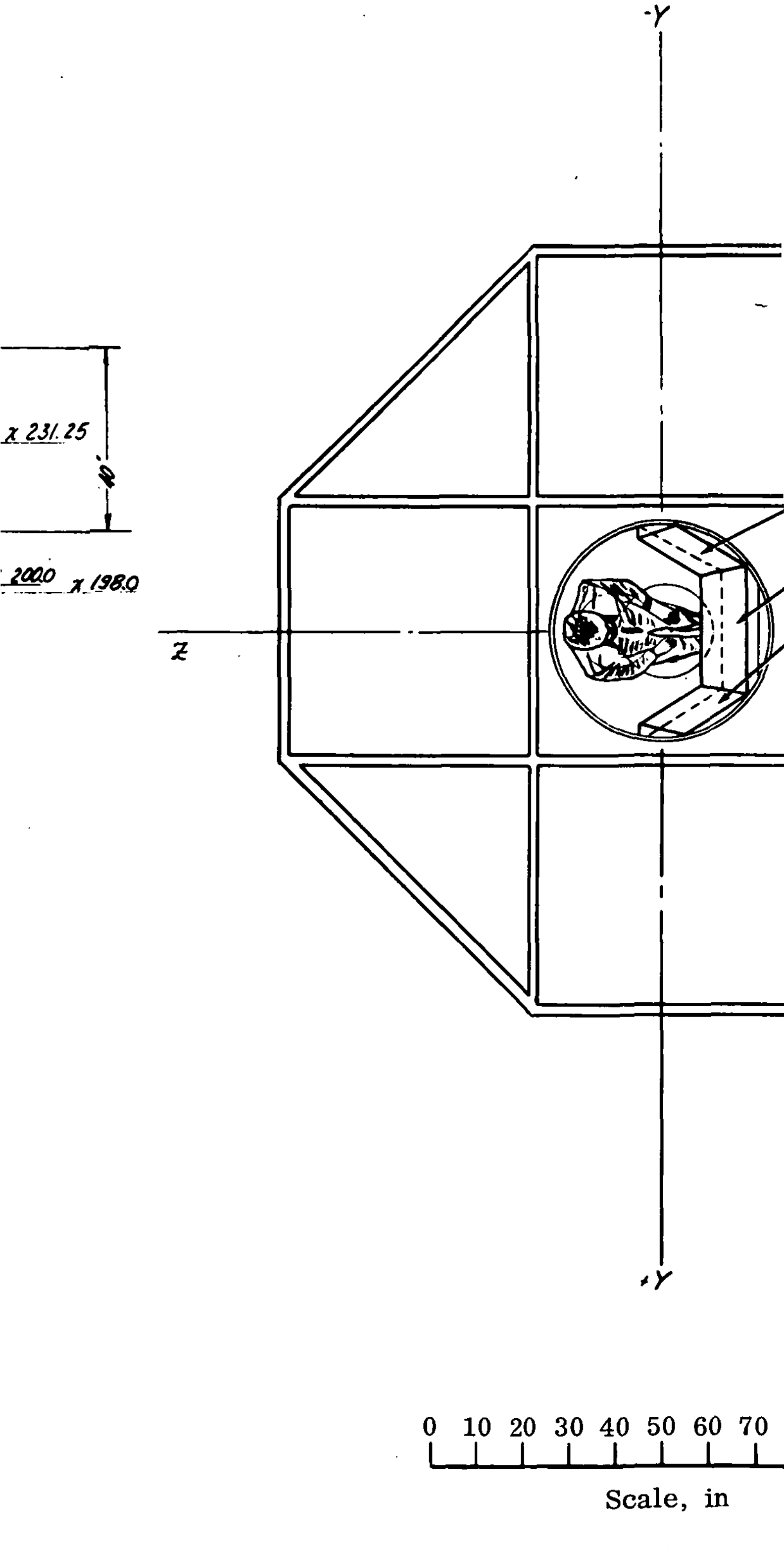


Fig. 6.3-4 Control & Display Layout

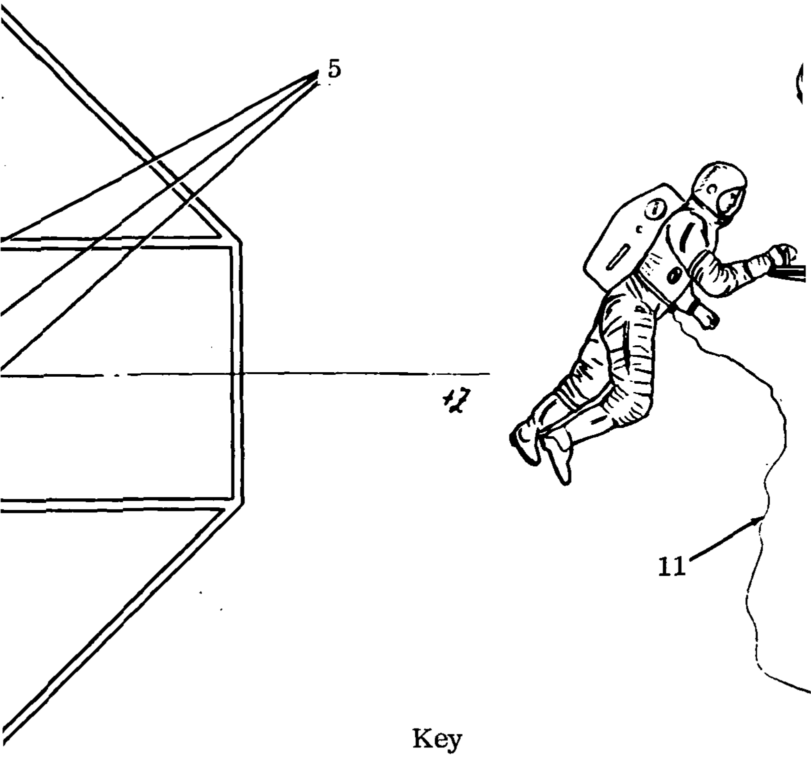


Cylindrical Airlock with Descent Compartment
Working Station



6.3-5

(2)



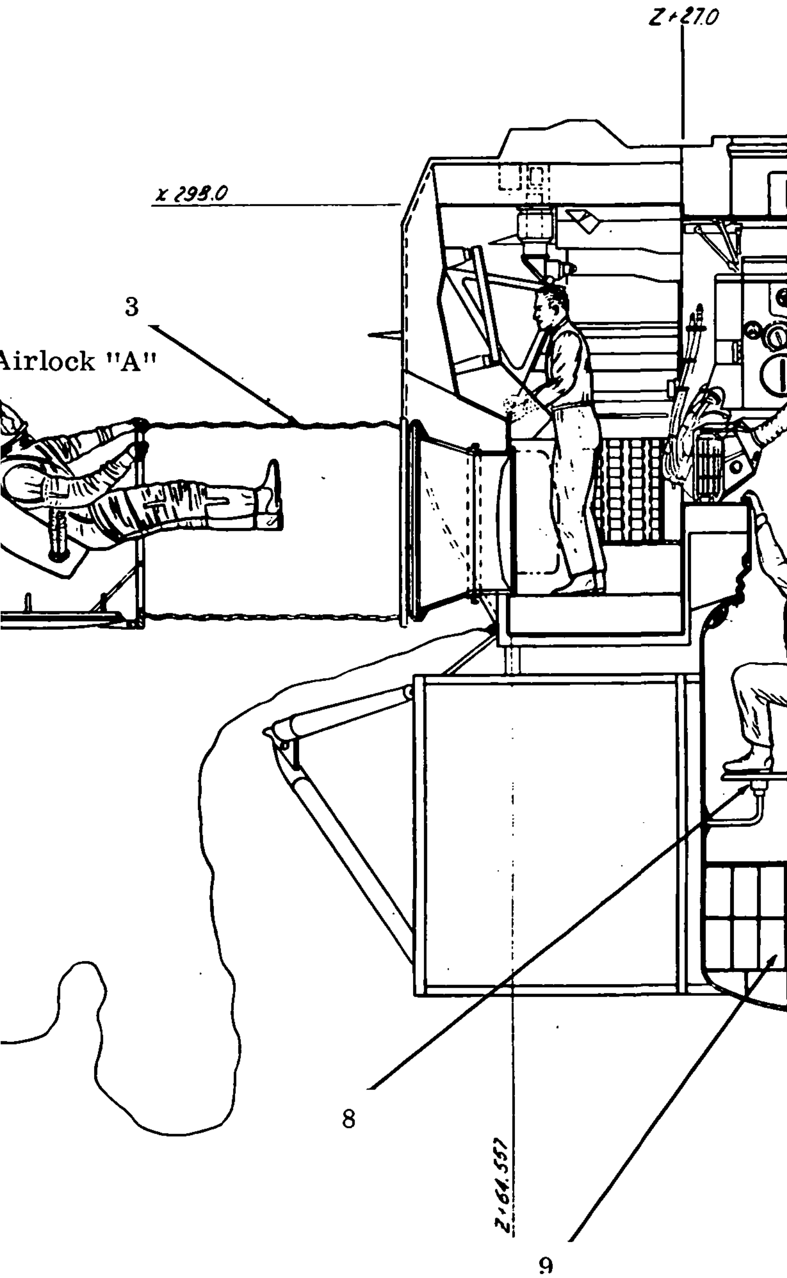
Key

1. Phase II Laboratory
2. Descent Stage (Ref.)
3. Cylindrical Airlock (Config "A") 65 cu ft
4. Descent Compartment 47 in Dia x 87 in.Hig
5. Work Station Console Panel Area 7.0 sq ft
6. Work Station Work Top : 10 in.x 10 in.x 2C
7. Work Station Storage: 8 cu ft
8. Work Station - Seat (16 in Dia)
9. Descent Compartment Bottom Storage: 30
10. Hatch Internal
11. Tether Line

90 100

6.3-5

3



n.

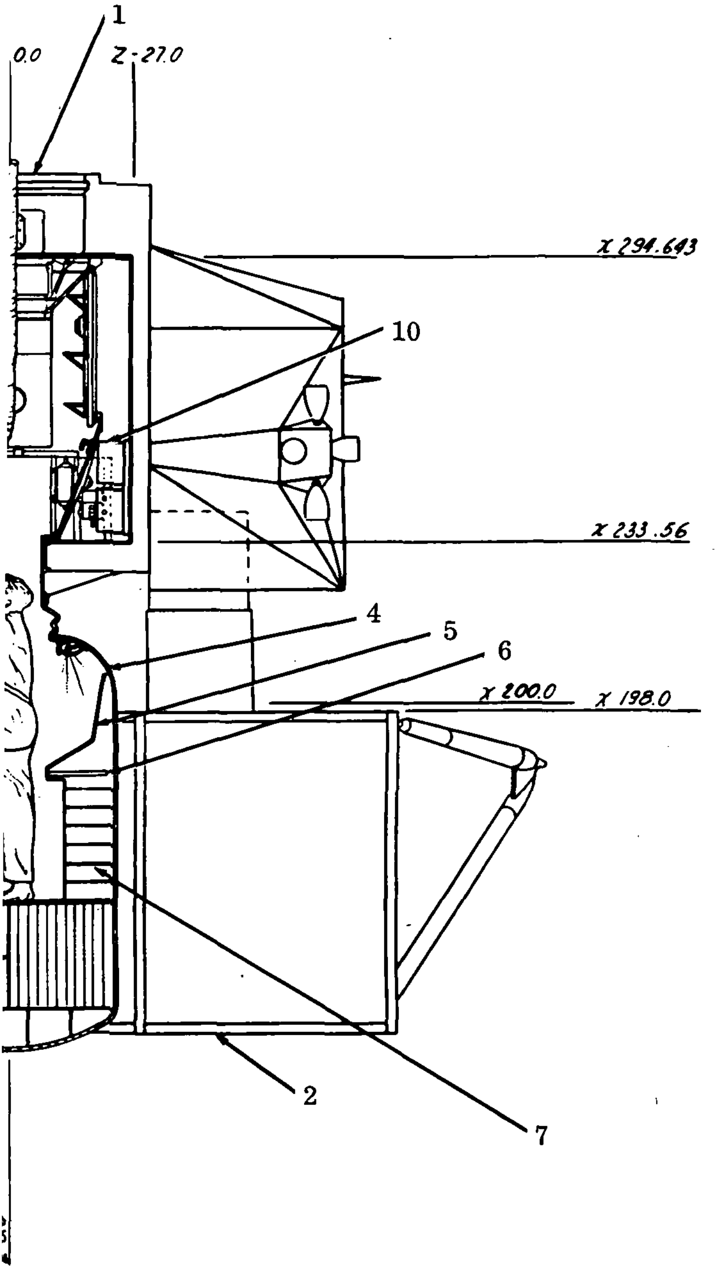
u ft

Cylindrical Airlo
Wo

View Lo
L.

6.3-5

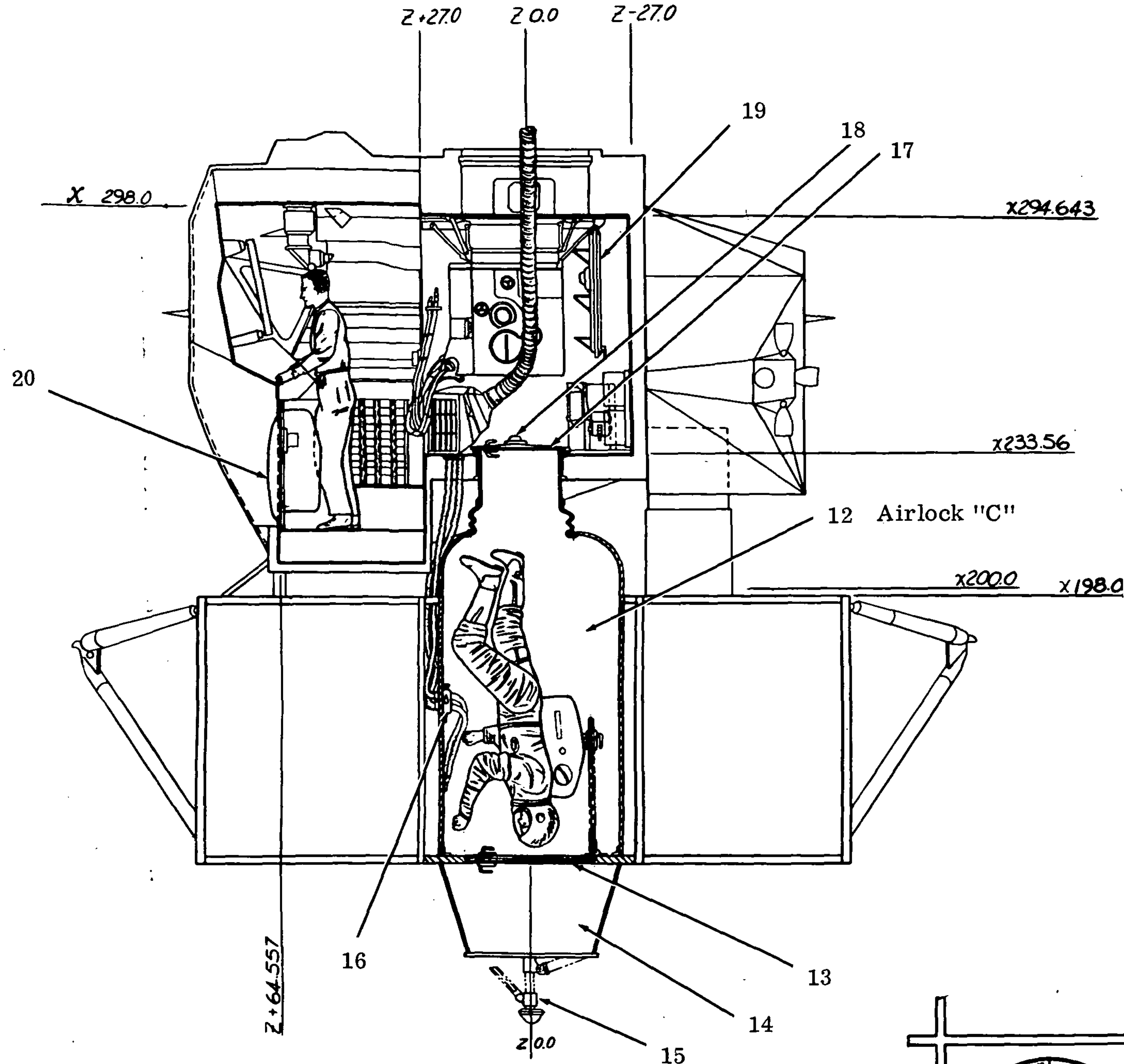
4



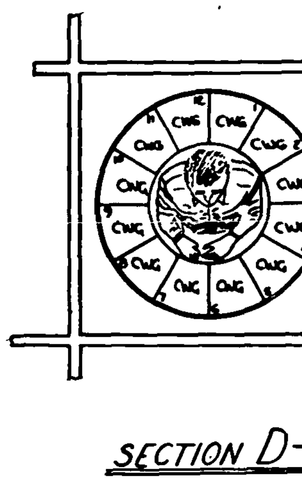
: with Descent Compartment
king Station

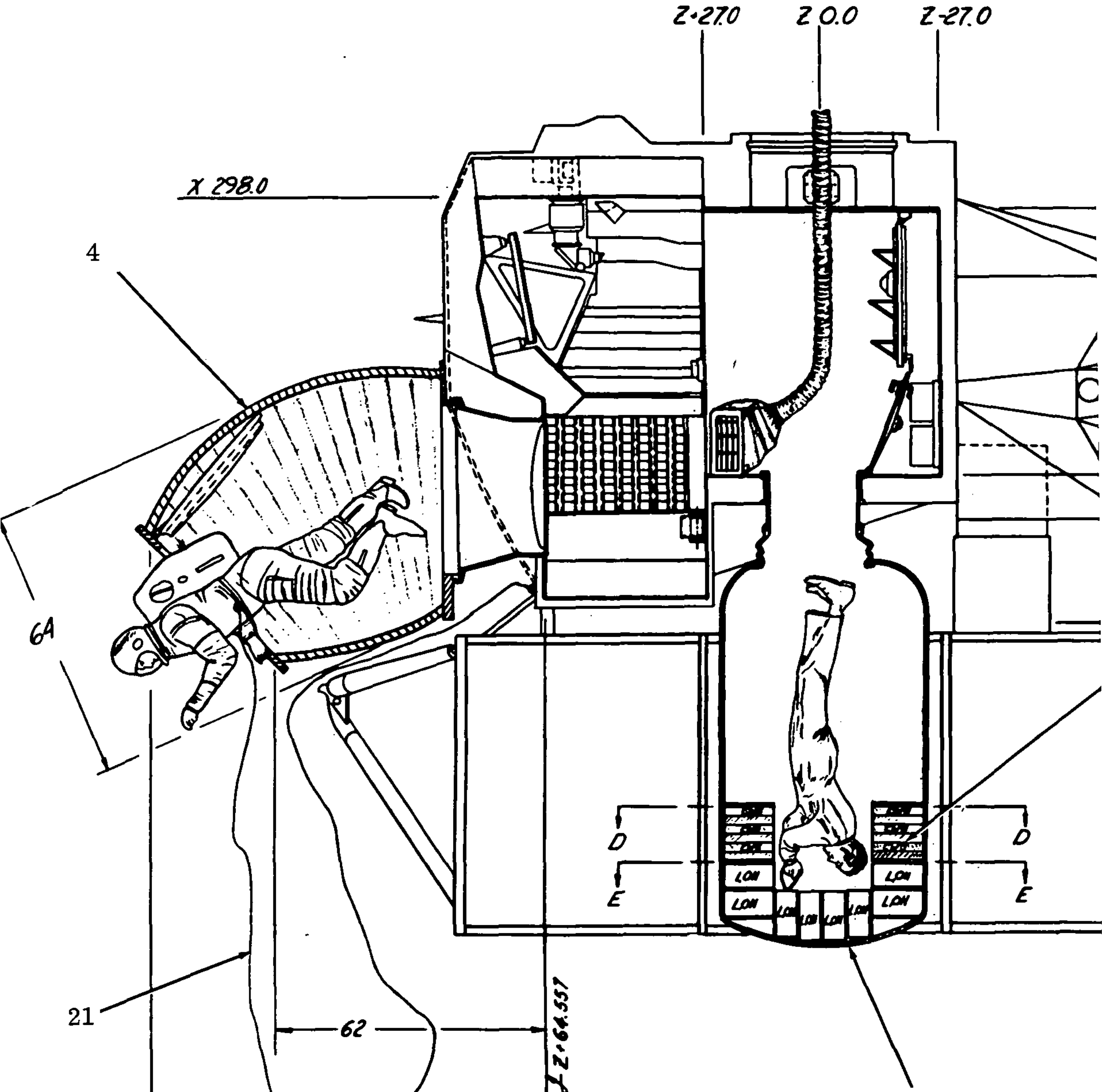
:ing Inboard
. Side

Fig. 6.3-5 Alternate Configuration



Descent Compartment as an Airlock
and/or Docking Tunnel

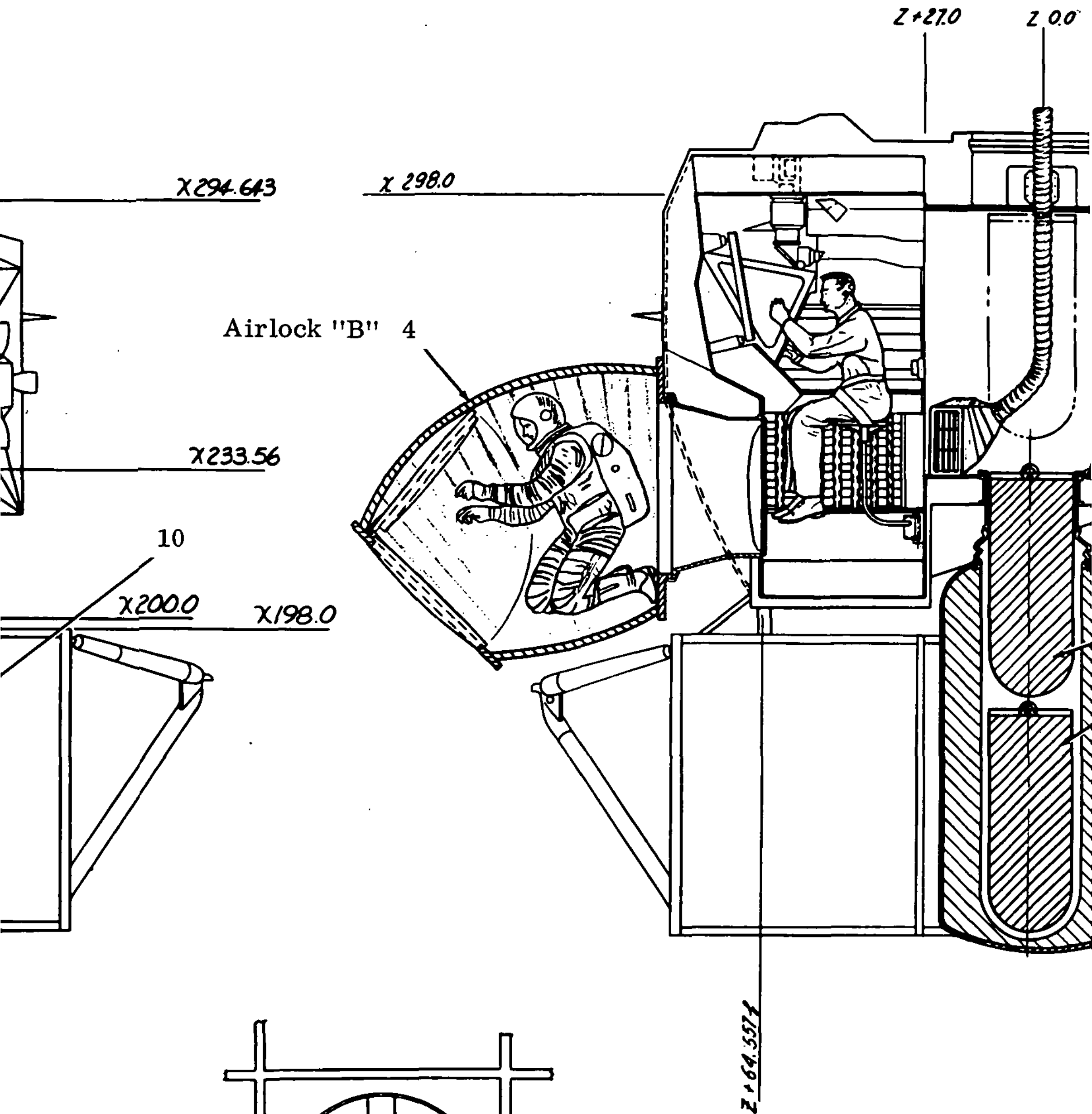




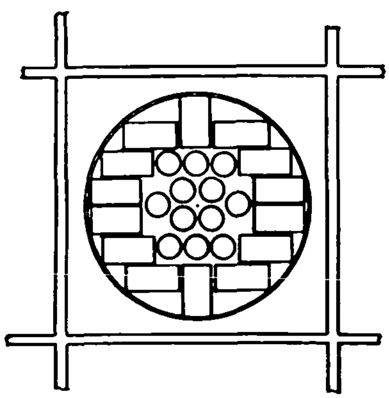
Shelter Airlock with Descent Compartment Storage

6.3-6

(2)

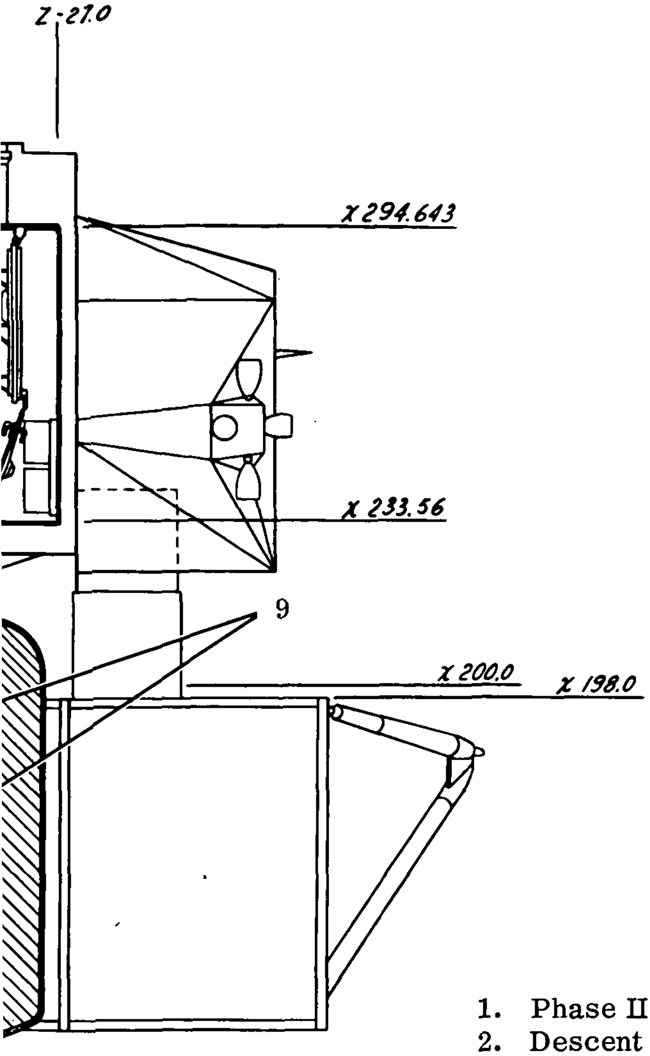


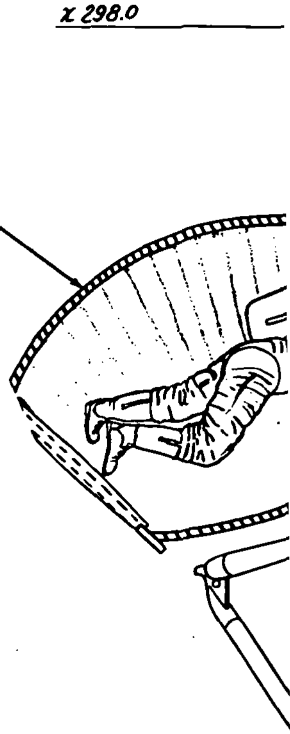
Shelter Airlock with Desc
Full Capacity St



SECTION E-E

6-3-6
(3)

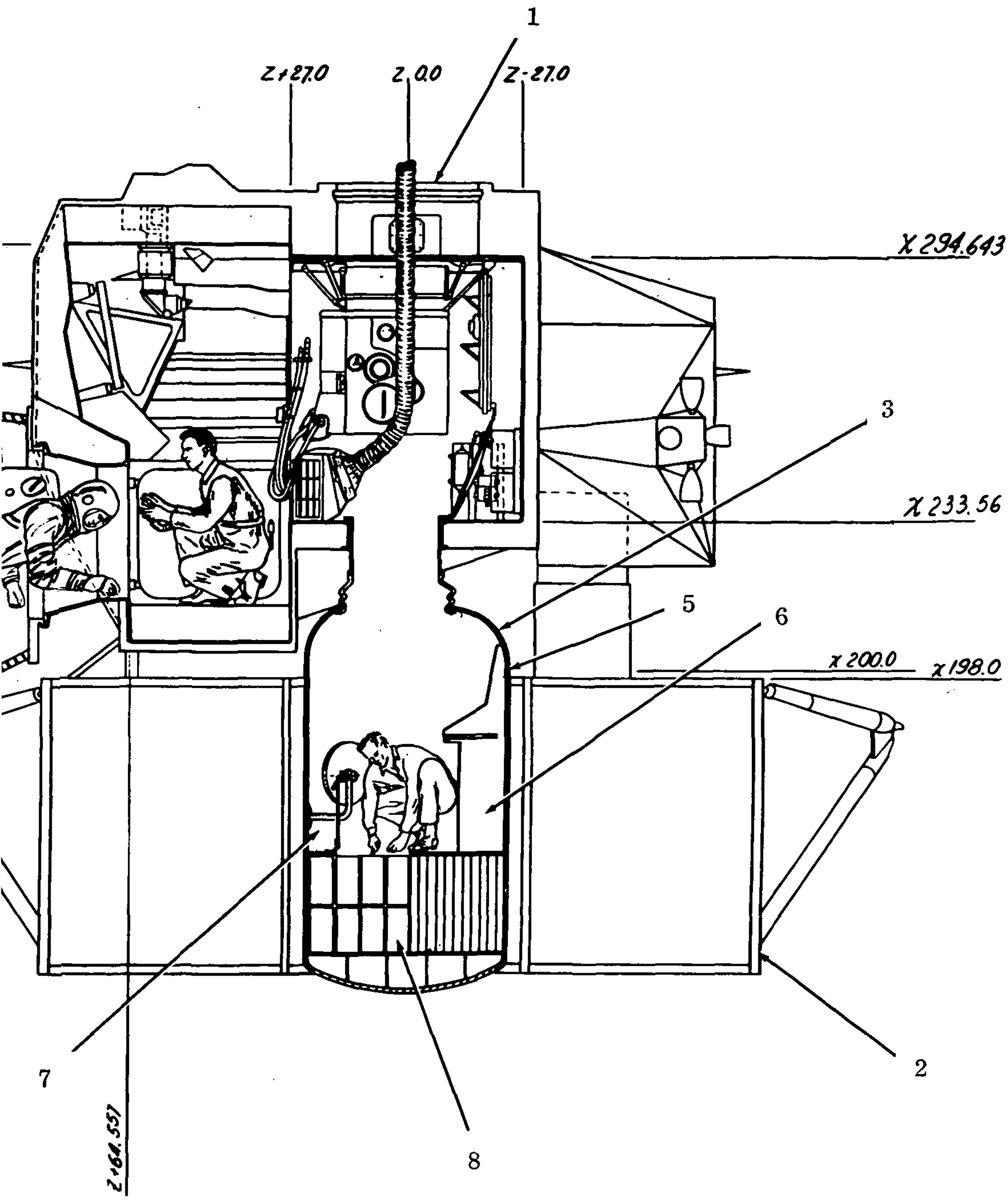




nt Compartment
rage

Key

1. Phase II Laboratory
2. Descent Stage (Ref.)
3. Descent Compartment
4. Shelter Airlock (Conf. "B") 85 cu ft
5. Work Station Console Panel Area 7 sq ft
6. Work Station Storage Area 8 cu ft
7. Work Area - Seat (Deployed)
8. Storage Area 30 cu ft
9. Descent Compartment-Full Capacity 85 cu ft
10. Constant Wear Garment (C.W.G.) 66 Units (7.4
11. LiOH Cartridges (PLSS) 36 Units (5.45 cu ft)
12. Descent Compartment as an Airlock (Config. "C
13. Descent Airlock External Hatch
14. Docking Tunnel
15. Docking Mechanisms (Ref.)
16. Enviromental Control Valves
17. Hatch - Internal
18. Pressure Dump Valve
19. Hatch - Upper
20. Hatch - Front
21. Tether Line



cu ft)

| 85 cu ft

Shelter Airlock with Descent Compartment
Working Station
and Storage

View Looking Inboard
L. H. Side

Fig. 6.3-6 Alternate Configuration

B

Grumman

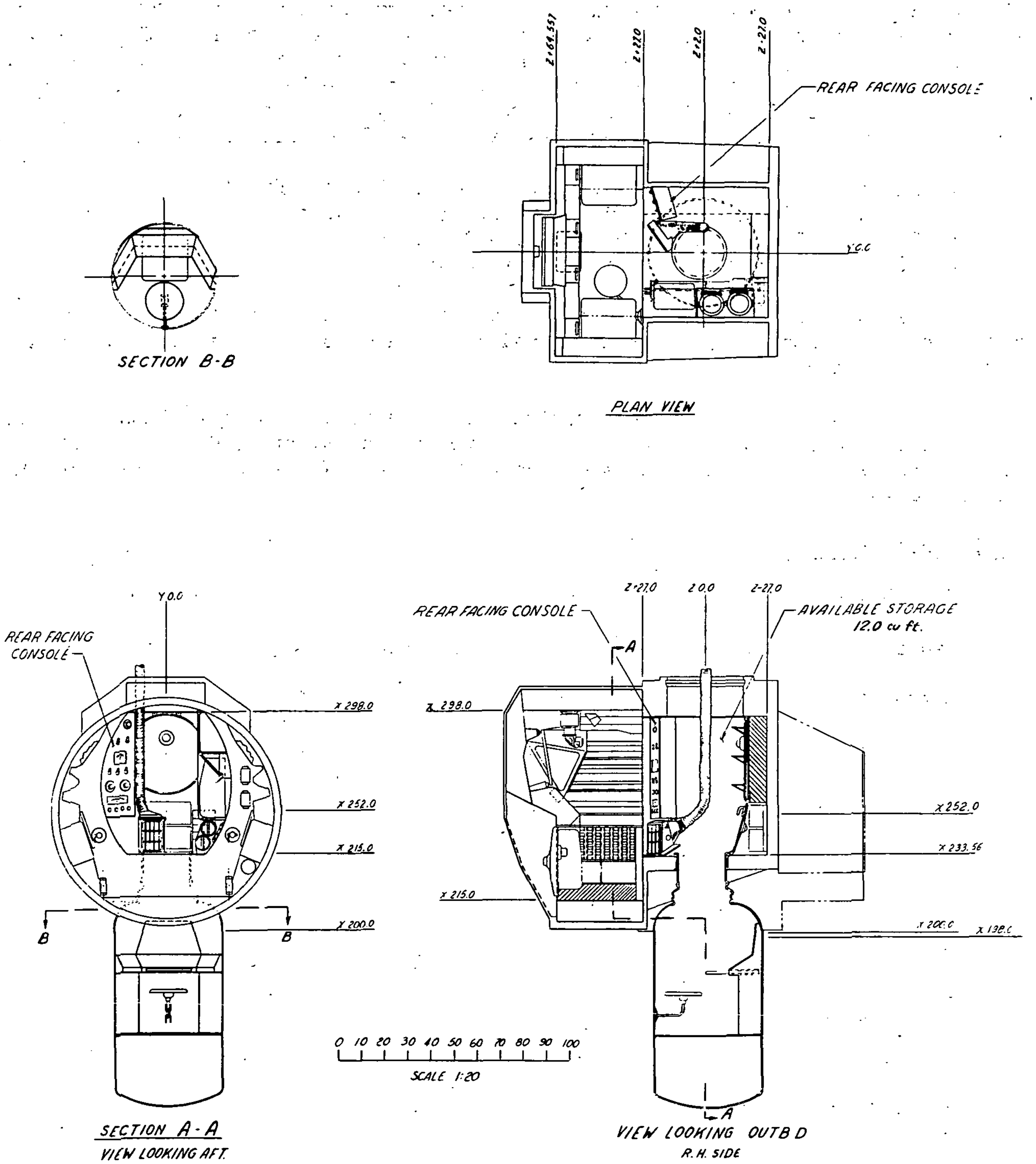


Fig. 6.3-7 Alternate Configuration - Deletion of Suit Loop - Addition of Rear Facing Console

6.4 STRUCTURAL ANALYSIS

6.4.1 Design Conditions

The Phase II Lab structure must satisfy the requirements resulting from the various phases of the mission profile for each particular flight category. The design criteria and environments for the LEM have been used to establish subsystem design concepts and feasibility for this study. It is anticipated that these requirements will not be exceeded when the final configurations, experiments and payloads have been determined. The flight categories being considered for the Phase II Lab are:

- 200 n.mi 28.5 deg Inclination Earth Orbit 45 days duration
- 19,350 n.mi Synchronous Earth Orbit 45 days duration
- 200 n.mi Earth Polar Orbit 45 days duration
- 80 n.mi Lunar Polar Orbit 35 days duration

Inasmuch as the Phase II Lab does not have a landing requirement, the design criteria resulting from descent, lunar landing and ascent are not considered in the analysis for these vehicles.

Tabulated below are the pertinent design requirements used to establish the integrity of the basic vehicle and subsystems. A factor of safety of 1.50 is applied to these limit conditions to obtain ultimate loads. The Phase II Lab coordinates are shown in Fig. 6.4-1

Limit Accelerations

Mission Phase	X		Y or Z	
Launch and Boost, S-V	g	rad/sec^2	g	rad/sec^2
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

Random Freq., cps.		Sinusoidal Freq. cps	
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 5 min along each of the three mutually perpendicular axes (X, Y, Z), in addition to the corresponding sinusoidal spectrum acting for 5 sec 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	C-5 at max level, db
9 to 18.8	136
18.8 to 37.5	142
37.5 to 75	146
75 to 150	143

Acoustics

Sound Pressure Levels in db External to LEM (Cont.)

(Re. 0.0002 dynes/cm^2)

Octave Band, cps	C-5 at max level, db
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

Preliminary Docking Loads (Limit) and Criteria

- Probe Contact:
  - o Axial Velocity 0.1 to 1.0 fps
  - o Radial Velocity 0.0 to ±0.5 fps
  - o Angular Misalignment ±10 deg
  - o Angular Velocity ±1.0 deg/sec
  - o Miss distance at probe ± 1 ft
- Loads:
  - o F_x = 2235 lb
  - o F_z = 3118 lb
  - o M = 8134 ft-lb
- Mass Properties
  - o Active Vehicle $M \simeq 2000$ slugs, $I \simeq 74{,}000$ slug-ft^2)-- C/M + S/M
  - o Target Vehicle $M \simeq 2200$ slugs, $I \simeq 1{,}150{,}000$ slug-ft^2) S-IVB + LEM
- Final Hard Surface Contact
  - o Axial Velocity 0.15 fps
  - o F_x = 5000 lb

)-- Max. permissible for single point contact on non-parallel surfaces.

6.4.2 Hard Point Provisions for Payload and Experiment Support Structure

6.4.2.1 General

A basic requirement for the integration of experiments and payload onto the spacecraft is that the primary structure will not require major modification. Where necessary, additional localized strength will be incorporated into the ascent and descent stages to provide attachment points for payload support structure.

Some preliminary studies and analysis have been carried out to determine the magnitude of additional local load capability at various potential hard points on the ascent and descent stage structures. In general, these hardpoints may be characterized into two groups. The first are those points at which no fittings or local stiffeners exist currently for LEM, but which may be adapted for concentrated load application through the use of attachment fittings, stiffeners and skin doublers. By this means concentrated payload support structure reaction forces can be delivered into the primary structure for internal load equilibrium without over-loading the existing members. The second group are those hardpoints at which fittings and stiffeners currently exist on LEM. These points may be used to react additional concentrated loads providing enough strength exists for the combined input loads. When necessary, it may be possible to increase the strength of these attachments by adding material thickness. The current studies are based solely on static load conditions to determine structural feasibility; in later phases of the program dynamic response analyses of equipment and payload items with support structures will be conducted to verify structural integrity. In addition to analyzing each payload and experiment local input into the primary structure, each flight category must be checked for the critical loading environments to ensure the overall structural integrity of the primary members.

6.4.2.2 Ascent Stage Hard Points

Figures 6.4-2 and 6.4-3 show existing hard points in the LEM ascent stage. The loads shown, applied to these points, are ultimate allowable loads with the fuel and oxidizer propellant tanks removed. These loads may be used for local design but are not necessarily applied simultaneously. The critical condition for the Labs is the 7.35g boost. The loads shown may be combined with the interstage loads from the descent stage for this condition only when applied in the directions shown.

Points R and S do not have existing fittings but may be adapted for the concentrated loads shown with minor modification. The remaining points have existing truss members joined to them by fittings or bulkhead lugs and may be readily picked up.

6.4.2.3 Descent Stage Hard Points

For effective usage of the LEM descent stage, hard point load distribution should remain unchanged. Basic hard points on the existing LEM are located at engine mounts, tank mounts, equipment shelf mounts, etc. The LEM descent stage primary structure as well as the local structure is designed for these loads. The loads are then transmitted by the structure to the trunnion points which provide reactions for the boost conditions. Obviously, any new hard point requirement must be analyzed utilizing the above constraints. As previously outlined, both a structural and dynamic analysis would be required to verify integrity. Any Lab II vehicle must remain within the weight and inertia envelope dictated by the LEM structure. All primary structural changes are to be compensated for by providing alternate load paths. For example, loads in the tie rod which is to be removed to allow the new water tank structural placement will pass through the tank truss.

The landing gear structure and the descent engine will be removed.

The descent stage hard point load capabilities are summarized below:

	LEM	Coordinates		Incremental Allowable Load, lb		
Hard Point	X	Y	Z	Px	Py	Pz
U_1	+196	+82	+27	±900	±750	±1030
U	+196	+82	-27	±900	±750	±1030

The above loads are increments which may safely be added to existing loads without requiring major re-analysis. Values shown are 1g (earth g) values and will be valid for all loading conditions. The above is based on the premise that equipment listed below is removed. The reference loads are shown in Fig. 6.4-4.

Ascent Stage Equipment Removed

-Y (left side)	W	-Y	Moment
M/M shield	6	50	300
Supports	11	50	550
Fuel	1920	71	136,200
Tanks	93	71	6,603
Plumbing	7	71	497
	2037 lbs		144,150 inch-lbs.

+Y (right side)			
M/M shield	6	50	300
Supports	11	50	550
Oxidizer	3080	45	138,500
Tanks	93	45	4,180
Plumbing	7	45	315
	3197 lbs.		143,845 inch-lbs.

6.4.3 Modifications to the LEM Descent Stage

The Lab II configurations are basically LEM structure, with some modifications where necessary. All modifications must be analyzed to meet the design criteria set forth by the 35 launch loading conditions studied in the LEM program. Any pertinent changes such as a max. $q\alpha$ (due to a different launch trajectory) will be incorporated into the design criteria. The basic seven groups of loading conditions will be the same as that of LEM. Primary ascent-descent stage interface loads will be proportional to those of the LEM.

Basic hardpoints on the LEM, which have their member components replaced for Phase II Lab application, require new environmental analysis. In many instances, careful design of racks or loading platforms will enhance local load carrying capability, especially in cases where the design is now limited by vibratory stresses.

Some of the proposed changes to the LEM descent stage are:

- Cryo tanks will replace the descent propellant tanks
- Two helium and two GOX tanks will be replaced by the Allis-Chalmers fuel cell assy, water, tank, etc.
- The MM shield will be replaced by the radiator support assy.
- Docking tunnel may be added in place of the descent engine.

As an alternate design, a low profile descent stage (LPDS) is being offered on a per-flight basis. This 30 in high descent stage is coupled with a LEM ascent stage. A more compact vehicle with greater useful volume is thereby attained. With certain payloads this Phase II Lab configuration can be injected into higher-inclination orbits. The cg of this vehicle will in general have a higher X location. New load data are being generated for the LPDS. A preliminary analysis for primary loads has been accomplished utilizing the ASTRAL* System. Any redundant critical local area will be analyzed using stiffness or energy methods. Another variation of the LPDS is the removal of one of the lower deck tie rods to facilitate the installation of one large tank. As an example of increase internal loading, Condition No. 1 (end of Boost 7.35 g ultimate) was checked by comparing two computations, representing the LPDS with and without this tie rod. When a member such as this is removed, a 56% increase in loads occurs in some of the local members. It is therefore, apparent that the removal of any tie rod type member would necessitate a complete re-analysis of the primary structure. A detail redesign of at least the two faces of the adjacent bays from which the member is extracted would be mandatory.

*Automated Structural Analysis using a large stiffness program on the IBM 7094. In this program, a three-dimensional mathematical model of the lattice array of primary structure is internally balanced against the applied loads.

6.4.4 Seven Psi Two-Gas System

A preliminary analysis of a two-gas system has been made to determine the magnitude of structural changes required to maintain the existing safety factors on pressure and/or the reduction in safety factors if existing structure is maintained. An ultimate factor of 2.0 was applied to limit loads for pressure acting alone and an ultimate factor of 1.5 was applied to limit loads for combined conditions of pressure and inertia forces due to landing and maneuver loads.

The two-gas system raises the pressure from a nominal 5 psi to 7 psi, and the relief valve setting from 5.8 psi to 7.8 psi, respectively. The relief valve pressure is considered as limit pressure.

There are a number of items in the ascent stage that are critical for pressure alone. The forward face in the cabin section is designed almost entirely by pressure with the exception of the front face beam. The cabin skins are chem-milled to a minimum thickness of 0.013 in with 0.030 in lands at the frames. The 0.013 chem-milled pockets are critical in hoop tension for pressure alone. The frames and 0.030 chem-milled pads are sized by diagonal tension loads due to panel buckling under primary loading conditions and should not be affected by an increase in pressure. These criteria also apply to the side skins in the mid section.

The X253 and X280 longerons in the cabin are critical for pressure loading. The critical areas extend through the splices at the +Z27 bulkhead and into the mid-section. The +Z27 bulkhead, which is the back pressure wall for the outer portion of the cabin, is critical under pressure loading. All of the hatches and windows are designed by local pressure loading. In the mid-section there are two horizontal decks at X277 and X253. These decks redistribute pressure loads from the +Z27 and -Z27 bulkheads. The deck at X294 forms the bottom of the docking hatch structure. The docking hatch structure is designed by combined loadings from pressure, docking, and maneuver loads. The increased pressure combined with docking and maneuver loads could require major structural changes in this area. Docking and maneuver loads will determine the magnitude of these changes. Approximately 50% of the -Z27 bulkhead is designed by pressure loading. There are also a large number of machined parts, end fittings, splices, clips, etc., which would be affected by a pressure increase.

In summary, a two-gas system on existing LEM structure would have an ultimate factor of 1.5 on pressure alone and 1.1 for combined loadings. Table 6.4-1 summarizes the critical areas and necessary changes to major components which would be required for a 7.8 psi system with ultimate factors of 2.0 and 1.5. Figures 6.4-3 and 6.4-5 show some of the affected areas given in the reference table.

6.4.5 Micrometeoroid Shielding (Acoustic Fatigue)

Micrometeoroid penetration considerations will determine the minimum average gage and skin spacing stand-off from the protected structure. However, the shielding must be designed for its ability to withstand sonic fatigue during the launch and boost condition.

For the LEM, typical micrometeoroid shielding, which also acts as thermal shielding, is an 0.006 aluminum alloy skin held away from the main structure by nylon standoffs. The standoffs offer point support and are spaced approximately 12 in. apart.

Vibration tests have been conducted on a flat specimen of this type construction (Ref. LTR 905-11001 - Results of Vibration Tests, LEM Structural Elements - C. Birn, Grumman, April 1965). A flat specimen was conservatively chosen since curved panels, such as those on the ascent stage, will offer greater resistance to acoustic fatigue. A partial failure of the washer head of the nylon standoff was encountered. The failure was not serious, however, since the standoff still continued to support the aluminum face sheet. After completion of these tests the specimen was exposed to an acoustical test at an overall sound pressure level of 150 db for 2 minutes (which is the design level) and no failures were observed. However, when the overall sound pressure level was increased to 154 db (which is an overload condition), the washer heads of three nylon standoffs failed. These failures allowed the face sheet to slide along the posts, thus eliminating the skin spacing required for protection. The standoffs are currently being redesigned to eliminate the stress concentration at the juncture of the washer and post. It is anticipated that the redesign will eliminate this type of failure.

Alternate methods of construction, see Fig. 6.4-6, were investigated using the techniques of ASD-TDR-63-820 (Structural Design for Acoustic Fatigue - Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, October 1963). A comparison was made of the following types of construction which are listed in order of preference for weight criteria:

1) Honeycomb panels
2) Skin with bonded doublers and ribs
3) Skin and rib
4) Corrugated panels
5) Beaded panels

Since the design reference data used were developed for aircraft applications, the lowest number of design cycles considered were a factor of 10-100 times greater than those anticipated during the launch and boost conditions. The gages required were, therefore, 5-30 times greater than that used for LEM. An exception was the honeycomb construction where the sum of the two face gages was only 1.5 to 2 times as great.

It is planned that the LEM type construction with improved design be used for the Phase II Lab, with an increase of skin gage as required for meteoroid shielding for the 14-day mission. Although increasing the gage is usually beneficial with regard to fatigue, a change in dynamic characteristics, especially of the substructure, will occur. Acoustic testing of the new configuration is therefore planned later in the program. As an alternate design approach, honeycomb or perhaps crushed honeycomb (bond-o-lite) face sheets will be investigated because of the apparent advantages over single sheet construction. Since the honeycomb may not provide the best meteoroid protection, due to its tendency to contain the generated gases in a single core cell, it is planned to also investigate the use of the other configurations mentioned above as alternatives.

6.4.6 Special Maneuvers

6.4.6.1 Interface Loads

For flights performing the artificial "g" experiment, it had originally been proposed in the work statement that the orbit be circularized using the SPS engine. A preliminary analysis of CSM-LEM interface loads during this maneuver was made by calculating rigid body modes using the S-IVB/LEM/CSM configuration. Subsequent redirection caused this investigation to be terminated. The preliminary analysis, reported below, shows that the gimbal angle should be restricted to 4.4 degrees so that allowable bending moments will not be exceeded.

Figure 6.4-7 shows the overall configuration.

	WEIGHT (lbs.)	Icg (Slug-ft^2)
SIVB	32,905	217,000
CM	20,000	34,336
SM	44,600	35,300
LEM	29,500	19,800
Total	127,005	3,523,056

The cg of the total system is at Sta. 3261.289.

It was assumed conservatively that the maximum SPS engine thrust approximately of 20,000 lb. can be applied throughout the full gimballing angle of 13.9 deg.

$$\ddot{\theta} = \frac{20,000 \sin 13.9 \ (3662.55 - 3261.289)}{3,523,056} = 0.04566 \text{ rad/sec}^2$$

$$\ddot{y} = \frac{20,000 \sin 13.9}{127,005} \times 32.2 = 1.218 \text{ ft/sec}^2$$

The moment at the LEM/CSM interface is:

$$M = \left[-\ddot{\theta}(x_{SIVB} - \bar{x}) + \ddot{y}\right] \frac{W_{SIVB}}{g} (54.00) + \left[-\ddot{\theta}(x_{LEM} - \bar{x}) + \ddot{y}\right] \frac{W_{LEM}}{g} (9.54)$$

$$- M_{cg\ SIVB} - M_{cg_{LEM}}$$

$$= \left[-0.04560\ (45.36) + 1.218\right] \frac{32,905}{32.2} (54.00)$$

$$+ \left[-0.04560\ (0.853) + 1.218\right] \frac{29500}{32.2} (9.54)$$

$$- 9896 - 902.9$$

$$M = -47{,}310 \text{ ft-lb}$$

If a magnification factor of 2 is used,

$$M_{design} = -94{,}620 \text{ ft-lb}$$

The LEM hatch, however, is designed to carry a moment of 30,000 ft-lb. This value can be met by restricting the gimbal angle to 4.4 deg.

6.4.6.2 Interface Loads for Combined Flight 523 to Flight 228 and CSM (Fig. 6.4-7)

A preliminary analysis has been made to study the interface loads due to docking Flight 523 to Flight 228 and the CSM. This study was carried out to determine if the hatch interface loads for which LEM is designed would be exceeded. The design conditions considered were (1) the mid-course correction maneuver using the SPS engine thrust, (2) docking maneuver loads, (3) attitude correction maneuver using the RCS thrusters. A rigid body solution shows that the current design conditions will not be exceeded, provided that the SPS engine gimbal angle is limited if it is required for inflight maneuver.

Approximate weights: LEM Lab 228: 17523 lb
LEM Lab 523: 25312 lb

Approximate moments of inertia Lab 228: 10950 slug-ft^2
Lab 523: 15700 slug-ft^2

The SPS Engine thrust is approximately 20,000 lb. Conservatively assuming that the SPS maximum engine thrust can be applied throughout the full gimballing angle of 13.9 deg:

Total weight of combined vehicle 107,435 lb
cg at station 3390.

$$Icg = 1.07 \times 10^6 \text{ slug-ft}^2$$

$$Mcg = 20{,}000 \sin 13.9 \text{ deg } (3662-3390) = 1.305 \times 10^6 \text{ in-lb; } 109{,}000 \text{ ft-lb}$$

$$\ddot{\theta} = \frac{1.09 \times 10^5}{1.07 \times 10^6} = 0.1015 \text{ rad/sec}^2$$

$$\ddot{y} = \frac{4820}{107435} \times 32.2 = 1.44 \text{ ft/sec}^2$$

Moment at hatch interface between Lab 523 and Lab 228

$$M = \left[-\ddot{\theta}\,(x-\bar{x}) + y \right] \frac{W523}{g} \times 9.5 - M_{cg_{523}}$$

$$= \left[-0.1015\ (26.9) + 1.44 \right] 787 \times 9.5 - 0.1015\ (15{,}700)$$

$$= 11{,}285 \text{ ft-lb}$$

Moment at hatch interface between 228 Lab and CSM

$$M = \left[-\ddot{\theta}\,(x_{229} - \bar{x}) + \ddot{y} \right] \frac{W_{229}}{y}\ x - M_{cg_{228}}$$

$$+ \left[-\ddot{\theta}\,(x_{523} - \bar{x}) + \ddot{y} \right] \frac{W_{523}}{g}\ x - M_{cg_{523}}$$

$$= 26607 \text{ ft-lb}$$

If a dynamic magnification factor of 2.0 is applied to the above moments, the resulting values will exceed the design limit moment of approximately 30,000 ft-lb used to design the LEM hatch. The above loads indicate that the SPS engine gimballing angle would have to be limited to approximately 7 deg for any maneuver of this type.

6.4.7 Equipment Supporting Structure

6.4.7.1 Phase II Lab Aft Equipment Bay

The aft equipment rack is attached to the -Z27 bulkhead at points A, B, H, A^1, B^1, H^1 (Fig. 6.4-8). The existing LEM aft equipment rack is designed for a gross weight of 990 lb. The design loads in the various truss members for the gross weight are given in the table. It is proposed that five 104 lb GOX tanks in the aft equipment bay replace two 67 lb GOX tanks and two 8 lb Helium tanks. This change increases the design gross weight from 990 lb to 1360 lb and moves the cg forward approximately six inches to -Z57. Based on the change in gross weight and neglecting the small cg shift, there would be a 39% increase in the truss member loads for the boost condition. Truss members AC and BC would have to be redesigned for the boost condition. Truss members AC and BC would have to be redesigned for the increased load in the 7.35 g boost condition. In addition, local redesign would be required where these members are attached to the -Z27 bulkhead. See Table 6.4-2 for the axial loads in rack truss members.

6.4.7.2 Ascent Stage - Mid-Section Canister - Phase I Lab

The mid-section canister is a cylindrical container pressurized to 11.5 psi and carries a maximum load of 125 lb. It is supported at -X233.5 and 2 in off centerline. A vertical acceleration of 7.35 g (ultimate) and 0.6 g lateral acceleration is experienced by the payload during launch and boost. These accelerations produce 950 lb vertical and 75 lb lateral loads. The cg of the load is assumed at 25 in below the top of the containers resulting in a moment at the top of 1875 in-lb. Loads and geometrical configuration of the canister are shown in Fig. 6.4-9.

The vertical component of 920 lb gives a peripheral reaction on the supporting rim of approximately 13 lb/in. The lateral load of 75 lb (1875 in-lb) produces a reaction on the supporting rim which varies as a sinusoidal distribution. As an average, the moment divided by the diameter gives a reactive load of 82 lb. Assuming the 82 lb acting over a quarter of the periphery produces a reaction of ±4.5 lb/in. The total unit load per inch then becomes 13 ±4.5 = 17.5 lb/in. maximum. This load is not critical and therefore the arrangement is feasible.

6.4.7.3 Viewfinder Installation

An optical viewfinder weighing approximately 30 lb is mounted in the LEM window opening by means of an adapter that replaces the window. An acceleration factor of 7.35 g (boost and launch condition) gives a total of 30 lb x 7.35 g, or 220 lb. This load has a moment arm of approximately 2 in relative to the peripheral connecting points, producing a moment about the periphery of 441 in-lb. The resulting reactive couple of 44 lb is assumed acting sinusoidally over the periphery. This sinusoidal distribution produces a maximum coordinate load of ±6.92 lb. The internal cabin pressure of 11.5 psi produces a peripheral load of $\frac{11.5 \times \pi D^2}{4 \pi D}$ or 28.75 lb/in. over a 10 in diameter circle. The maximum total applied load is therefore 28.75 + 6.92, or 35.67 lb.

The window bolting pattern was established primarily to prevent rotation of the joint thereby maintaining air-tightness integrity. The new load therefore will not influence the overdesigned bolting pattern since strength was not the original prerequisite.

6.4.8 Materials

The major materials problems associated with the Phase II Lab missions in addition to those of the LEM are those imposed by the increased mission time and the different environmental conditions created by the various mission profiles. These conditions in many cases will affect or alter the choice of materials originally made for the LEM.

Some of these areas where changes, and in most cases additional testing, would be required are:

- Non-metallics: The toxicity and materials outgassing analysis as established by Engineering Materials and Crew Systems for LEM are being reviewed in light of present Phase II Lab requirements. Assuming the crew environment established for LEM, the effect of increased time on materials already evaluated must be studied. It may be assumed that those materials already rejected for use on LEM will also be rejected for use on Phase II Lab; however, a close look and possible re-evaluation of approved materials will be necessary. Materials are now evaluated for a total of 3 days in contrast to contemplated missions of 45 days and more. Since the quantity of outgassed products per material may have to be reduced because of increased mission time, and because increased degradation may take place, retesting in some cases may be necessary.

- Compatibility: One of the more difficult problems arising from extended missions is compatibility. Many of the materials, metallics and non-metallics alike, are questionable under extended exposure to fuels and/or oxidizers. The use of gaseous oxygen may also present problems for certain materials.
- Transparencies: The mission profile and time of some of the AES missions will require additional testing of these materials. The effect of prolonged UV radiation on the visibility, the number of micro-meteoroid hits the windows must withstand and other criteria would affect, and possibly alter, the materials under evaluation for LEM.
- Thermal control coatings: The requirements for these coatings depend on the mission profile. Stable coatings such as LTV-602 white silicone paint are available; however, the weight penalty in using these may be excessive. Anodize as a thermal control coating is being used on LEM, and with varying processing parameters could answer many Phase II Lab requirements; however, the thermal control system used on LEM was established solely that for specific mission.

Table 6.4-1

7 PSI TWO GAS SYSTEM

REQUIRED STRUCTURAL REVISIONS

FRONT FACE AND CABIN (See Fig. 6.4-5)

DRAWING	CRITICAL AREAS	TYPE OF LOADING	REMARKS
Front Face Lower Blkh'd (1)	Horizontal Stiffeners Machined Webs	Membrane and Bending Stresses Due to 15.6 PSI	The horizontal stiffeners on the front-face are designed by stiffness requirements necessary to obtain compatible deflections at the front face vertical beam and the side skin. The moments of inertia of these stiffeners would have to be increased for 15.6 PSI as would the thickness of the machined webs.
Cabin Window Frame (3)	Entire Machining	Normal and Bending Loads from 15.6 PSI on Glass and Adjacent Structure	The frame supports the window, and beams the loads laterally to the front face beam and side skin. With zero margins on the existing structure the safety factor of 2.0 on pressure alone will be reduced to 1.5.
Front Face Window	Glass	Normal Pressure	The present LEM window is still under development and will be tested to ultimate 11.6 PSI. At 15.6 PSI the same procedure will have to be followed.
Front Face Lower Center (6)	Machined Webs	15.6 PSI Bending and Membrane Stresses	Increase thickness of machined webs.
Front Face Upper Center (5)	Machined Webs	15.6 PSI Bending and Membrane Stresses	Increase thickness of machined webs.
Front Face Canted Panel (7)	Chem Milled Webs	15.6 PSI Bending and Membrane Stresses	Increase thickness of chem milled webs.

Table 6.4-1 (Cont.)

7 PSI TWO GAS SYSTEM (Cont.)

REQUIRED STRUCTURAL REVISIONS

FRONT FACE AND CABIN

DRAWING	CRITICAL AREAS	TYPE OF LOADING	REMARKS
Panel Brow (4)	TBD		
Panel Cheek (2)	TBD		
Front Face Hatch		Normal Loading Due to 15.6 PSI	Redesign for 15.6 PSI
Skin L/H Upper (25)	Chem Milled Pockets	Membrane Stresses due to 15.6 PSI	The skin material is 2219-T81, F_{ty} = 49000 PSI. Holding membrane stresses to F_{ty} would require a min. t of .016. There are .030 lands under the frames that attach to these skins. These frames and lands in general are critical for diagonal tension loads which are a maximum when the pressure is zero.
Skin R/H Upper (20)	Average t = .013		
Skin X 280 to 252 R & L/H. (21)			
Skin X 252 to 228 R & L/H. (22)			
Skin L/H Lower (24)			
Skin R/H Lower (23)			

Table 6.4-1 (Cont.)

7 PSI TWO GAS SYSTEM (Cont'd)

REQUIRED STRUCTURAL REVISIONS

FRONT FACE AND CABIN

DRAWING	CRITICAL AREAS	TYPE OF LOADING	REMARKS
Upper Window Frame & Glass		Normal Load from 15.6 PSI on window	Requires Redesign
X 280 Long. (26)	+ Z27 Blkh'd to front face	Tension	Requires Approx. 34% increase in area
X 252 Long. (27)	+ Z27 Blkh'd to front face	Tension	Requires Approx. 34% increase in area
Frames (30)		Bending due to pressure	
MID SECTION See Fig. 6.4-3			
+ Z27 Blkh'd (14)	Stiffeners & Webs	15.6 PSI Membrane & Bending Stress	Increase Thickness of Machined Webs & Stiffeners
-Z27 Blkh'd (15)	Stiffeners & Webs	15.6 PSI Membrane & Bending Stress	Increase Thickness of Machined Webs & Stiffeners
Lower Side Skin (7)	Chem Milled Pockets	Bending & Membrane stresses due to 15.6 PSI	Increase Min Gage to .016
UPR Skin (5) CTR Skin (6)	Chem Milled Pockets	Bending & Membrane stresses due to 15.6 PSI	Increase Min Gage to .016
X253 Deck (23)	Shear Webs Y44.6 Cap & Cap Splice at +Z27 Blkh'd	Shear & Axial load	15% increase in Shear Webs 15% increase in cap area at tZ27 Blkh'd

Table 6.4-1 (Cont.)

7 PSI TWO GAS SYSTEM (Cont.)

REQUIRED STRUCTURAL REVISIONS

MIDSECTION

DRAWING	CRITICAL AREAS	TYPE OF LOADING	REMARKS
X 294 Deck (25)	Shear Webs and Axial loader members	Shear & Axial Load	This Deck is designed primarily by pressure loads combined with docking loads and mid-course correction loads. Since the docking and mid-course correction loads can occur on the Labs. A redesign may be necessary in this area. To determine the extent of redesign the primary loads will have to be determined.
(30) (26) (22) (1) (2)	Docking Tunnel	Shear & Axial Load	This Deck is designed primarily by pressure loads combined with docking loads and mid-course correction loads. Since the docking and mid-course correction loads can occur on the Labs. A redesign may be necessary in this area. To determine the extent of redesign the primary loads will have to be determined.

113

Truss Member	Landing Conditions						
	IA	IC	IIB	IIC	IIIA	IIID	I
AC	-1484	+2163	-1713	-2083	-1539	-2020	-2
BC	+2270	-3094	+2471	+2776	+1560	+1957	+3
BD	+ 932	-1013	+1429	+ 55	+ 461	-1325	+1
KH	+ 340	- 317	+ 261	+ 144	- 316	- 469	+
HE	+ 529	- 477	+1801	-1213	+1278	-2638	+1
A'C'	-1484	+2163	-2083	-1713	-2020	-1539	-2
B'C'	+2270	-3094	+2776	+2471	+1957	+1560	+3
B'D'	+ 932	-1013	+ 55	+1429	-1325	+ 461	+
K'H'	+ 340	- 317	+ 144	+ 261	- 469	- 316	+
H'E'	+ 529	- 477	-1213	+1801	-2638	+1278	-

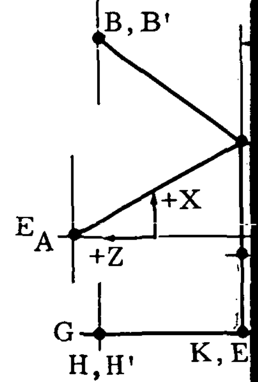
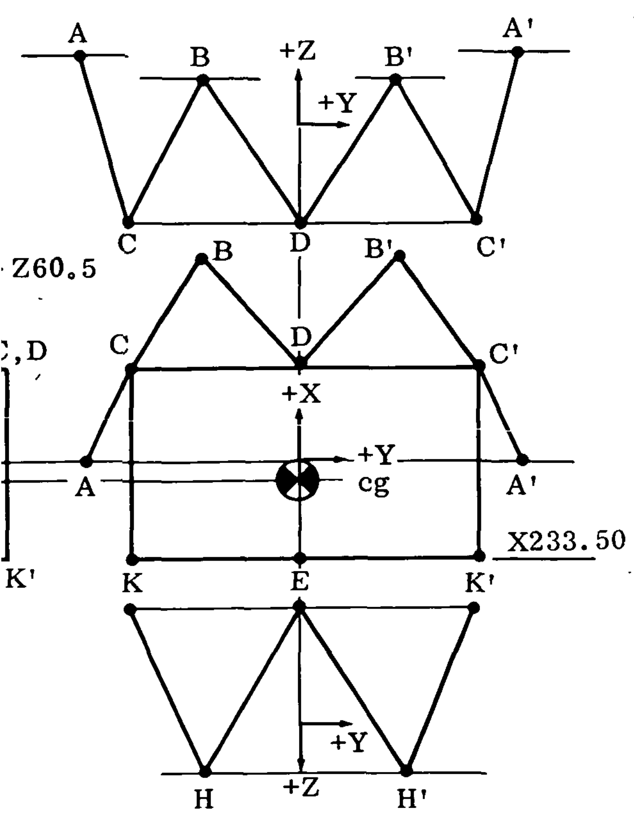


Table 6.4-2

AXIAL LOADS TRUSS

xial Loads in Rack Truss Members (Gross Wt = 990 lb)

		Boost				Vibratory Conditions, *Random gs					
		7.35g		n_z=+.1g	n_z=-.1g	n_y=+3.5g	n_y=-3.5g	n_x=+3.5g	n_x=-3.5g		
/B	IVC	A_1	A_2	F_{1a}	F_{1b}	F_{2a}	F_{2b}	F_{4a}	F_{4b}	F_{3a}	F_{3b}
370	-2613	-3029	-3053	+1168	-1996	- 689	- 138	-1862	+1034	-2662	+1782
150	+3351	+3688	+3687	- 97	+1101	+ 729	+ 274	+2258	-1254	+1423	- 391
114	+ 212	+ 343	+ 373	+1986	-1888	- 975	+1072	+ 219	- 122	-2787	+2787
144	+ 67	- 91	- 118	+1137	-1165	- 102	+ 73	- 64	+ 35	-1478	+1478
112	- 866	- 299	- 165	+1889	-1952	-2277	+2213	- 142	+ 79	-2320	+2320
513	-2370	-3006	-3077	+1168	-1996	- 138	- 689	-1862	+1034	-2662	+1782
351	+3150	+3669	+3706	- 97	+1101	+ 274	+ 729	+2258	-1254	+1423	- 391
212	+1114	+ 431	+ 285	+1986	-1888	+1072	- 975	+ 219	- 122	-2787	+2787
67	+ 144	- 83	- 125	+1137	-1165	+ 73	- 102	- 64	+ 35	-1478	+1478
366	+1112	- 107	- 357	+1889	-1952	+2213	-2277	- 142	+ 79	-2320	+2320



* All Conditions Include N_x = +1g

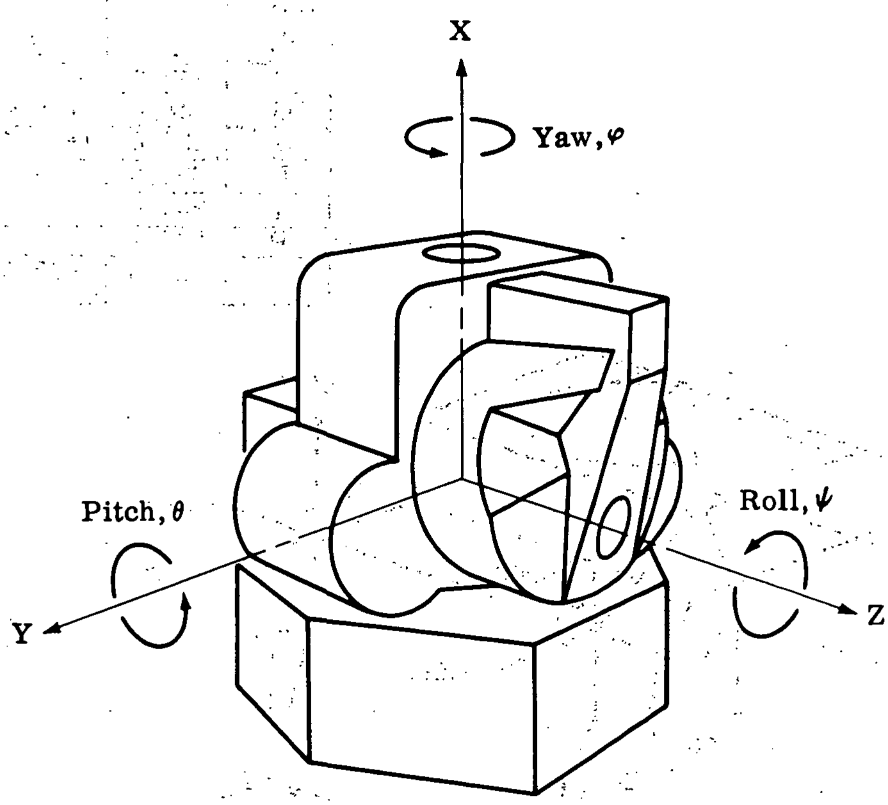
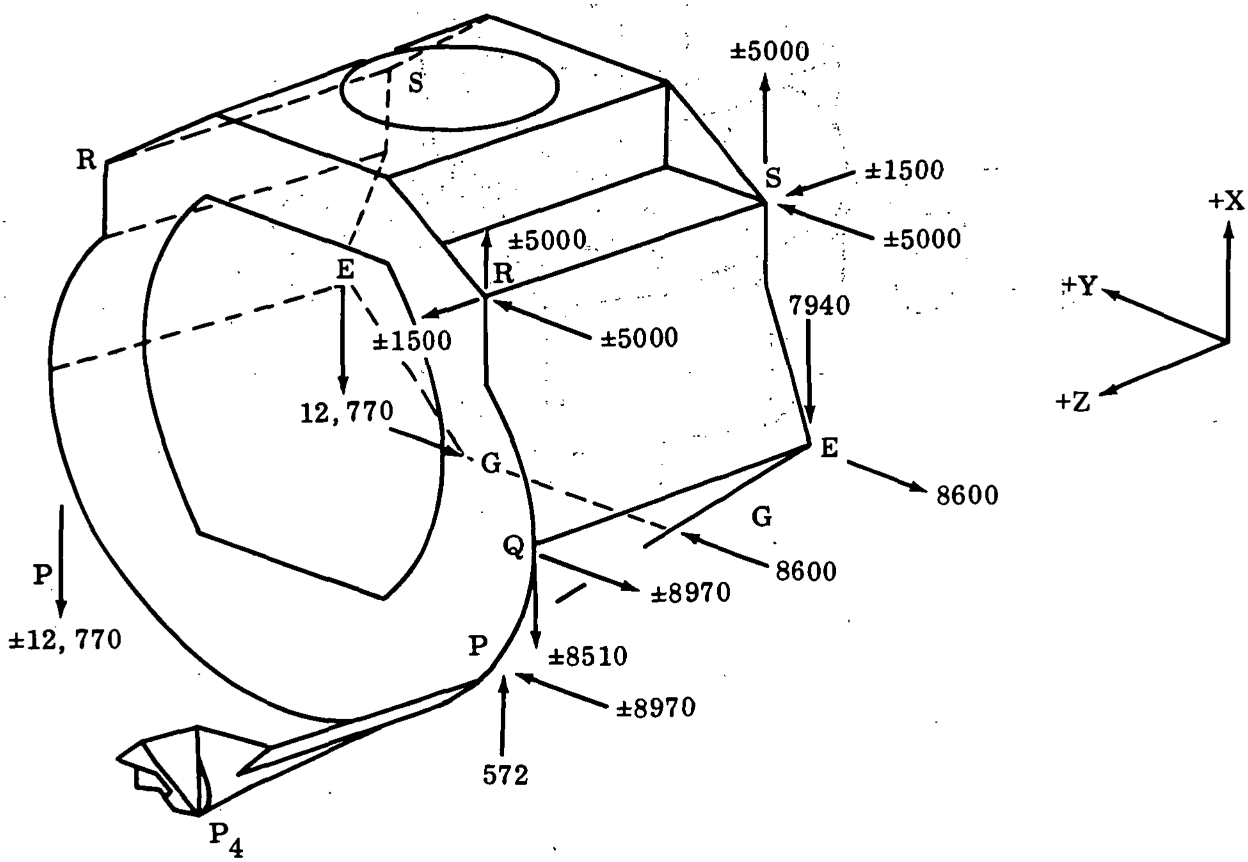


Fig. 6.4-1 Lab Reference Axes

Hard Pt.	X	Y	Z
E	253.5	±45.0	-27
G	228.0	±18.4	-27
S	294.6	±36.7	-27
R	294.6	±36.7	+27
Q	252.0	-46.8	+27
P	229.4	±43.7	+27
P_4	211.3	±22.5	+64.6



Note: Loading (in lb) is symmetrical except where shown.

Fig. 6.4-2 Ascent Stage Mid-Section

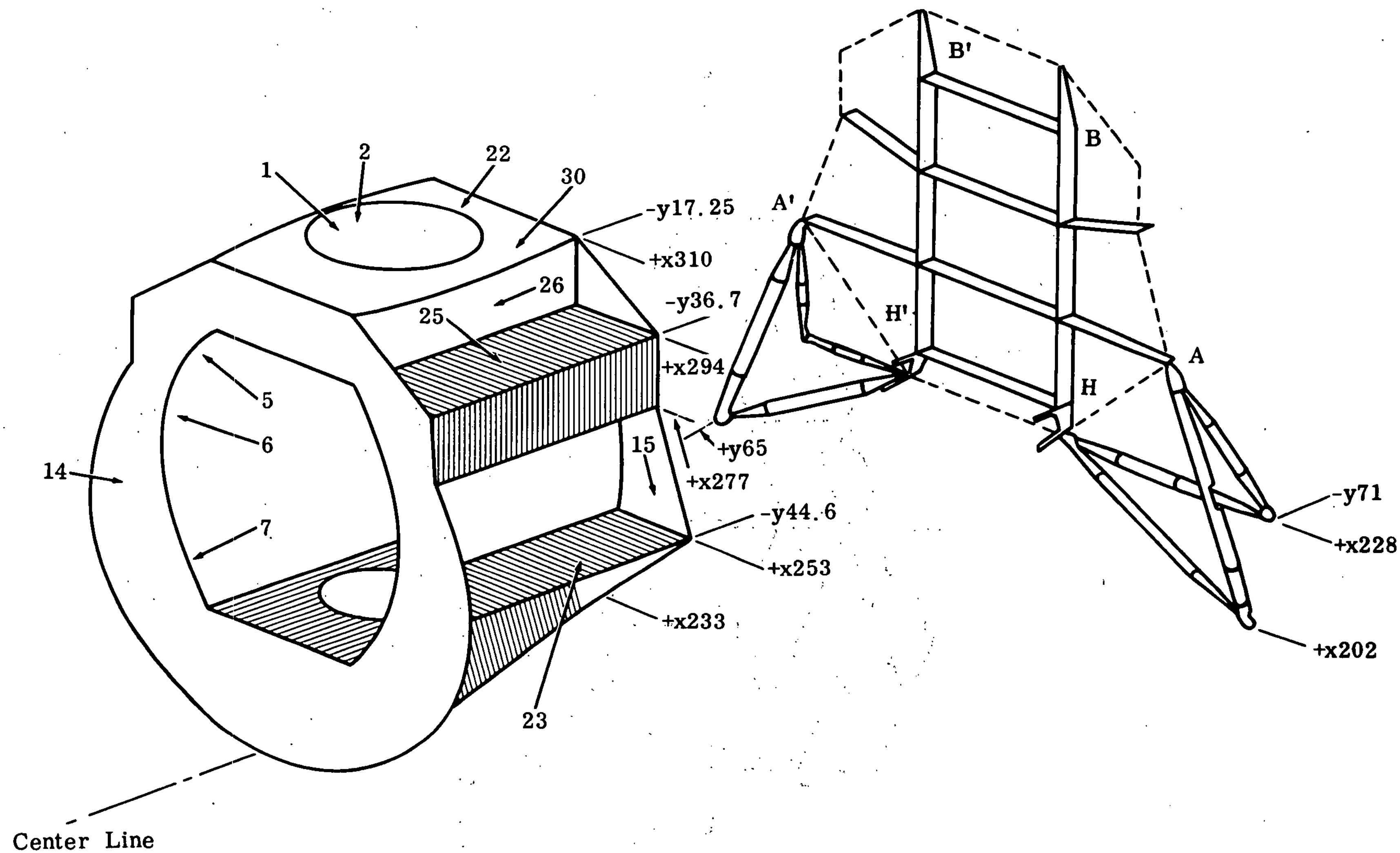


Fig. 6.4-3 Ascent Stage Mid-Section

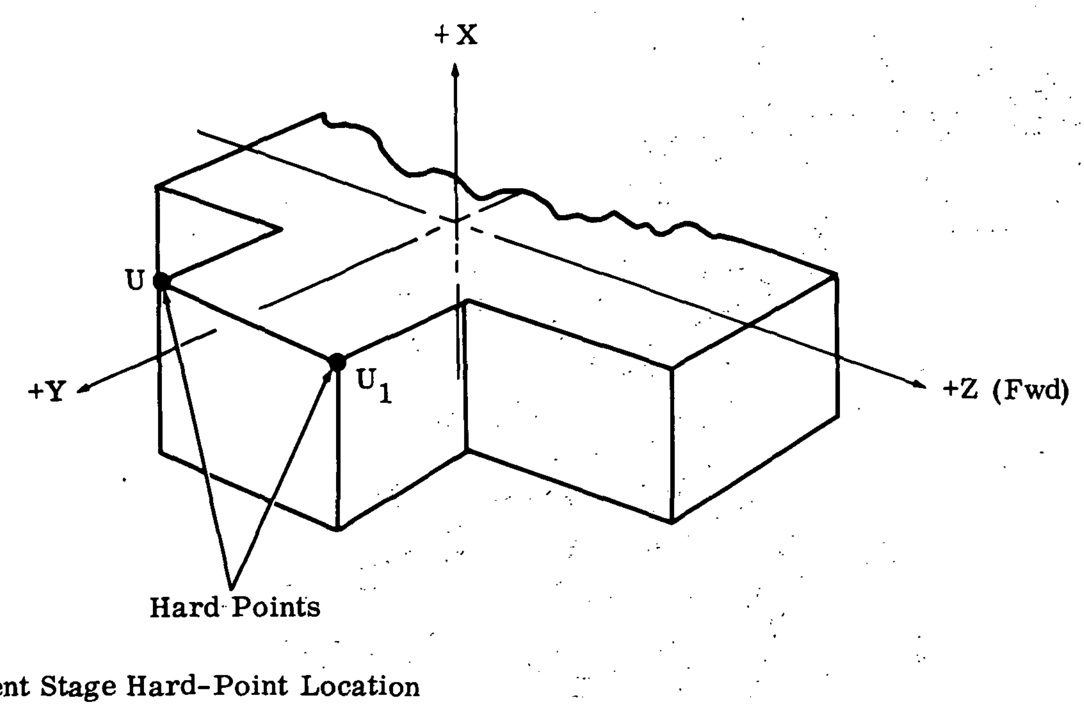


Fig. 6.4-4 Descent Stage Hardpoints

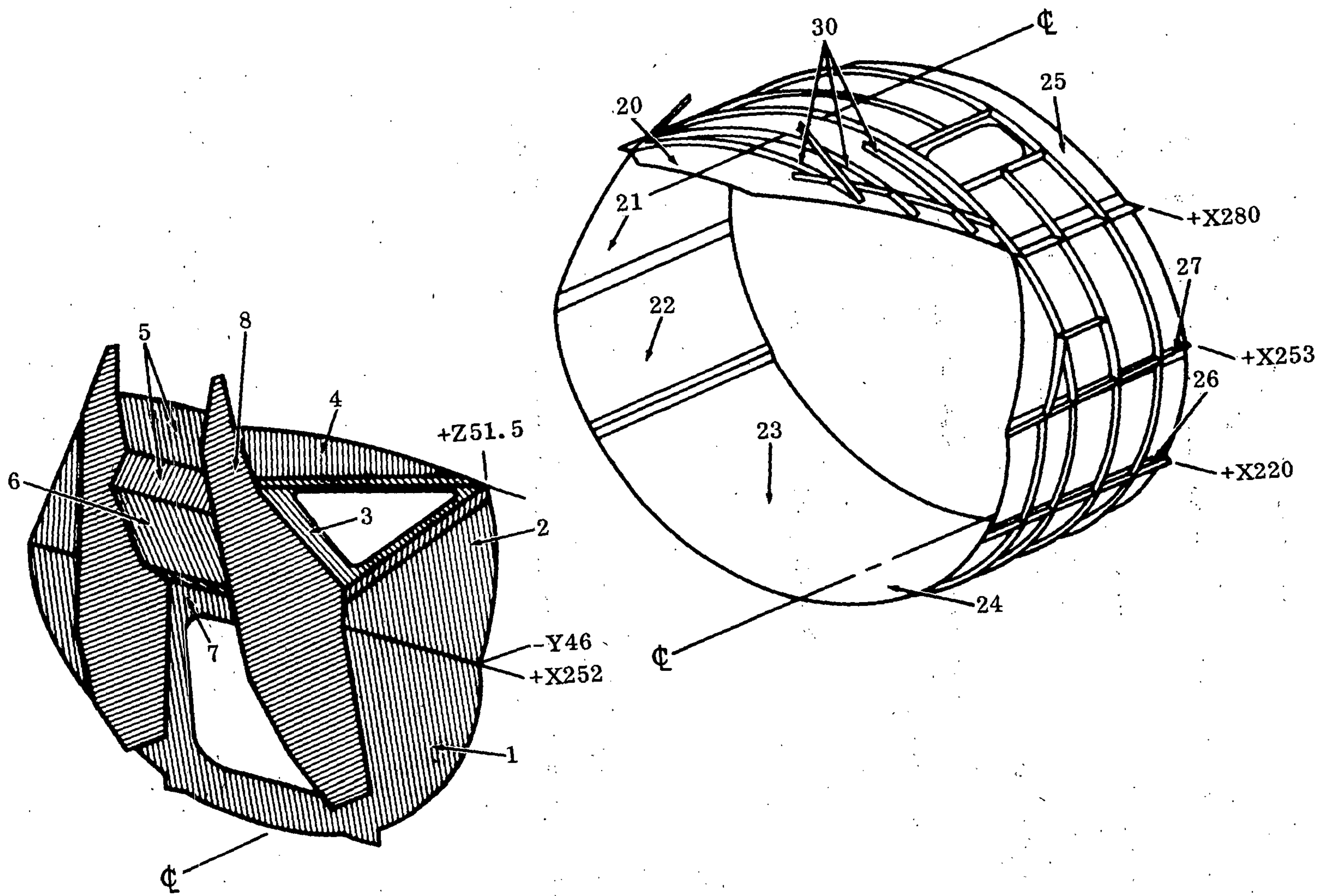
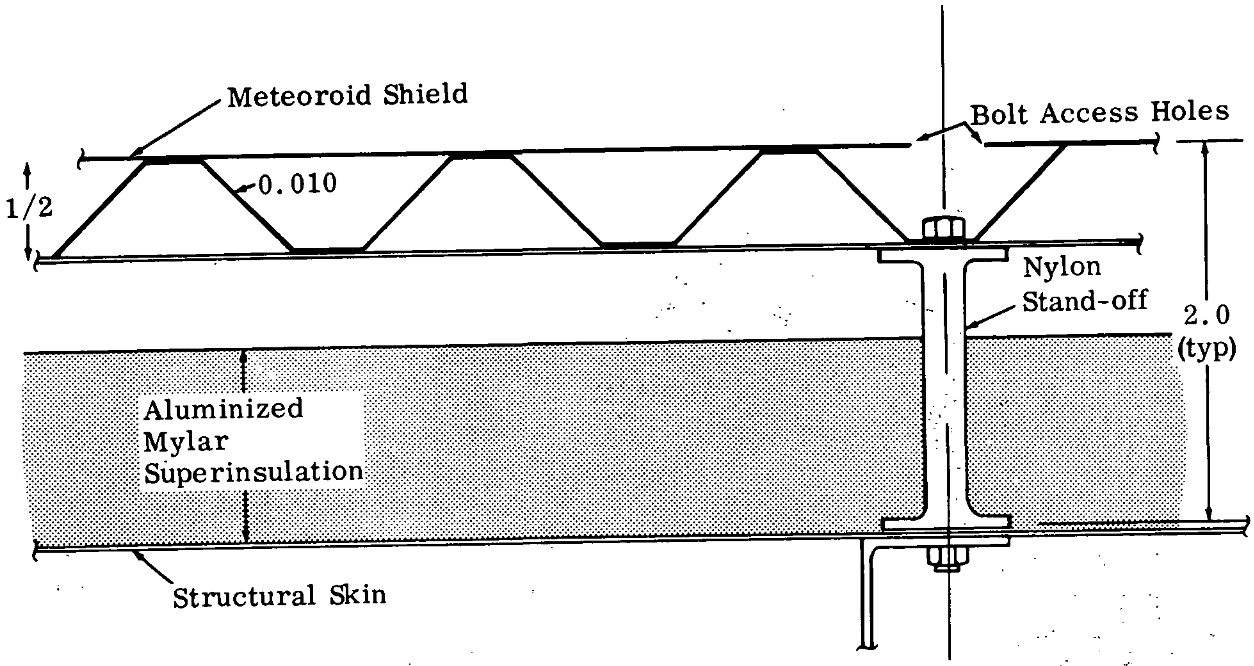
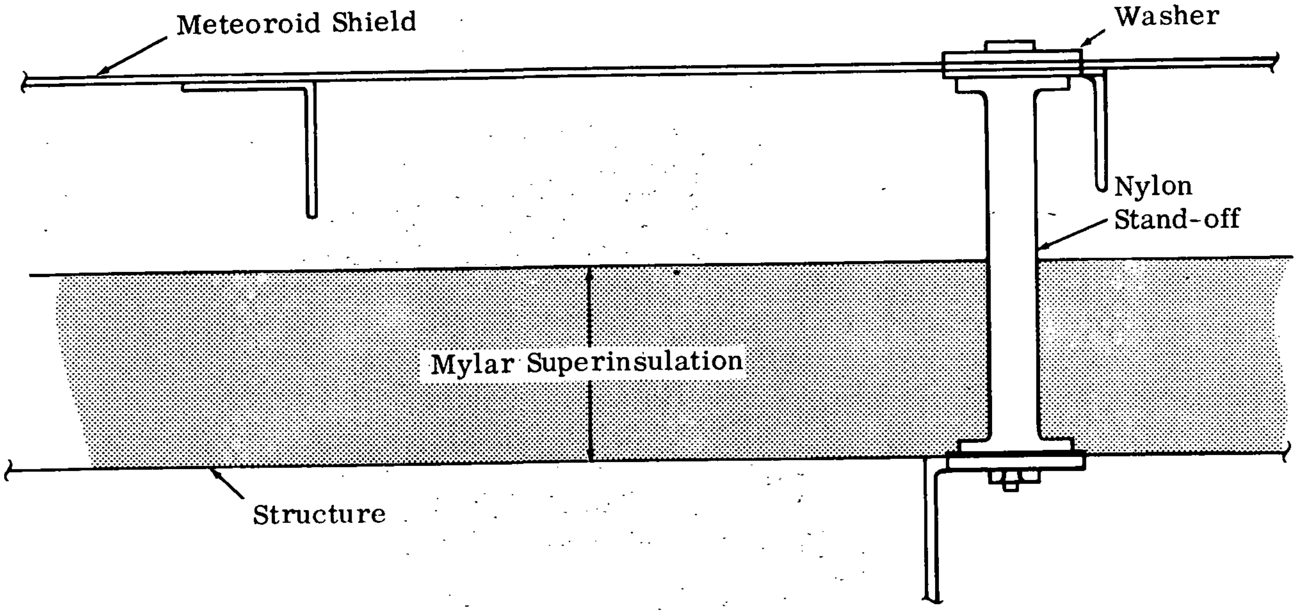


Fig. 6.4-5 LEM Ascent Stage Front Face & Cabin



A. Corrugation-Stiffened Shield



B. Sheet - Stiffener Shield

Fig. 6.4-6 Alternate Meteoroid Shield Supports

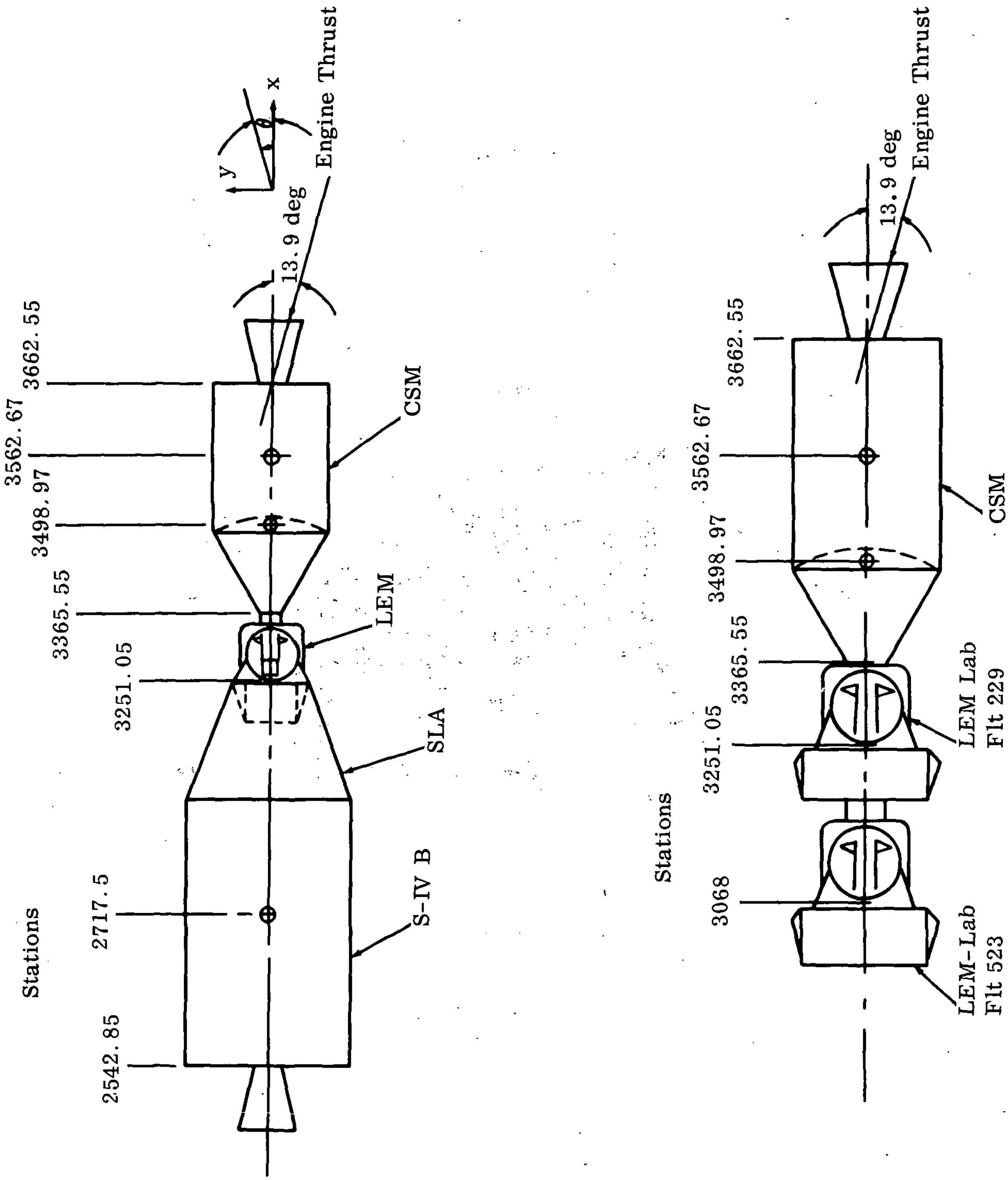


Fig. 6.4-7 S IV b - LEM - CSM , 2 LEMS-CSM

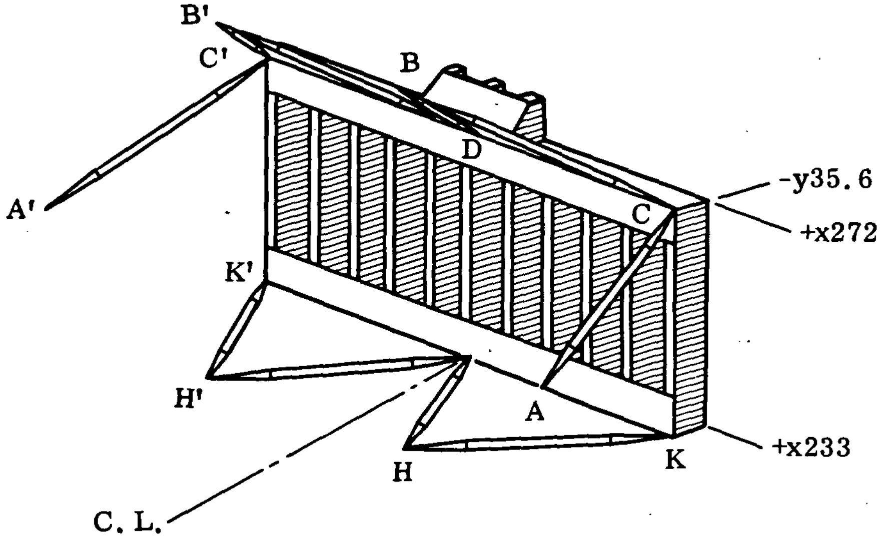
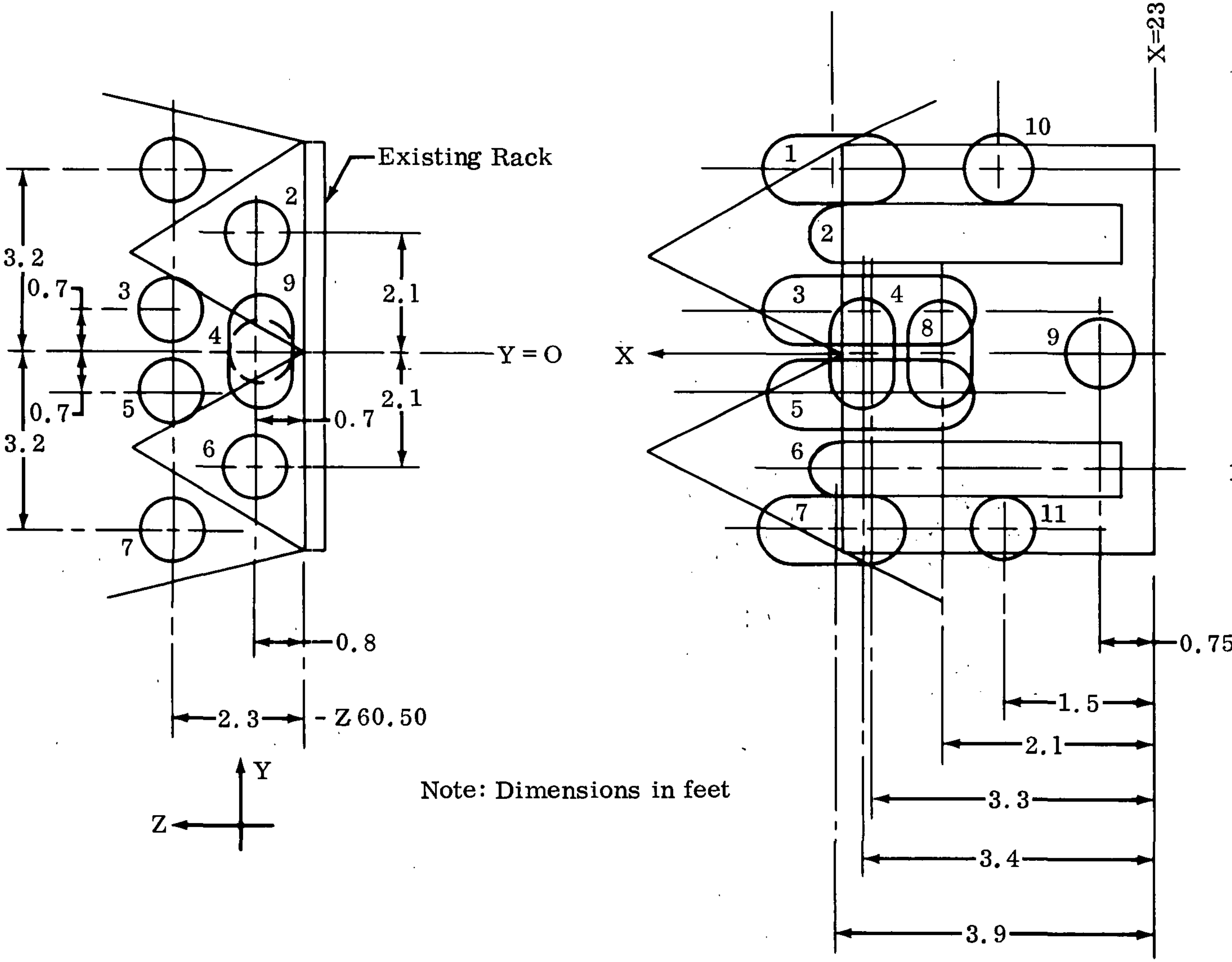


Fig. 6.4-8 Aft Equipment Rack



Key		Wt, lb
1	RCS Fuel	106
2	AC Fuel Cell	164
3	RCS Oxidizer	202
4	CSM Water Tank	15
5	RCS Oxidizer	202
6	AC Fuel Cell	164
7	RCS Fuel	106
8	CSM Water Tank	15
9	GOX Accumulator	9
10	RCS He	13
11	RCS He	13

Fig. 6.4-9 Fuel Cell - Aft Equipment Rack

Grumman

7. REFERENCES

4.2-1 LMO-310-229: "Current Status of the RCS Engine", 2 July 1965.

4.2-2 LSP-300-14 C: "Attitude and Translation Control Assembly Specification".

4.2-3 LMO-500-229: "Request for Implementation of a Simplified RCS Jet Select Logic in the ATCA", 7 Dec. 1964.

4.2-4 MIT Instrumentation Lab Report R-499: "Design Principles of the Lunar Excursion Module Digital Autopilot", July 1965.

4.4-1 IOM-64-46: "Personnel Radiation Safety Monitoring Package for Phase I Lab ACS: Lisa, J, Grumman, 9 Sept. 1965.

4.4-2 Report No. 553243-5: "Study of Human Factors and Environmental Control - Life Support System", Vol. 5, Garrett AiResearch Mfg. Co.

4.4-3 Davenport, E.W., Congdon, S.P., Pierce B.F.: "Minimum Volumetric Requirements of Man in Space", AIAA, 1963.

4.4-4 IOM-65-53: "Medical and Behavioral Package for Phase I Lab - AES", Lisa, J. and Kelvin, A, Grumman, 9 Sept. 1965.

4.4-5 Federal Standard No. 595: "Colors", 1 March 1956.

4.4-6 SID 63-1392, NASw-775: "Biomedical and Human Factors Requirements for a Manned Earth Orbiting Station - Final Report", North American Aviation, Inc., 18 Nov. 1963.

4.4-7 RAC 1781 (ARD-FR-63-144); NASw 776: "Biomedical and Human Factors Requirements for a Manned Earth Orbiting Station - Final Report", Republic Aviation Corporation, Inc., Jan. 1964.

4.4-8 ANSA SP-70: "Conference on Nutrition in Space and Related Waste Problems", 27-30 April 1964.

CONFIDENTIAL

Grumman Aircraft Engineering Corporation • Bethpage, New York

4395

CONFIDENTIAL