# NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY, PHASE III FINAL REPORT

VOLUME II
Concept and Feasibility Analysis

PART A Class 1 Hybrid RNS

PREPARED FOR NASA-MSFC UNDER CONTRACT NAS8-24714 DRL NO. MSFC-DRL-196, LINE ITEM 3

BOOK 2
System Definition

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**MAY 1971** 

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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## FOREWORD

This document contains the results of the system design definition effort, including the stage/engine interface, performed during the Phase III Nuclear Shuttle Definition Study for the Class 1 Hybrid Reusable Nuclear Stage (RNS) concept. This work was accomplished for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama, under Contract NAS8-24714. The final report was generated to fulfill the requirements of DRL No. MSFC-DRL-196, Line Item 3, and it covers the period from May 1, 1970 to May 1, 1971.

The study effort described in this volume was performed under the direction of Dr. R.J. Holl and Dr. K.P. Johnson, with responsibility for specific activities as follows:

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- K.M. Anderson Structures Design
- M. Berry Propulsion Design
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- D. Crosby Insulation Design
- L.B. Goda Structures and Insulation Design and Analysis
- C. Goetz Radiation Levels Analysis
- V. Jacobs Propulsion Design
- R. Luna Reliability Analysis
- R.F. Manoske Propulsion Analysis
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#### PREFACE

The material contained in this document represents a portion of the final report documentation for the Phase III Nuclear Shuttle System Definition Study. The study effort was performed as a 12-month extension to the existing Nuclear Flight System Definition Study Contract (NAS8-24714), with the objective of establishing Phase A conceptual definition for two classes of reusable nuclear shuttle concepts. The first concept class is characterized as a 33-ft.-diameter configuration that is launched integrally to orbit by a Saturn V INT-21 vehicle. The second concept class is characterized as a modular configuration which is assembled in earth orbit from modules carried to orbit in a space shuttle.

The final report documentation has been organized to provide separable information for the two concepts, where appropriate, and to combine report material common to both concepts in singular documents. The total documentation for the study is listed below, with this document identified in the left margin.

o	Volume I:	Executive Summary
	Volume II:	Concept and Feasibility Analysis
		Part A - Class 1 Hybrid RNS
o •		Book 1 - System Analysis and Operations Book 2 - System Definition
		Part B - Class 3 RNS
0		Book 1 - System Analysis and Operations Book 2 - System Definition
	Volume III:	Program Support Requirements
0		Part A - Class l Hybrid RNS
0		Part B - Class 3 RNS
0		Part C - Test Program Analyses and SRT Requirements
	Volume IV:	Cost Data
0		Part A - Class l Hybrid RNS
0		Part B - Class 3 RNS
О	Volume V:	Schedules, Milestones, and Networks
o	Volume VI:	Reliability and Safety Analysis
0	Volume VII:	RNS Project Requirements

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# Section 1 DESIGN SUMMARY

This section contains a brief description of the Reusable Nuclear Shuttle (RNS) Class 1 Hybrid (1-H) concept. The vehicle is based in low earth orbit (260-nmi altitude, 31.5-degree inclination) and provides transportation in a shuttle mode to more distant destinations. Its design mission is a round trip to a 60-nmi lunar polar orbit. It is maintained and replenished in earth orbit by the space shuttle.

A sketch of the Class 1 Hybrid RNS configuration is shown in Figure 1-1 which illustrates the selected configuration and provides a locator for some of the features which were evaluated. It consists of three distinct modules which can be assembled and disassembled in space. The aft module, called the propulsion module, contains NERVA and a small run tank of propellant. The propellant module provides the main propellant tank and minimal propellant management subsystems. At the forward end of the stage is a command and control module (CCM) which contains most of the functional equipment and all of the expendables except for main stage LH<sub>2</sub>. The auxiliary propulsion engines are located on outriggers on the CCM, which are visible in the sketch. This module is replaced between missions in earth orbit, thereby effecting a replenishment of expendables and all scheduled maintenance.

Both the propulsion module and the CCM are designed to be transported to earth orbit within the cargo bay of the space shuttle. This facilitates replacement of the CCM, as noted, and of NERVA, as might be required because of failure or to extend the lifetime of the RNS beyond that of the engine. The RNS is resupplied with LH<sub>2</sub> in earth orbit by the space shuttle between missions.

The total propellant capacity of the stage is 300,000 lb of  $LH_2$ , of which 10,850 lb of  $LH_2$  is contained in the run tank on the propulsion module. The

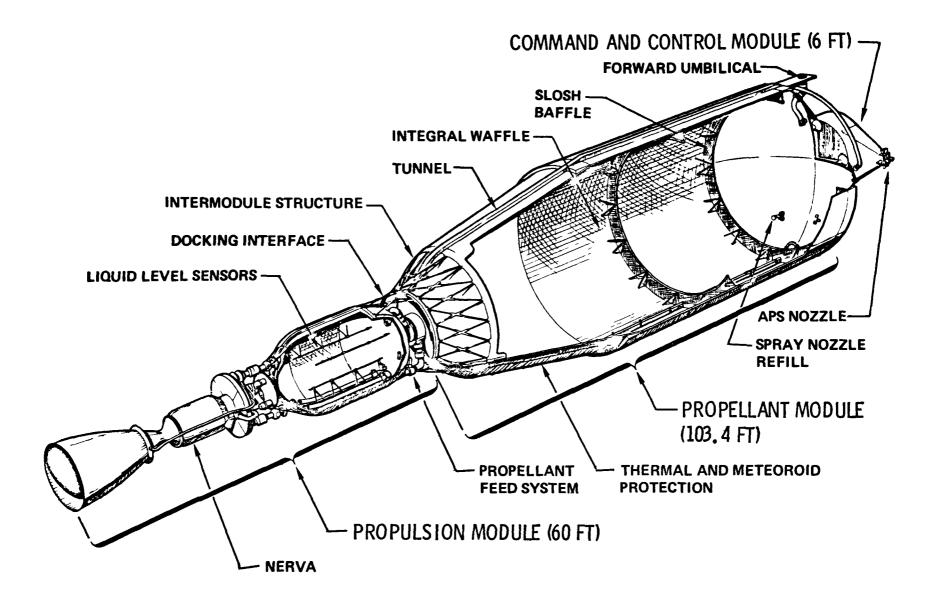


Figure 1-1. Class 1 Hybrid RNS

modules are contained within a 10-degree half-angle cone subtended by the NERVA reactor which resulted from a combined optimization of structural and shield weights during Phase II. The run tank diameter on the propulsion module is constrained to 160 in. to limit the radiation shield weight, but still provide adequate volume to allow nearly autonomous operation, independent of resupply by the propellant module. This autonomy simplifies the operating requirements imposed on the stage and reduces the RNS development requirements. The forward location of the CCM is selected for each of replacement.

The RNS design and operations concept minimizes orbital support requirements. The space shuttle is utilized to deliver replacement modules and to resupply propellant. No permanent, manned, orbital facilities are required for maintenance or propellant resupply.

A detailed weight statement for the RNS Class 1 Hybrid is given in Table 1-1. Entries are shown for each of the modules as well as for the total vehicle. The system description contained in the work breakdown structure provided as part of the study guidelines is used with additional items added to cover unique components.

Table 1-1
WEIGHT SUMMARY FOR CLASS 1 HYBRID RNS

		Modules Weight (lb)			
Code	Description	Pro- pellant	Pro- pulsion	Command and Control	Total Vehicle Weight, (lb)
2.00	Structure	(21,110)	(1,300)	(720)	(23,130)
2.01	Propellant tank assembly	17,150	570		
2.02	Thrust structure	470	170		
2.03	Forward skirt	620	250		
2.04	Aft skirt	720			
2.05	Tunnel and fairings	490			
2.06	Exterior finish and sealer	210	20		
2.07	Antislosh baffles	360	60		
2.08	Equipment support structure	230	160	360	
2.09	Equipment module structure			360	
2.10	Additional structure Payload adapter Access	640 220	<b></b> - 70		
3.00	Meteoroid/thermal protection	(6,250)	(710)	(110)	(7,070)
3.01	Insulation	2,470	430		
3.02	Meteoroid protection	3,780	280	110	
4.00	Docking/clustering	(280)	(80)	(280)	(640)
4.01	Forward docking structure	80	80	80	(010)
4.02	Aft docking structure	200		200	
4.03	Clustering structure				
5.00	Main propulsion	(520)	(30,630)	(560)	(31,710)
5.01	NERVA engine	(3.20)	27,300	500	(==, )
5.02	External disc shield for NERVA		2,900		
5.03	Purge system				
5.04	Propellant scavenging system and sensors				
5.05	Propellant feed system	110	140		
5.06	Pressurization system		60		
5.07	Prepressurization system				
5.08	Pneumatic system				
5.09	Fill and drain/orbit refueling	120	60	60	
5.10	Ground and emergency vent	160			

Table 1-1 (Continued)

		Modules Weight (lb)			
Code	Description	Pro- pellant	Pro- pulsion	Command and Control	Total Vehicle Weight, (lb)
5.11 5.12 5.13	Flight vent Integrated chilldown system Refill system	60	50 70 50		
6.00 6.01 6.02 6.03	Auxiliary propulsion Reaction control system Retro system Ullage system		(160) 160 	(950) 950 	(1,110)
7.00 7.01 7.02 7.03 7.04 7.05 7.06 7.07 7.08 7.09	Astrionic system/ astrionics Guidance, navigation and control Instrumentation Command and control Electrical power Electrical networks Environmental control Propellant management Onboard checkout Data management	(255)  35 10 40 160  5 5	(345) 20 15 10 130 150 10 5 5	(1,905) 310 210 140 785 85 60 315	(2,505)
8.00 8.01 8.02	Safety/ordnance system Safety system Ordnance system	 			
9.00	Contingency	(1,480)	<b></b>	(200)	(1,830)
10.00	Subtotal RCS propellant	29,865	33,375	4,725 (1,250)	67,995 (1,250)
11.00 11.01 11.02 11.03	Residual propellant Liquid propellant Vapor vented Vapor	(9,030) 400  8,630	(440) 100  340	  	(9,470)
12.00	Reserve flight performance				(1,700)
13.00 14.00 14.01 14.02 14.03 14.04	Propellant boiloff Impulse propellant Leave earth Arrive moon Leave moon Arrive earth				(288, 830) 174, 330 37, 960 26, 210 50, 330
	Total	NA	NA		369, 245



# Section 2 SYSTEM REQUIREMENTS

The analyses of the design and operations of the RNS are contained in Book 1 of this volume. A brief summary of the system requirements established in that document is provided in this section to complement the system definition.

#### 2.1 MISSION APPLICATIONS

Three classes of missions are proposed for the RNS: interorbital shuttle (lunar and geosynchronous), unmanned planetary, and manned planetary. These are all performed in a reusable shuttle mode. The design implications of these are presented in Section 2 of Book 1 and more detailed mission descriptions and performance data are documented in the Mission Planning Handbook (MDC G0595).

The lunar shuttle mission provides the basis for RNS design requirements in this study. This mission entails transfer of cargo and men to and from a 60-nmi polar lunar orbit, operating from a low circular earth orbit at 260 nmi and 31.5-degree inclination. The design mission consists of eight mainstage burns, which provides for plane rotation at lunar orbit injection and transearth injection. Mission timelines are based on a 54.6-day repeating cycle. The top level mission timeline is shown in Table 2.1-1. The reference mission considers delivery of a 110,000-lb payload to lunar orbit with return of only the 20,000-lb crew module to earth orbit. This mission is used for design purposes only; a four-burn mission, without the plane change maneuvers in lunar orbit, is considered nominal for performance purposes.

Table 2. 1-1
MISSION TIMELINE
CLASS 1 HYBRID

		Propulsion Parameters					
Event	Initiation Time (hr)	l Impulse Propellant (lb)	Cooldown Propellant (lb)	Steady- State Time (sec)	Total Run Time (sec)	<sup>2</sup> Cooldown Time (hr)	
TLI	0	165,760	7,300	1,750	2,700	108	
3 <sub>Mid-course</sub>	15, 37, 67 (typ)	1,000	-	500	50 <b>0</b>	-	
LOI-1	180	10,730	770	70	330	12	
<sup>4</sup> LOI-2	120	5,370	400	25	260	12	
LOI-3	132	19,330	1,250	160	460	27	
TEI-1	518	11,860	850	82	350	12	
<sup>4</sup> TEI-2	530	3,900	300	0	230	5	
TEI-3	542	8,200	600	43	290	11	
3 <sub>Mid</sub> - course	552, 557, 595 (typ)	500	-	250	250	-	
EOI	614	47,910	2,800	470	930	45	
	Total =	274,560	14,270				
TLI Translunar injection  LOI-1 Lunar orbit injection (into 24-hr elliptical capture orbit)  LOI-2 30-deg plane change maneuver  LOI-3 Circularization maneuver at 60 nmi  TEI-1 Injection maneuver to elliptical department orbit  TEI-2 30-deg plane change maneuver  TEI-3 Transearth injection  EOI Earth orbit injection (260 nmi)  NOTES: 1 Including chilldown (56 sec) through PSOV closure.  2 Or time to next maneuver, whichever is less.  3 Idle mode operation.					t)		

4 Throttle mode operation, 30-deg plane change.

## 2.2 RNS OPERATIONS

The prelaunch, launch, and mission phases of the RNS system operations are analyzed in Section 3 of Book 1 to establish a basis for the RNS design. The functional flow of operations and method of reporting is summarized in Figure 2.2-1 for major categories of operations which have been abstracted from the top and first level functional flow diagrams reported in Volume VII. The entries in Figure 2.2-1 are indexed according to the functional flow designation (FF), the MSFC study task numbers (T), and the report sections in Book 1 (S). Major features of these operations and their implications for the RNS design are summarized here.

The Class 1-H propellant module is assembled at Michoud and subjected to cold flow testing at the Mississippi Test Facility (MTF). The propulsion module run tank is assembled at Huntington Beach and subjected to cold flow testing with an engine simulator at MTF. Engine mating and interface verification tests are conducted at KSC. The CCM is assembled and checked out at Huntington Beach. Propellant modules are transported by barge while the propulsion module run tank and command and control module are transported by air (super guppy).

Each RNS module is launched to orbit separately and assembled in orbit. The envelope of the Class 1-H propellant module permits an 84-percent launch availability with existing S-IC and S-II structure using wind bias trajectories. The Class 1-H RNS is assembled without requiring a space tug or external support systems. The CCM is launched first. It acquires the propellant module which is launched second and docks to it. The propulsion module is launched last and is self-stabilized for the assembly operation which is performed under control of the CCM. Fluid and electrical couplings are accomplished in orbit using remote assembly mechanisms.

Propellant resupply is a major orbital support operation. Selection of RNS fleet size and missions scheduling obviates the requirement for an additional reservoir of propellant tankage in orbit as a tank farm. The space shuttle delivers LH<sub>2</sub> directly to the RNS performing a propellant transfer under

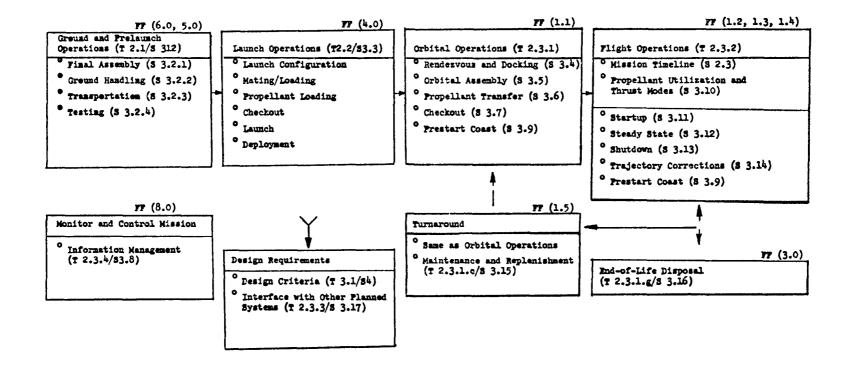


Figure 2.2-1 RNS OPERATIONS SUMMARY

linear acceleration provided by the space shuttle. Prior to initiating the mission, propellant is vented to reject the heat from propellant tank chill-down and orbital heating during refueling. The tank is subsequently topped off to begin the mission with propellant at 16 psia.

Checkout of orbital assembly interfaces is provided by the CCM during the assembly operations. The RNS performs autonomous onboard checkout for the orbital countdown. Component functional check is utilized to avoid the consumption of expendables and NERVA criticality associated with simulated operations. A nominal processor requirement of 8,200 equivalent adds per second and 25,000 words of storage has been identified for onboard checkout. Except for a small increase in instrumentation, no additional components or subsystems are required to accomplish RNS checkout.

The ground monitors the RNS performance and intermittently provides information to the RNS via uplink as required. Ground processing is performed for fault prediction and trend analysis evaluation between missions. The primary RNS data interface is to the ground utilizing an estimated transmission rate over ground stations of only 8,500 bits per second. Hence no requirement for communication satellite relay is anticipated.

The RNS is oriented in the gravity-gradient-stable, local-vertical orientation during long-term coast phases in earth and lunar orbits. This precludes the need for active attitude control. The RNS operates in a limit cycle mode during the translunar and transearth coast periods, and during both of the 24-hour lunar phasing orbits. The navigation and guidance subsystem will remain dormant during the gravity-gradient-stabilized periods; 36 attitude maneuvers have been imposed to establish vehicle attitude for RNS operations. A separate maneuver is also performed by the APS before translunar injection or transearth injection to permit the RNS to leave the vicinity of the space station before initiating full-thrust NERVA operation.

The propellant utilization and NERVA thrust modes were defined for the reference lunar shuttle mission profile in Table 2.1-1. Six burns are performed using NERVA at full thrust. A throttle mode (45,000-1b thrust) is

employed for the two lunar orbit plane change maneuvers. NERVA idle mode operation is used for midcourse maneuvers. The RNS propulsion module operates autonomously to provide aftercooling propellant to NERVA after all burns and to accomplish throttle mode maneuvers and midcourse corrections. The run tank is refilled prior to each full thrust operation.

The startup operations have been defined for the RNS. These begin with propellant settling provided at a 3.2-lb thrust level by the APS (this results in accelerations less than 2 x 10-5 g). Settling is completed at high thrust using the NERVA startup thrust ramp. A thrust hold is integrated into the startup ramp at the throttle point to permit completion of propellant settling and propellant module pressurization. The propellant feed system is chilled down during the initial phase of propellant settling and the run tank is refilled before initiating the NERVA thrust ramp. The run tank operates autonomously during the startup operation and uses NERVA bleed gas for an autogenous bootstrap startup. The propellant tank is pressurized and brought on-line to restore the steady-state propellant level in the run tank before its level has dropped below 5,000 lb LH<sub>2</sub>.

Use of the navigation and guidance system with two star trackers and a strapdown inertial measuring unit provides adequate trajectory accuracy for an autonomous navigation and guidance approach.

During the steady-state operation, the run tank in the propulsion module acts as a surge tank. A control system was defined to regulate the pressures in both the run tank and main propellant tank in addition to the LH<sub>2</sub> level in the run tank. This propellant management control system has been simulated to demonstrate its capability to regulate the startup and shutdown ramp, refill the run tank after startup when the propellant module has been brought on-line, to adjust to acceleration head changes during burn, and to respond to flow rate changes for the NERVA emergency mode operation. Simulations of thrust vector control have established engine gimbal requirements and determined the attitude excursions following startup both with and without pretrimming the NERVA thrust vector prior to startup. The advantages of this initial trim operation were established.

RNS operations for shutdown and aftercooling have been defined. Because of the long times and large number of pulses involved in providing cooldown during a mission, the requirements to provide propellant to NERVA at specified conditions during aftercooling can impose severe penalties on the RNS design. The recommended approach uses a surface tension device to provide saturated LH2 from the run tank for aftercooling pulses. The mission performance implications of aftercooling were established. The payload delivery to lunar orbit was increased by 8,400 lb by crediting the cooldown contribution to mission velocity. A potential payload gain of 23,540 lb was identified if cooldown could be eliminated entirely. This evaluation indicated that a major portion of that payload gain could be achieved if a high-temperature radiator system could be integrated with NERVA. Trajectories have been defined for orbital injection accounting for dispersions in cooldown propellant which permit reaching the final target orbit without imposing additional impulsive requirements on the RNS. The desirability of trimming the engine thrust vector through the vehicle cg has been identified to reduce attitude disturbances during pulsed aftercooling as well as prior to startup as described earlier.

The requirements for trajectory midcourse correction were evaluated. It was found that multiple impulsive midcourse maneuvers or a single impulsive correction early in the trajectory are preferable to a single impulse maneuver at the end of the cooldown phase. Trajectory correction utilizing vectored cooldown thrust is also considered competitive with early impulse corrections.

RNS maintenance is accomplished by module replacement at the assembly level. The CCM containing the functional subsystems is recycled to the ground each mission for maintenance and replenishment of expendables. The Phase III maintenance study considering multiple replacement modules, a single CCM and in situ maintenance has reaffirmed the advantages of the CCM concept and its minimal orbital support requirement. At the end of NERVA life, it is recommended that the propulsion module be disposed from earth orbit (or lunar orbit in the event of a failure) by a reusable chemical tug and propellant modules recycled on an unscheduled basis.

The evaluation of RNS operations and interfaces with other candidate system elements has indicated that RNS operations require minimal orbital support. Elements considered and found to be unnecessary include an orbital propellant depot, an orbital maintenance facility, communications satellites, and remote manipulator units. The space tug can be used for payload handling, although its functions could be adequately provided by a CCM from the RNS. A lunar lander size tug is utilized for NERVA disposal. Thus, the major support system for the RNS is the space shuttle which provides initial delivery of RNS modules to orbit and subsequent propellant resupply as a tanker vehicle. Of course, the Saturn V INT-21 launch vehicle is used for the propellant module.

## 2.3 DESIGN CRITERIA

The design criteria for each of the major subsystems used as a basis for the design analysis are presented in Section 4 in Book 1. The major considerations and sources of data for these will be summarized here.

The basis for structural design criteria is contained in "Guidelines for Strength Analysis Test and Assessment Requirements", MSFC Memorandum S&E-ASTN-AS-70-55, dated June 5, 1970. The memorandum defines terminology and data sources. The principal source of material properties is "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5A, February 8, 1966. Space shuttle load factors are defined by MSFC Memo PD-SA-70-269, dated November 13, 1970. The space shuttle launch is manned. Critical for launch of the Class 1H propellant module on the INT-21 launch vehicle are defined by 'Ground Rules for INT-21 Launch Vehicle Definition Studies, Revision B", MSFC Letter S&E-CSC-L-70-239, dated August 24, 1970. The launch will be unmanned. Launch vehicle allowables and wind criteria implications are identified in Boeing Report D5-15804-2, "Application of Saturn V Intermediate Launch Vehicles to Space Station Missions - Final Technical Report", dated September 4, 1970. The ground rule applied for the INT-21 launch is that the RNS module payload will not impose loads exceeding the capability of existing S-IC and S-II

structures. All RNS pressure vessels are designed such that pressure stabilization is not required for any ground launch or mission operation. The propulsion module run tank is launched dry and unpressurized.

The space meteoroid environment is defined in "Natural Environment Criteria for the NASA Space Station", D. K. Wiedner, Editor, NASA TMX-53865 dated October 31, 1969. The damage criterion for tankage is that there will be no penetration of the tank wall. Experimental test data is used for armor effectiveness. The thermal environment is defined by two documents: "Terrestrial Environment (Climatic) Criteria Guidelines for Use In Space Vehicle Development," NASA-TMX-53872, September 1970; and "Space Environment Criteria Guidelines For Use in Space Vehicle Development" (1969 Revision), NASA-TMX-53957, October 1969. High-performance insulation characteristics have been established using test data obtained from Contract NAS8-21400. Hypervelocity test results were used for meteoroid armor effectiveness. The thermal and meteoroid protection systems impose no requirements for vehicle orientation during any operations or mission phases.

The docking and clustering mechanism designs accommodate tolerances established with reference to an ITT laser radar system performance and consider the resultant of a 10 lb-sec impulse for maneuvering an empty propellant module. Docking forces are not used to actuate or lock latching mechanisms. The RNS or its separate modules (excluding the CCM) will be passive for all docking operations while providing functions to permit automatic rendezvous and docking.

Main propulsion system design criteria are established for the NERVA engine in the following documents: "NERVA Program Requirements Document", SNPO-NPRD-1, January 19, 1970; "NERVA Reference Data (Full Flow Engine)", AGC Report S-130-CP-090290-FL-Preliminary, April 1970. Propellant conditions are derived from AGC Letter 7410:1075, July 15, 1970 which includes a steady-state operating pressure of 26-psi saturated liquid with zero NPSP. Reduced flow rates are permitted at zero NPSP and

saturated liquid for saturation pressures below 26 psi to provide autogenous start capability. The RNS will provide propellant conditions for a NERVA malfunction mode; however, the total pressure need not exceed 26 psi for such a mode. During pulsed aftercooling, the RNS will provide saturated liquid to the bypass line at a pressure exceeding 16 psia. The NERVA engine will provide pressurant flow as required for all RNS operations except during pulsed aftercooling. Fluid line interfaces will provide for assembly and disassembly in orbit.

The auxiliary propulsion system is located in the command and control module and provides thrust for: (1) attitude control during coast phases,

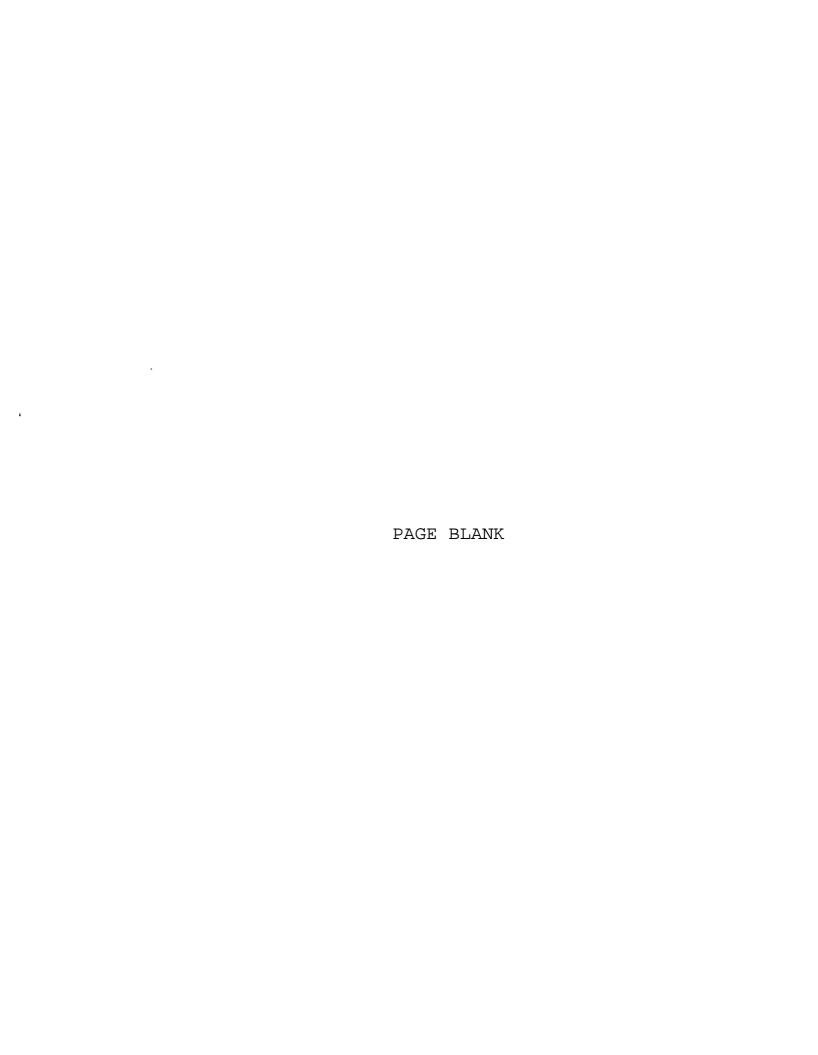
- (2) attitude maneuvers, (3) attitude control during cooldown thrusting,
- (4) separation maneuvers, (5) roll control during main engine burns,
- (6) rendezvous maneuvers, and (7) propellant settling. The APS motor configuration is designed to fail operational with subsequent failure accommodated by use of alternate engines for a particular maneuver.

The RNS has capability for navigation and guidance, data management, command and control, and power functions independent of payload. The RNS provides autonomous capability for orbital checkout, fault isolation and detection, and emergency detection. Uplink and downlink capability for data and control will be provided with the ground in necessary support system elements. The RNS navigation and guidance policy provides for maximum practical utilization of aftercooling pulses for final velocity attainment, midcourse correction, and/or rendezvous maneuvers. Electronic technology expected in the 1974 time period is used. The NERVA power requirements are defined by the NERVA documents cited previously.

The NERVA structural dynamic model is defined by "Dynamic Analysis Report," ANSC Report S038-CP090290-F1, September 1970. The lateral acceleration transient used to excite the dynamic model is based on Saturn V launch data contained in "Review of Loads Table and Acoustic Levels," MSFC Letter S&E-ASTN-AA-70-42, May 12, 1970.

Data on NERVA and its radiation sources are based on "NERVA Flight Engine Common Radiation Analysis Model", AGC Report RN-TN-0583, May 1969. The fundamental radiation and criterion was a dose of 10 rem per mission to a manned capsule located 11 ft ahead of the RNS. Radiation damage to materials is established from multiple data sources contained in the open literature; however, the Radiation Effects Information Center (REIC) operated by Battelle Memorial Institute is considered as the primary source.

The RNS will have a capability of performing 10 missions over a period of 3 years. It will be designed to achieve a reliability at 0.975 with a confidence level of 90 percent for the in-transit phases of the mission. No single failure will cause loss of mission. Accordingly, the functional subsystems of the RNS are designed to fail operational.



# Section 3 RNS SYSTEM DEFINITION

This section contains an overall description of the Class I-Hybrid RNS vehicle. Detailed hardware trees for each module are given in the following sections.

#### 3.1 VEHICLE CONFIGURATION

Figure 3.1-1 shows an inboard profile drawing of the assembled Class I—Hybrid vehicle. This figure can be used to describe the overall vehicle and the location of the major functional equipment. This RNS configuration contains three major modules: the command and control module (CCM) and the propulsion module both launched by the space shuttle, and a 33-ft-diameter propellant module which is launched on a Saturn INT-21 vehicle.

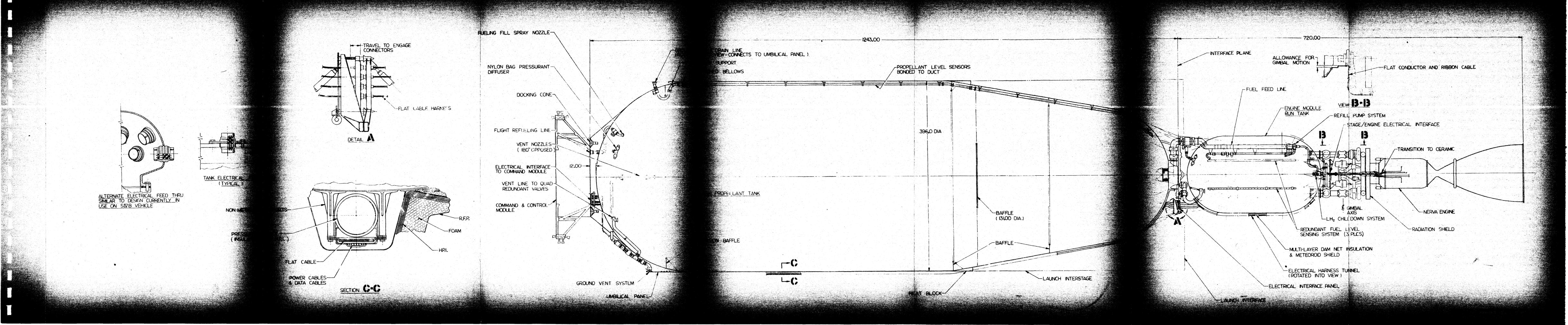
The interfaces between the propulsion module and the propellant module and between the CCM and the propellant module, which represent orbital assembly planes for the RNS, are indicated on the drawing. The propulsion module contains a run tank and the NERVA engine. The thrust structure between the engine and the run tank is shown. The main propellant feed subsystem supplies liquid hydrogen to the engine from the run tank via two separate 10-in-diameter tank penetrations. The NERVA supplied pump shutoff valves interface at the run tank penetrations. At rated thrust conditions the combined outflow from both of these feed ducts is a total of 91.9 lb/sec of hydrogen.

Antivortexing and filtration screens are located inside the tank around each of these feed duct penetrations. Due to the spacing of the NERVA dual pumps, two individual screens will be used, one over each exit port. These screens will provide 100-micron filtration in the current design. Because of the chilldown conditioning requirement for the NERVA engine, provision

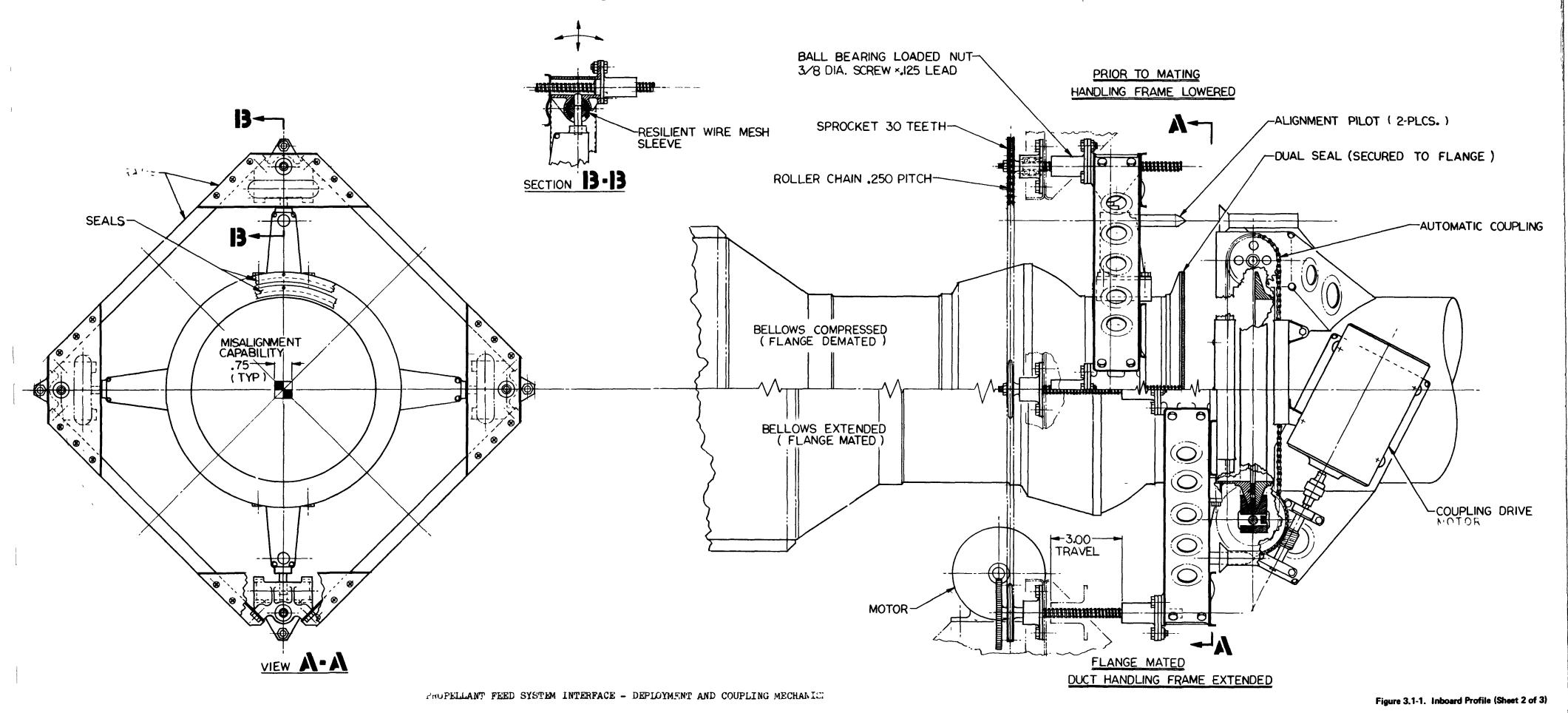
is made to open the antivortex, filtration screens during the chill and before initiation of engine prestart. Propellant inflow to the propulsion module run tank is accomplished by a 12-in.-diameter internal tank feed line extending the length of the tank. This duct, which is designed for collapse pressure, contains two 8-in.-diameter flow control valves located at the tank bottom. These two motor-driven control valves are actuated through the data management subsystem by liquid level sensors located in the run tank. This system is utilized to maintain a constant liquid level in the run tank during engine operation.

At the forward penetration of the run tank the feed duct exits and is routed up to the interface plane. The section of ducting from the forward dome penetration to the interface plane is a linear section of stainless steel ducting utilizing a compensator and two gimbal joints at either end. This system of flexible elements will provide the linear deployment required in order to perform the automatic coupling at this interface. The 12-in.-diameter internal feed line is fabricated from aluminum alloy. Bolted connections are used at the stainless steel transition sections containing the 12-in.-diameter gimbal joints utilized as flexible elements. Dual pressure activated static seals are used in the feed system with automatic leak check capability.

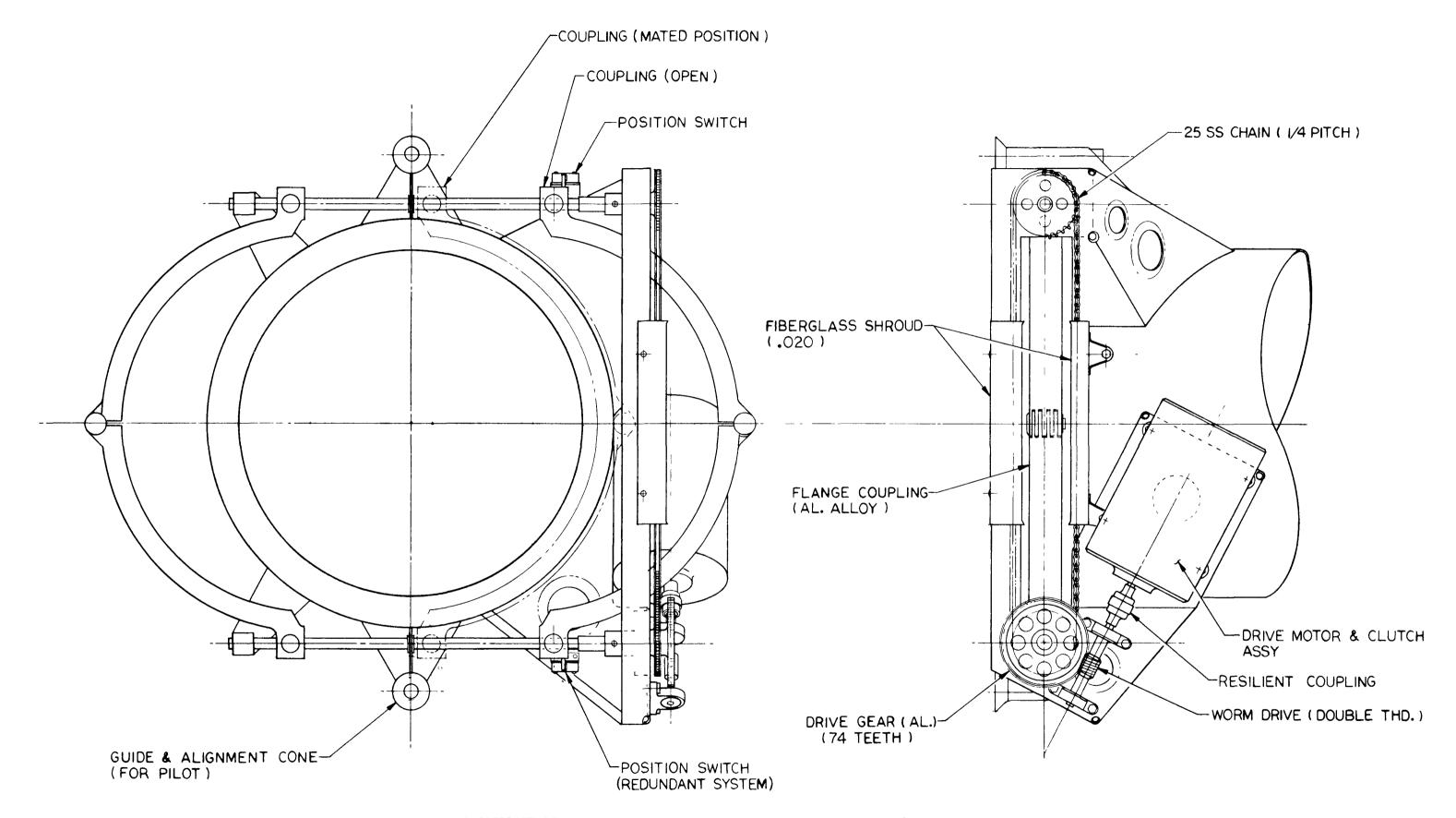
Expulsion pressurization is utilized in the run tank as well as the propellant module. This gas is obtained from a NERVA engine tap-off downstream of the turbine. The engine supplies a duct from the turbine tap-off to the engine/stage connect panel. At this position the run tank picks up this 1-1/4-in.-diameter duct, and it runs along the outside of the run tank, covered by insulation and meteoroid armor. Pressurization control valves are located external to the tank in the forward dome area. The 1/2-in.-diameter penetration enters the forward ullage and terminates in a spray nozzle diffuser. A diffuser is used to prevent ullage collapse. A tee is provided in this pressurization system, and the line is run from the tee to the interface plane. The pressurization duct, using a conventional quick-disconnect coupling, is routed to the electrical connector panel located at











PROPELLANT FEED SYSTEM INTERFACE - AUTOMATIC COUPLING SYSTEM

Figure 3.1-1. Inboard Profile (Sheet 3 of 3)

the interface. Deployment of the pressurization duct utilizes the deployment mechanism for the electrical coupling panel. These are the only fluid couplings crossing the interface plane between the propulsion module and the propellant module.

The flight vent is located in the forward region of the propulsion module run tank. This system utilizes quad redundant valving and two propulsive vent nozzles which are located 180 degrees apart in the forward skirt region of the run tank. The nozzles are pointing aft to aid in propellant settling during venting. The vent system extends into the forward dome ullage space using a single penetration.

The propulsion module also contains an ambient gas auxiliary propulsion system. It is used to stabilize the module during the assembly sequence with control provided by a local gyro package. It is located in the forward skirt region of the run tank and uses a 25-in.-diameter titanium sphere for gas storage and two sets of nozzles, three per cluster, located 180 degrees apart on the outer surface of the run tank forward structure. Recharge of this sphere is accomplished from the NERVA engine by tapping off from the pressurization line in the forward skirt of the propulsion module.

The run tank is refilled with propellant from the propellant module prior to every full-thrust operation. The refill system consists of two parallel mounted submerged ac-motor-driven pumps. These pumps are mounted in a manifold which is identical to the manifold utilized for the two 8-in.-diameter flow control valves. The pumps intake from this main feed manifold and discharge via control valving to the 4-in.-diameter riser that runs to the ullage of the run tank. The pumps accomplish the transfer against a pressure head between the two tanks.

Orbital refill, which is performed every round trip, utilizes the tanker as the active element. The run tank refueling operation is accomplished without the use of the motor-driven pumping system. Fluid is transferred through the main feed system and discharges through the spray nozzle into the ullage space of the run tank.

The propulsion module contains an integrated stage/engine recirculating chilldown system. This system conditions the NERVA engine inlet ducting, turbopumps, and related valving. It contains two parallel mounted ac-motor-driven pumps that are submerged at the bottom of the propulsion module run tank. These pumps discharge to a single line which penetrates the run tank and then separates into two ducts which enter the engine inlet ducting down-stream of the PSOV valves. As presently conceived, the PSOV's contain a boss to provide this interface connection. During the chilldown cycle, the PSOV valves are closed, and flow proceeds downstream into the feed ducts and through the NERVA turbopumps. The engine supplies a chilldown return line that runs from the customer connect panel to the discharge side of both pumps. The stage returns the chilldown flow via quad-redundant valving back to the run tank. This closed-loop system provides conditioning for all of the NERVA inlet hardware to insure a reliable start.

In addition to performing the engine preconditioning, the chilldown system provides conditioning for the intermodule feed ducting between the propulsion module run tank and the propellant module. This is accomplished by the second leg of this recirculation system. Pump discharge, in addition to being routed down to the engine, is also routed into the main feed duct manifold. It then proceeds up the 12-in.-diameter feed duct to the propellant module sump. Both of the isolation valves in the propellant module are open to enable return flow to the propellant module. The chilldown return valves are mounted to the run tank thrust structure.

The propellant module feed system contains two 8-in.-diameter, motor-operated, on-off type valves. These valves are located in the sump fitting of the propellant module. The inlet to both of these valves is shrouded by an antivortex filtration screen. Hydrogen is expelled from the propellant

tank through these two valves through the sump and into a 12-in.-diameter stainless steel duct which runs to the interface. The stainless steel duct contains two gimbal joints for thermal and operational deflections. At the interface plane, the duct flange is soft mounted and contains an automatic coupling mechanism to make the connection with the run tank. The intermodule feed duct utilizes a dual series mounted, pressure actuated seal configuration to complete this connection.

The forward skirt region of the propellant module contains a ground umbilical panel. This provides a disconnect for the ground fill-and-drain function. Drain is accomplished by tank pressurization. A 4-in.-diameter system is used employing a butterfly-type, pneumatic-actuated, fill-and-drain valve. A section of ducting runs from the valve to the forward dome of the propellant tank and penetrates the dome into an internal duct that runs to the base sump of the propellant tank. This riser will be constructed of aluminum ducting. Stainless steel gimbal joints will be used for flexibility above the tank and will be connected to the aluminum sections with conventional bolted flanges with static seals. The riser is supported with sliding-type vibration mounts along the inside of the propellant tank. The ground vent and relief system is also located on the forward umbilical. This system is utilized during the ground fill operation and also in the event of an inadvertent pressure buildup in the tank. It consists of a vent and a relief valve close coupled to the umbilical panel vent and a 6-in.-diameter duct running to a penetration in the forward dome of the propellant tank. An internal section continues to the top of the dome and terminates in an open flange to provide the vent function.

The flight vent and relief system is sized at a 2-1/2-in.-diameter and contains a set of quad-redundant on-off type control valves and discharges through two nozzles located 180 degrees apart. The flight vent duct tees into the ground vent and relief system downstream of the vent and relief valve. Thus, both the ground and vent release system and the flight vent and release system utilize a single tank penetration.

The forward umbilical also contains a ground pressurization disconnect of a 1/2-in.-diameter with a shutoff valve and the associated line that runs from the umbilical panel to a separate dome penetration. The dome penetration terminates in a nylon bag diffuser. This configuration prevents impingement and resulting ullage collapse during pressurization. The ground-only function for pressurization tees into the flight pressurization system on the forward payload adapter structure. The propellant module flight pressurization system is an on-off type which is controlled from strain gage pressure transducers located in the ullage region of the propellant tank. This system has the following three discrete flow capabilities: a 4-lb/sec capability that is required for prepressurization, a 0.6-lb capability for expulsion pressurization during NERVA full-thrust operation, and a 0.4-lb/sec control capability. Each control leg of this system contains quad-redundant control valving. These valves are mounted forward on the payload adapter. A 1-1/4-in.-diameter stainless steel pressurization duct extends from the aft interface of the propellant module to this forward payload adapter location. This duct is shrouded by a fairing over the entire run of the propellant module. At the aft interface of the propulsion module, the duct is routed to the electrical connect panel where the quick disconnect provides the connection to the propulsion module run tank and down to the customer connect panel between the NERVA engine and the stage.

Located in the forward dome area of the propellant tank is the in-flight refueling system. This system contains four control valves mounted on the payload adapter and terminates in a spray-type nozzle in the tank. The duct running from the tank penetration to the payload adapter interface contains three 4-in.-diameter gimbal joints to provide for the required working deflections. The duct is hard mounted at the interface.

The CCM interfaces with the propellant module at the forward portion of the payload adapter. A 4-in.-diameter refueling connection is made at this interface. The CCM contains a straight section of 4-in.-diameter ducting. This duct contains two gimbal joints, a pressure volume compensator, and

the baseline deployment mechanism. The flange coupling mechanism is located on the propellant module refueling duct. This automatic coupling interface utilizes dual static seals and automatic leak-check ports. This section of feed-through ducting in the CCM enables refueling of the main propellant tank and the propulsion module run tank with the CCM in place.

The CCM also contains the cryogenic auxiliary propulsion system for vehicle control. This system utilizes central tankage that feeds two sets of thrustor pods located 180 degrees apart. The thrustor pods are located on outriggers emanating from the CCM. Outboard placement of these nozzles is provided to reduce plume impingement on the propellant module. Centralized propellant storage for the APS and the fuel cells is located within the CCM. This tankage consists of low-pressure storage spheres, a turbopump system, and high-pressure, hot-gas storage accumulators.

Section BB details how the flight cable harnesses will cross the gimbaled interface plane between the engine and the run tank. Section CC shows the external tunnel configuration which contains a 1-1/4-in.-diameter pressurization line supported on two standoffs that are bonded to the tank wall. The standoffs also form the support for both flat cable retaining brackets and round cable retaining brackets. The entire standoff assembly is shrouded by an aluminum fairing and the baseline thermal/meteoroid protection subsystem.

A typical electrical feedthrough design is shown at the left end of the drawing. In this concept, the glass-sealed electrical feedthroughs which enter the hydrogen tank are statically sealed to a center face plate. The face plate in this configuration will contain a cluster of connectors depending on requirements. The plate itself will then be bolted to a single port in the tank via the baseline dual static seal design.

Sheet 2 shows a detailed view of the automatic coupling mechanism that is used for the large-diameter feed ducting. It crosses the plane between the propulsion module and the propellant module. The upper half of this sectional

view shows the duct in the normal position after docking and latching have been accomplished. The lower section shows the duct deployed and the coupling made. This is accomplished in two steps—first deployment, and then coupling. A linear deployment mechanism is located on the propulsion module compensator feed duct. The propulsion module feed duct flange is attached to the handling frame of a floating cross member. This arrangement permits flange freedom for tolerance absorption during the deployment and coupling operations. The flange contains two alignment pilots that engage conical guides located on the propellant module feed duct flange.

The frame corner fitting contains the ball bearing loading nuts that accept the four drive screws. The drive screw assembly is hard mounted to the propellant module upper thrust structure. When the threaded drive screws are rotated, the frame assembly is extended linearly the deployment distance of 1-1/2 in. as shown. The screws are chain driven by a worm wheel gearing system using an electric motor drive. The coupling mechanism located on the propellant module feed duct is shown on sheet 3. The automatic coupling operation is initiated after the deployment operation is completed. This mechanism consists of two V-couplings. The coupling sections are supported and operated by left- and right-hand threaded drive screws. The drive screws are chain driven by the same worm wheel gearing system. Sealing is accomplished by dual pressure-actuated seals as shown on sheet 2.

The method used for connection of the electrical panels, both at the CCM to propellant module interface and at the propulsion module to propellant module interface, is shown in Detail A of sheet 1. The initial alignment motion is supplied by structural docking and latching. Ball bearing screw jacks which are chain driven by electric motors raise the lower panel to the first engaged position. This aligns the connectors with their mating almost to within pin engagement tolerances without actually engaging the pins. Position switch talkback is obtained before the final pin engagement stroke is initiated. This will prevent pin binding and result in reliable mating and demating. The ball and jack drive screws and motor driving mechanism are similar to that described for the duct deployment system.

# 3.2 STRUCTURES

A summary of the RNS structural design is contained in this subsection.

# 3.2.1 Loading Summary

The RNS Class 1 Hybrid propellant module was designed to comply with the Saturn INT-21 prelaunch, launch, and ascent design load envelope for an unmanned condition. The loading envelope is shown in Figure 3.2-1. The module interfaces with the S-II at Station 2519 and the 30-degree nose cone weighing approximately 2,500 lb at Station 3633. The prelaunch condition as well as the in-flight wind profile used for the maximum  $q-\alpha$  condition was based on NASA TMX-53872. Maximum vehicle acceleration of 4.387 g was also investigated. It proved to be the least severe of the two launch conditions. The current design loading of 2,540 lb/in. at the S-II interface was accommodated by accepting the resulting minimum launch availability of 84 percent during winter.

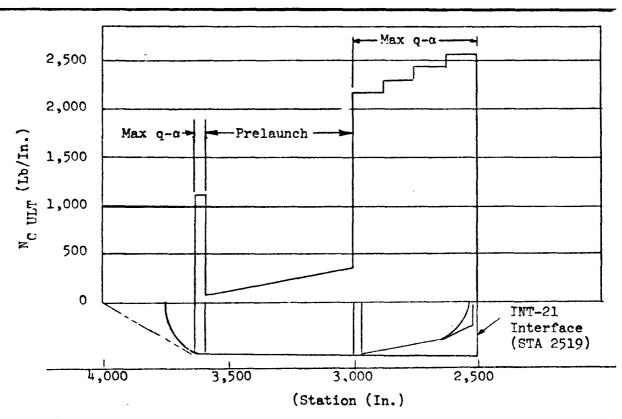


Figure 3.2-1 CLASS 1-H APPLIED LOAD DISTRIBUTION

The membranes of the propellant module tank were designed for a burst pressure of 29 psi. The maximum compression load (335 lb/in.) at the base of tankage sidewalls occurs during prelaunch when the unpressurized propellant module is stacked on the launch vehicle. The remaining exterior structural components, the heat blocks and interstage, were designed by a maximum  $q-\alpha$  condition.

The MDAC SB-15 computer program was used to generate the mission operation loads with the engine gimballed hard over at 5.7 degrees under full thrust (75,000 lb). The resulting component design limit loads are shown in Table 3.2.1. The propulsion module tankage membranes were designed for 30 psi.

Table 3.2.1 COMPONENT LIMIT LOADS

Module	Component	Moment (inlb x 106)	Shear (lb)	Axial Load (lb)
-	Thrust structure	0.74	5,750	69,750
Propulsion				
	Intermodule skirt	2.47	5,120	67,850
	Intermodule thrust structure	2.47	5, 120	67,850
Propellant				
	Payload adapter	3.42	2,680	16,820
Command and control	Cylinder	3.42	2,680	16,820

### 3.2.2 Structural Description

A layout of the Class 1-Hybrid structural configuration is shown in Figure 3.2-2. It is contained on 11 sheets and located at the end of this description so that the sheets can be folded out while reading the text.

# 3.2.2.1 Propellant Module

The propellant tank, fabricated from 2014-T6 aluminum alloy, was sized to contain 289,150 lb of LH<sub>2</sub> with a 5 percent ullage volume. It consists of a hemispherical forward dome, an integrally stiffened cylindrical section, and a 10-degree half angle conical aft dome, all fusion butt-welded. The domes are of monocoque construction. To compensate for manufacturing tolerances, 0.005 in. was added to the theoretical membrane thickness to arrive at all final thicknesses. Weld land thickness was held constant throughout the tank to avoid tapered welds.

The forward dome is comprised of two Y-rings and two tiers of gore sections and has a manhole for access at the pole of the dome (View AA-AA sheet 10). The Y-ring at the equatorial plane shown in view Y sheet 10 has an integrally reinforced flange for attachment of the forward heat block. The Y-ring at the 30 percent line (View Z sheet 10) also incorporates a flange for payload adapter attachment. The aft tier of gore sections has five gores while the forward tier has seven. Machined bosses are provided to accommodate the supports and penetrations required for the plumbing hardware. Twenty-four equally spaced slosh baffle support pads are also incorporated in the dome.

The tank cylindrical section is comprised of six segments which employ an isogrid stiffening pattern. This pattern, shown in View X sheet 10, consists of a gridwork of equilateral triangles over the tank sidewall surface with a rib height of 1.12 in., a rib thickness of 0.060 in., and a rib length of 35 in. The membrane thickness is 0.117 in. The fill and drain line supports attach to inserts which are installed in the nodes of the isogrid pattern.

The aft dome consists of four components: a transition section, a truncated cone, a Y-ring, and a spherical cap. The transition section, shown in View V sheet 9, is ellipsoidal in shape and provides an integrally reinforced flange for the aft heat block. The truncated cone consists of six gore sections and incorporates pads for baffle support attachment. The Y-ring shown in View T sheet 6 has lugs machined into it for the intermodular thrust structure attachment. Pads are incorporated around the lugs to reduce the stress level for the point loads which are introduced tangentially to the dome surface. The spherical end cap is fabricated from four gore sections and includes attach provisions for the sump.

Three slosh baffles and a geysering baffle are incorporated in the tankage design. Their location is shown in the main view on sheet 1. All four baffles lie in station planes with the membranes of the slosh baffles attaching directly to the tank walls and to rings which are supported by struts. The struts which incorporate self-aligning bearings attach to fittings mounted to inserts installed in the nodes of the isogrid pattern at 32 equally spaced peripheral locations around the tank. Nylon cord is used to tie the membranes to both the rings and the tank. It is also used as an edge member for the geysering baffle membranes and to attach the baffle to fittings mounted to the intermediate slosh-baffle ring at eight equally spaced locations.

The forward and aft heat blocks (Views V and Y on sheets 9 and 10) which must keep the heat flow into the propellant tank small compared to the heat flow through the insulation blanket (thermal conductance < 1 Btu/hr/°F) are of all fiber glass honeycomb sandwich construction. Each heat block consists of one ring of five panels spliced together with 0.020-in. titanium straps and mechanical fasteners. A typical splice is shown in Section AM-AM on sheet 10. Channel sections fabricated from fiber glass are used for panel longitudinal framing members. Machined aluminum sections are employed for the circumferential framing members. The face sheets are fabricated from fiber glass cloth which has a density of 0.066 pci, a modulus of 5.0 x  $10^6$  psi, and an allowable compressive yield stress of 50,000 psi in the longitudinal direction.

The core is made from NP 1/4-21-4.0, which is an epoxy phenolic hexcel core with a density of 4.0 pcf. HT 424 adhesive is used for bonding the face sheets to the core. It has a density of 0.130 psf per ply.

Cutouts are provided in the heat blocks at the tunnel ends for the cabling runs and the pressurization line. The edges of the cutouts are potted with fiber glass epoxy and have their skins reinforced locally. The umbilical panel shown in View Y of sheet 10 is machined from a piece of 2-in. plate stock and is bolted to the forward heat block at the heat block/nose cone separation plane. Explosively activated pull pins are utilized to attach it to the nose cone.

As with the heat blocks, fiber glass construction is used for the intermodular thrust structure to prevent excessive heat input into the propellant tank. This component is protected from the environment during boost by the launch interstage so an open-type truss structure was employed in order to take advantage of light weight, low heat transfer, and easy accessibility to internal installations. The laminated strut arrangements shown in View U-U of sheet 7 consist of X-member subassemblies comprised of a central tubular cast titanium splice fitting to which four laminated tubes with tapered titanium end fittings are installed. A self-aligning bearing is provided in each fitting to minimize alignment problems. The laminated struts are designed so that the longitudinal fibers resist the axial loads, with internal and external radial plies providing reinforcement in the circumferential direction. A closing frame (View S-S on sheet 5) which is basically a channel section is provided at the aft end of the conical thrust structure. It incorporates integrally machined attach points for the struts and structural latches (Section AD-AD and View AB on sheet 5). Support for the docking cones is also included in its design. The docking cones are stabilized by a pair of struts (Section AC-AC on sheet 5) which attach to the titanium splice members.

The payload adapter shown in View Z on sheet 10 which has the same thermal conductance requirements as the heat blocks is also of fiber glass honeycomb construction. Its construction is similar to that of the heat blocks except

for the framing members. Because of depth limitations, the edges of the panels are potted with fiber glass epoxy. The panels are spliced together in the same manner as that employed for the heat blocks. Section AN-AN on sheet 10 depicts a typical splice joint. An integrally machined frame (View AA-AA on sheet 10) which is basically a channel section is attached to the forward end of the adapter. It has provisions for mounting the docking probes and structural latches. The electrical interface panel and the propellant in-flight refill line coupling are attached to this frame. Stabilization of the docking probes is accomplished by pairs of struts that attach to lugs machined in the frame and inserts potted into the panels. Local reinforcement is provided around the inserts. Stabilization of the electrical panel and the refill line coupling is accomplished in a similar manner except that the struts attach to the inboard edges of these components rather than the frame. Valves for the plumbing hardware are mounted on panels which attach to potted inserts in the adapter panels.

The interstage (View V on sheet 9), which is jettisoned when the stage reaches orbit, is fabricated from 7075-T73 aluminum alloy. The outer panel or skin is integrally stiffened with J-section stiffeners spaced approximately 6 in. apart and has stabilizing frames located 29 in. on center. It is formed from six panels that extend the full length of the interstage with an integrally reinforced cutout for a 2 by 3 ft access door. Integrally machined lips are provided for lap splicing of the panels with mechanical fasteners.

The field joint with the S-II utilizes the existing S-II hole pattern.

Circumferential separation with the aft heat block employs a design similar to that used on the S-IVB in which a tension strap is severed by a controlled detonating fuse (CDF). Compression loads are resisted by the butt-joint effect. Structural support is also provided for 16 equally spaced thrustors which provide the booster separation impulse. The support attach points are integrally reinforced to resist the thrustor loads.

#### 3.2.2.2 Propulsion Module

The maximum size of the propulsion module is governed by the 15-ft-diameter, 60-ft-long shuttle cargo bay. The tank length was determined by engine

length and space allocations for the docking system and the propellant transfer lines. The diameter was defined by the radiation-shield zone. The shadow shield zone half-angle of 10 degrees was generated by extending a line from the aft outboard corner of the reactor through a point tangent to the aft dome of the main propellant tank. These constraints produced a tank with a capacity of 10,850 lb of LH<sub>2</sub> with a 5-percent ullage volume. The tank is fabricated from 2014-T6 aluminum alloy and consists of two hemispherical domes and an integrally stiffened cylindrical section, all fusion butt-welded. To compensate for manufacturing tolerances, 0.005 in. was added to the theoretical thickness to arrive at all final membrane thicknesses. Weld land thickness was held constant throughout the tank to avoid tapered welds.

The one-piece domes are of monocoque construction fabricated from a forging. Integrally machined attach lugs shown in View B-B on sheet 3 and Section F-F on sheet 2 are provided on the domes for skirt and thrust structure attachment. Pads are incorporated around the lugs to reduce the stress level for the point loads which are introduced tangentially to the dome surface. Plumbing, astrionic probe support points and penetrations are integrally reinforced. Access to the tank interior is provided through a manhole shown in View C-C on sheet 4 with a bolted cover at the pole of the forward dome. An isogrid pattern (View R on sheet 3) which has a rib height of 0.560 in., a rib thickness of 0.035 in., and a rib length of 10.130 in. is employed to stiffen the cylindrical section of the tank. The membrane thickness is 0.051 in. The point level support system and the fill-and-drain line supports are attached to inserts installed in the nodes of the isogrid pattern. Two slosh baffles and a geysering baffle (View D-D on sheet 2) are installed inside the tank. Their location is shown in the main view on sheet 1. Except for size the slosh baffle design and method of attachment are identical to the baffles in the main propellant tank. The geysering baffle is a scaled down version of that in the main propellant tank. However, its tension ties attach to fittings mounted to tank sidewall node inserts.

Since there is a low thermal conductance requirement for the thrust structure (View A-A on sheet 2) and forward skirt, and these components are protected from the launch environment by the shuttle cargo bay, a truss-work of struts (View P-P on sheet 4) fabricated from fiber glass was selected for their configuration. Except for physical dimensions, the design is identical to that employed for the intermodular thrust structure. A ring frame shown in View C-C on sheet 4 is provided at the forward end of the skirt to resist the strut induced radial or kick loads and to support the docking probes. The propellant feed line disconnect and the electrical interface panel are also mounted on this frame. Each component is stabilized by a pair of struts (View P-P on sheet 4) fabricated from 6061-T6 aluminum alloy tubing that attach to the fiber glass struts. Attach lugs shown in View Q on sheet 4 for the skirt struts and support points for the structural latches are machined into the ring frame which is basically a channel section. The thrust structure closing frame (View A-A on sheet 2) was designed to pick up the 12 equally spaced 3/4-in.-diameter attach points on the 56-in.-diameter bolt circle of the engine upper-thrust structure (UTS). This is a mastered hole pattern. In order to provide the most direct load path, the thrust structure struts attach to the interface ring at these bolt locations. Cutouts are incorporated in the ring to provide clearance for the propellant inlet lines. Electrical wiring harnesses are supported off the UTS as they traverse the interface plane. Integrally machined lugs for attachment of the thrust structure struts are incorporated in the design of the frame which is a channel section.

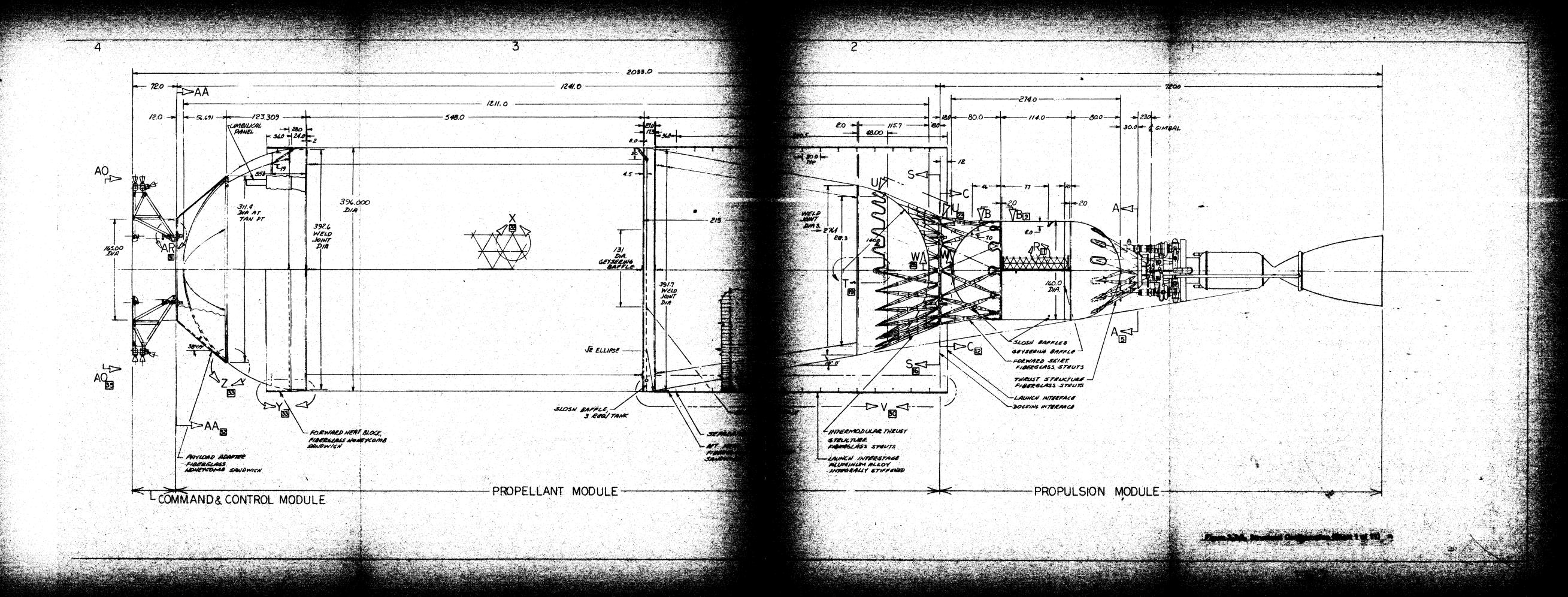
#### 3.2.2.3 Command and Control Module

The command and control module (CCM) shown in View AO-AO on sheet 11 consists of a cylindrical section plus a set of outriggers. Since the span between nozzle tips exceeds 15 ft, the module is mounted with its axis perpendicular to that of the shuttle. This reduces the cylindrical section diameter from a possible maximum of 15 to 13.78 ft. The cylindrical section is fabricated from two 180-degree segments which are integrally stiffened with an isogrid pattern (View AP-AP on sheet 11) which has a rib height of 0.420 in., a rib thickness of 0.050 in., and a rib length of 4 in. The

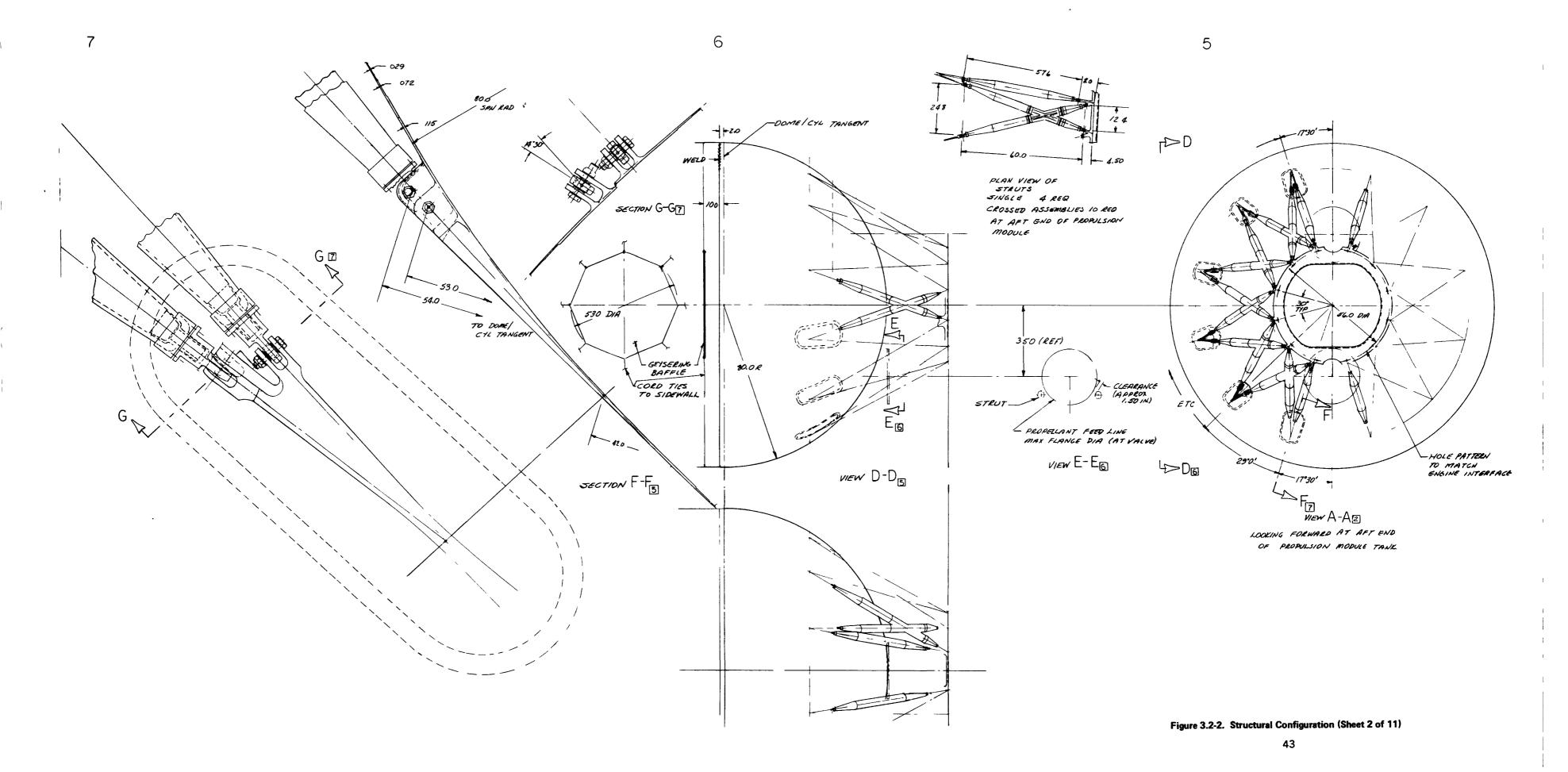
membrane thickness is 0.025 in. Lips which are shown in Section AQ-AQ on sheet 11, are machined into the panel edges for segment joining with mechanical fasteners. Astrionic equipment panels and APS pressure bottle and accumulator supports attach to inserts installed in nodes of the grid pattern. The integrally machined closing frames are channel sections, but include provisions for attaching docking probes to the forward frame and docking cones to the aft frame. The probes and cones are stabilized by pairs of struts which attach to the segment gridwork nodes. The electrical interface panels and the propellant in-flight refill line coupling and handling frame also mount to the frames. They are stabilized in the same manner as the docking probes and cones. The outriggers are an open space truss fabricated from extruded angles. The four main members which attach to the closing frames also attach to a common fitting at the apex of the truss. The APS engines are mounted to this fitting. Meteoroid protection is furnished by a 1-in. layer of rigid foam and an external fiber glass cover sheet. The foam is bonded to the outside surface of the module.

The docking subsystem shown in View AR-AR on sheet 9 consists of four cylindrical probe assemblies (including shock absorbers and pull-in mechanisms) located on one module, and a mating set of drogue cones mounted on the other module. The extended portions of the probes have a flexible section at the tip, which is deflected along the cone surface and enters a latch pocket at the vertex. The latch pocket contains inclined-plane latching cams which are spring loaded closed and probe deflected open to accomplish the catch. Probe release is effected by actuating four pull-solenoids to retract the cams. The flexible sections are then retracted, pulling the rigid sections of the probes into the cones, to align the modules. Further retraction of the probe mechanisms draws the aligned modules into contact. Structural latches are actuated to provide a rigid connection between modules.

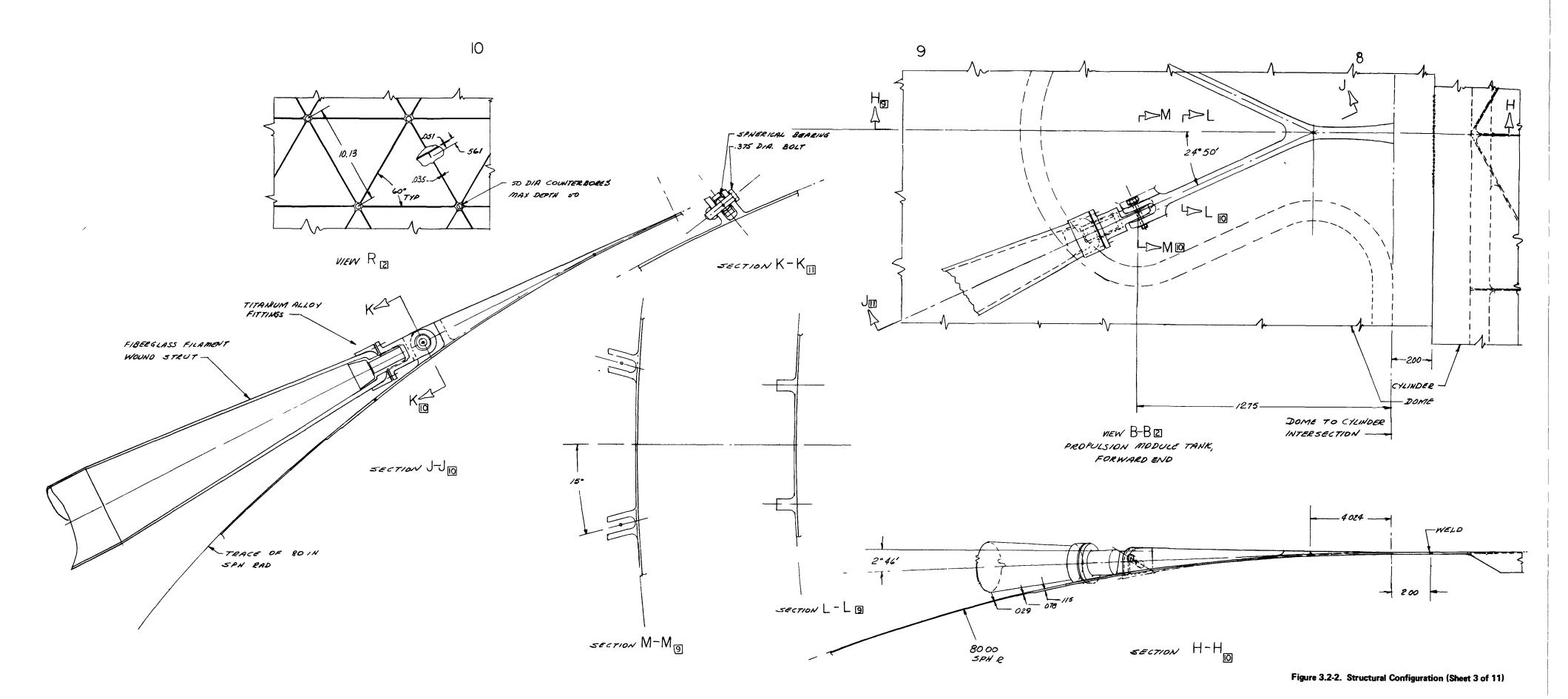
The probe components are: the probe casing and flange, the hard probe, retractor, flexible probe, probe screw jack, actuator, helical springs, and solenoid deactuating operated ratchet. The hard probe and retractor are concentric within the casing. The flexible probe is attached to the outer end of the retractor. One spring is located between the casing and the hard



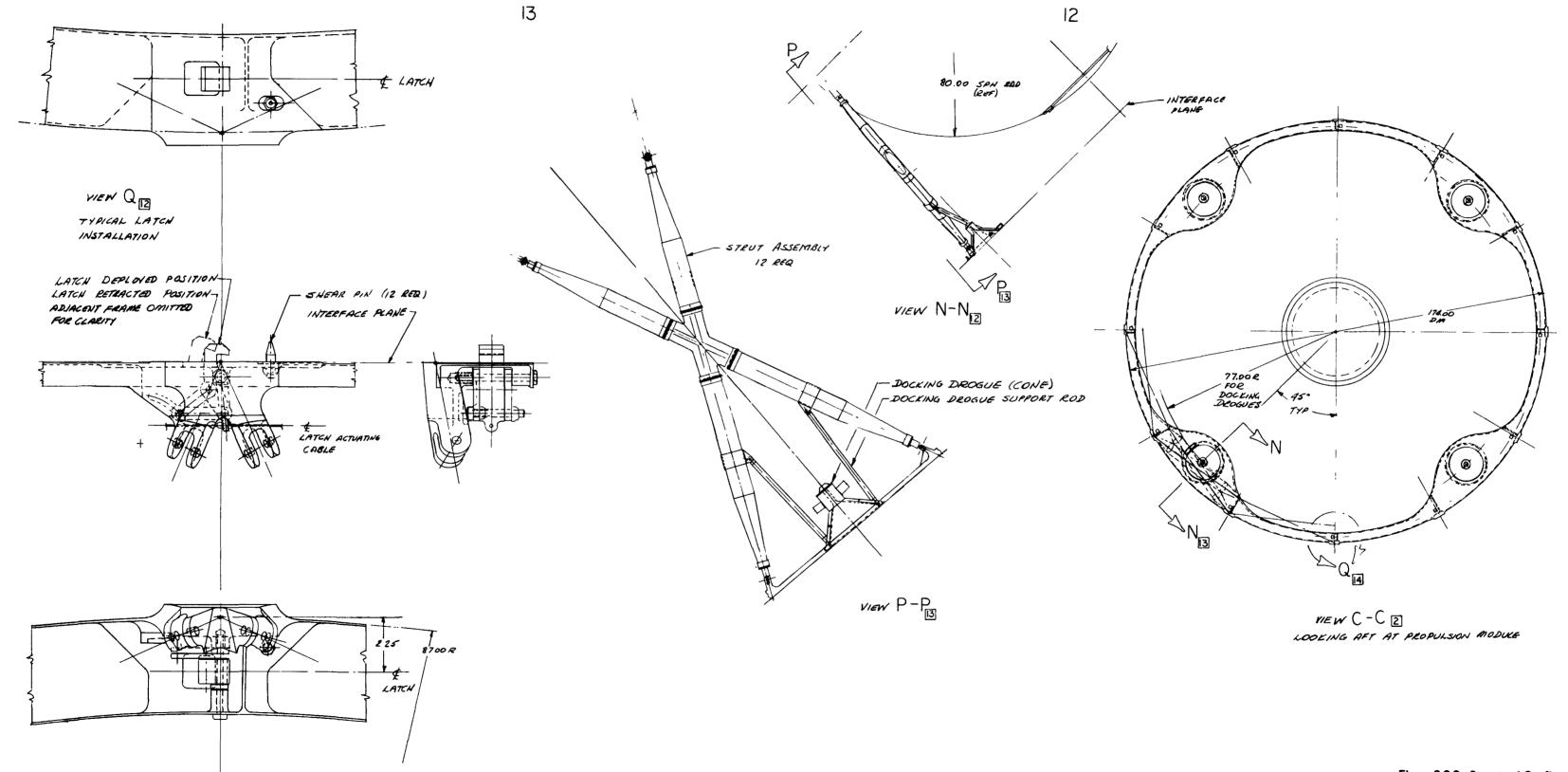




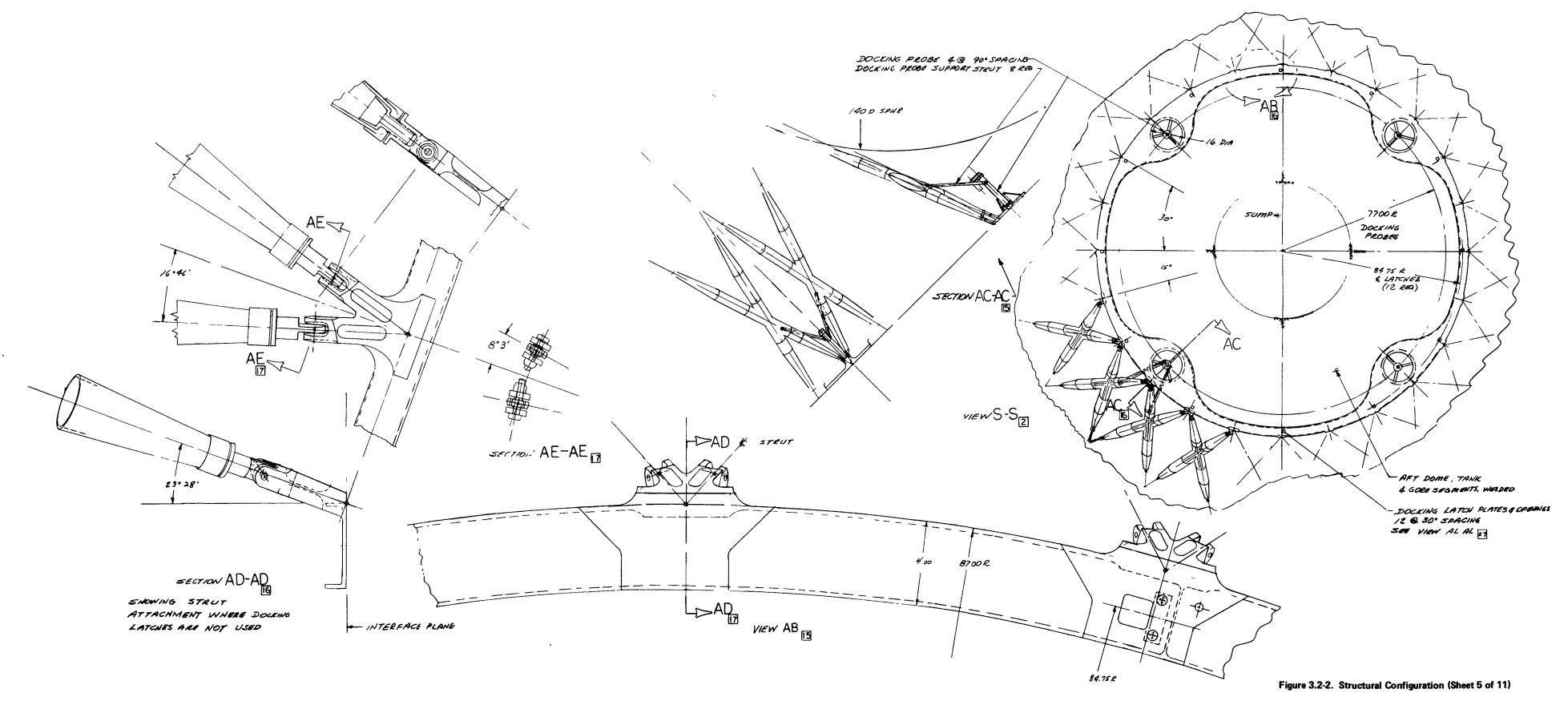




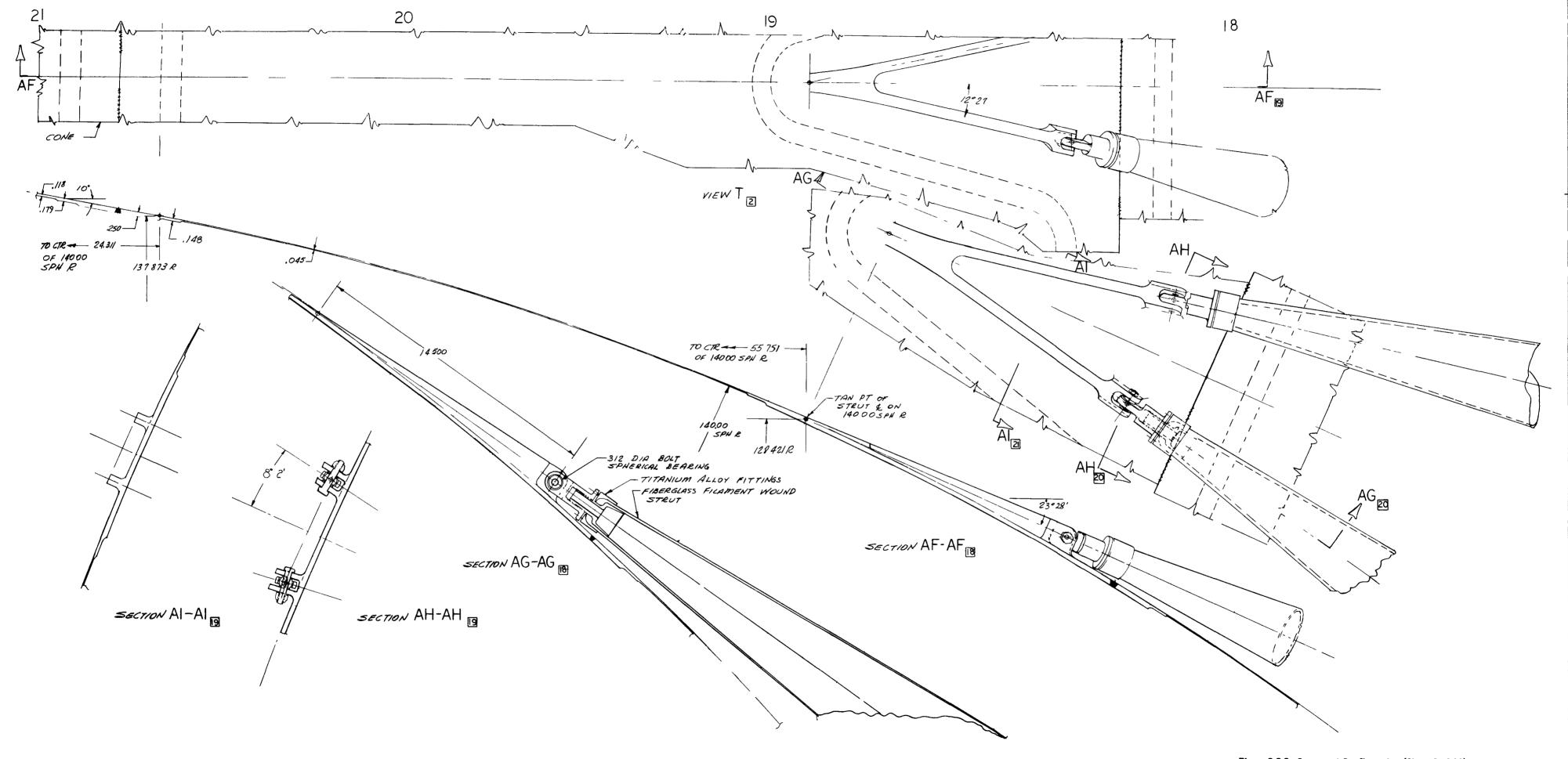














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OF

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Figure 3.2-2. Structural Configuration (Sheet 7 of 11)

22



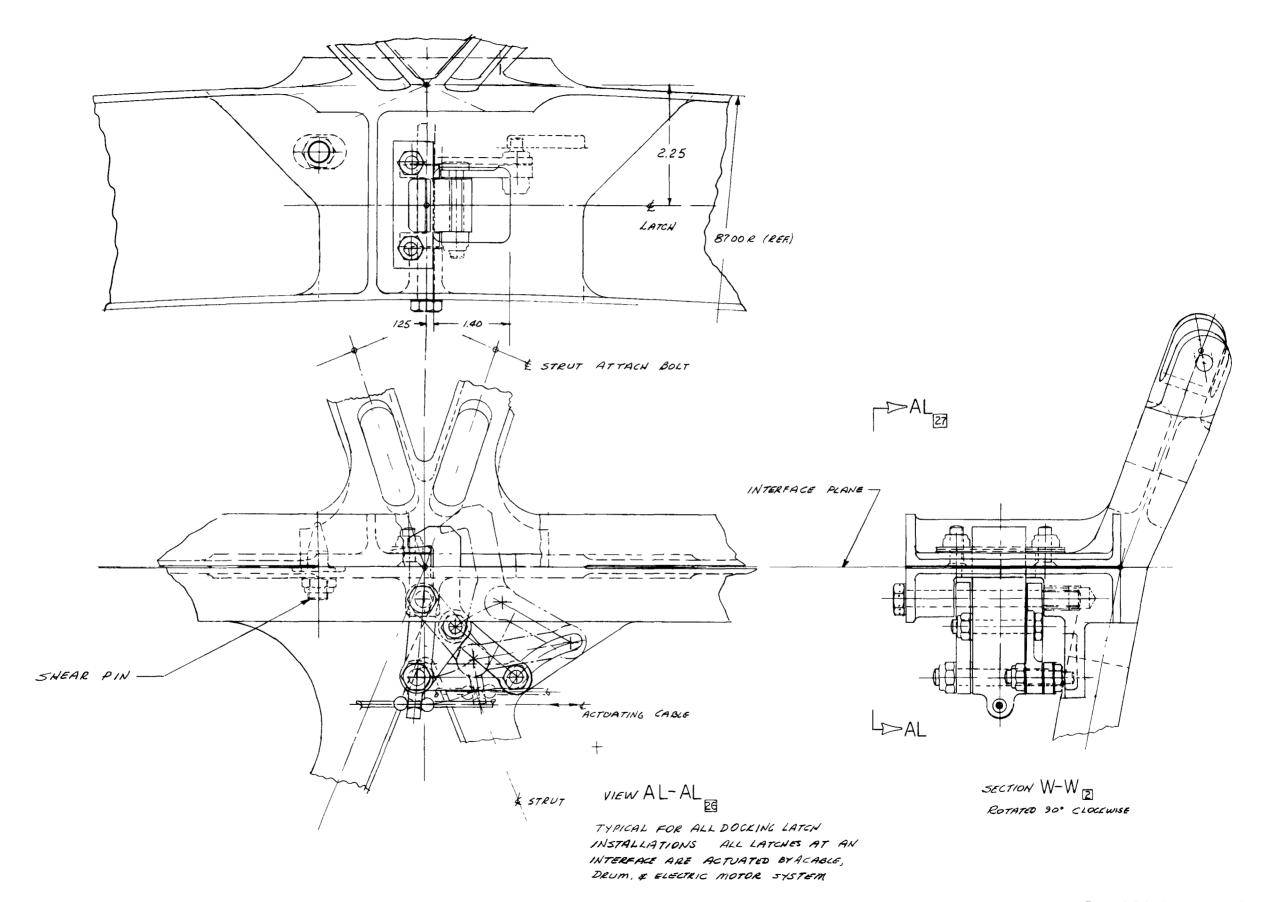
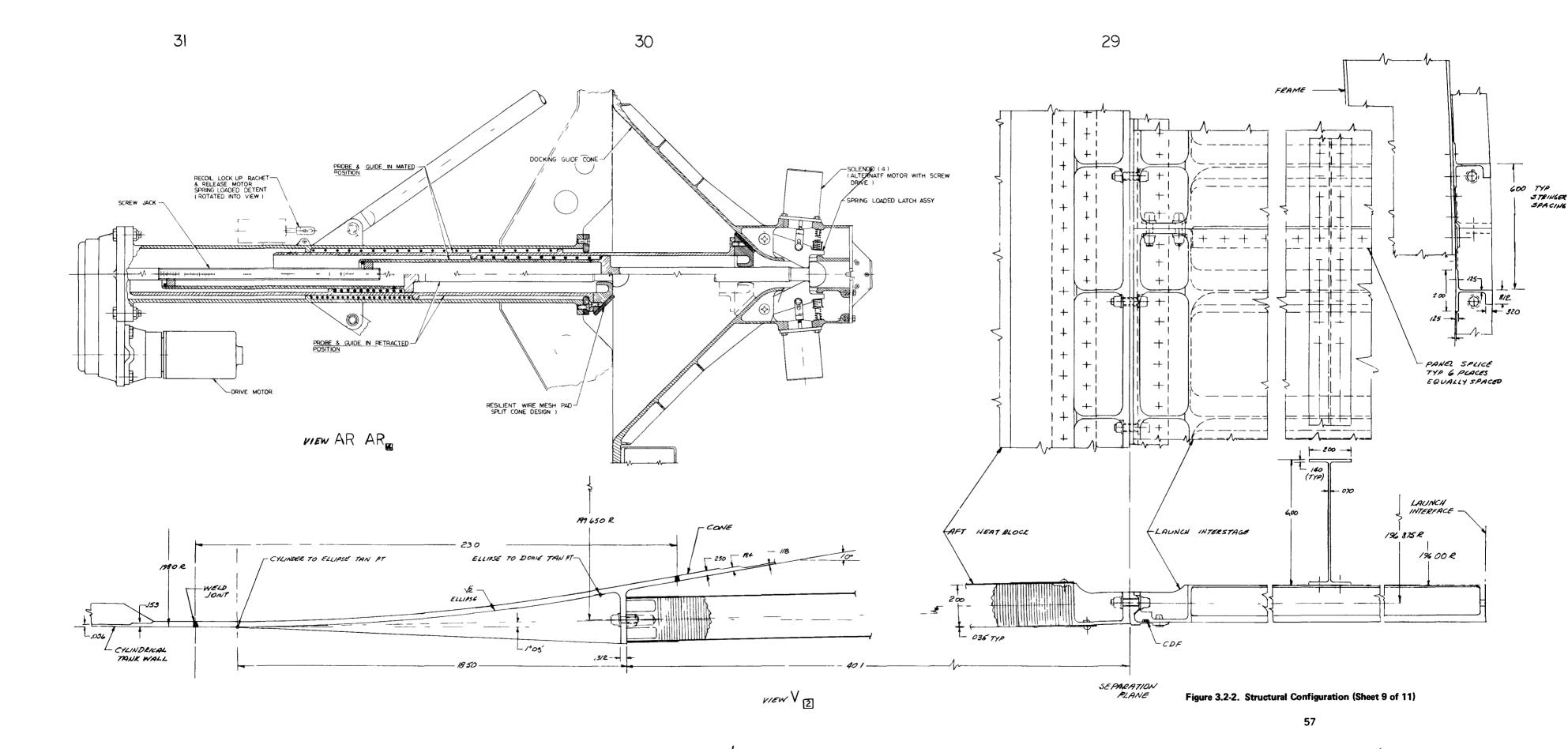


Figure 3.2-2. Structural Configuration (Sheet 8 of 11)







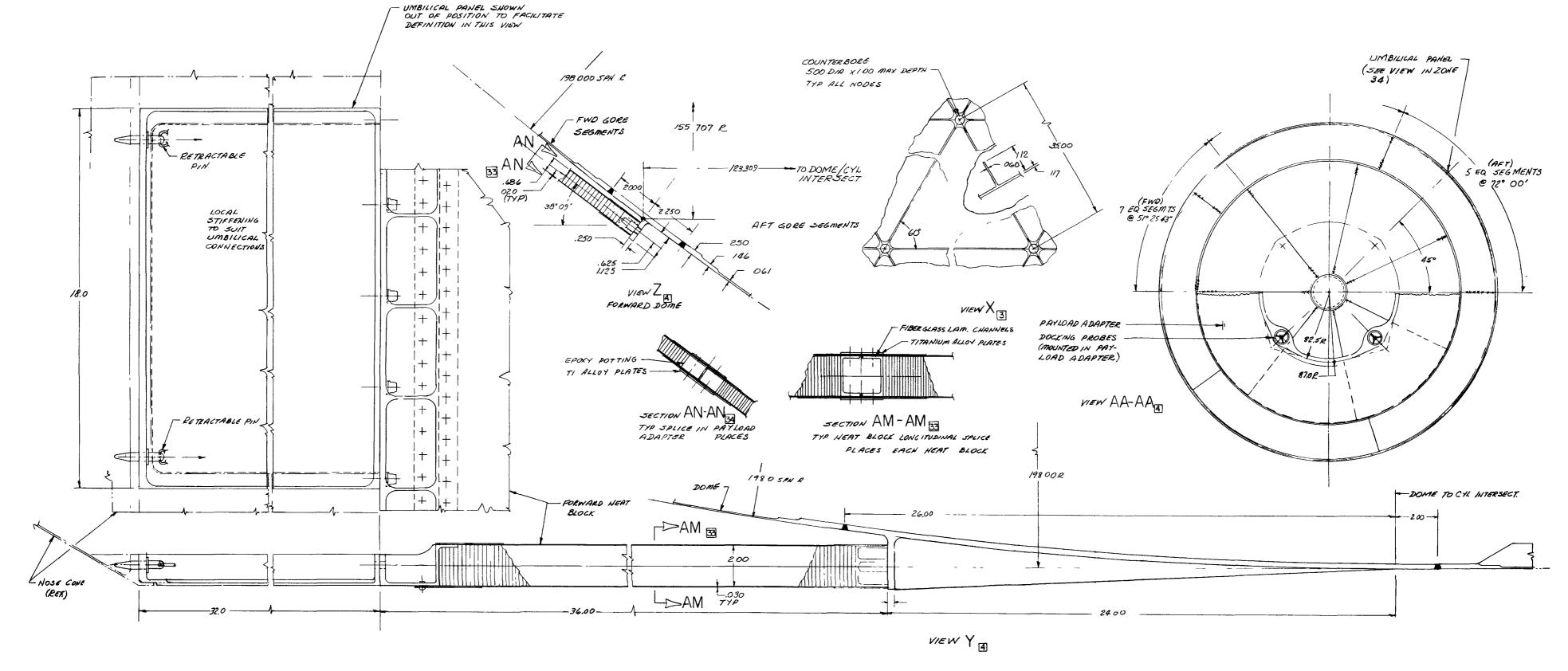
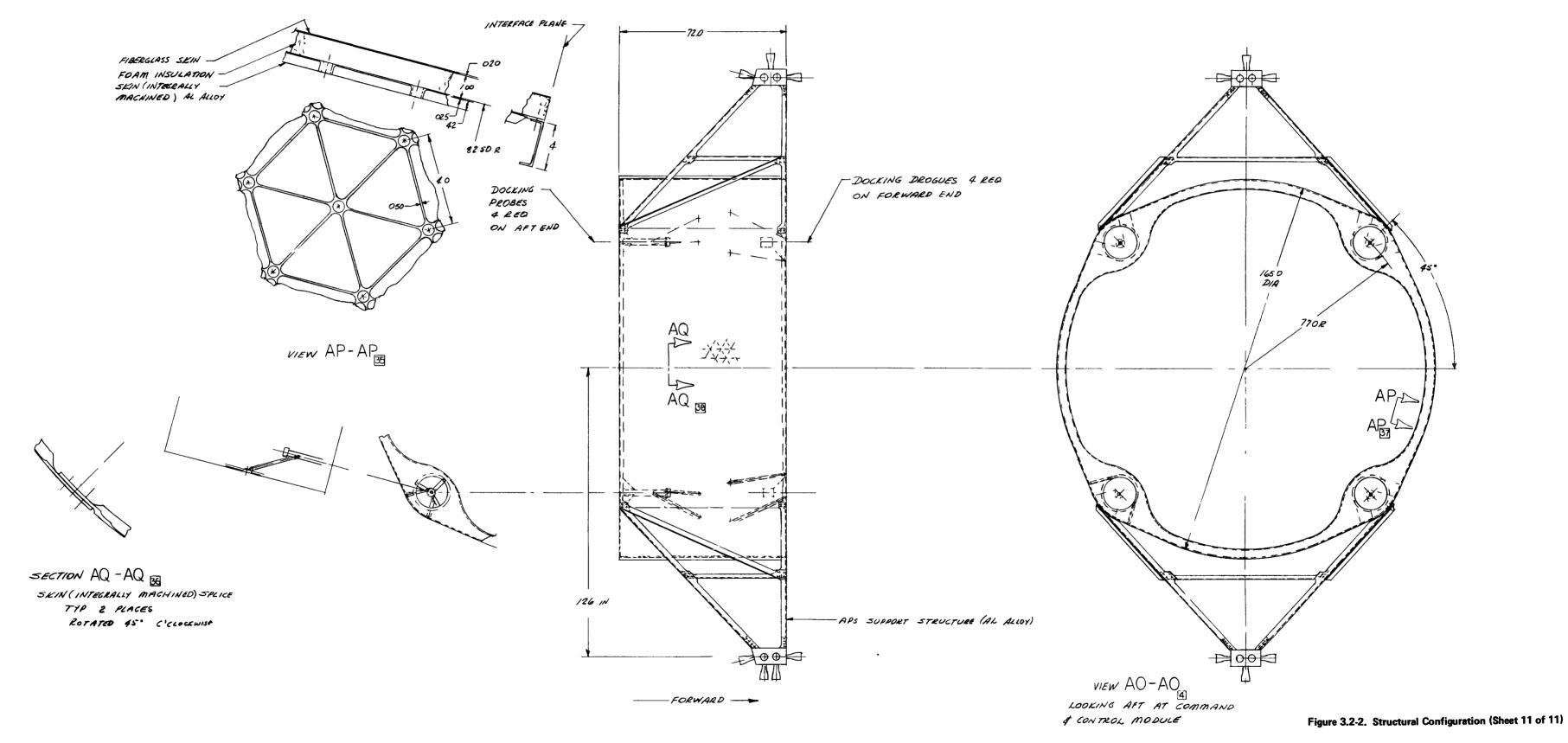


Figure 3.2-2. Structural Configuration (Sheet 10 of 11)







probe; the other between the hard probe and the retractor. The springs tend to hold the hard probe and flexible probe in the extended position, but may be compressed either by the screw jack, to retract, or by forces due to docking impact. The ratchet detent prevents rebound.

Operation of the main drive retractor motor is initiated when the extended flexible probe tip is captured by the latch at the vertex of the cone. The (weaker) retractor spring is compressed first, drawing the rigid probe into the vertex of the cone. Continued rotation of the screw jack retracts the hard probe into the casing to pull the modules together.

The structural latching system shown in View AL-AL and Section W-W on sheet 8 is actuated after the docking system has aligned and joined the two modules. The hook-type latches are located at 12 points around the interface frame adjacent to the truss skirts structure attach points. They are all activated simultaneously by a single cable driven by a reversible drum and motor assembly. A braking system incorporated in the motor holds the latches in either the closed over-center or open positions.

The latch and link assemblies are attached to machined supports in the aft module interface frame with the axes lying in a radial plane of the frame. Each assembly consists of a hook and four links. Motion of the hook is controlled by a pin riding in a machined slot in the frame. Upon actuation, the hook travels through clearance holes in the mating frames and engages an adjustable striker plate mounted on the opposite frame. The frames are locked as the links are rotated to their over-center position. Unlatching is accomplished by reversing the direction of cable travel which returns the hook to its normal unlocked position. A shear pin is provided at each latch for alignment and transfer of shear loads between modules.

# 3.2.3 Mass and Dynamic Properties

Rigid and flexible body properties were prepared for structural dynamics and powered flight attitude control analyses. These properties were determined using the MDAC computer program DA02, Determination of Vibration

Modes by K-Matrix Displacement Method. This program provides the normalized bending deflection, slope, bending moments, and shears. Rigid-body mass, center of mass, and inertia are also generated. Variation of these characteristics throughout the mission has been established. A lunar delivery payload model of 95,000-lb in weight and 140-ft long and of uniform mass distribution was assumed in these calculations. The return payload used was uniform and 15,000-lb in weight and 20-ft long. Table 3.2-2 summarizes the rigid and flexible body properties obtained. Also shown in this table are the control arms for a forward and aft auxiliary propulsion system (APS) location. The forward location of the APS would be in the CCM with the aft location on the forward part of the run tank.

Figures 3.2-3, 3.2-4, and 3.2-5 present the bending deflections for the first three modes. These relative deflections are normalized to a value of unity at the NERVA gimbal point (Station 100). The attitude gyros would be located in the CCM Station 1651. Plots for normalized bending moments and shears and the other loading condition are also available.

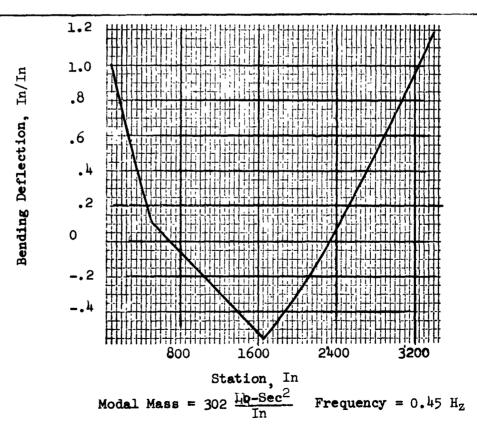


Figure 3.2-3 FIRST MODE BENDING DEFLECTION

Table 3.2-2
RNS CLASS 1 HYBRID MASS DATA

Mission Phase or Loading Condition	Vehicle Mass (lb-sec <sup>2</sup> in1)	Location Station Number	Vehicle Inertia About CG (lb-sec <sup>2</sup> in.)	Engine Gimbal Control Arm (in.)	First Mode Body Bending Frequency (Hz)	First Modal Mass (lb-in 1 sec <sup>2</sup> )	Second Mode Body Bending Frequency (Hz)	Second Modal Mass (1b-in 1 sec <sup>2</sup> )	Third Mode Body Bending Frequency (Hz)	Third Modal Mass (lb-in1 sec <sup>2</sup> )	APS Contr Forward Location	ol Arm (in.) Aft Location
Earth coast of fully assembled vehicle begin TLI burn, 98,000 lb payload	1,206	1,297	7,55 x 10 <sup>8</sup>	1,197	0.45	301	0.92	2,092	2.84	10,589	390	880
Translunar coast 98,000 lb payload	756	1,318	7.43 x 10 <sup>8</sup>	1,218	0.52	353	1 02	4,865	3.38	3,002	369	901
Lunar orbit coast 98,000-1b payload	655	1,380	7.24 x 10 <sup>8</sup>	1,280	0.54	391	1.03	5,099	3.43	3,842	307	963
Lunar orbit coast 15,000-1b payload	440	737	1.36 x 10 <sup>8</sup>	637	0.84	841	4.5	187	5.79	1,507	950	320
Transearth coast 15,000-1b payload	313	725	1.35 x 10 <sup>8</sup>	625	0.93	1,704	4.68	195	5.82	1 412	962	318
Final earth orbit coast 15,000-lb payload	243	765	1 33 x 10 <sup>8</sup>	665	1.19	1 732	4.96	313	6.53	463	922	348

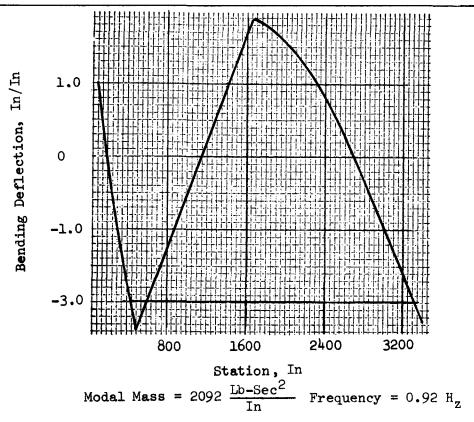


Figure 3.2-4 SECOND MODE BENDING DEFLECTION

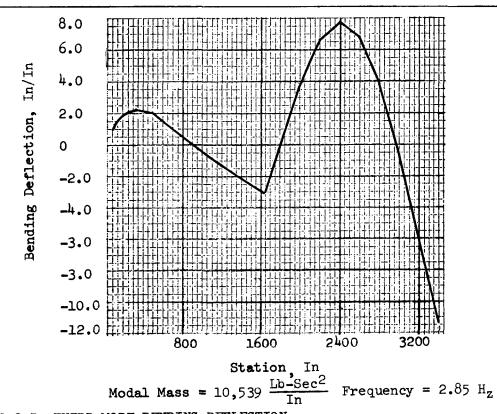


Figure 3.2-5 THIRD MODE BENDING DEFLECTION

#### 3.3 METEOROID/THERMAL PROTECTION

This subsection identifies the design conditions and describes the subsystems for meteoroid and thermal protection

# 3.3.1 Design Conditions

The meteoroid protection system of the RNS will provide at least a 0.9974 probability of no tank penetration in one lunar mission. The mission duration is 27.5 days embedded within a 54.6-day repeating cycle measured from initial RNS startup in earth orbit to completion of aftercooling upon return to earth orbit. Based on the analyses described in Section 4.3.3 of Book 1, the following criteria are established:

Criterion	Survival Probability			
Full cycle (54.6 days)	0.994			
Lunar mission (27.5 days)	0.9974			
Lunar mission during transit (9.5 days)	0.9987			

An average mission surface temperature of  $370^{\circ}R$  was adopted for the thermal protection system design. Surface coatings are considered degraded by the space environment and a value of 0.32 used for absorptivity and 0.96 for emissivity. The thermal conductivity for DAM/Dacron net high-performance insulation is  $2.0 \times 10^{-5}$  Btu/hr-ft- $^{\circ}R$  for a mission temperature range of 400 to  $40^{\circ}R$ . The natural layer density of 96 layers per inch is utilized. The density of the blanket is 4.1 lb/ft<sup>3</sup>, exclusive of installation. The heat input to the tank is based on the propellant utilization history during the mission and considers the reduced heat capacity of an offloaded tank. The resulting equivalent times are defined in Section 4.3.7 of Book 1 considering premission and mission phases. The analysis in Section 4.3.11 of Book 1 indicates that it is most economical to vent the tank in earth orbit prior to the mission. The tank must then be topped off with the initial condition for the propellant being

approximately 16 psia. The thermal protection system design parameters are summarized as follows:

	Propellant Module	Run Tank
Tank volume (ft <sup>3</sup> )	69,000	2,590
Tank surface area (ft <sup>2</sup> )	9,706	964
Heat short insulated area (ft <sup>2</sup> )	402	230
Propellant loading (lb LH <sub>2</sub> )	289,150	10,850
LH <sub>2</sub> saturation pressure after topping off (psia)	16.0	16.0
Full tank equivalent time (hr)		
Before mission	430	430
During mission	1,190	1,298
Total	1,620	1,728

## 3.3.2 Subsystem Description

The integral thermal/meteoroid protection system is shown on 9 sheets in Figure 3.3.-1. This figure identifies the insulation and meteoroid protection components that make up the complete system and is located at the end of this subsection to facilitate use while reading the description. Thermal protection for the stage is provided by three blankets of HP1, and meteoroid protection is furnished by a layer of polyurethane foam encased by a fiber glass shroud.

View AA on sheet 2 shows the manhole cover insulation and the forward dome insulation which is made up of 26 pie-shaped segments. The three blankets that make up each segment are staggered as shown and are supported at the periphery of the manhole cover by nylon studs. The outer edges of the uppermost blankets are laced to each other to hold the entire assembly in the proper position. Each blanket of the manhole cover insulation is installed

separately, and the cover of the outer manhole cover insulation blanket is laced to the outer cover of the forward dome insulation. Three concentric gas inlet rings supply helium purge gas to the manhole and forward dome HPI blankets. These rings are attached to study which are supported by fiber glass rings. The insulation covers are laced together as shown in View K on sheet 2.

The thermal/meteoroid protection system attachments to the forward heat block and the forward dome are shown in View B on sheet 3. The forward heat block is insulated on both sides. The outer insulation is a part of the sidewall insulation. The forward edges of the three blankets which make up each insulation panel are staggered. The relatively warm outer blanket is attached to the warmest or forward portion of the structure. The relatively cold inner blanket is attached to the aft or cold portion of the structure. All insulation is supported by studs inserted through the sandwich core of the heat block. The foam/fiber glass shroud is detailed in subsequent views. The two inner blankets of the forward dome-heat block insulation intersection are secured at the aft edge to studs bonded to the tank wall. The edges of the outer blanket are laced as shown in View K on sheet 2.

Purge gas is supplied from an inlet line near the forward edge of the heat block and flows to the insulation via passageways within the honeycomb sandwich structure.

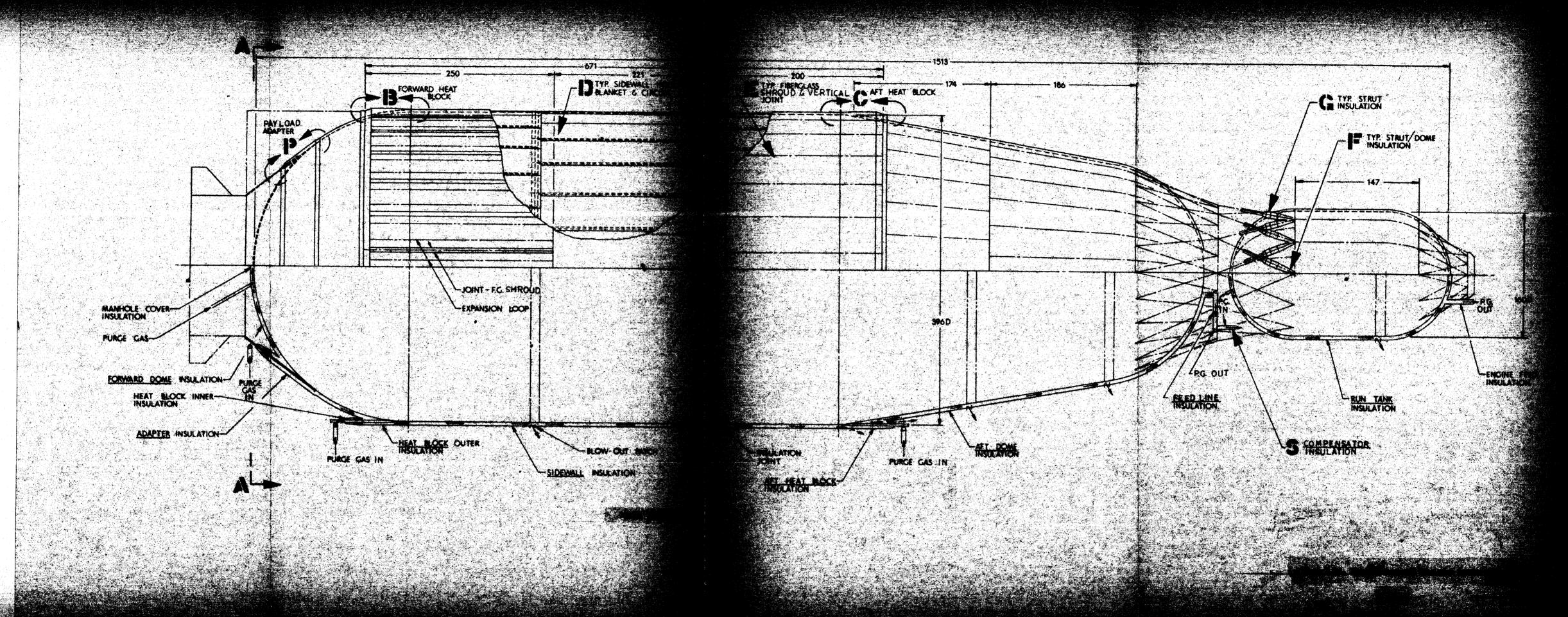
A typical sidewall thermal/meteoroid protection panel and the insulation joints are shown in Views D and E on sheets 4 and 5. As shown in the main view of sheet 1, the sidewall insulation is divided into three tiers, each of which is divided circumferentially into 26 panels. Each panel is approximately 48 in. wide by 220 in. long and is composed of three HPI blankets, a layer of foam, and the fiber glass shroud. Each blanket contains 17 layers of doubly aluminized mylar with net separators, sandwiched between two face nets. The face nets shown in View D have border and longitudinal reinforcing strips, 12 in. center to center, formed by impregnating the net with resin. Each blanket is held together by small nylon studs and buttons located 12 in. on

center in the longitudinal and lateral directions. The inboard cover net of each blanket has four tabs at each end. At the forward end, these tabs support the blanket via four fiber glass inner connector strips which attach to studs on the tank wall. The inner strips continue aft and outboard, through the HPI and foam, to the forward end of the fiber glass shroud. Here they are attached to and support the shroud. Four fiber glass outer connector strips are also provided for insulation support. These are riveted to the tabs that are located on the aft ends of the cover sheets and extend outboard and aft, through the foam, to anchor the aft ends of the panels to the fiber glass shroud.

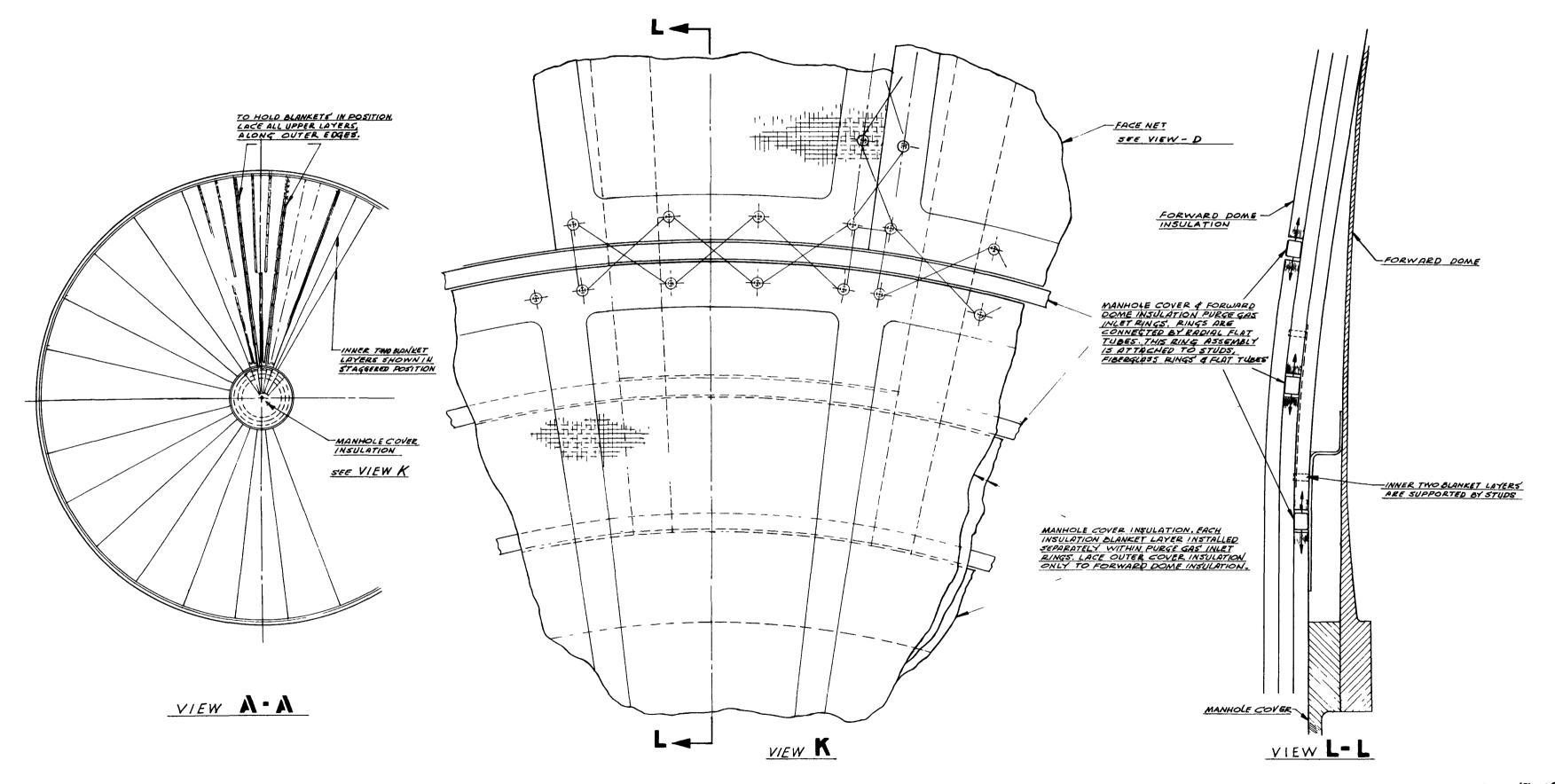
The lower view shows a section through the circumferential joint. Each of the three blankets is tapered at the ends to make a lap joint which is approxmately 12 in. wide. The inner surface of the foam contains a gridwork of pumpout channels, 6 in. apart, extending axially the length of the sidewall and circumferentially around the tank. These channels intersect largerarea headers at the panel joints which, in turn, connect with vent ports in the fiber glass shroud.

The fiber glass shroud is shown in View E on sheet 5. Each panel contains two expansion loops which serve as a tensioning device. On installation, these loops are held open by wedges. After installation, the wedges are removed and the loops close. This tensions the shroud and compresses the foam. The reason the shroud is 6 in. narrower than the insulation blankets is for installation if the shroud splice. As shown in the lower view, which is a typical longitudinal joint, a 6-in. section of flexible foam is installed between shroud panels and a fiber glass splice section riveted to the adjoining outer sheets. The thermal blankets are staggard in the splice area.

The aft heat block and conical dome insulation are shown in View C on sheet 3. Both the inside and the outside of the heat block are insulated. The aft tier of the tank cylinder insulation and meteroid bumper overlap the heat block. The aft ends of the individual insulation blankets are terminated in a staggered configuration as at the forward heat block. The inside insulation



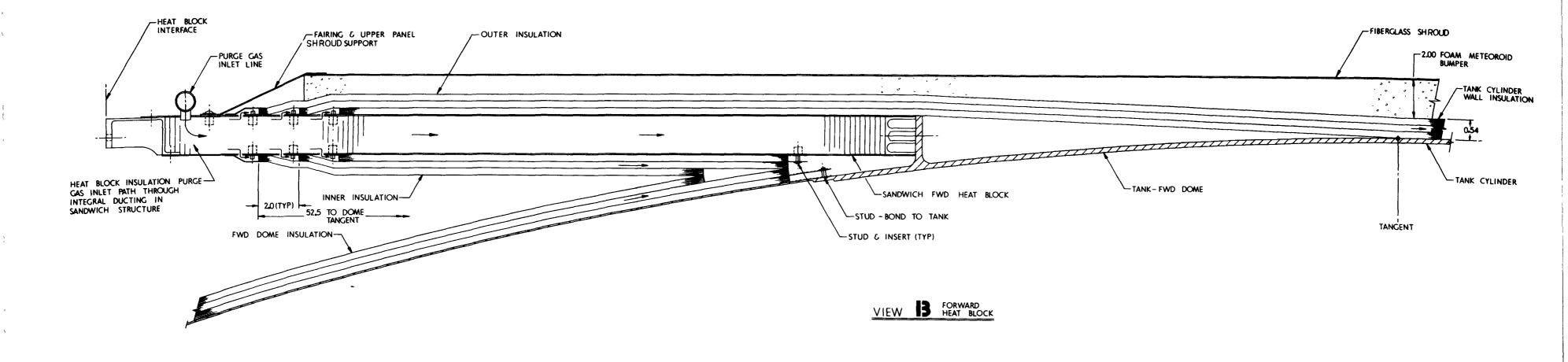




MARHOLE COVER INSULATION

Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 2 of 9)





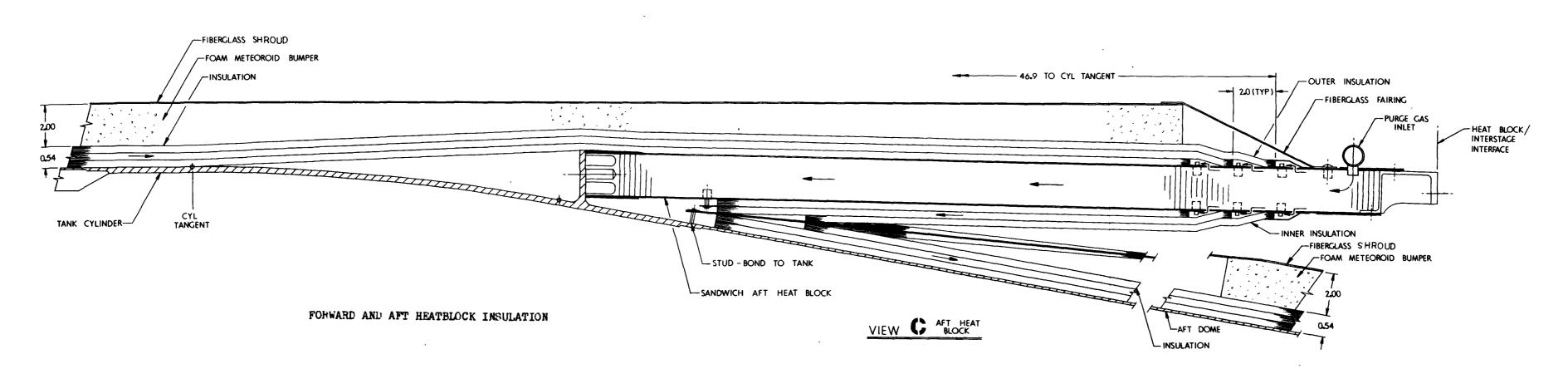
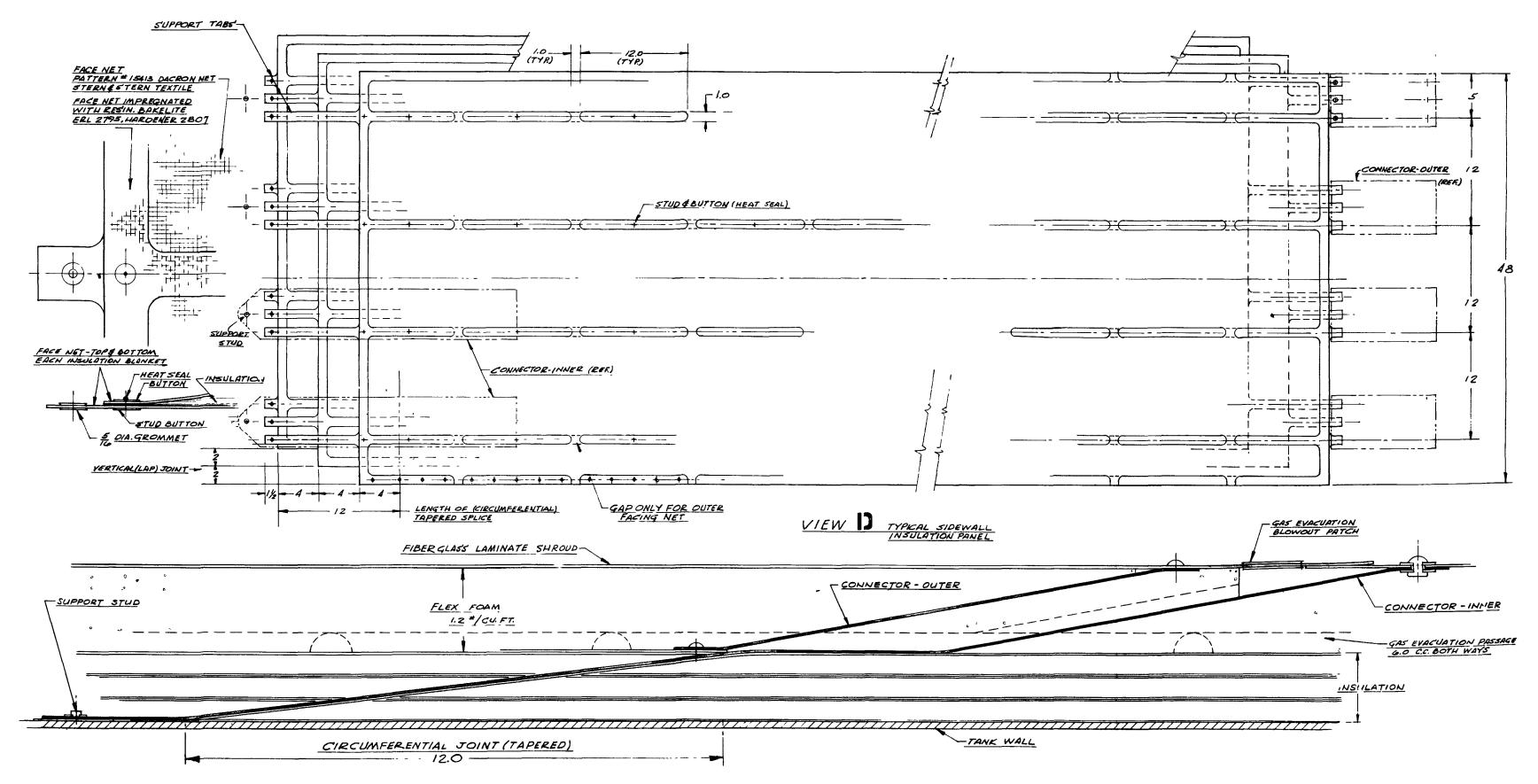


Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 3 of 9)

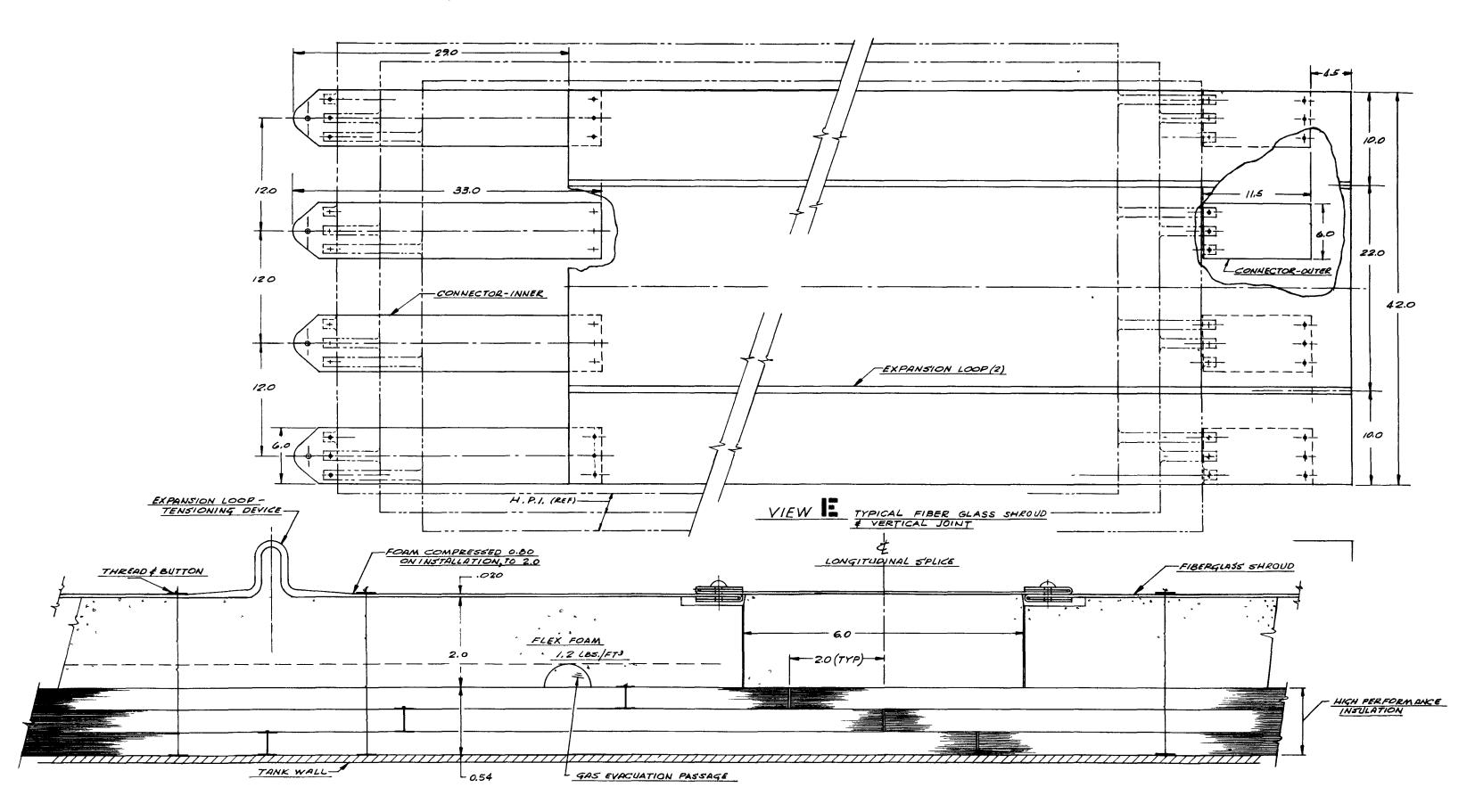




SIDEWALL INSULATION

Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 4 of 9)





FIBER GLASS SHROUD

Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 5 of 9)



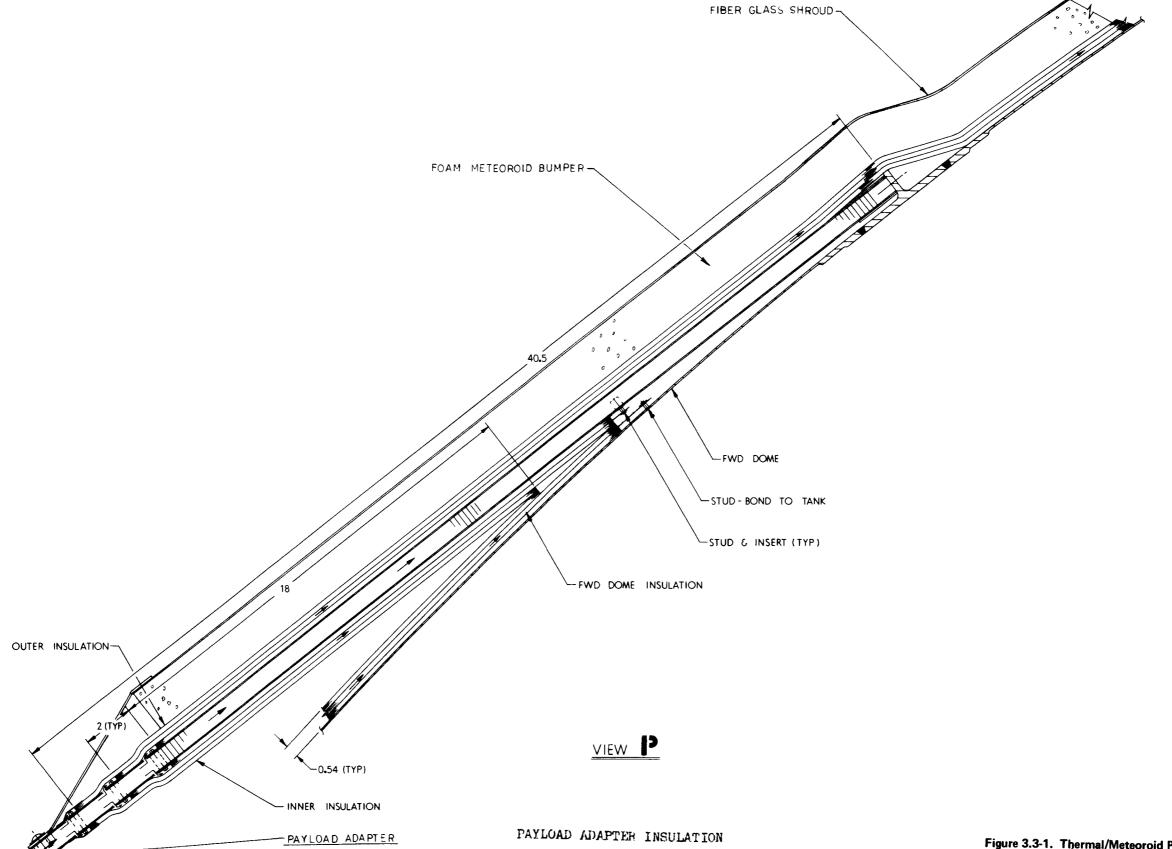
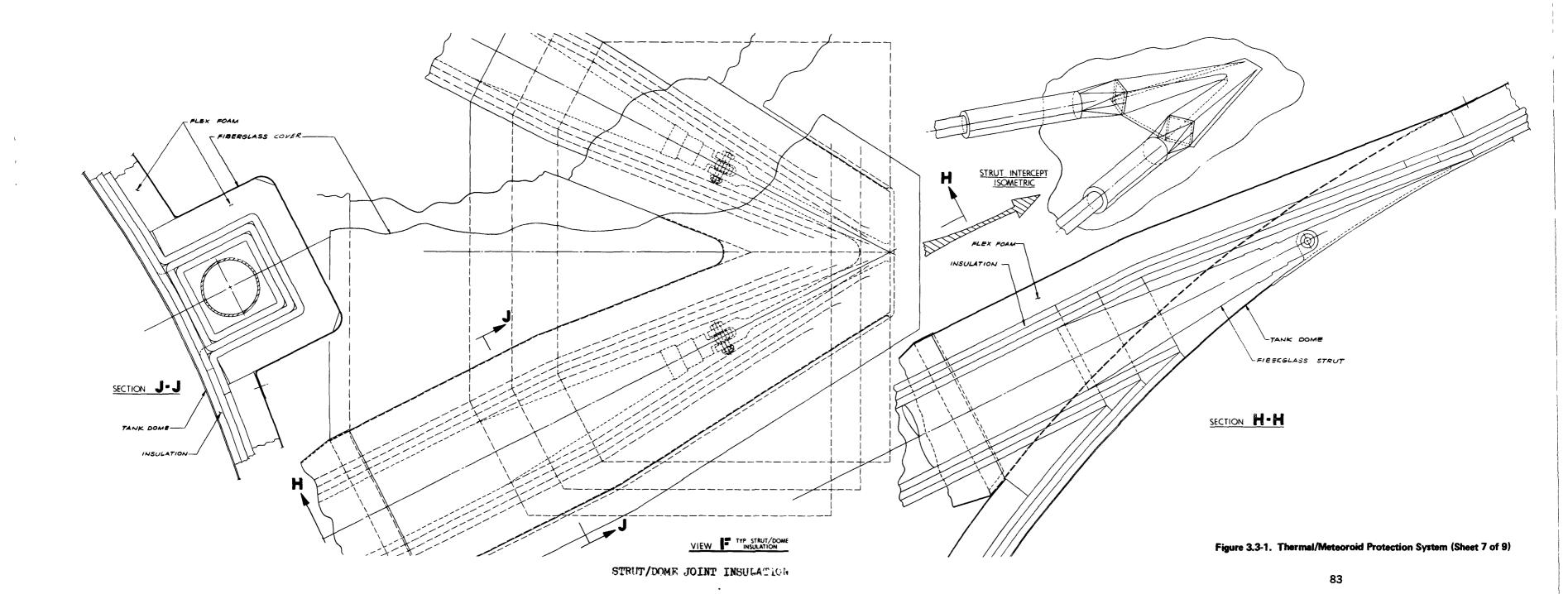
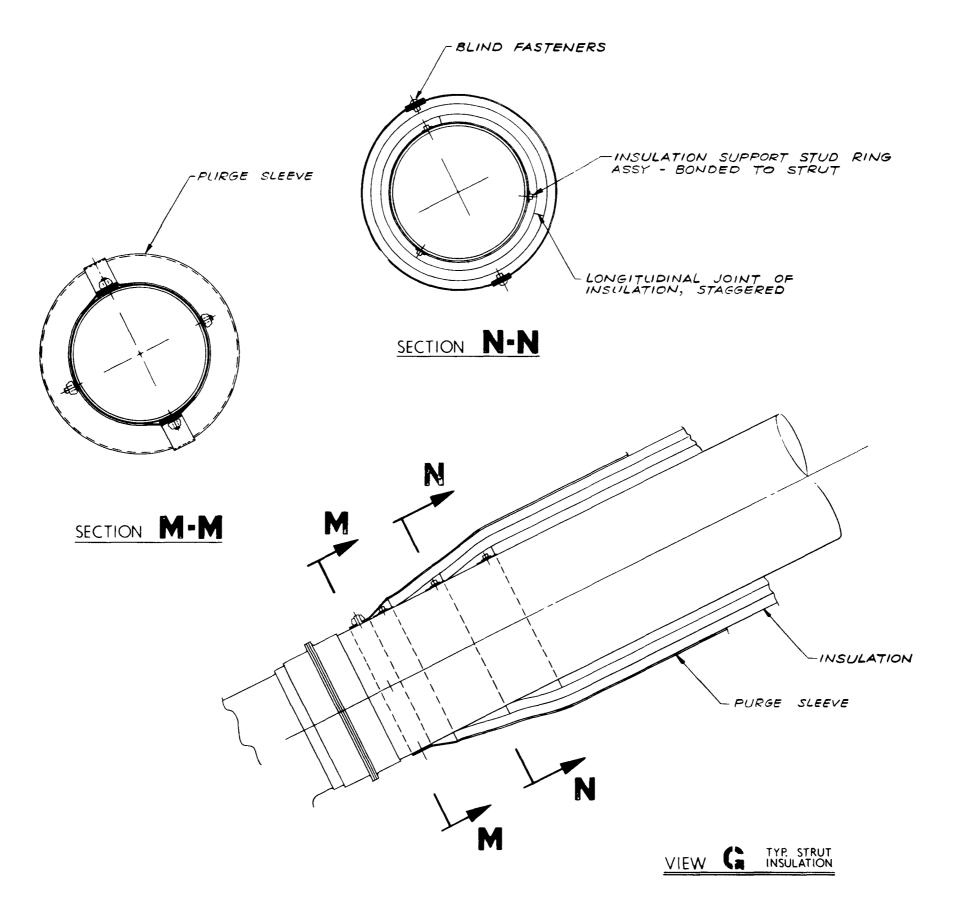


Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 6 of 9)





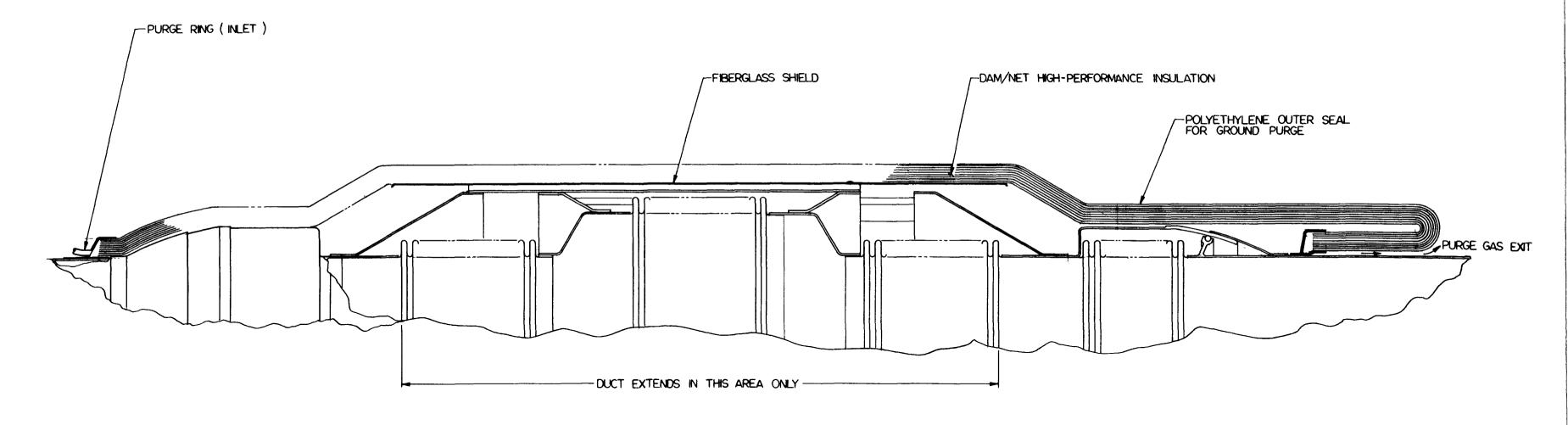




STRUT INSULATION CLOSE OUT

Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 8 of 9)





VIEW 5

COMPENSATED BELLOWS INSULATION

Figure 3.3-1. Thermal/Meteoroid Protection System (Sheet 9 of 9)



is supported on studs at the forward end of the heat block. The aft dome insulation is supported by its coversheet, and the shroud is supported by fiber glass straps from studs which are bonded to the tank. The fiber glass straps are insulated, as shown, to reduce their effective conductance.

View P on sheet 6 shows the thermal/meteoroid protection system for the payload adapter and forward dome. It is similar to the aft heat block and conical dome insulation. Both the inside and outside of the payload adapter are insulated and the dome insulation and meteoroid bumper overlap the adapter. The forward ends of the insulation blankets are terminated in a staggered configuration.

Insulation of the compensated bellows sections is shown in View S on sheet 9. The insulation is retained by channel sections welded to the duct. A small tube is manifolded into the forward channel to purge the insulation during ground hold. The insulation blanket is wrapped around the gimbals and pressure volume compensator bellows and finally takes a U-configuration and attaches to the aft channel manifold. The U-overlap will accommodate the linear deployment motion required for the duct. The entire outer surface of the insulation is encased in a mylar purge sleeve.

The insulation concept for the struts of the intermodular thrust structure is shown in Views F and G on sheets 7 and 8. The dome thermal/meteoroid composite is cut out in a triangular pattern at the strut intersection points with the thermal blanket cutouts staggered. Insulation blankets are laid up around the struts in a square pattern with their edges staggered to match those of the dome thermal blankets. A V-shaped fiber glass/foam cover with the legs of the V having a square cross-section is installed over the insulated struts. It is riveted to the dome fiber glass shroud. The foam terminates at the edge of the fiber glass cover. This is also the transition juncture where the insulation necks down to be wrapped around the struts. The blanket assemblies are retained by lacing the outer blankets in a manner similar to that shown in View K on sheet 2. The blankets terminate in a

staggered configuration at the opposite end as shown in View G on sheet 8. The inboard cover net of each blanket has three tabs that attach to studs bonded to the struts. A plastic purge sleeve encases the insulated strut.

The prelaunch helium purge system is shown in the main view on the first sheet. It is integrated with the structural and meteoroid/thermal protection systems. Purge gas flow, indicated by the arrows, utilizes gravity for the most effective displacement of the higher-density residuals by helium. The outer fiber glass shroud forms the purge gas container for the cylindrical portions of the vehicle, the payload adapter, the aft end of the hemispherical dome, and the conical dome. The exterior joints of the shroud are sealed, and the vent ports are closed by means of burst diaphragms during prelaunch. A plastic diaphragm is stretched across the pole of the forward dome and supported by the payload adapter for containment of purge gas.

#### 3.4 MAIN PROPULSION

This subsection defines the operating conditions and describes the main propulsion subsystems.

### 3.4.1 Operating Conditions

The ANSC fluid line interfaces with the RNS consist of: (1) feed duct (two required, 10.5-in. diameter), (2) aftercooling bypass line, 3-in. diameter, and (3) pressurant line, 2-in. diameter. The isolation valves for these lines are currently located on the engine side of the engine/stage interface.

NERVA LH<sub>2</sub> flow rate requirements for nominal performance are: (1) 91.9 lb/sec for full power and (2) 0.7 lb/sec during aftercooling pulse. The steady-state operating pressure is 26 psia saturated liquid with zero NPSP. Reduced flow rates are permitted at zero NPSP and saturated liquid according to Figure 4.5-2 in Book 1 to provide autogenous start capability. The RNS also provides propellant conditions for a NERVA malfunction mode at a maximum pressure of 26 psia. Saturated liquid is provided to the bypass line for aftercooling at a pressure exceeding 16 psia.

The NERVA and stage LH<sub>2</sub> feed system is chilled down prior to operation. Tank pressures are regulated by a propellant management control system according to the pressure schedule defined in Section 3.12.2 in Book 1. The nominal tank pressures for this schedule are 26.3 psia in the propulsion module and 28.7 psia in the propellant module. The vent settings permit this nominal level to be exceeded by 0.3 psia. A 40 percent increase in the main feed system flow rate is permitted to refill the run tank during full-power operation. Separate expulsion and control pressurization functions are provided at 0.6 and 0.4 lb/sec of GH<sub>2</sub> for use subject to the requirements of the propellant management control system. A flight vent flow rate of 0.6 lb/sec is provided. Pressurant is delivered to the module pressurization systems at the NERVA tap-off pressure of 850 psia. Ground vent and relief functions are provided in multiple modes with a maximum flow rate of 10 lb/sec provided. A maximum flow rate for orbital refueling of 2,000 gpm is provided.

## 3.4.2 Schematic

The schematic of the propulsion system for the Class 1 Hybrid RNS is shown in Figure 3.4-1. The two separate modules that contain the propulsion system elements, the propulsion module and the propellant module, are shown. The interface plane down the center of the schematic indicates the remote coupling interface between these modules.

The propellant feed system for this vehicle contains two normally closed, motor-driven shutoff valves located in the propellant module. These two 8-in. valves are parallel manifolded. During full-power operation, flow is introduced to the valve inlet in a pressure-fed mode from the propellant tank and proceeds through a 12-in.-diameter duct at a flow rate of 91.9 lb/sec into the propulsion module run tank. Internal of the propulsion module run tank the 12-in.-diameter riser duct tees into two 8-in.-diameter ducts, each terminating in an 8-in.-diameter propellant flow control valve. These control valves are analog type motor-driven valves that are controlled

through the data management system using information from liquid level sensors located in the propulsion module run tank. This system maintains a constant propellant level during steady-state operation. Propellant outflow from the run tank to the NERVA engine is accomplished through two separate tank bottom penetrations. These 10-in.-diameter penetrations exit the tank and are close coupled with the two NERVA engine PSOV shutoff valves. Flow proceeds through these shutoff valves to the NERVA engine main turbopump inlets. All of the stage propellant control valves are submerged and have antivortex and filtration screening at the valve inlets. The two propellant module shutoff valves and the two propulsion module control valves effectively provide a quad-redundant configuration to provide high reliability.

Expulsion pressurization for both the propulsion module run tank and the propellant module is accomplished by tapping off 850 psi, 230°R hydrogen gas from the NERVA turbine discharge. This gas is run through a 1-1/4-in.-diameter duct across the interface plane to the propellant module. At the propulsion module, two flow rate systems are provided: an expulsion flow rate of 0.6 lb/sec and a controlled flow rate of 0.4 lb/sec. Both of these loops use quad-redundant 1/2-in.-diameter direct-acting solenoid valves for control. These valves are controlled through the data management subsystem using information from strain gage pressure-sensing elements located in the run tank. This bang-bang system provides the flow into the propulsion module run tank via two controlling orifices. The same system is utilized for the propellant module with the addition of a larger flow rate capacity required for prepressurization. The third flow loop in this system is sized for the 4 lb/sec prepressurization requirement which occurs during NERVA bootstrap start. This flow control is accomplished utilizing four 1-1/4-in.-diameter, pilot-operated solenoid valves. These solenoid valves are indirectly controlled using the information from strain gage pressure sensors in the ullage of the propellant tank. The other two flow control loops for the propellant module are identical to that used on the propulsion module. Flow calibration is accomplished through three individual choked orifices as shown.

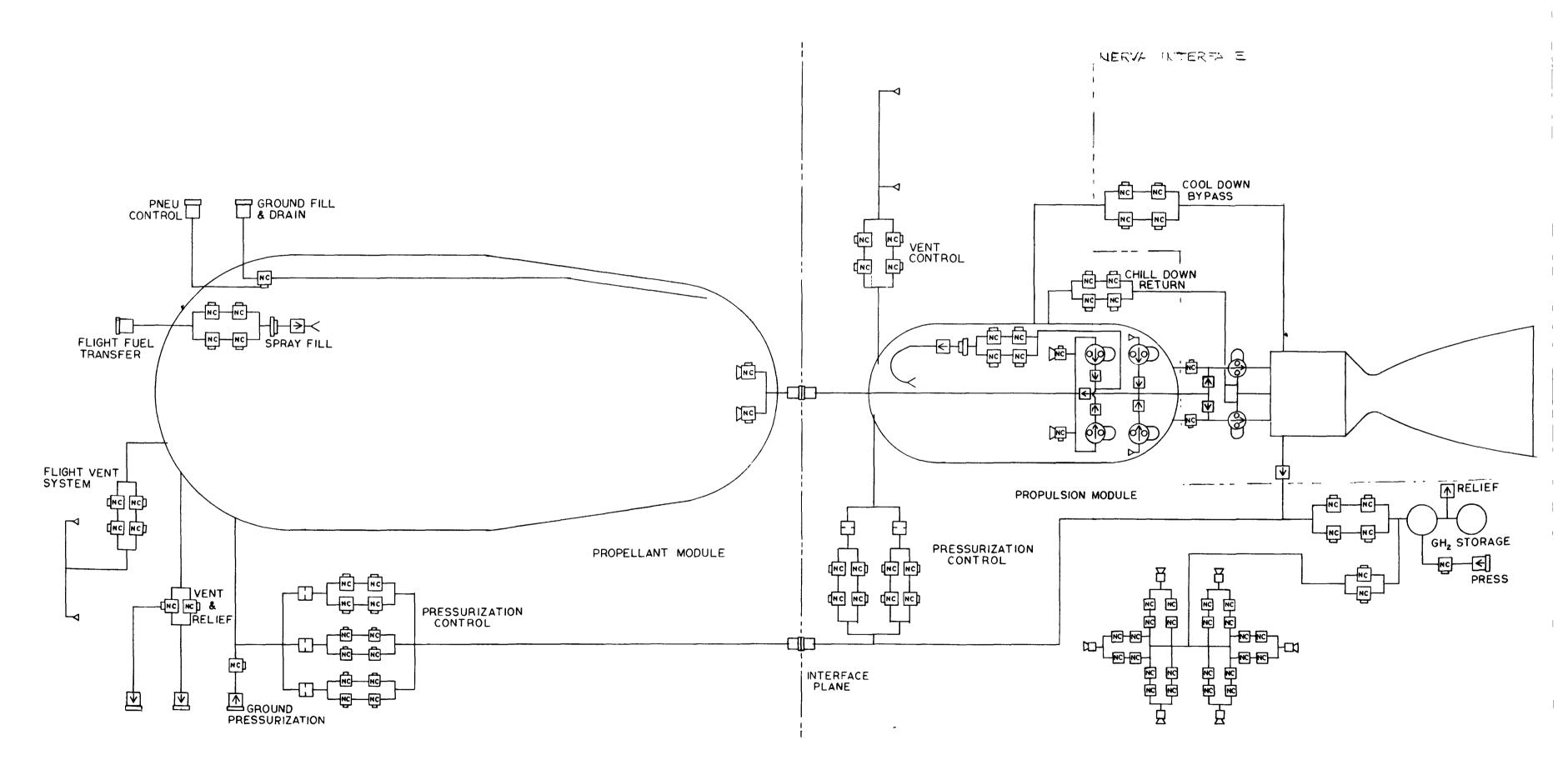


Figure 3.4-1. Propulsion System Schematic



A ground-only pressurization loop is also included for the propellant module. Ground pressurization is required since the propellant module is launched with LH<sub>2</sub>. This loop consists of a normally closed 1/2-in.-diameter solenoid valve and a ground pressurization disconnect. The ground pressurization disconnect is located on the forward umbilical panel in the forward skirt area on the propellant module. The propulsion module is launched dry so that ground pressurization functions are not required. The propulsion module contains a simplified monopropellant attitude control system that is used for stabilization during orbital assembly of the vehicle. This system is depicted in the lower right hand corner of the schematic. The system utilizes NERVA engine hydrogen gas from the same turbine topoff that is used for pressurization. This gas is in the 300°R range and approximately 800 psi, stored in 25-in.-diameter titanium spheres. This system is basically a blowdown type system which permits high-pressure stored gas to be vented through any one of six nozzles located 180 degrees apart in clusters of three on the outer periphery of the propulsion module. Each of the nozzles is controlled by a set of quad-redundant, normally closed, 1/4-in. solenoid valves. The system is armed by opening the two parallel mounted, 1/2-in.-diameter solenoid valves at the storage tank discharge. The system has provisions for initial ground loading via a ground disconnect and a normally closed ground fill valve. The storage spheres are also provided with relief provisions. A set of quad-redundant recharge direct-acting solenoids connect the spheres to the NERVA engine pressurant gas tap-off. These valves are actuated to recharge the spheres for reuse.

The propulsion module contains a flight vent and relief system. This system contains four normally closed 2-1/2-in.-diameter, pilot-operated solenoid valves located in a quad set. These valves are designed for a maximum pressurant inflow of 0.6 lb/sec. The valves located external of the run tank terminate in two propulsive vent nozzles routed 180 degrees apart on the outer surface of the upper structure of the propulsion module. The vent valves are commanded by the data management subsystem using information from strain

gage pressure sensors. An emergency relief mode is provided by the emergency detection system. The same basic system is used for flight venting of the propellant module. This system is also sized for an expulsion flow rate of 0.6 lb/sec. The 4 lb/sec startup prepressurization rate was not used as the sizing criteria for this vent system since the quad-redundant nature of this system would require a second failure to occur in order to necessitate utilization of a full flow vent system capability. In addition to the flight vent and relief system, the propellant module, which is launched wet, requires a ground vent and relief system. This system contains a vent and relief valve that is a combination pneumatically controlled vent valve and an absolute pressure relief valve utilizing a single flow path. Pneumatic control capability is a ground-only function. These valves are used to permit venting of the hydrogen tank during fill and also to provide a primary safety device in the event of inadvertent pressure buildup. A 6-in.-diameter duct runs from both the vent and relief valve to a disconnect located in the forward umbilical panel of the propellant module. In addition, a 1/4-in. pneumatic control line is also run to the vent and relief valve. This line provides the 475-psig helium actuation pressure for commanded venting. In conjunction with the ground vent and relief function, the propellant module contains a ground-only fill and drain system. This system uses 4-in.-diameter ducting and is capable of flowing 3,000 gpm of hydrogen at a supply pressure of 50 psi. Ground fill is accomplished through the forward umbilical panel and enters through the ground fill and drain disconnect. Close coupled to the disconnect is a 4-in.-diameter butterfly type fill and drain valve. This valve is pneumatically controlled for ground usage only. As shown, a 1/4-in.-diameter, 475-psi helium control line is also routed to this valve via a disconnect on the umbilical panel. From the valve a duct runs to the propellant tank, through the tank penetration, and a riser runs along the inside of the tank down to the tank bottom. This riser provides the fill function as well as the expulsion drain function.

The propellant module contains an in-flight refueling system. This system consists of a fuel transfer disconnect, a set of motor-driven, quad-redundant

control valves, a flow meter, an antibackflow check valve, and finally, a spray nozzle. The spray nozzle is located in the ullage space of the propellant module. This system is 4 in. in diameter and has a capacity of 3,000 gpm maximum flow rate. This system is utilized for propellant module refueling after every round trip. Flow is introduced into the tank via the spray nozzle to prevent pressure surges and over pressurization of the tank. Refueling is accomplished with the vehicle in a settled condition. The check valve located in the system prevents disturbances from being propagated up through the refueling system and eliminates excessive pressure surges in the system. A similar system is incorporated in the propulsion module run tank and is integrated with the run tank refill system. The refill system is utilized after every NERVA engine burn to refill the propulsion run tank from the propellant tank. This system operates in the following manner: two submerged, parallel mounted motor-driven centrifugal pumps located in the run tank discharge through two antiflow check valves into the baseline spray fill refueling system. These two pumps intake from the main feedline and discharge into the run tank. Fluid is obtained from the 12-in.-diameter main feed duct through the two 8-in.-diameter propellant shutoff valves located in the propellant tank. Antibackflow check valves are incorporated at both pump discharges, and also in the propellant line tap-off. These check valves prevent pump surges and backflow and permit independent pump operation in the event of a single pump failure.

The propulsion module run tank also contains an integrated engine/stage chilldown conditioning system. This is a closed-loop recirculation system using two submerged ac-motor-driven centrifugal pumps located in the bottom of the run tank. These pumps intake from the run tank and discharge through two antibackflow check valves through a 2-in.-diameter duct that exits the tank and tees to the two main NERVA pump inlet ducts. These lines enter below the PSOV valves. In the conditioning operation the PSOV valves are closed and a flow rate of 1.5 lb/sec for each pump is injected into each duct. This flow proceeds through the main feed duct to the NERVA turbopumps. Upstream of these valves the tap-off takes the return flow manifolded from

both engine pumps to a common return line. The return line crosses the gimbal plane and flow is introduced back into the run tank via a set of quadredundant shutoff valves located on the propulsion module. This flow system accomplishes NERVA engine conditioning. In addition, flow is also introduced into the main feed duct riser and directed forward into the propellant feed ducting and up to the isolation valving internal of the propellant module. The 8-in.-diameter isolation valves are open during this operation, thus enabling a conditioning of the feed system from the propulsion module run to the propellant module. Each of the ac-motor-driven centrifugal pumps has a nominal capacity of 2 lb/sec against a pressure head of 3.5 psia.

#### 3.5 AUXILIARY PROPULSION

The auxiliary propulsion system (APS) described in this section is located in the command and control module (CCM) and provides all APS functions during RNS operation. The stabilization system located on the propulsion module is only used during vehicle assembly and disassembly and was described in the last subsection together with the propulsion system schematic.

#### 3.5.1 Design Conditions

The APS provides thrust for: (1) attitude control during coast phases, (2) attitude maneuvers, (3) attitude control during cooldown thrusting, (4) separation maneuvers, (5) roll control during main engine burns, (6) rendezvous maneuvers, and (7) propellant settling. Common storage of propellant for the cryogenic fuel cells and APS is utilized. Long-term orbital storage of the RNS will be in the local-vertical, gravity-gradient-stable orientation to minimize attitude control impulse requirements.

The impulse budget for attitude control, maneuvers, and propellant settling is shown in Table 3.5-1. The associated thrust level requirements are 100 lb for pitch, roll, and yaw; 200 lb for longitudinal maneuvers, and 3.2 lb for propellant settling. The 100-lb thrust level requirement, combined with a minimum valve operating time of 30 msec, yields a 3 lb-sec minimum impulse bit.

Table 3.5-1
APS ATTITUDE CONTROL IMPULSE BUDGET

Maneuver	Impulse (lb-sec)
Coast attitude control	1,800
Attitude maneuvers	145,000
Attitude control for aftercooling	38,800
Separation	49,400
Roll control	11,300
Rendezvous	108,000
Propellant settling	40,000
Subtotal	394,300
Contingency (15 percent)	58,700
Total	453,000

The APS motor configuration selected in Section 4.6.2 of Book 1 contains a total of ten 50-lb thrust motors in each of two pods. Rationale for this selection and contingency operating modes is presented in that section. In the normal operating mode, two of the 50-lb motors are used to obtain the 100-lb thrust level. In addition to the 10 attitude control motors, a 1.6-lb thrust propellant settling motor will be provided in each pod.

## 3.5.2 Schematic

The baseline cryogenic  $\mathrm{LO_2/LH_2}$  APS system contains two thrustor pods and a central propellant supply. The thrustor pods are located 180 degrees apart mounted on outriggers which extend 3 ft from the CCM to prevent plume impingement. Each pod contains 11 thrustors, as discussed in the previous subsection. Each thrustor contains quad-redundant control valving. High chamber pressure thrustors are utilized with film cooling for the nozzles.

The cryogenic APS system schematic and integrated propellant storage for fuel cells are shown in Figure 3.5-1 located at the end of this subsection. Gaseous hydrogen and oxygen in the temperature range of 200 to 300°R is supplied to the thrustors and fuel cells from a central propellant conditioning system which uses low-pressure liquid storage for both fluids. Gas-driven centrifugal pumps are utilized in conjunction with heat exchangers to supply the high-pressure warm gas required for thrustor operation. The gas is then stored in accumulators at 1,000 psia. Thrustors operate from the accumulators in a pressure-fed mode. The fuel cells will also obtain their reactants in a pressure-fed mode from these accumulators. Redundant pressure regulators to reduce the pressure to 100 psia are provided for fuel cell operation. Liquid hydrogen and liquid oxygen are each stored in low-pressure tanks at about 20 psia. Propellant orientation and acquisition in these tanks are provided by a surface tension system. Each of the propellant tanks contains a ground-fill system for reactant replenishment. Each propellant tank contains a series of quad redundant valves that are pressure-sense actuated to provide the ground vent and relief requirements during fill. As a backup flight relief system, a combination burst disc relief valve is provided in the accumulator system to compensate for any overpressure in the accumulator. This uses a pressure-driven piston which forces a cutting edge through the burst disc. The burst disc is backed up with a relief valve. The propellant tanks also contain an expulsion pressurization system which is utilized to feed propellant to the turbopumps. This expulsion pressurant is obtained by tapping off from the accumulators in the system. Control is provided by a bang-bang pressure sensor control system. A quad set of valves is utilized for this function.

The basic propellant conditioning loop operates as follows: low-pressure propellant is expelled from the storage tank through a shutoff valve to the turbopump inlet. The turbo portion of the pump is driven by the exhaust gas products of a gas generator. The gas generator has two control valves and obtains its propellants by tapping off from the accumulators. The gas generator is igniter actuated. High-pressure liquid then leaves the turbopumps via an

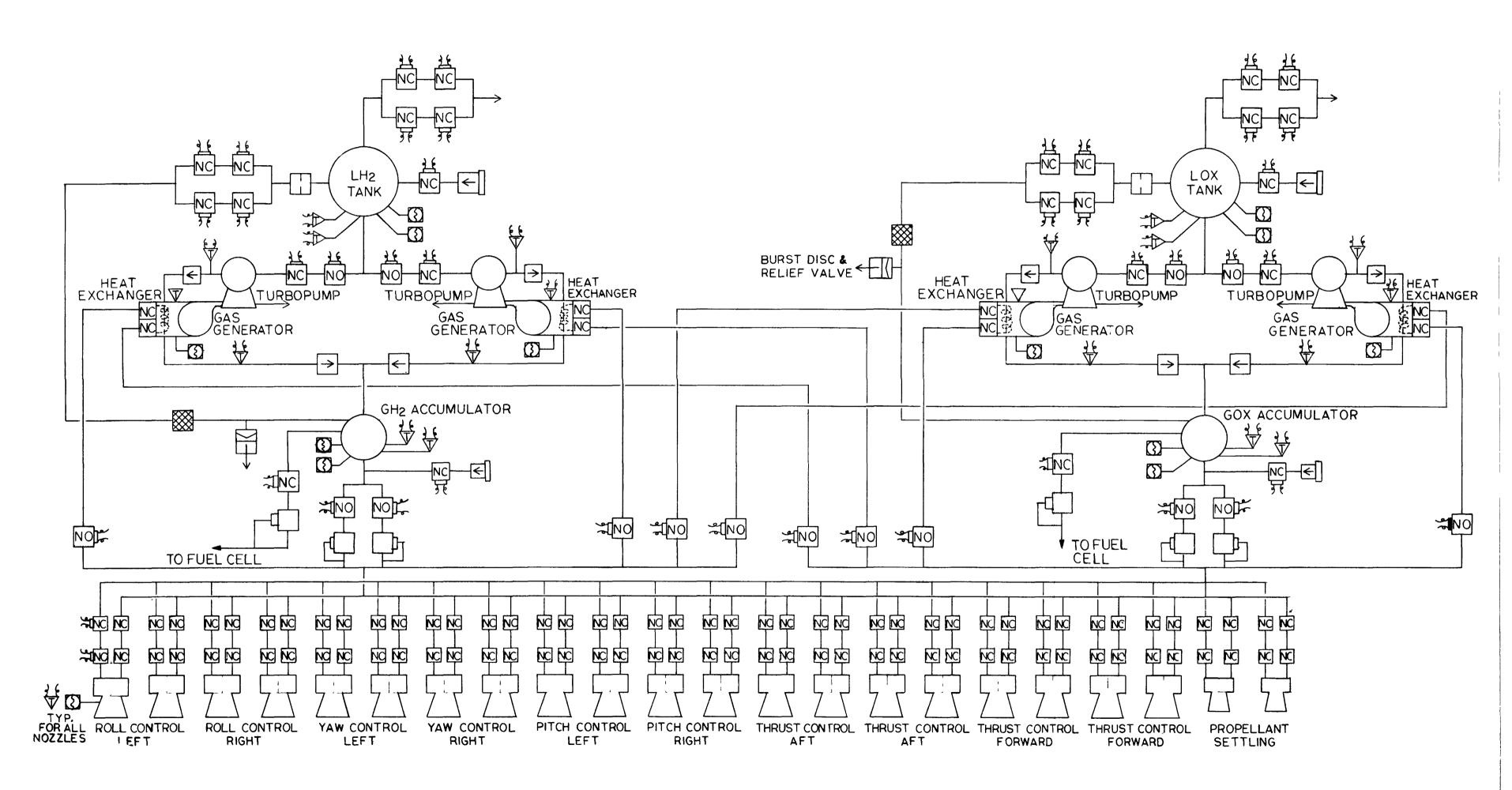


Figure 3.5-1. Auxiliary Propulsion System



antibackflow check valve, which prevents disturbances from being transmitted back to the pump, and flows through a heat exchanger which is an integral part on the gas generator. This heat exchanger provides the high-temperature gas required to be stored in the accumulator. The LO<sub>2</sub> and hydrogen systems each have a completely redundant propellant conditioning loop. The redundant loop is a standby loop. Any failure in the primary operational loop is detected by the inability of the accumulator in that loop to be able to be recharged to the required pressure. In the event of this type of failure, the active loop is then isolated by squib-operated isolation valves and the second or standby loop is activated.

The accumulators discharge through isolation valves and then pressure regulators to a central manifold that supplies the reactants at the proper pressure for all thrustor operations. The thrustor system and the fuel cells operate in a pressure-fed mode using the regulated gaseous propellant from the accumulator. When the accumulator pressure drops below a preset level, the conditioning system is turned on, gas generator ignitors actuated, and a recharge of the accumulator is initiated. Propellant is admitted to the gas generator providing the energy to start the turbopump and to warm the heat exchanger. When the pump and heat exchanger have reached operating condition, propellant is admitted to the conditioning system from the pressure storage tank. The conditioning system continues to operate until the predetermined upper pressure level is reached in the accumulator. The system has been sized for the total RNS impulse requirement 455,000 lb-sec utilizing an Isp of 365 sec and a mixture ratio of 4. To satisify this total impulse, 1,250 lb of propellant are required: 260 lb of hydrogen and 1,000 lb of oxygen. For the fuel cell requirement, 265 lb of propellant is provided (28 lb of hydrogen and 228 lb of oxygen). This brings the total requirement to 278 lb of hydrogen and 1,228 lb of oxygen.

The storage tanks were designed to a 30-psia pressure. The accumulators were sized to handle the 16,400 lb-sec impulse, sufficient for two of the largest attitude maneuvers in sequence. The propellant conditioning system is sized to operate on a continuous makeup basis.

#### 3.6 ASTRIONICS

A block diagram of the astrionics system is shown in Figure 3.6-1. Capability is provided for autonomous mission performance, including navigation, guidance, control, electrical power, and emergency fault detection. The system architecture is characterized by the use of a data bus for intermodule and intersubsystem communication. A data bus terminal dedicated to NDICE components on the propulsion module uses the stage data bus to communicate with the NDICE processor located forward in the command and control module.

Each subsystem function is controlled via signals sent through the data bus which are locally decoded. Data required for checkout and operation of the subsystem is accumulated through the normal RNS instrumentation channels and routed to the processor in encoded form to provide monitoring and control. For the operational RNS, a requirement for 732 channels of instrumentation (including NERVA) with a frequency response of 8,800 samples per second has been established. Development vehicles would use 1,152 channels and about a 5-fold increase in frequency response. Data to be sent to ground are routed through the command and control data bus terminal to the PCM encoder where addressing and framing is accomplished prior to PSK-modulated transmission on the 1.024 MHz telemetry subcarrier of an S-band channel like the 2,287.5-MHz carrier. In earth orbit the data are stored between ground stations and dumped at a minimum rate of 8.3 x 10<sup>3</sup> bits/sec based on 160 minutes per day viewing time. At lunar distances, the continuous minimum rate is 900 bits/sec.

The transponder responds to interrogations from the ground and utilizes the antenna components in the command and control subsystem. Uplink commands received from the ground are decoded and routed to central processor for action.

The emergency detection system (EDS) processor accepts hardline signals from each of the critical functions in the various modules and has the capability of independently providing controlling signals to correct situations

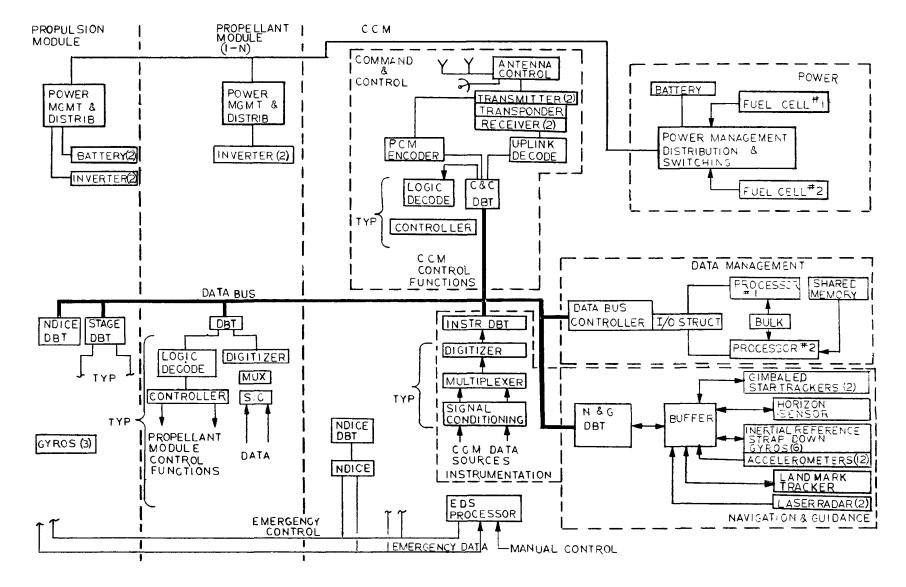


Figure 3.6-1 ASTRIONICS BLOCK DIAGRAM

without assistance of the central processor. The action taken is communicated to the central processor in the form of an alert. Control is effected by the EDS using direct action through the controllers in the various modules. Crew control can be exercised through the EDS for manned missions.

### 3.6.1 Navigation and Guidance

The autonomous baseline navigation and guidance subsystem for the RNS is shown in Figure 3.6-2. An unknown landmark tracker is used as the primary navigation sensor in conjunction with a strapdown IMU. This sensor and associated electronics are capable of landmark selection and tracking including correlation of intensity pattern and generation of scanning signals. The indication of landmark acquisition and gimbal angles at the time of acquisition can be stored in the optical buffer until the processor is ready for that information. The processor determines navigation parameters from this data.

A horizon sensor of the conical scanning type is used for coarse navigation, backup attitude control, and initial orbit determination after wakeup. Two

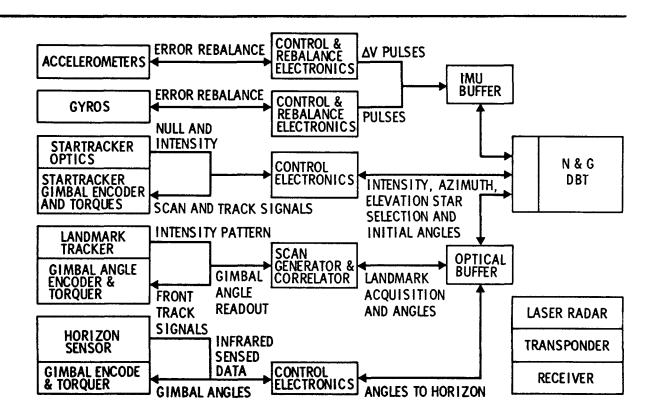


Figure 3.6-2 NAVIGATION AND GUIDANCE BLOCK DIAGRAM

rotating sensor heads are utilized. The entire sensor is mounted on gimbals permitting easier acquisition of the earth during a wakeup phase of operation. The times of crossings of the horizon sensor line of sight of the earth horizon are used to accomplish the estimate of the local vertical direction. This information can be read into the optical buffer where it is prepared for the data bus transfer to the RNS processor.

Accelerometers are used to update orbit parameters, determine the guidance commands, and for impulse management. Two ranges are provided to allow for measurements at both full thrust and during aftercooling. The accelerometers are rebalanced by electronics located on or adjacent to the sensor. The rebalance pulses are accumulated in an IMU buffer, which communicates with the central processor through the data bus.

Star trackers are used as the primary attitude sensor. Two star trackers are included as a part of the autonomous system. Each is mounted on a set of gimbals. The star tracking optics and detector provide an error signal to torque the gimbals. The intensity of the star being tracked is also measured. The gimbal angles and star signal intensity can be read by the optical input/output buffer, and stored until the processor is ready for the information. Search commands are generated in the processor and sent to the star tracker gimbals where the commands are reduced to gimbal angle signals for the star tracker gimbals. Ball-bearing gyros are used for short term attitude reference. The gyros are rebalanced by the electronics which are mounted on or near the gyro sensor. The gyro rebalance pulses are accumulated in the IMU buffer. The gyros (and accelerometers) are mounted in a redundant dodecahedron strapdown configuration.

A transponder and receiver are included to allow for ground tracking and ground commands, and dual scanning laser radar systems provide range, range rate and orientation data for active rendezvous and docking operations. A minimum stabilization and control capability is provided as part of the propulsion module to provide stable RNS orientation during assembly and CCM replacement. This consists of three gyros and the associated control package for the ambient gas APS.

# 3.6.2 Electrical Power

Redundant fuel cells supply 28-vdc primary power for the RNS. Two regulated capillary matrix type alkaline cells of 2-kw capacity each have been selected consistent with the space shuttle fuel cell to be developed. Secondary power is supplied by rechargeable Ag-Zn batteries. The ac power requirements are satisfied by the use of inverters.

The fuel cells, control, and rechargeable peaking batteries are located in the CCM. The reactant storage is shared with the cryogenic APS. The tap-off from the APS accumulators which stores gas at 1,000 psi and 300°R, will be regulated to about 100 psi and conditioned by the fuel cell to between 460 and 620°R. A battery is located on the propulsion module to regulate module power and satisfy peak module demands during engine operation. During refurbishment, when the CCM is not attached to the RNS, this battery supplies power to monitor, command, and control the RNS or the propulsion module.

A block diagram of the electrical power subsystem is shown in Figure 3.6-3.

## 3.6.3 Data Management

A centralized processor approach using a data bus concept and an autonomous engine control processor was selected for this subsystem. The RNS processor system architecture utilizes redundant processor in a 1 + 1 configuration. The failure of the primary processor allows for the switchover to the secondary processor without loss of mission objectives. The primary responsibility of the secondary processor is to remain in synchronization to allow for an efficient transfer of control. The processor and data bus configuration is shown in Figure 3.6-4. A shared section of memory is provided to insure switchover to the secondary computer. Bulk storage capability is also allowed for. The radiation environment is not constraining for the processors which will be located forward in the CCM.

The instrumentation subsystem provides the primary source of data for all mission operations and checkout. This accomplished by the use of local signal conditioning in each module and a group of 16-channel multiplexers with a digitizer associated with each multiplexer. Once digitized, the data

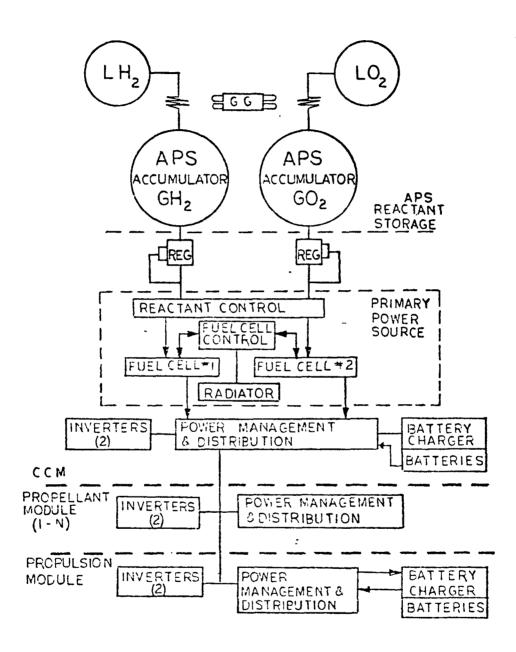


Figure 3.6-3 ELECTRIC POWER BLOCK DIAGRAM

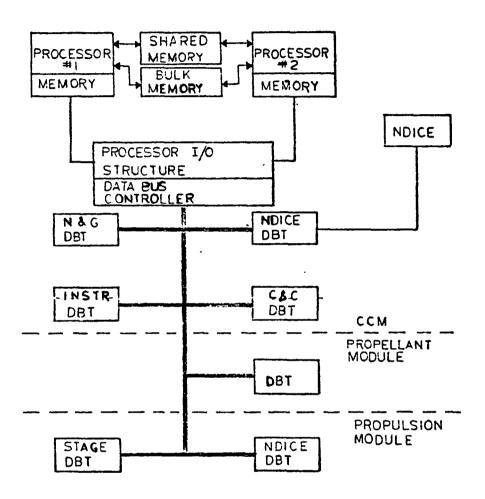


Figure 3.6-4 DATA MANAGEMENT BLOCK DIAGRAM

are put on the data bus for use by the central processor. The generation of commands throughout the vehicle is accomplished by encoded signals sent on the data bus and decoded locally in each module. The decode logic then drives a controller which acts as power amplifiers that have the capability of energizing the function to be controlled. Should it be required to hold a particular function, the controller will provide memory or latching and a second command will be required to unlatch the functions. This approach is standardized throughout the vehicle and localized to each module.

The limiting requirement for the RNS data management function appears to be the reliability of the processor and the ability to provide for an efficient switchover to a backup processor.

#### 3.6.3.1 Processor Requirements

Each processor has a reliability requirement of about 38,500 hours mean time before failure. This likely will require internal redundancy. The total peak processing requirements for the RNS are about 241,000 equivalent adds/sec exclusive of engine control. This corresponds to a 4-μsec add time.

The high-speed, random-access storage requirement is about 32,000 words which provides about 5,000 words of procedure in dynamic storage. The bulk storage requirement is 70,000 words; however, the sensitivity to this requirement is small as a magnetic tape or similar high capacity storage device is postulated.

The major requirements for the RNS processor are for data compression, navigation, guidance and control, and the overhead for the executive functions. The early estimates of the NERVA engine control processing requirements to meet present specifications are substantially above the current stage requirements.

#### 3.6.3.2 Data Bus

The selected data bus concept is fundamentally the time sharing of a single digital line to transmit data between modules and subsystems. Several data bus approaches are presently under development. A data bus concept

compatible with the space shuttle is required because of physical interconnection during assembly and maintenance operations. The present developmental efforts use from 1 to 3 lines and have transfer rates from 1 to 5 MHz with either Manchester or bipolar formats.

Any of the data bus implementations presently under development would satisfy the requirement of the RNS based on the requirement for the RNS developmental vehicle of  $0.5 \times 10^6$  bits per second. It is expected that the data bus concept selected for the leading programs such as the space shuttle will be used for the RNS. Eight data bus terminals are required. Although the data bus controller can be implemented in either hardware or software, the processing requirements for the RNS assumed software as the worst case.

#### 3.7 RADIATION ENVIRONMENT

The radiation environment was defined during engine operation and after shutdown. These results were applied for: (1) radiation effects on the materials, components, and subsystems in the RNS; (2) nuclear heating of the propellant; and (3) orbital maintenance operations.

The PATCH point kernel code described in Section 4.5.11 of Book 1 was used in the definition of the radiation levels exterior to the engine. Data on engine radiation sources during reactor operation were based on the May 1969 Common Radiation Analysis Model (Reference 1) as modified by Reference 2.

<sup>1.</sup> A.D. Wilcox, B.A. Lindsey and M.A. Capo (WANL), "NERVA-Flight-Engine Common Radiation—Analysis Model, "RN-TM-0583, Aerojet General Corporation (May 1969).

<sup>2. &</sup>quot;Final Report of Shield System Trade Study," S054-023, Volume I, Book 2, Aerojet Nuclear Systems Co. (July 1970).

The integrated gamma and fast neutron doses are shown in Figure 3.7-1 following 52 minutes of NERVA operation at 1,575 Mw. Figure 3.7-2 shows the time to accumulate a dose of 1 rem at 2 different times after final shutdown. A schematic representation of total irradiation over the full RNS lifetime is shown on Figure 3.7-3 for regions of interest in assessing equipment suitability. The levels cited are the maximum encountered in the region.

#### 3.8 RELIABILITY

The reliability analysis for this phase of the RNS project consisted of a failure mode effects analysis followed by a criticality analysis. The overall results produced a reliability prediction of 0.9576 for the Class I Hybrid compared with a 0.9750 reliability goal. Values are for the active portions of the mission which are the sum of (1) the time from the initiation of engine operation for translunar injection burn to the completion of cooldown in lunar orbit and (2) the time from the initiation of engine operation for the burn of the transearth transfer maneuver to the completion of cooldown in earth orbit. These predictions must be considered preliminary at this point in the

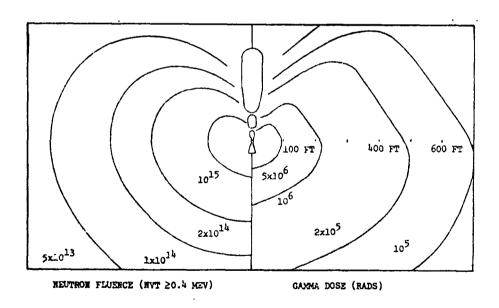


Figure 3.7-1 RADIATION ENVIRONMENT INTEGRATED OVER 52 MINUTES OF NERVA OPERATION AT 1575 MW

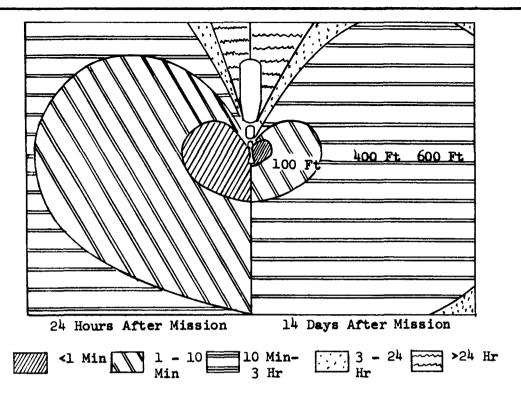


Figure 3.7-2 RADIATION ENVIRONMENT AFTER SHUTDOWN

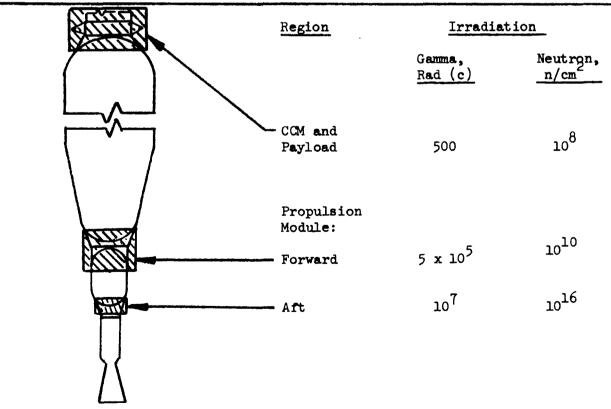


Figure 3.7-3 RADIATION EXPOSURE TO RNS EQUIPMENT (10 MISSIONS)

design cycle. The predictions are based on a single failure analysis, and some designs are not sufficiently detailed to do a detailed reliability analysis. Adequate failure rates are lacking for some components and some specific failure modes are questionable.

The reliability allocations for the Class 1 Hybrid modules, systems, and subsystems are shown in Table 3.8-1. The equivalent reliability predictions are given in Table 3.8-2. In several areas the reliability allocations were used as the prediction for structure, safety, and a prediction of 0.9950 was used for the NERVA. The NSF in the table indicates that there are no identifiable single failures in the corresponding subsystem.

The detailed reliability and safety analyses with the specific failure mode effects analysis worksheets and the specifics on the criticality analysis (prediction analysis) are given in Volume VI.

Table 3.8-1
RELIABILITY ALLOCATION

·	System	System Totals	ССМ	Propellant Module	Propulsion Module
2.0	Structure	0.9987	0.9998	0.9992	0.9997
3.0	Meteoroid	0.9975	0.9999	0.9978	0.9998
5.0	Main Propulsion	0.9893	-	0.9970	0.9923
	5.01 NERVA	0.9950	-	-	0.9950
	5.05 Propellant Feed	0.9981	-	0.9988	0.9993
	5.06 Pressurization	0.9979	_	0.9988	0.9991
	5.09 Fill	0.9991	_	0.9999	0.9992
	5.10 Ground Vent	0.9998	-	0.9998	-
	5.11 Flight Vent	0.9994	-	0.9997	0.9997
6.0	Auxiliary Propulsion	0.9970	0.9971	-	0.9999
7.0	Astrionics	0.9927	0.9934	0.9997	0.9996
	7.01 Guid, Nav, and Control	0.9990	0.9992	0.9999	0.9999
	7.04 Electrical Power	0.9967	0.9967	-	-
	7.05 Electrical Networks	0.9985	0.9990	0.9998	0.9997
	7.09 Data Management	0.9985	0.9985	-	-
8.0	Safety	0.9998	0.9999	0.99995	0.99995
	Totals	0.9750	0.9901	0.99365	0.99125

Table 3.8-2
RELIABILITY PREDICTION

	System	System Totals	CCM	Л	Prope Mod		Prop Mod	ulsion dule
2.0	Structure	0.9987	0.9998		0.9992		0.9997	
3.0	Meteoroid	0.9974	0.9999+		0.9975		0.9999	
5.0	Main Propulsion	0.9936			0.9999		0.9937	
	5.01 NERVA	0.9950						0.9950
	5.05 Propellant Feed	0.999998				0.999998		NSF
	5.06 Pressurization	NSF				NSF		NSF
	5.09 Fill	0.99871				0.999994		0.99872
	5.10 Ground Vent	0.99998				0.99998		
	5.11 Flight Vent	NSF				NSF		NSF
6.0	Auxiliary Propulsion	0.9721	0.9722				0.9999	
7.0	Astrionics	0.9955	0.9962		0.9997		0.9996	
	7.01 Guid, Nav, and Control	0.9990		0.9992		0.9999		0.9999
	7.04 Electrical Power	0.9995	(	0.9995				
	7.05 Electrical Networks	0.9985	ı	0.9990		0.9998		0.9997
	7.09 Data Management	0.9985	I	0.9985		otas eve		<b>-</b> -
8.0	Safety	0.9998	0.9999		0.99995		0.99995	
	Totals	0.9576	0.9682		0.9963		0.9927	
NSF	- No single failure.							



# Section 4 PROPULSION MODULE

This section contains a description of the propulsion module starting with a summary of the overall module configuration and concluding with a listing of the module hardware organized according to the system provided in the study guidelines.

#### 4.1 CONFIGURATION

The propulsion module consists of the NERVA plus a run tank together with subsystems to perform docking, module latching, propellant feed, flight vent, pressurization, orbital refueling, engine stage chilldown, and attitude control.

The module shown in Figure 4.1-1 is transported to earth orbit by the space shuttle. After it is deployed it utilizes its attitude control system for stabilization while being docked with the propellant module. Docking drogues (cones) and structural latches are incorporated in the forward skirt. Power for docking and latching is supplied by a low capacity Ag-Zn battery which is recharged by the fuel cells contained in the CCM.

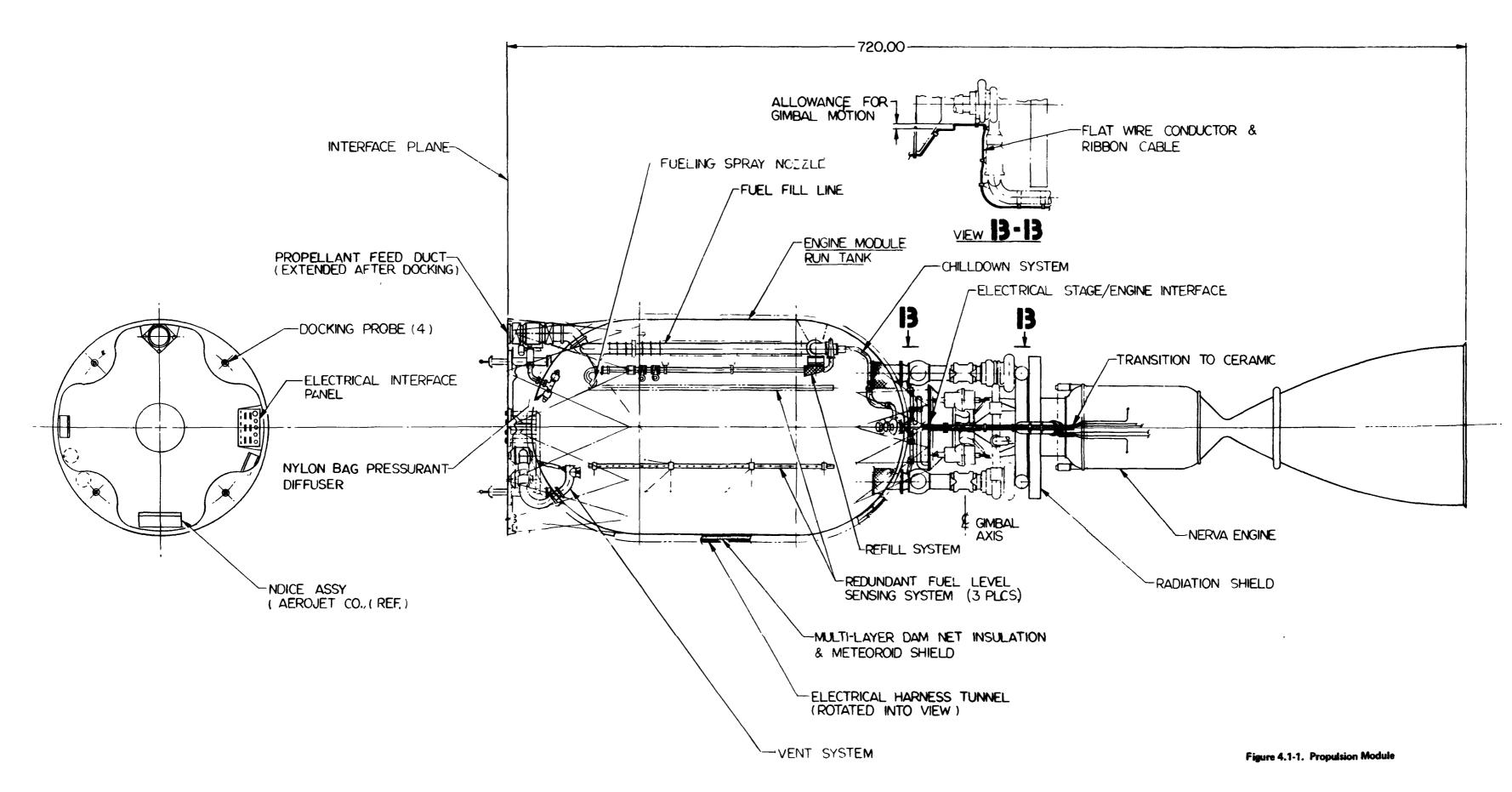
The tank diameter was defined by the radiation shield zone. The shadow shield zone half angle of 10 degrees was generated by extending a line from the aft outboard corner of the reactor through a point tangent to the aft dome of the main propellant tank. The tank sidewalls are integrally reinforced with an isotropic grid pattern to prevent bucking during engine operation. The domes are hemispherical with the feed line offset a maximum in order to obtain the longest tank while still penetrating the dome normal to its surface. Lugs are machined in the domes for attachment of the thrust structure and forward skirt fiber glass X-member strut assemblies.

Fiber glass was utilized to minimize heat flow into the propellant tank. Thermal protection of the tank is provided by three blankets of DAM/net insulation. Meteoroid protection is provided by a 2-in. layer of foam encased by a 0.010-in.-thick fiber glass shroud.

The main feed duct originates at the module interface and contains two gimbal joints and a pressure volume compensator, and has capability for linear deployment to accomplish automatic assembly. The 12-in. feed duct penetrates the forward dome, runs the entire length of the tank, and terminates with two 8-in. -diameter control valves. Propellant outlet is through two 10-in. -diameter ducts to which the NERVA PSOV valves are mounted. Inlet to these lines is through an antivortexing filtration screen. The flight vent system penetrates the tank in the ullage region and has its quad-redundant valving mounted to the forward skirt. The external pressurization line runs the full length of the tank and has a conventional quick-disconnect coupling at the aft end which mounts to customer connect panel at the NERVA interface. The forward end of the line penetrates the dome in the ullage region and terminates in a pressurant diffuser which utilizes a nylon bag to prevent pressurant impingement and ullage collapse.

A two-level flow control pressurization system is employed which contains separate sets of quad-redundant valves mounted to the forward skirt. The integrated engine/stage chilldown conditioning system is submerged in the aft dome region of the tank. It consists of two parallel motor driven pumps whose discharge is routed to both the NERVA interface and the RNS feed system. Two additional motor-driven centrifugal pumps are mounted in the tank bottom. They are utilized in conjunction with the orbital refueling system to enable refilling of the run tank from the propellant module. The details of all cross interface plumbing from the NERVA to the propulsion module are defined in Section 7 (NERVA interface).

The module contains a simplified gas attitude control system which is recharged by hydrogen gas from the NERVA engine. Tap-off is accomplished in the same manner as the expulsion pressurant gas. The system is basically a blowdown type system which permits high-pressure gas to be vented to any





of the attitude control nozzles. The system is armed by opening two parallel mounted solenoid valves on the storage tank discharge. A simple control system incorporating gyros and control logic is provided.

The astrionic equipment is effectively shielded from the radiation environment by the run tank. Signal conditioning, multiplexing, and digitizers for instrumentation; command decode and drivers and data bus terminals are physically mounted on this module. Flight readiness of the module is determined utilizing the capability of the onboard checkout system in the CCM via the data bus. Since the propulsion module is a space resident element, fault prediction sensors are included and replacement is on an unscheduled basis-only upon the occurrence of a failure. Additionally, the NERVA engine checkout will be performed by NDICE.

The data bus transfers instrumentation and command information in digital form between the CCM and the propulsion module. DC primary power is distributed and used in the module electromechanical functions. Local inverters are used for ac-motor-driven valves. EDS is used to gather information on critical parameters and distribute safing commands. Parallel wiring systems are employed with flat cable used for the majority of functions carried between the PVARA and the top of the run tank. Round ribbon cable is employed for functions in the engine area. An external tunnel is provided along the run tank.

#### 4.2 HARDWARE TREE

A description of the equipment contained in the propulsion module, including the specific design condition and the weight is contained in this subsection. The organization and numbering format is that given in the study guidelines.

# Propulsion Module Hardware Tree

	Description	Design Conditions/ Requirements	Weig <b>ht (</b> lb)
2. 00 Stru	cture		
2.01	Propellant Tank—2014-T6 Aluminum		570
•	Forward dome—hemispherical, monocoque construction, 0.029 in. thick by 160-in. diameter by 80 in. long, one-piece dome, forging	30 psia at end of burn	
•	• Aft dome—same as forward dome	30 psia at end of burn	
•	Cylinder—integrally stiffened 60-degree waffle, membrane thickness 0.051 in., rib height 0.561 in., rib length	Membrane— 30 psia at end of burn	
	10.13 in., rib thickness 0.035 in., 160-in. diameter by 116 in. long, 2 segments, each segment fabricates from 0.750 in. x 10 ft x 22 ft plate.	Stiffeners— engine opera- tion, gimbaled hard over (336 lb/in.)	
•	103 ft of welding including domes.		
2.02	Engine Thrust Structure—fiber glass, space truss truncated cone, aft diameter 60 in., forward diameter 45 in., length 45 in., 24 tubular struts fabricated into 12 X-member subassemblies, 3.75-in. diameter by 0.065 in. wall by 58.8-inlong	Engine operation, gimbaled hardover (12, 540 lb/strut), minimize heat short to tank	170

# Propulsion Module Hardware Tree (Continued)

	Description	Design Conditions/ Requirements	Weight (lb)
2.03	Forward Skirt—fiber glass, space truss truncated cone, forward diameter 174 in., aft diameter 160 in., length 70 in., same configuration and number of struts as engine thrust structure, 4.25-in. diameter by 0.065-in. wall by 81.3-inlong struts	Engine operation, gimbaled hardover (9,460 lb/strut), minimize heat short to tank	250
2.06	Exterior Finish and Sealer	Prevention of corrosion	20
2.07	Baffles	Propellant settling	60
	Antislosh—2 reqd., 120-in. and 150-in. diameter rings fabricated from 2.0-in. diameter by 0.049 in. wall 6061-T6 Al tubing, ring support struts 16 reqd per baffle, fabricated from 1.5-in. diameter by 0.035-in. wall 6061-T6 Al tubing, nylon cloth (0.375 lb/sq yd) membranes		
•	Geysering—1 reqd, octagon, 53 in. across flats, nylon cloth (0.375 lb/sq yd) membrane, nylon chord edge member and tension tie		
2.08	Equipment Support Structure—7075-T73 Al alloy sheet metal and machined brackets	Maximum acceleration and vibration	160
2.10	Additional Structure—provision for cutouts and doors		70

	Description	Design Conditions/ Requirements	Weight (lb)
3.00 The	rmal/Meteoroid Protection		
3.01	Insulation—Tank Area 960 ft <sup>2</sup> Blanket—Sidewall-96 layers 0.00015-in. double-aluminized mylar with dacron net spacers, 3 blankets of 32 layers each, 4 ft x 12.5 ft panels, total insulation thick- ness 1.0 in.	Tank heat input (90 btu/hr), pressure in space (10-4 torr),	430
•	Blanket—Forward and aft dome. Same as sidewall except pie-shaped panels		
•	Blanket Attachment—fiber glass straps 0.015 in. x 4 in. x 24 in., nylon tank attach studs 0.5-in. dia x 0.4 in. long		
•	Purge System—gas manifold system, mylar shroud	He atmos- phere prior to launch	
3.02	Meteoroid Protection	RNS P(0) = 0.9974	280
•	Flexible Foam Blanket—outside of insulation 2 in. thick, density 1.2 lb/ft <sup>3</sup> Shroud—outside of foam 0.010 fiber glass laminate, 4 ft	baseline lunar mis- sion away from earth (27 days)	
	x 12.5 ft panels		
4.00 Doc	king/Clustering		
4.01	Forward Docking Structure-cone assemblies, 4 reqd, 14 in. diameter x 45 degree cone, integrally stiffened, aluminum support struts and attach hardware, solenoid driven spring loaded latching assembly.	Longitudi- nal position ±5 in., lateral posi- tion ±5 in., angle pitch or roll	80

Propulsion Module Hardware Tree (Continued)

	Description	Design Conditions/ Requirements	Weight (lb)
		±3°, longi- tudinal velo- city ±0.1 ft/ sec, lateral velocity ±0.1 ft, pitch angular velo- city ±0.2 deg/ sec, roll angular velo- city ±0.02 deg/ sec, maxi- mum rela- tive impact velocity 0.2 ft/sec	
5.00 Mai	n Propulsion		
5.01	NERVA Engine (less 500 lb for NDICE in CCM)		<b>27,</b> 3 <b>0</b> 0
5.02	External Disk Shield for NERVA	10 rads with payload attenuation of 3	2,900
5.05	Propellant Feed System  8 in. diameter throttle valves—2 reqd, full flow analog visor type, motor—driven (120vac, 400 Hz), planetary gear trans—mission, metallic main gate seal, opening motion—linear seal, withdrawal—90-degree rotational	91.9 lb/sec LH <sub>2</sub> flow at 30 psia	140

	Description	Design Conditions/ Requirements	Weight (lb)
•	Feed Duct-12 in. diameter stainless steel ducting 0.035 in. x 54 in. long	30 psia opera- operating pressure	
•	12 in. nominal diameter pressure volume compensator	±1.00 in. extension	
•	12 in. nominal diameter gimbal joints—2 required	±8 degrees angulation	
•	12 in. nominal automatic coupling and deployment assembly including a deployment rack and motor	±1.00 in. extension	
•	Fuel Feed Line-12 in. diameter internal ducting 6061-T6 aluminum 0.035 in. x 276 in. long	Collapse pressure	
•	Bolted flange connection at run tank, 2 segment coupling at interface, dual static seal configuration both ends	Automatic leak check, maximum leakage 10 <sup>-5</sup> SCCM	
5.06 Pr	essurization System—Expulsion		60
•	1-1/4 in. diameter disconnect normally open	4 lb/sec GH <sub>2</sub> p = 850 psia T = 225°R	·
•	1/2 in. diameter 24 vdc direct acting solenoids, 8 reqd	0.6 lb/sec GH <sub>2</sub> p = 850 psia at T - 225°R	
•	1-1/4 in. diameter stainless steel ducting, 0.017 x 325 in. long	p = 850 psia	

	Description	Design Conditions/ Requirements	Weight (lb)
•	1-1/4 in. diameter metallic flexible braided hose sections	p = 850 psia	
•	Bolted flange connections at ends, with dual static seals and intermediate welded joints	Maximum leakage 10 <sup>-5</sup> SCCM	
5.09 Or	bit Refueling		
•	4 in. diameter spray bypass valve—4 reqd, planetary gear transmission, full flow visor type, metallic main gate seal, open motion—linear seal, withdrawal, 90 degree rotational, mechanical spring loaded, override—normally closed, motor driven (120vac, 400 Hz)	3,000 gpm p = 40 psia T = 40°R	60
•	4 in. diameter normally open disconnect		
•	4 in. diameter check valve flapper type (2 sections)		
•	4 in. diameter stainless steel ducting, 0.035 x 300 in. long	p = 45 psia	
•	4 in. nominal diameter gimbal joints	p = 45 psia	
•	Bolted flange connections with dual static seal ends and inter- mediate welded joints	Maximum leakage 10 <sup>-5</sup> SCCM	
5.11 Fl	ight Vent		50
•	2-1/2 in. diameter pilot operated quad blowdown valves—4 reqd	0.6 lb/sec GH <sub>2</sub> at 29 psia T = 40°R	

	Description	Design Conditions/ Requirements	Weight (lb)
•	2-1/2 in. diameter x 0.016 in. stainless steel ducting	p = 29 psia	
•	Bolted flange connections with dual static seal ends and intermediate welded joints	Maximum leakage 10- <sup>5</sup> SCCM	
5.12 In	tegrated Chilldown System		70
•	Centrifugal Pumps-motor driven (120 vac 400 Hz), submerged in run tank—2 required	2 lb/sec LH <sub>2</sub> at 3.5 psia	
•	2 in. diameter check valves—flapper type (split design)5 reqd	2 lb/sec LH <sub>2</sub>	
•	2 in. diameter shutoff valves—normally closed, pilot operated solenoid type—4 required	2 lb/sec LH <sub>2</sub>	
•	2 in. diameter x 0.035 in. stainless steel ducting		
•	2 in. diameter (nominal) gimbal joints		
•	Bolted flange connections with dual static seals at ends and intermediate welded joints		
5.13 R	efill System		. 50
•	Centrifugal pumps ac-motor driven (120 vac 400 Hz) submerged in run tank—2 reqd	5 lb/sec LH <sub>2</sub> at 3 psia	
•	3.25 in. diameter check valves—flapper type (split design)—2 reqd	5 lb/sec	

	Description	Design Conditions/ Requirements	Weight (lb)
•	3.25 in. diameter x 0.035 in. stainless steel ducting		
•	3.25 in. diameter (nominal) gimbal joints		
•	Bolted flange connections with dual static seals at flanges and intermediate welded joints	Maximum leakage 10 <sup>-5</sup> SCCM	
6.00 Auxili	ary Propulsion		
6.01 R	eaction Control System	Module stabilization during assembly and maintenance	160
•	Gaseous hydrogen storage sphere, 25 in. diameter, titanium, 2 reqd	p = 1,200 psia	
•	1/2 in. solenoid valves direct acting—2 reqd		
•	1/4 in. fill disconnect		
•	1/2 in. relief valve		
•	1/4 in. nozzle control solenoids directing acting—24 reqd		
•	Tubing—welded joints		
7.00 Astrio	nics		
7.01 Na	avigation Guidance and Control		20
•	3 gyros and electronic package to generate ambient gas APS commands as required	Maintain stable attitude during assembly and maintenance.	

Description	Design Conditions/ Requirements	Weight (lb)
	- Kequii ements	Weight (Ib)
	Drift rate ≤0.5 degree/ hr	
Optical corner cubes	Cooperative target for docking operations	
7.02 Instrumentation (exclusive of engine)		15
• 18 transducers for sensing	80% of analog channels	
<ul> <li>10 channels of signal conditioning</li> </ul>	60% of analog channels	
<ul> <li>2 analog multiplexers—MSI,</li> <li>16 channel</li> </ul>		
• 2 analog to digital converters 10 bit resolution	1 part in 1,024 resolution, 0.1% accuracy, 1 per multi- plexer for encoding analog data	
7.03 Command and Control		10
• Logic decoder	Accept serial input instructions from data bus terminal	
Controllers with memory as required	Accept decoded signals and drive con- trollable functions— up to 10 amps (those with	

Description	Design Conditions/ Requirements	Weight (lb)
	memory turned off by separate command)	
7.04 Electric Power		130
<ul> <li>2 Ag-Zn batteries with</li> <li>1.7-kwh capacity each</li> </ul>	Supply peak- ing power, discharge to 50% or less,	
<ul> <li>Power management, cabling and distribution package</li> </ul>	Power distri- bution, switch- ing and battery recharge management	
• Power distribution	Round con- ductor wir- ing, all Polyimide insulation, copper conductors	
• 2 inverters frequency—400 Hz voltage—120 vrms	Redundant powe to drive 2 chilldown pumps and 2 refill pumps	r
7.05 Electrical Networks		150
<ul> <li>Emergency detection, data bus, manual control, and engine function cabling between station 0 and top of run tank</li> </ul>	Flat conductor cables, all polyimide insulation, copper conductors	

Description	Conditions/ Requirements	Weight (lb
• Connectorless terminations for engine-stage interface	3,000 lines, increased reliability by eliminating socket/pin connections	
<ul> <li>Module interface connectors and blind mating panel</li> </ul>	Motor driven	
7.06 Environmental Control		
<ul> <li>Controlled emmissivity coatings and internal electrical heaters as required by each subsystem</li> </ul>	Included in each subsystem	
7.07 Propellant Management		10
<ul> <li>3 redundant probes with discrete point level sensors</li> </ul>		
7.08 Onboard Checkout		5
• Sensors for EDS	EDS moni- toring of critical functions	
7.09 Data Management		5
• 2 data bus terminals	NDICE, stage	

# Section 5 PROPELLANT MODULE

The section contains a description of the propellant module starting with a summary of the overall module configuration and concluding with a listing of the module hardware organized according to the system provided in the study guidelines.

#### 5.1 CONFIGURATION

The propellant module provides propellant storage during the mission. Other functions are minimal resulting in a simple module which is passive and responsive to external control. It contains subsystems to perform docking, module latching, propellant feed, ground vent and relief, ground fill, flight vent, pressurization, and orbital refuelling.

The module shown in Figure 5.1-1 is boosted to orbit by the Saturn INT-21 launch vehicle. The baseline probe/drogue system is employed for docking with the probes mounted to the orbital interstage (aft) and drogues (cones) mounted to the payload adapter. This system has the capability of soft docking with the last few inches of drawup accomplished by the probe. The propellant module is passive during rendezvous and contains optical corner cubes to cooperate in the alignment and ranging.

The propellant tank is composed of a hemispherical forward dome, an integrally stiffened cylindrical section, and a 10-degree half-angle conical aft dome. The configuration of the aft dome was a result of a combined structural and radiation shielding optimization. The sidewall is reinforced with an isotropic (60 degree) grid pattern to prevent buckling of the unpressurized tank when it is stacked on the launch pad. The Y-rings are provided at each end of the tank cylindrical section, at the transition between the aft dome cone and spherical cap, and in the forward dome for attachment of the

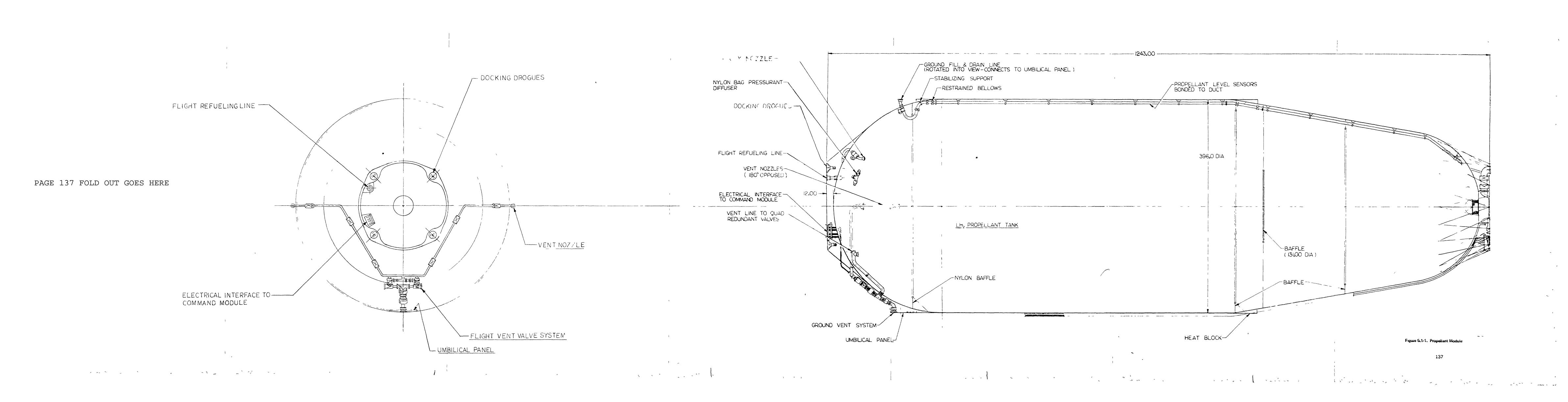
heat blocks, intermodular thrust structure, and payload adapter. A sump is incorporated in the design to minimize residuals.

The heat blocks are of fiber glass honey comb sandwich construction. They transmit the applied loads imposed by the various design conditions (i. e., maximum acceleration,  $\max \alpha$ -q, etc.). In addition they minimize heat flow into the propellant tank compared to the heat flow through the insulation blanket (i. e., thermal conductance <1 BTU/hr/°F). The intermodular thrust structure must also keep heat flow into the tank low. Since the component is protected from the atmospheric environment during boost by the earth launch interstage which is jettisoned when the stage reaches orbit, an open-type truss structure is employed. It consists of tubular fiber glass struts fabricated into X-member subassemblies with metal end fittings containing self-aligning bearings.

The launch interstage is an integrally stiffened aluminum structure with circumferential rings. Integrally machined lips are provided for segment joining. A controlled detonating fuse (CDF) circumferential joint similar to the design employed on the Saturn S-IVB is provided to sever the tension strap attaching the launch interstage to the aft heat block.

The payload adapter, a truncated cone of fiberglass honeycomb sandwich construction, provides the required thermal insulation to the tank. It incorporates support provisions for four docking cones for Command and Control Module (CCM) mating.

The thermal/meteoroid protection subsystem is designed as an entity becaus of the mutual interactions between the two functions. It consists of three blankets of HPI which are held in contact with the sidewall of the LH<sub>2</sub> tank by a layer of compressed flexible foam. The foam is restrained by a tensioned fiber glass skin. Airloads during boost are transferred to the tank sidewall via the skin, foam, and HPI. The fiber glass and foam protect the HPI from damage by aero forces and heating. The foam contracts or expands with changes in tank radius. It must accommodate a sidewall length change of -2.7 in. and a change of radius of -0.8 in, when the unpressurized tank is cooled to LH<sub>2</sub> temperature.





Two 12-in. -diameter motor-driven tank isolation feed valves are mounted to the sump. Inlet to the valves is through an antivortexing, filtration screen. Outlet is through the sump to a 12-in. -diameter feed duct which contains two gimbal joints and the baseline remote coupling mechanism. Orbital refueling is accomplished by a 4-in. -diameter duct that is hard mounted to the payload adapter interface and runs into the tank ullage space. This duct contains flexible elements for thermal and operational deflections and terminates in a spray nozzle that prevents pressurant surges. This duct also has the automatic coupling mechanism at its forward end. Both the ground vent and relief, which is utilized during ground fill, and the quad-redundant flight vent systems are located in the ullage region of the tank. The systems are integrated and require a single tank penetration only. The external pressurization line runs the full length of the tank and has a conventional quickdisconnect coupling at the aft end which mounts to the electrical connector deployment panel. The forward end of the line penetrates the dome in the ullage region and terminates in a pressurant diffuser which utilizes a nylon bag to prevent pressurant impingement and ullage collapse. The ground fill and drain line originates at the umbilical panel which is attached to the forward heat block. This 4-in. -diameter line which contains a shutoff valve and gimbal joints runs the entire length of the tank terminating at the tank bottom. Support for the line is provided by sliding type vibration mounts. Drainage of the tank is accomplished through pressurization.

Flight readiness of the module is determined utilizing the capability of the onboard checkout system in the CCM. Since the module is a space resident element, fault prediction sensors are included. The module is replaced on an unscheduled maintenance basis only upon the occurrence of a failure, however, standby redundancy is provided to allow mission initiation with specific components inoperative. Data bus terminals are provided fore and aft in this module. The data bus transfers instrumentation and command information in digital form between the CCM and the propellant module. DC primary power is distributed to the propellant module with local inverters employed for ac motor-driven valves. The EDS is used to gather information on critical parameters and distribute safing commands from the CCM.

#### 5.2 HARDWARE TREE

This subsection contains a description of the equipment contained within the propellant module together with the corresponding design condition and weight.

### Propellant Module Hardware Tree

Description	Design Conditions/ Requirements Weight (lb
2. 00 Structure	
2.01 Propellant Tank-2014-T6 alumin	num 17,150
<ul> <li>Forward dome-hemispherical monocoque construction,</li> <li>0.061 in. thick by 396 in. dialogous by 198 in. high, 12 ft x 21.5 sheet, 12 gores, 2 Y-rings,</li> <li>0.250 in. thick by 28 in. long 5 in. x 2.5 ft x 36 ft forging,</li> <li>3 sections</li> </ul>	of burn ft
<ul> <li>Aft dome-10° cone, monocoq construction</li> </ul>	ue 29 psia at end of burn
<ul> <li>Shoulder-0.070 in. thick by 23 in. long, 4.5 in.</li> <li>x 2 ft x 36 ft forging,</li> <li>3 sections</li> </ul>	
• Cone-0.118 in. thick by 326 in. long, 17.5 ft x 30 ft sheet, 6 segments	
<ul> <li>Y-ring-0.250 in. thick b</li> <li>48 in. long, 8 in. x . 45</li> <li>x 24.5 ft forging, 3 sect</li> </ul>	ft
<ul> <li>Spherical cap-0.045 in. thick by 245 in. dia by 67 in. high, 12.5 ft x 16.5 ft sheet, 4 gores</li> </ul>	

	Description	Design Conditions/ Requirements	Weight (lb)
•	Cylinder—integrally stiffened, 60° waffle, membrane thickness 0.117 in., rib height 1.120 in., rib length 35.0 in., rib thickness 0.060 in., 396 in. dia by 548 in.long, 6 segments, each segment fabricated from 1.5 in. x 17.5 ft x 48 ft plate.	Membrane— End of burn (29 psi)  Stiffeners— Prelaunch (335 lb/in.)	
•	1,450 ft of welding		
2. 02	Intermodular Thrust Structure—fiber glass, space truss truncated cone, aft dia 174 in., fwd dia 246 in. length 87 in., 48 tapered tubular struts fabricated into 24 X-member subassemblies, 5.0 in. dia by 0.045 in. wall by 100 in. long struts	Engine operation, gimbaled hardover (6,300 lb/strut), minimize heat short to tank	470
2.03	Forward Heat Block-396 in. dia by 36 in. long, one ring comprised of 3 ft x 20 ft panels, the panels employ sandwich construction with 0.030 in. fiber glass face sheets and core 2.0 in. thick.	Max α-q (1,100 lb/in.), minimize heat short to tank	620
2.04	Aft Heat Block-Same as forward heat block except 0.035 in. thick face sheets	Max α-q (2,125 lb/in.), minimize heat short to tank	720
2. 05	Tunnel and Fairings— Semi-monocoque construction (rib stiffened) - 7075-T73 aluminum alloy	Burst and crushing pres-sure during launch	490
2.06	Exterior Finish and Sealer	Prevention of corrosion	210

	Description	Design Conditions / Requirements	Weight (lb)
2. 07	Baffles	Propellant settling	360
•	Antislosh—3 reqd, 342 in., 356 in. and 300 in. dia rings fabricated from 3 in. dia by 0.065 in. wall 6061-T6 aluminum tubing, ring support struts - 32 required per baffle, fabricated from 2 in. dia by 0.049 in. wall 6061-T6 aluminum tubing, nylon cloth (0.375 lb/sq yd) membranes		
•	Geysering-1 reqd, octagon, 132 in. across flats, nylon cloth (0.375 lb/sq yd) membranes, nylon cord edge member and tension tie		
2. 08	Equipment Support Structure—7075-T73 Al alloy sheet metal and machined brackets	Maximum accelera- tion and vibration	230
2.10	Additional Structure		
•	Payload Adapter-fiberglass truncated cone, forward dia 165 in., aft dia 305 in., length 80 in., one trucated ring comprised of four 6.7 ft x 20 ft panels. Same material and construction as heat blocks except 0.020 in. thick face sheets and 0.686 in. thick core.	Engine operation, gimbaled hardover (240 lb/in.), minimize heat short to tank	640
•	Access— Provision for cutouts and doors.		220

	Description	Design Conditions/ Requirements	Weight (lb)
2.11	Launch Interstage— 7075-T53 Al alloy, 396 in. dia by 440 in. long, integrally stiffened, 0.050 in. skin, J-section stiffeners 1.75 x 0.125 x 0.75 x 0.375 in., I-section frames 6.0 x 0.70 x 2.0 x 0.14 in., 6 segments, each segment fabricated from 2.0 in. x 17.5 ft x 38 ft plate	Max α-q (2,540 lb/in)	8,790
3.00 Thern	nal/Meteoroid Protection		
3.01 Ir	Blanket—Sidewall - 51 layers 0.00015 in. double aluminized Mylar with dacron net spacers, 3 blankets of 17 layers each 4 ft x 18.5 ft panels  Blanket—Aft Dome, same as sidewall except 4 ft x 14.5 ft panels  Blanket—Forward Dome, same as sidewall except pie-shaped panels  Blanket Attachment—fiber glass straps 0.015 in. x 4 in. x 24 in., nylon tank attach studs 0.5 in. dia x 0.4 in. long  Purge System—gas manifold system, mylar shroud	Tank heat input (1500 Btu/hr) pressure in space (10-4 torr), inert gas atmos- phere, no cryo-pumping (prelaunch)	2,470

	Description	Design Conditions/ Requirements	Weight (lb)
3.02 Meteo	roid Protection  Flexible Foam Blanket— outside of insulation 2 in. thick, density 1.2 lb/ft <sup>3</sup> , compressed to 1.2 in. on installation  Shroud—outside of foam 0.020 in. fiber glass laminate, 4 ft x 18.5 ft panels, tensioned to 0.80 in. compression of foam	RNS P(0) = 0.9974, baseline lunar mission away from earth (27 days)	3,780
4.00 Dockin	ng/Clustering		
4. 01	Forward Docking Structure— cone assemblies, 4 reqd, 14 in. dia. x 45 deg cone, integrally stiffened, aluminum support struts and attach hardware, solenoid driven spring loaded latching assy.  Aft Docking Structure— probe assemblies, 4 reqd, 5 in. dia. x 23 in. long, aluminum support struts and attach hardware	Longitudinal position ±5 in., lateral position ±5 in., angle pitch or roll ±3 deg, longitudinal velocity ±0. l ft/sec, lateral velocity ±0. l ft, pitch angular velocity ±0. 2 deg/sec, roll angular velocity ±0. 02 deg/sec, maximum relative impact velocity 0. 2 ft/sec	200
5.00 Prope	llant Module Description		
5.05 P	Fropellant Feed System  8 in. dia throttle valves—2 reqd  Full flow binary visor type, metallic main gate seal, opening motion—linear seal, withdrawal,	91.9 lb/sec LH <sub>2</sub> 30 psia	110

Description	Design Conditions/ Requirements	Weight (lb)
90 deg rotational induction motor-driven (120 vac, 400 Hz), planetary gear transmission		
<ul> <li>Feed Duct-12 in. dia ducting stainless steel 0.035 in. x</li> <li>54 in. long-</li> </ul>	30 psia oper- ating pressure	
<ul> <li>12 in. nominal dia gimbal joints with coupling segments (2 reqd) and a motor and drive screws</li> </ul>	±8 degrees angulation	
<ul> <li>Bolted flange connection at tank,</li> <li>2 segment coupling at interface,</li> <li>dual static seal configuration</li> <li>both ends</li> </ul>	Maximum leakage 10 <sup>-5</sup> SCCM	
5.06 Pressurization System-Expulsion		70
• 1-1/4 in. dia pilot operated solenoid valve, 4 required 24 vdc, planetary gear transmission, open motion—linear seal, withdrawl, 90 deg rotational, mechanical spring loaded, override—normally closed	4 lb/sec GH <sub>2</sub> p = 850 psia T = 225°R	
• 4 in. dia disconnect, normally open		
<ul> <li>4 in. dia check valve, 2 sectioned flapper type</li> </ul>		
• 4 in. dia x 0.035 in. stainless steel ducting	p = 45 psia	
• 4 in. nominal dia gimbal joints	p = 45 psia	

	Description	Design Conditions/ Requirements	Weight (lb)
•	Bolted flange connections with dual static seal ends and welded intermediate joints	Maximum leakage 10 <sup>-5</sup> SCCM	
•	4 in. normally closed butterfly valve pneumatically controlled	30 psia 3,000 gpm 40°R	
•	1/4 in3 way direct acting solenoid valve	475 psig	
•	1/4 in. quick disconnect coupling normally closed	475 psig	
•	1/2 in. dia direct acting solenoid valve, 24 vdc	0.6 lb/sec p = 30 psia T = 225°R	
•	1/2 in. dia quick disconnect normally closed	0.6 lb/sec p = 850 psia T = 225°R	
•	1-1/4 in. dia disconnect, normally open	4 lb/sec GH <sub>2</sub> p = 850 psia T = 225°R	
•	1/2 in. dia 24 vdc direct acting solenoids valves, 8 required	0.6 lb/sec GH <sub>2</sub> p = 850 psia at T = 225°R	
•	1-1/4 in. dia x 0.017 in. stainless steel ducting	p = 850 psia	
•	1-1/4 in. dia metallic flexible braided hose sections	p = 850 psia	
•	Bolted flange connections with dual static seals at ends and welded intermediate joints	Maximum leakage 10 <sup>-5</sup> SCCM	

Description	Design Conditions/ Requirements	Weight (lb)
rbit Refueling/Fill and Drain		120
4 in. dia spray bypass valve— 4 required, full flow binary visor type, metallic main gate seal, motor driven (120 vac, 400 Hz)	3,000 gpm p = 40 psia T = 40°R	
Ground Fill and Drain—4 in. dia x 0.016 x 1200 in. aluminum ducting—internally mounted		
Orbital Fill-4 in. dia x 0.035 in. stainless steel ducting with dual static seals at end flanges	Maximum leakage 10 <sup>-5</sup> SCCM	
Untied bellow sections		
1/4 in. welded tubing		
round and Emergency Vent		160
6 in. normally closed poppet disconnect		
4 in. (poppet balanced) relief valve	2 lb/sec GH <sub>2</sub> at at psia	
6 in. vent and relief valve (pneumatically actuated)	11 lb/sec GH <sub>2</sub> at 29 psia	
1/4 in. 3-way direct acting solenoid valve	, para	
	rbit Refueling/Fill and Drain  4 in. dia spray bypass valve— 4 required, full flow binary visor type, metallic main gate seal, motor driven (120 vac, 400 Hz)  Ground Fill and Drain— 4 in. dia x 0.016 x 1200 in. aluminum ducting—internally mounted  Orbital Fill—4 in. dia x 0.035 in. stainless steel ducting with dual static seals at end flanges  Untied bellow sections  1/4 in. welded tubing round and Emergency Vent  6 in. normally closed poppet disconnect  4 in. (poppet balanced) relief valve  6 in. vent and relief valve (pneumatically actuated)  1/4 in. 3-way direct acting	Description  Conditions/Requirements  rbit Refueling/Fill and Drain  4 in. dia spray bypass valve— 4 required, full flow binary visor type, metallic main gate seal, motor driven (120 vac, 400 Hz)  Ground Fill and Drain— 4 in. dia x 0.016 x 1200 in. aluminum ducting—internally mounted  Orbital Fill—4 in. dia x 0.035 in. stainless steel ducting with dual static seals at end flanges  Untied bellow sections  1/4 in. welded tubing  round and Emergency Vent  6 in. normally closed poppet disconnect  4 in. (poppet balanced) relief valve  6 in. vent and relief valve (pneumatically actuated)  1/4 in. 3-way direct acting

	Description	Design Conditions/ Requirements	Weight (1b)
	/4 in. quick disconnect coupling, normally closed		
s	o in. dia x 0.035 in. stainless steel ducting with dual static seals at bolted flange connections	Maximum leakage 10-5 SCCM	
• ≀	Untied metal bellows sections		
	o in. and 4 in. dia tubing with welded intermediate joints		
• 1	/4 in. tubing all welded		
5.11 Flig	ght Vent		60
Ç	2-1/2 in. dia pilot operated quad blowdown valves—4 required	0.6 lb/sec GH <sub>2</sub> at 29 psia T = 40°R	
s c a	2-1/2 in. dia x 0.016 in. stainless steel ducting with dual static seals bolted flange and connections and welded intermediate joints	p = 29 psia Maximum leakage 10-5 SCCM	
7.00 Astrioni	cs Systems/Astrionics		
7.01 Gui	dance, Navigation and Control		
• (	Optical corner cubes	Cooperative target for docking operations	
7.02 Inst	rumentation		35
• 2	22 transducers for sensing	80% of analog channels	

Description	Design Conditions/ Requirements	Weight (lb)
• 17 signal conditioning circuits	60% of analog channels	
<ul> <li>2 analog multiplexers—MSI,</li> <li>16 channel</li> </ul>		
<ul> <li>2 analog to digital converters,</li> <li>10 bit resolution</li> </ul>	1 part in 1024 resolution, 0.1% accuracy, 1 per multi- plexer	
7.03 Command and Control		10
• Logic decoder	Accept serial input instructions from data bus terminal	
Controllers with memory     as required	Accept decoded signals and drive control-lable functions—up to 10 amps (those with memory—turned off by separate command)	
7.04 Electrical Power		40
<ul> <li>Power management distribution assembly and cabling</li> </ul>	Power distribution and switching	
Power distribution	Round copper conductor wiring—Kapton insulation	

Description	Design Conditions/ Requirements	Weight (lb)
• 2 inverters Frequency-400 Hz Voltage-120 v RMS	Redundant power for ac valve actuation	
7.05 Electrical Networks		160
<ul> <li>Emergency detection, data bus, manual control, and engine function cabling</li> </ul>	Flat conductor cable, poly-imide or kapton insulation, copper conductors	
7.06 Environmental Control	<b>.</b>	
<ul> <li>Controlled emmissivity coatings and internal electrical heaters as required by each subsystem</li> </ul>	Included in each sub-system	
7.07 Propellant Management		
<ul> <li>Point level sensors mounted on ground fill line</li> </ul>		
7.08 Onboard Checkout		5
Sensors for emergency detection	EDS monitoring of critical functions	
7.09 Data Management		5
• 2 data bus terminals	Forward and aft	
Total (including 1,480 lb contingency) Less jettison of interstage Total operational weight		38, 655 -8, 790 29, 865

# Section 6 COMMAND AND CONTROL MODULE

This section contains a description of the command and control module (CCM) starting with a summary of the overall module configuration and concluding with a listing of the module hardware organized according to the system provided in the study guidelines.

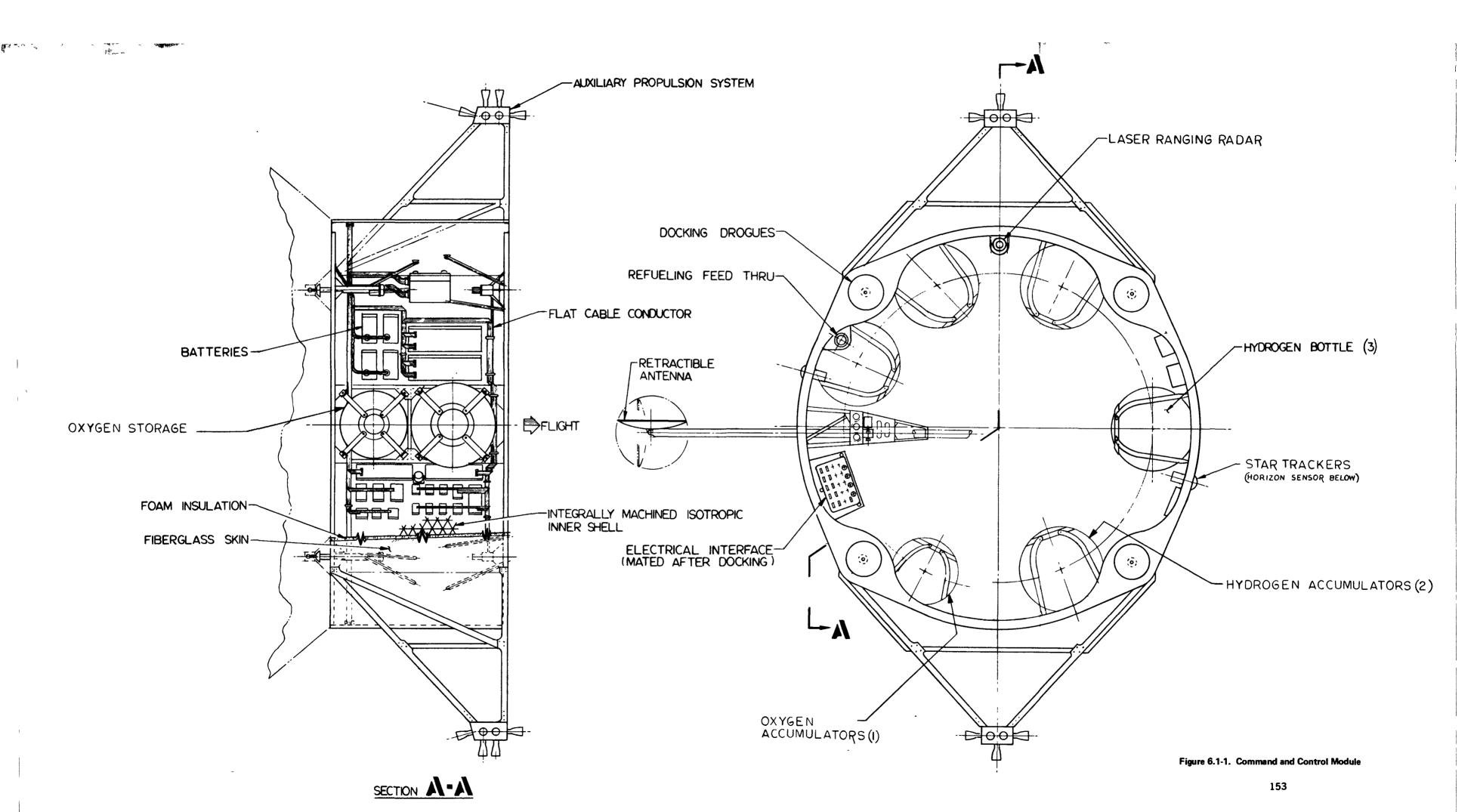
#### 6. 1 CONFIGURATION

The CCM is located at the forward end of the RNS. It contains the entire navigation and control function including the sensors and processing capability required to implement autonomous navigation. Primary power source is also included in the CCM as well as the cryogenic auxiliary propulsion system. The major components of the NERVA Digital Instrumentation and Control Electronics (NDICE) are physically contained in the CCM. Communication to the RNS is via a data bus.

The current RNS operating plan calls for return of the CCM to earth for maintenance and refurbishment subsequent to completion of every mission. The objectives of this plan are: (1) replenishment of consumables, (2) verification of functionality, (3) verification of redundancies, (4) calibration and adjustment of components, and (5) replacement of limited-life hardware. This provides effective maintenance since over 90 percent of potential RNS failures are located on this module. Space shuttle transportation, which provides a protective environment during boost and entry, will be used for recycling. The CCM will include all hardware required to accomplish orbital onboard checkout including recalibration, aided by ground support equipment, prior to each mission phase.

The CCM, shown in Figure 6.1-1, consists of a cylindrical section employing isotropic integrally stiffened skin and a set of outriggers. The CCM is 13.8 ft in diameter, 6 ft in length, and weights 5,975 lb when fully fueled with expendables. The construction of the integrally machined isogrid structure permits ease of component mounting, since mounting holes at the grid intersections are part of the structure. An integral shroud concept is utilized for meteoroid protection. It consists of a thin layer of rigid foam and a fiber glass shell. Outriggers support the APS nozzles, canted 15 degrees so that the heating from the exhausts of the aft nozzles does not exceed the material limits in the forward dome area. The baseline probe/drogue system is utilized for docking. In order to enable refueling of the main propellant tank in orbit with the CCM in place, a feedthrough refueling duct is provided internally to the CCM. This 4-in.-diameter duct contains a compensator and two gimbal joints in addition to the automatic deployment and coupling mechanism.

Autonomous navigation of the RNS uses a strap down inertial measuring unit which includes accelerometers, an unknown landmark tracker, and a horizon sensor. The horizon sensor also serves as a backup for the primary attitude reference, consisting of two startrackers. All sensors are located within the CCM in close proximity to each other to establish close coordination and correlation of data acquired. Provision for receiving ground transmission of uplink data will be made as a backup to the nominal autonomous navigation scheme. Storage of the propellants for the cryogenic auxiliary propulsion system (LO2/LH2) and the primary power fuel cell system are integrated, using common storage containers. The propellant tankage and conditioning equipment is located circumferentially within the CCM. This equipment consists of: (1) hydrogen and LO2 storage spheres, (2) turbopumps, (3) gas generators, (4) high-pressure accumulators, and (5) propellant control valving. Fluid ducting is run from storage accumulators circumferentially to the APS motors located on outriggers 180 degrees apart. Eleven APS motors are mounted on each outrigger. These motors include ten 50-lb-thrust motors, two in each orthogonal plane, and one aft-facing 1. 6-lb-thrust motor for propellant settling. Deflectors between adjacent motors are provided to protect against burnthrough.





Fuel cell reactants are tapped off of the high-pressure APS accumulators. After conditioning, these reactants are supplied to redundant fuel cells. The fuel cells proposed are of the type currently under development for the Space Shuttle and Space Station programs. These cells, generating 2 kw, will be the primary source of vehicle power. Two rechargeable, low weight, AgZn batteries will be provided to supply peaking emergency power.

Redundant processors, capable of satisfying all stage and engine processing requirements, are connected to a central high-speed memory to form the RNS processing complex. A bulk storage, auxiliary memory unit holds all operational and checkout procedures and data for fully autonomous functional and checkout operation of the RNS. Communications between these processors and other module subsystems are carried on the data bus under supervision of the data bus controller. The maximum traffic rate anticipated for a development vehicle is about  $0.5 \times 10^6$  bits per second. This maximum load is derived primarily from transmission of data from the modules to the data bus controller before the compression operation. An independent, hardwired emergency detection system providing emergency commands as well as payload display and manual override is provided.

Telemetry and uplink communications are carried out by redundant transmitters and receivers compatible with current space communications networks.

#### 6.2 HARDWARE TREE

This subsection contains a description of the equipment contained in the command and control module together with the corresponding design conditions and weight.

# Command and Control Module Hardware Tree

	Description	Design Conditions/ Requirements	Weight (lb)
2.00 Str	acture		
2. 08	Equipment Support Structure—7075-T73 Al alloy sheet metal and machined brackets	Maximum acceleration and vibra- tion	360
2. 09	Equipment Module Structure		360
	Center Section-7075-T73 Al alloy plate, integrally stiffened, 60 deg waffle, membrane thickness 0.025 in., rib height 0.420 in., rib length 4.00 in., rib thickness 0.050 in., 165 in. dia by 72 in. long, 2 segments, each segment fabricated from 1.0 in. x 6.5 ft x 22 ft plate	Engine operation gimbaled hardover (285 lb/in. compression)	
•	Outriggers—space truss 10 ft base by 3 ft height, 7075-T73 angle sections	APS operation (100 lb thrust)	
3.00 Met	eoroid/Thermal Protection		
3. 02	Meteoroid Protection-rigid foam layer 1.00 in. thick, density 2.1 lb/ft <sup>3</sup> , shroud outside foam 0.020 in. fiber glass laminate	RNS P(O) = 0.9974, baseline lunar mission away from earth (27 days)	110
4.00 Doc	king/Clustering		
4.01	Forward Docking Structure—Cone assemblies, 4 reqd, 14 in. dia x 45 deg cone, integrally stiffened, aluminum support struts and attach hardware	Longitudinal position ± 5 in., lateral position ± 5 in., angle, pitch or roll ±3 deg, longi-	80
4. 02	Aft Docking Structure—probe assemblies, 4 reqd, 5 in. dia x 23 in. long, aluminum support struts and attach hardware	tudinal velocity ±0.1 ft/sec, lateral velocity ±0.1 ft, pitch angular	200

	Description	Design Conditions/ Requirements	Weight (lb)
		velocity ±0. 2 deg/sec, roll angular veloc- ity ± 0. 02 deg/sec, maxi- men relative impact velocity 0. 2 ft/sec	
5.00 Main	Propulsion		
5.00 N	erva Engine (NDICE)		500
5.09 O	rbit Refueling		60
•	$4$ in. dia $\times$ 0.035 in. stainless steel ducting— $48$ in. long with dual static seal flanges at both ends	30 psia, 3,000 gpm LH <sub>2</sub>	
•	2 Segment Coupling Flanges, coupling segments, motor + drive screws		
•	4 in. dia pressure volume compensator		
•	4 in. dia gimbal joints— 2 reqd		
6.00 Auxili	ary Propulsion		
6.01 R	eaction Control System	Total impulse = 455,000 lb/sec.	950
•	Aluminum spherical storage tanks, 2014-T6 Al, 0.040 in. Weight oxygen = 1,000 lb Weight LH <sub>2</sub> = 250 lb	Isp = 365 sec p = 30 psia T = 40°R	
•	Storage high-performance insulation—DAM/net		

Description	Design Conditions/ Requirements	Weight (1b)
• Oxygen accumulator sphere 2014-T6 A1, 1.23 ft. dia x 0.53 in.	3,000 psia T = 360°R SF = 2.5	
<ul> <li>Hydrogen accumulator sphere,</li> <li>Ti-6A1-4V 3.9-ft dia</li> <li>x 0.48 in.</li> </ul>	3,000 psia T = 260°R SF = 2.5	
<ul> <li>Thrusters—high pressure film cooled nozzles - 22 required</li> </ul>	Thrust 50 lb— 20 required, thrust 1.3 lb- 2 required	
<ul> <li>Heat exchanger—conditioners helical tube annular shell, stainless steel, external fiber glass insulation—2 required</li> </ul>		
<ul> <li>Thruster control valves, direct acting solenoids, normally closed—48 required</li> </ul>		
<ul> <li>Squib operated closed, plunger type isolation valves-12 required</li> </ul>		
• Regulators—4 required		
<ul> <li>Normally closed direct acting solenoid valves—32 required</li> </ul>		
<ul> <li>Normally open direct acting solenoids—3 required</li> </ul>		
<ul> <li>Turbine driven centrifugal pumps-2 required</li> </ul>		
<ul><li>Burst disk relief valves—</li><li>2 required</li></ul>		
• Check valves—4 required		
<ul> <li>Gas generators and igniters—</li> <li>4 required</li> </ul>		

	Description	Design Conditions/ Requirements	Weight (lb)
•	Filters-2 required		
•	Tubing, all welded joints except connections at components, dual static seals at ends		
7.00 Astric	onics		
7. 01 C	Suidance, Navigation and Control		310
•	2 star tracker on gimbal mounts each which cover ±60 deg conical field of view, each tracker covers 120 deg of opposite hemispheres	4 arc sec pointing accuracy	
•	Horizon sensor-160 deg field of view, conical scanning type with two rotating sensor heads-gimbal mounted	0. 1 deg pointing accuracy, course attitude determination; backup position, velocity determination	
•	Landmark tracker on gimbaled mount-120 deg conical field of view	4 arc sec point- ing accuracy, determine position and velocity vector during orbital operations	
•	Inertial measuring unit—6 gyros in redundant dodecahedron strapdown configuration	Determine vehicle attitude in inertial space. Drift rate not to exceed 0.05°/hr	

Description	Design Conditions/ Requirements	Weight (lb)
• 12 accelerometers-6 high range, 6 low range	High range 1 g to 10 <sup>-3</sup> g, low range 10 <sup>-3</sup> to 10 <sup>-6</sup> g. Scale factor error not to exceed 0.05%	
• 2 scanning laser radar systems	12 km range, range accuracy 0.2% or 10 cm, range rate accuracy 1% or 0.5 cm/sec	
<ul> <li>Optical corner cubes for rendezvous and docking</li> </ul>	Cooperative target for space rendezvous	
7.02 Instrumentation		210
<ul> <li>225 transducers—pressure, temperature, flow voltage, etc.</li> </ul>	80% of analog channels	
• 135 signal conditioning circuits	60% of analog channels	
• 18 ea 16-channel MSI analog multiplexers	Data switching and programming	
• 18 ea 10-bit analog to digital converters	l part in 1,024 resolution, 0.1% accuracy encoding of analog data, l per multiplexer	

Description	Design Conditions/ Requirements	Weight (1b)
7.03 Command and Control		140
• 2 S-band transmitters	Dual redundant, compatible with DSIF/MSFN	
<ul> <li>2 receivers and uplink command decoders</li> </ul>	Dual redundant, compatible with DSIF/MSFN	
• Tracking transponder	Allow for ground tracking	
<ul> <li>2 omni antennas, 1 steerable directional antenna</li> </ul>	Omnidirectional for near earth- steerable for lunar distances	
<ul> <li>Data programmer to control and sequence instrumentation channels</li> </ul>	Capable of reprogramming to multiple modes (estimate 8)	
<ul> <li>PCM encoder to format, address, and tag data blocks</li> </ul>	Format compatible with DSIF/MSFN processing capability	
• Logic decoders	Accept serial input instructions from data bus terminal	
Controllers with memory as required	Accept decoded signals and drive control-lable functions up to 10 amps (those with memory—turned off by separate command)	

Description	Design Conditions/ Requirements	Weight (lb)
7.04 Electrical Power		785
2 fuel cells—regulated capillary matrix type with alkaline electrolyte. 2 kw capacity each	Redundant cells—each capable of supplying max after- cooling power of 1.2 kw plus peaking power recharge. 317 kwh total/ mission	
<ul> <li>Hydrogen and oxygen reactant storage integrated with APS tankage. 300°R and 100 psia from accumulator</li> </ul>	250 lb of reactant and 100 lb of tankage included	
<ul> <li>2 batteries—AgZn rechargeable.</li> <li>1.25 kwh capacity each</li> </ul>	To provide emergency and peaking power for CCM subsystems, 50% max discharge.	
• 2 inverters frequency-400 Hz voltage-120 v RMS	Redundant pwr for motor driven valves for APS and fuel cell reactant control	
<ul> <li>Power management regulation, and switching assembly. Power distribution busses.</li> </ul>	Provide redundant buses for backup components, fault sensing and switching	

Description	Design Conditions/ Requirements	Weight (lb)
Power and inter-subsystem functional distribution	Flat and round wire, copper conductors with kapton insulation	
<ul> <li>Instrumentation reference supply, 5 vdc</li> </ul>	0.01% voltage reference	
7.05 Electrical Networks		85
Emergency detection, data bus and manual control cabling	Conductor cables, kapton or polyimide insulation, copper conductors	
<ul> <li>Module interface connectors and blind mating panel</li> </ul>	Mounted on motor driven panel	
7.06 Environmental Control		
<ul> <li>Controlled emmissivity coatings and internal electrical heaters, as required by each subsystem</li> </ul>	Included in each sub- system	
7.07 Propellant Management		
<ul> <li>Point level sensors and flow meters in APS tankage</li> </ul>	Included in instrumentation	
7.08 Onboard Checkout		60
<ul> <li>Procuedures stored and executed by DMS</li> </ul>	Software	

Description	Design Conditions/ Requirements	Weight (1b)
<ul> <li>Emergency detection and com- mand generation logic assembly— 50 functions capacity</li> </ul>	Independent detection and safing. Capable of accepting manual inputs from payload	
7.09 Data Management		315
• 2 processors in 1 + 1 configuration—32 bit word, 4 µsec add, 32,000 word high speed storage	Redundant processors with reli- ability of 38,500 hr MTBF	
<ul> <li>Shared high speed memory, 8,000 words, 32 bits, 1 μsec cycle time</li> </ul>	Multiple access channels—1 for each processor	
<ul> <li>Auxiliary memory, 10<sup>6</sup> bit storage capacity, magnetic tape</li> </ul>	Bulk storage of all operational and checkout procedures	
<ul> <li>Data bus controller/processor I/O</li> </ul>	Buffer processor to interfacing circuitry	
System time base	Provide time base data for procedure control	
• 4 data bus terminals	NDICE, N&G, C&C, and instrumentation 0.5 x 10 <sup>6</sup> bits/ sec data rate	
Total dry weight (including 200 lb continge	ency)	4,725
RCS propellant	}	1,250
Total operational weight		5,975
	ı	•

# Section 7 NERVA INTERFACE

The NERVA interface section contains the engine description, a description of the functional interfaces between NERVA and the stage, the physical interfaces between NERVA and the stage using an interface control drawing, and a summary of interface recommendations.

The NERVA engine is delivered for assembly to the nuclear stage with the following separate subassemblies: (1) a nuclear engine module assembly, (2) an assembly consisting of the stage-mounted portion of the NERVA digital instrumentation and control electronic system, (3) two PSOV assemblies, and (4) a cooldown supply module (CSM) assembly.

#### 7.1 NERVA ENGINE

This section contains an operational description of the NERVA engine, physical configuration considerations, and NERVA performance summary. The requirements for thrust vector control, cooldown, and engine structural dynamics are reviewed.

#### 7.1.1 Description

The NERVA engine (Figure 7.1-1) utilizes a nuclear reactor to provide heat to liquid-hydrogen propellant in a "full-flow" cycle and thus obtain a high-specific-impulse propulsive force. Thrust is generated by hydrogen which is heated under pressure in the reactor core and expelled through a De Laval nozzle. The hydrogen is supplied from the tank by means of dual turbopumps and flows through cooling passages in the nozzle wall and reflector before reaching the reactor. Energy transferred to the hydrogen in the cooling passages is extracted by the full-flow turbines to drive the pumps. Bypass valves control the output of the turbopumps and thus regulate chamber pressure.

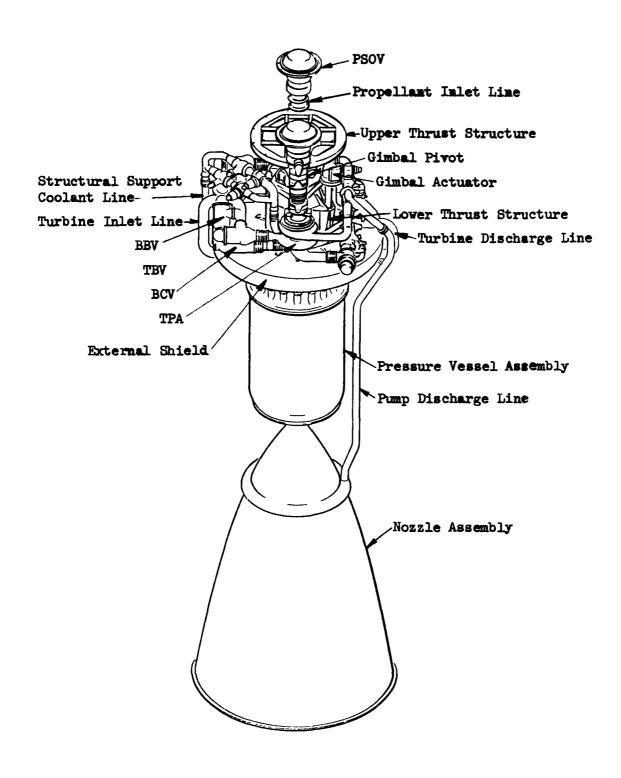


Figure 7.1-1 NERVA ENGINE

Reactor power is regulated to maintain a desired chamber temperature by control drums and by structural support coolant valves which control the hydrogen density in the reactor support structure.

NERVA performance characteristics are summarized in Table 7.1-1. Two basic elements of engine control are turbine power and reactivity. Both are used in the control of the primary engine variables: chamber temperature and pressure as demanded by the engine programmer. Inputs to the programmer come from the stage or ground-test control and are typically the start command, set points, shutdown, and emergency actions.

The NERVA engine reliability allocation is 0.995 for the 10-hour operating life. The engine will incorporate means of preventing accidental criticality during all ground and space operations.

The engine is being designed for maintainability both on the ground and in space. The fluid flow paths are illustrated in the schematic, Figure 7.1-2. Propellant flows from the propulsion module tank through propellant shutoff valves (PSOV) to the turbopumps. After leaving the turbopumps, the flow divides between the reflector, the structural support system, and structural support bypass flow. Flow through the structural support system controls the reactivity of the nuclear subsystem in conjunction with the control drums.

Table 7. 1-1
NERVA ENGINE DESIGN

Life		10 hrs 60 cycles	
Chamber	temperature	4,250°R	
Specific in	mpulse (vacuum)	825 sec	
Chamber	pressure	450 psia	
Thrust (va	acuum)	75,000 lb	

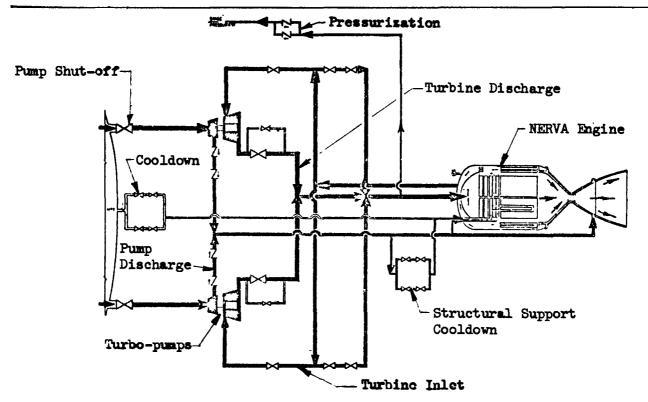


Figure 7.1-2 NERVA SCHEMATIC

Structural support bypass flow cools the reactor core support plate, but is not used to control reactivity. Flows from the reflector, structural support bypass, and structural support system are combined to exit from the pressure vessel into the turbine. Part of the flow is bypassed around the turbine, using the turbine bypass control valve (TBCV) for control of chamber pressure. The flow from the turbine is then reintroduced into the pressure vessel and further heated in the reactor core before exiting from the nozzle. Part of the flow in the turbine exhaust is diverted through the stage pressurant check valve (SPCV) for propulsion and propellant module pressurization. In cooldown, a separate tank fluid line is used, controlled by the cooldown system control valve (CSCV) for removing decay heat from the reactor.

The NERVA interface and the engine overall geometry, including interpump spacing, which affects tank bottom geometry and tank bottom penetration, are primarily dictated by current ground testing removal and replacement

constraints. Current ground removal and replacement capabilities, and a ground maintenance policy are not necessarily compatible with desired flight maintenance and flight maintainability capabilities. However, at present, stage design philosophy only constrains the interface between the engine and the run tank by flight constraints. The propulsion module used for the MDAC RNS concept integrates the engine with a small run tank. This eliminates the requirement for remote engine separation at the run tank/engine interface. This interface could therefore be designed with primary flight requirements; namely, closed-space pumps, minimum length ducting, and optimum fluid and electrical connector locations. The only interface that would then be required to have remote capability would be the interface between the propulsion module and the test stand for ground testing.

# 7.1.2 Thrust Vector Control

Based on a 1.5-degree thrust vector misalignment for the NERVA and stage interface, a minimum engine position gimbal limit of ±3 degrees has been established by controls studies. Table 7.1.2 summarizes the engine gimbal requirements.

Studies have shown that it is highly desirable to have the capability of trimming the NERVA prior to start. With this capability the NERVA misalignment would be established during its first use and pretrimmed out for subsequent uses. With the first use being translunar injection, requiring on the order of half an hour of operation, the effect of the relatively short attitude transient on the velocity errors at cutoff will be minimal. For the subsequent NERVA operations, many of very short duration, the vehicle attitude transient could be highly reduced by pretrimming the NERVA.

Table 7.1-2
ENGINE GIMBAL REQUIREMENTS

Maximum Engine Deflection	±3 deg
Maximum Engine Rate	0.25 deg/sec
Maximum Engine Acceleration	$0.5  \mathrm{deg/sec}^2$

The engine manufacturer should provide the stage contractor with a log book containing the geometric misalignment of the mounting plane for each engine. Sufficient adjustment should be allowed in the actuator end fitting to adjust the actuator length to account for this misalignment.

The NERVA gimbal actuator model being used by MDAC in control system studies was obtained from ANSC letter 7410:1071 dated 10 July 1970. This letter states that the actuator can be thought of as:

- A. Reversible 28-vdc motor.
- B. Multistage gear transmission.
- C. Ball screw mechanism.
- D. Rate and position feedback.
- E. Compensated servopower amplifier.

The letter further states that the actuator will meet or exceed the deflection, rate, and acceleration requirements listed in the table. ANSC is designing the actuator for a maximum force output of 20,000 lb. Preliminary calculation by MDAC indicates that the static load could be greater than the present actuator maximum force capability. Therefore, the design conditions that ANSC is using should be reviewed.

The gimbal actuator transfer function given by ANSC in the referenced letter is:

$$\frac{\theta(s)}{\theta c(s)} = \frac{8310}{s^3 + 200 s^2 + 1774 s + 8040}$$

where:

- $\theta$  is actuator position and  $\theta$ c is the commanded actuator position
- s is the laplace transformation variable.

This transfer function has been converted by MDAC for controls studies to:

$$\frac{\theta(s)}{\theta c(s)} = \frac{(6.4)^2}{s^2 + 2(0.695)(6.4) s + (6.4)^2}$$

To obtain the above function, a third order pole at 196 radians was dropped since it will not affect the attitude control system.

Control system studies have indicated that the actuator transfer function is not optimum. In general the bandwidth of this system is greater than necessary with it contributing very little to the required control system attenuation. It should be possible without sacrificing low frequency phase lag to obtain a pole-zero configuration which would provide more high frequency attenuation to the total vehicle control loop. In other words, in designing the actuator with its attendant response characteristics the effect on the total vehicle control system should be considered.

# 7.1.3 Cooldown Thrust

The vehicle orbital attitude disturbances resulting from pulsed aftercooling can be a very significant contribution to total coast attitude control propellant consumption. These disturbances result from, and are proportional to, the thrust vector misalignment. Three alternatives for thrust vectoring during cooldown are possible: (1) not controlling the engine angular position,

- (2) positioning and maintaining the engine mechanically "centered," and
- (3) trimming the effective thrust vector through the vehicle cg.

The first of these alternatives results in excessive coast attitude control propellant usage and is totally unacceptable. The second is an improvement, but could still result in an excessive requirement. In the third alternative an active control system would be used periodically to retrim the thrust vector. In this approach the disturbances resulting from aftercooling would be minimal. The weight saving (in coast attitude control propellant and tankage) will far offset the added complexity of providing for active thrust vector control during coast. The NERVA gimbal actuator should be designed to allow for periodic retrimming. After trimming the actuator should lock and hold in the last position.

### 7.1.4 Structural Dynamics

Engine/stage structural dynamic analyses were conducted during the Phase II and III studies. These analyses show that these dynamics could be a problem

for vehicle configurations where the engine is launched integrally with the stage. In the baseline concept the NERVA is brought to orbit as part of the propulsion module in the space shuttle cargo bay. In an alternate mode the propulsion module attached to a propellant module is launched integrally by an INT-21. In previous candidate configurations of Class 1 the NERVA is attached to the stage by an ice-cream-cone-shaped lower LH<sub>2</sub> tank. This configuration was studied to assess its launch dynamics.

The data sources used in these studies are shown below:

- A. Saturn INT-21 booster was assumed.
- B. A 10-deg half-angle cone aft LH<sub>2</sub> dome and fiber glass honeycomb sandwich thrust cone were used for the ice cream cone configuration.
- C. The NERVA dynamic model was obtained from Reference 7-1. The free-free data obtained from Reference 7-2 for the "B" configuration of the NERVA in the 0.45 to 225 deg X-Y plane were used. The first six modes of this model (which are not component modes) were used. The resonant frequencies of these modes are 3.34, 14.34, 18.14, 36.19, 44.09, and 47.96 Hz.
- D. Two percent structural damping was used for the NERVA.
- E. The lateral acceleration transient used to excite the dynamic model was obtained from Reference 7-3. The data characteristic of release and lift-off was used. This transient has appreciable energy at 2.46, 4.50, 5.37, 7.99, 9.30, and 11.2 Hz.

#### References for Section 7.1

- 7-1 Dynamic Analysis Report. Aerojet Nuclear System Company Report, S038-CP090290-F1, September 1970.
- 7-2 Structural Information Requested by McDonnell Douglas Corporation. Aerojet Nuclear System Company Letter 7410:0214, 12 October 1970.
- 7-3 Review of Loads Table and Acoustic Levels. MSFC Letter S&E-ASTN-AA-70-42, 12 May 1970.

#### 7.2 RNS/NERVA FUNCTIONAL INTERFACE

This section defines the functional interface between the NERVA engine and the RNS propulsion module. This interface is covered for each of the three technologies: structural, fluid, and electrical.

# 7.2.1 Structural

Structural attachment is provided between the NERVA engine and the run tank thrust structure. The function of this interface is to transmit all engine gimbal, actuator and inertial loads to the thrust structure which distributes these loads into the propulsion module propellant tank. The most severe design condition for this interface occurs with the engine gimbaled hard over at 5.7 degrees (based on  $\sqrt{2}$  x 3 degrees for control plus 1.5 degrees for misalignment) under 75,000 lb of thrust. This condition produced the following ultimate loads:

Moment  $1.04 \times 10^6$  in.-lb Shear 8,050 lb Axial 97,500 lb

These ultimate loads resulted in a maximum compressive point load of 25,420 lb at the strut attach points. The engine manufacturer should verify these loads and provide the stage contractor with a loads envelope for the interface plane. The actual actuator location should be reviewed to determine the impact on stage-induced loads. These loads should be distributed uniformly by the upper thrust structure and not introduced into one set of struts only.

Launch of NERVA on the propulsion module inside the space shuttle cargo bay was investigated, employing the preliminary load factors shown in Table 7.2-1. The NERVA engine was assumed to be supported at the nozzle throat as recommended by the engine manufacturer. The load factors are based on MSFC memo PD-SA-70-269, dated 13 November 1970.

#### 7.2.1.1 Biological (Disk) Shield

The current NERVA design provides for a removable disk shield with a weight of 10,000 lb which can be used to provide biological shielding for manned missions. For Class 1-H, geometry is used to reduce the radiation dose to the payload. This reduces the requirement for the external shield to 2,900 lb.

Table 7.2-1
PRELIMINARY ACCELERATION LOAD FACTORS -SPACE SHUTTLE PAYLOAD COMPARTMENT

(Based on payload at cg location. Sign conventions based on orbiter reference datum, Level II requirements)

	Longit	ıdinal (X)	Late	ral (Y/Z)
Mission Phase/Event	Steady (g)	Dynamic (g)	Steady (g)	Dynamic (g)
Launch release transient (within 2 sec of release)	+1.5	±2.0	-	±2.0 (Y & Z)
Lift-off +5 sec	+1.5	±0.25	-	±0.25 (Y & Z)
Max q-alpha region (35 to 55 percent booster burn)	+2.0	±0.40	-0.75 (Z)	±1.5 (Y & Z)
Maximum acceleration (80 to 100 percent booster burn)	+3.0	±0.25	-0.5 (Z)	±0.25 (Y & Z)
Cutoff/separation (within 2 sec of booster cutoff)	-	±3.0	-	±2.0 (Y & Z)
Separation +5 sec	+1.5	±0.25	-	±0.1 (Y & Z)
Maximum acceleration (60 to 100 percent orbiter burn)	+3.0	±0.25	-	±0.1 (Y & Z)
Reentry	-1.0	-	-4.0 (Z)	±0.1 (Y & Z)
Landing/taxiing/braking	-1.0	-	-2.0 (Z)	±2.0 (Z)
			0.5 (Y)	±0.5 (Y)

# 7.2.1.2 Mass Properties

The current calculated weight for the NERVA engine without the external shield in a flight operating condition is 27,728 lb, including 500 lb for the stage-mounted portion of NDICE.

The cg location without the external shield is at station 128, or 128 in. below the engine/stage interface.

Moment of inertia values for the operating engine (dry) taken about the gimbal point are

Roll axis	$3,800 \text{ slug-ft}^2$
Pitch axis	83,618 slug-ft <sup>2</sup>
Yaw axis	83,507 slug-ft <sup>2</sup>

### 7.2.1.3 Structural Dynamics

In the MDAC baseline, NERVA is launched in the space shuttle cargo bay. However, for the current engine baseline launch by the INT-21, Phase III analyses showed that NERVA restraint is required to limit lateral displacements. Two specific concepts of engine restraint have been considered for the INT-21 case. These are (1) lateral ties between the engine at the nozzle throat and ascent shell and (2) axial struts between the thrust structure and engine pressure vessel. These concepts are shown in Figure 7.2-1.

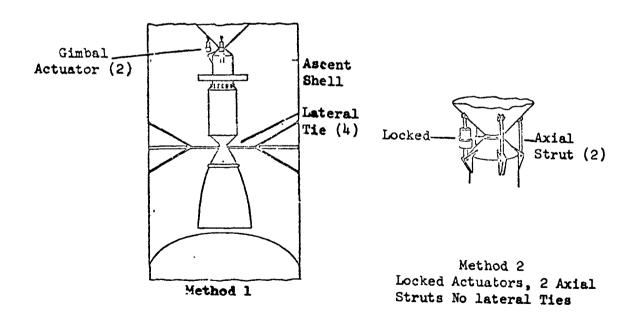


Figure 7.2-1 ENGINE SUPPORT SCHEMES

Tables 7.2-2 and 7.2-3 list the resonant frequencies obtained for the standard and hybrid launch configurations. This is not the baseline launch configuration selected for the hybrid. Also shown in these tables are the resonant frequencies for various restraint concepts and spring rates. As can be seen from these data, lateral ties between the nozzle throat and ascent shell are a far more effective method of raising the frequency than the axial struts. As can be seen from these data, for a typical case, the first cantilevered frequency is raised from 0.97 to 2.34 Hz and 0.63 to 2.01 Hz for the standard and hybrid launch configurations, respectively.

In the case of the MDAC baseline space shuttle transportation mode, NERVA is attached to the propulsion module and is launched to orbit inside the cargo bay of the space shuttle as shown in Figure 7.2-2. The propulsion module is deployed in orbit by the space shuttle payload deployment mechanism. The module is launched with its propellant tank dry and unpressurized.

Launch and boost loads associated with shuttle launch impose requirements on the propulsion module and NERVA which exceed those anticipated for space nuclear engine operation. Table 7.2-1 provides acceleration load factors for the space shuttle. Based on these loads and the low unrestrained frequencies shown in Table 7.2-3, the capability of providing for engine lateral support such as indicated in Figure 7.2-2 is recommended. This scheme would use retractable structure to allow deployment.

### 7.2.2 Fluid Conditions

The propellant conditioning requirements for NERVA steady state full power operation are defined by Figures 7.2-3 and 7.2-4, derived from AGC Letter 7410:1075, 15 July 1970, which includes a steady-state operating pressure of 26 psia, saturated liquid, with zero NPSP. Reduced flow rates are permitted at zero NPSP, and saturated liquid for pressures below 26 psia to provide autogenous start capability. The RNS design provides for a NERVA malfunction mode. However, the total pressure (saturation pressure plus NPSP) will not exceed 26 psia for such a mode.

During pulsed aftercooling, the RNS provides saturated liquid to the bypass line at a minimum pressure of 16 psia.

Table 7.2-2
RESONANT FREQUENCIES (Hz)
STANDARD CONFIGURATION

(10-Degree Aft Dome)

		Thru	Axial Struts Between the Thrust Structure and Pressure Vessel			al Ties Betwee e and Ascent S Tie at Nozzle	
Number	Without Restraint	1 x 10 <sup>6</sup> lb/in.	2 x 10 <sup>6</sup> lb/in.	4 x 10 <sup>6</sup> lb/in.	$5.0 \times 10^3$ lb/in.	10 x 10 <sup>3</sup> lb/in.	25 x 10 <sup>5</sup> lb/in.
. 1	0.97	1.53	1.56	1.57	1.79	2.34	3.50
2	4.92	6.26	6.26	6.26	4.92	4.92	4.92
3	6.26	7.71	8.09	8.32	6.26	6.26	6.27
4	16.12	16.12	16.13	16.13	16.12	16. 12	16. 12
5	17.75	17.75	17.75	17.76	17.75	17.75	17.76
6	21.45	24.01	24.43	24.69	21.45	21.47	21.48

[77

Table 7.2-3

RESONANT FREQUENCIES

INTEGRAL LAUNCH OF PROPULSION MODULE (HYBRID)

Mode Number	Without Restraint	10 <sup>4</sup> lb/in. Lateral Tie Between the Engine and Ascent Shell
1	0.63	2.01
2	2.28	2.47
3	4.66	4.66
4	6.55	6.55
5	9.26	9.26
6	14.25	14.25

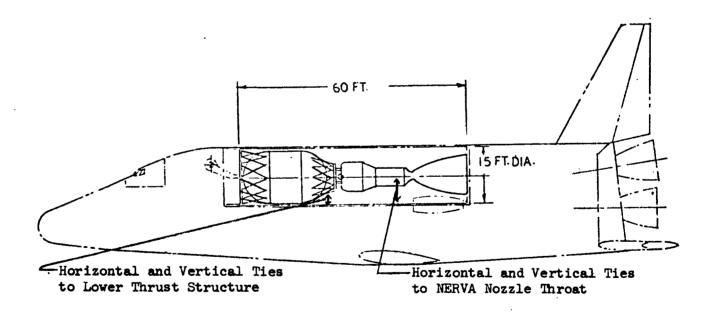


Figure 7.2-2 PROPULSION MODULE IN ORBITER CARGO BAY

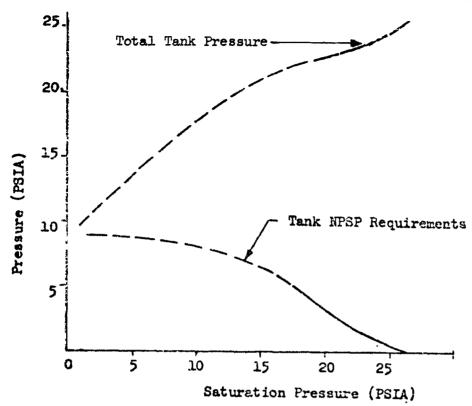


Figure 7.2-3 RNS PRESSURE REQUIREMENTS

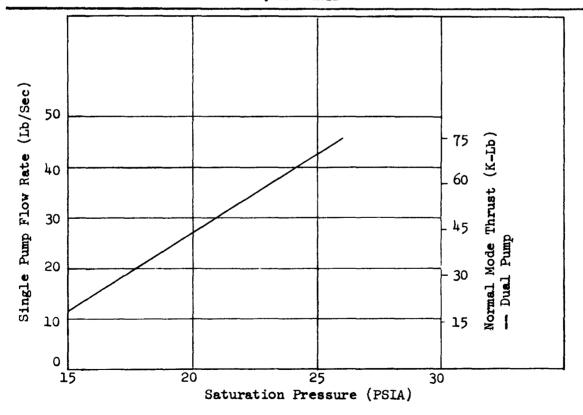


Figure 7.2-4 NERVA PUMP PERFORMANCE FOR SATURATED LIQUID AND ZERO NPSP

The pressurization system operates with NERVA bleed gas delivered at 225 °R. Separate gas storage for prepressurization is not provided. This approach makes full use of NERVA bootstrap startup capability. Stage pressurant demand is summarized in Table 7.2-4 for the various thrust modes and operations.

Prior to startup is is necessary to chill down the active portion of the RNS feed system to ensure propellant conditions for NERVA and to accomplish a predictable startup operation. The feed system interfaces that require conditioning include the two legs of the NERVA feed system between the turbopump and the run tank, and the interfaces between the RNS modules. These are summarized in Table 7.2-5. All the stage feed ducting uses two basic types of flexible elements—gimbal joints and linear pressure volume compensators—which account for a major portion of the weights of those systems. Chilldown time requirements were based on the minimal permissible time for chilldown of each interface, taking into consideration film boiling heat transfer for a duct initially at ambient temperature and providing a margin of safety for flow surges. An integrated stage/engine pump-fed

Table 7.2-4
RNS PRESSURANT DEMAND

Operation	Flow Rate (lb/sec)		
Steady-state expulsion (including run tank prepressurization)	0.58		
Steady state with pressure control active	0.64		
Propellant module pressurization	5.58		
Full-power run tank refill	0.81		
NERVA emergency mode	0.35		

Table 7.2-5 RNS CHILLDOWN REQUIREMENTS

Interface	Components	Mass (lb)	Length (ft)	Equivalent Boiloff (lb LH <sub>2</sub> )	Chill Time (sec)
NERVA (each side)	PSOV 9 in. feed duct* Turbopump PDKVA	973	8.9	92	43
Run tank/ propellant module	12-in. feed duct*	263	11	28	34

chilldown system which is located in the run tank is employed. Its operation is integrated with the run tank refill function.

Figure 7.2-5 shows a schematic of the integrated system concept compatible with the current NERVA interface. The propulsion module run tank contains redundant submerged ac motor-driven centrifugal pumps. An inverter is provided for each motor to utilize the dc power bus. Each pump is sized for full system chilldown capacity. In normal operation at reduced flow the pumps will operate at a higher head. The parallel manifolded pumps discharge via two antibackflow check valves into a header that directs flow forward to the stage main propellant feed ducting and aft to the engine. Return for stage feed duct chilldown is accomplished with the refueling spray nozzle bypass system on the run tank and the duct blocking valves located in each propellant module. This system permits conditioning of the propellant module to propulsion module external feed ducting. NERVA feed system chilldown conditions the inlet ducting to the NERVA turbopump, the pump, and pump discharge ducting to the location of the pump discharge valve (PDKVA). There are two such sections for the duel turbopump configuration. The pump shutoff valve (PSOV) and pump discharge valve are closed during chilldown.

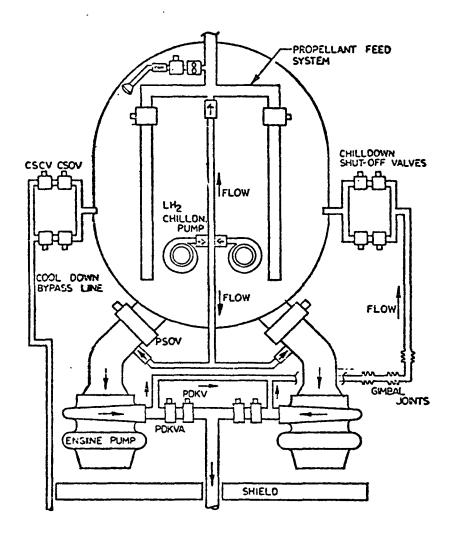


Figure 7.2-5 INTEGRATED CHILLDOWN SYSTEM

# 7.2.3 Electrical

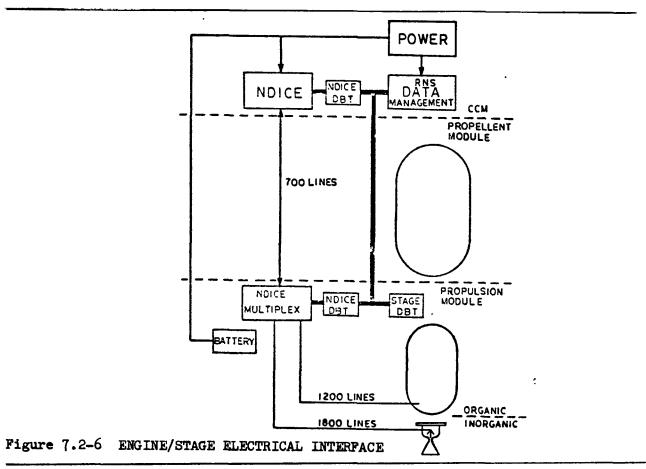
Electrical interfaces between NERVA and RNS subsystems exist both in the CCM and in the propulsion module. The interface in the CCM is accomplished by using the stage data bus between the NDICE and the RNS data management subsystem. The stage data bus is shared by NDICE for transmission of multiplexed data from the propulsion module to the CCM where dedicated data bus terminals for NDICE are assigned. A battery integral to the stage power subsystem is provided for propulsion module peaking power requirements. Signal conditioning, multiplexing and digitizing of engine instrumentation, and decode of engine control signals are performed by the NDICE components on the propulsion module prior to (for instrumentation) or subsequent to (from control signals) transmittal on the data bus. Figure 7.2-6 shows the functional interface between stage and engine electronics.

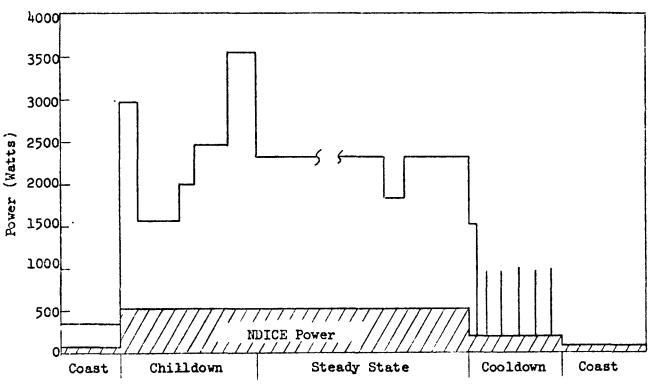
#### 7.2.3.1 Power

The NERVA engine requires 28-vdc power at various power levels, depending on which phase of the mission the engine is executing. Figure 7.2-7 shows an engine power demand profile for a single burn. Two power levels are shown: (1) NDICE power, which is dissipated in the CCM, at 500 w during engine operation, 200 w during cooldown, and 60 w during coast periods; (2) total power at 2,300 w with 3,500 w peaks during engine operation, 200 w with 1,000 w peaks during aftercooling and 60 w during coast. Alternating current power requirements will be satisfied by the use of local inverters in each module. Engine requirements will be satisfied by engine inverters. Precision reference instrumentation power supplies will be integral to the local instrumentation package.

Power quality will be 28 ±4 vdc and will be distributed as required to the engine from the forward portion of the run tank. The vehicle skin will not be used as a return path for power or signals, but will serve as a noncurrent carrying reference. Environmental control will be provided internal to the equipment and use a portion of this power for internal electrical heaters.

400 Hz ac ±1 percent will be available as a reference frequency in the propulsion module, as will the data bus clock of 0.5 MHz.





TYPICAL POWER PROFILE FOR A NERVA BURN

Figure 7.2-7

#### 7.2.3.2 Instrumentation

NERVA instrumentation will be conditioned, multiplexed, and digitized prior to insertion on the RNS data bus. A dedicated data bus terminal is provided on the propulsion module for NERVA instrumentation and control functions. The instrumentation channels have multiple (eight estimated) internally programmed sequences of sampling which are commanded by a single mode set instruction transmitted on the data bus. Calibration capability will be included on individual instrumentation channels and commanded by an encoded signal from the data bus. Provision is allowed for hardline routing of a limited set of emergency functions to the CCM.

Allowance is made for 266 engine analog instrumentation channels for operational vehicles and 407 channels for development vehicles. Ground test instrumentation is separable and independent of these allowances. The digitizer will encode to 10 bits with an accuracy of 0.1 percent.

### 7.2.3.3 Control

Control of engine functions will be performed exclusively by NDICE. Control signals will be generated by NDICE components in the CCM and transmitted on the stage data bus to the propulsion module. These commands will be decoded, and appropriate drivers in the NDICE components on the propulsion module will effect control. Provision is made for hardline control of a limited number of emergency functions from the CCM to the NERVA engine. Engine gimbal signals will be supplied by the stage NG&C subsystem and the actuators controlled by stage drivers mounted on the propulsion module.

Engine checkout operations will be performed by procedures stored in NDICE and data for evaluation will be supplied through the operational data channels.

#### 7.2.3.4 Information Transfer

Information will be transferred between the NDICE and the stage data management subsystem in the CCM. Two following classes of data are identified:

A. Stage Commands to NDICE-Specific commands to control RNS operations will be required to be acted upon by the NDICE. Characteristically these would include (1) prestart, (2) engine start, (3) set

- thrust or throttle, (4) shutdown, (5) hold cooldown pulse, (6) checkout, (7) instrumentation mode set, and (8) various emergency commands. These commands will be transmitted, in encoded form, on the RNS data bus.
- B. Status and Data Messages Various status and data messages will be transmitted between the NDICE and the stage data management subsystem (DMS). These could include state computation results, health information, estimates of time to next event, processor activity monitors, and specific data. It is expected that a continuous flow of encoded data will cross the RNS data bus between NDICE and the DMS during the mission.

### 7.2.4 Mission Operations

The RNS mission operations impact the NERVA functional interface through specification of thrust modes for mission maneuvers, steady-state operating times, constraints on the startup ramp, and aftercooling utilization. The overall mission timeline was presented in Table 2.1-1 (Book 1) which gives the propellant utilization and operating times for various mission maneuvers. The thrust modes and steady-state operating times associated with this mission timeline are presented in Table 7.2-6. Typically a throttle mode operation is utilized if the steady-state burn time at full thrust is very short. Idle mode operations are employed for small impulses in lieu of the APS. Additional idle mode operations are also postulated for separation maneuvers prior to TLI and TEI-1. Idle mode operations for rendezvous maneuvers are also postulated after LOI-3 and EOI. The NERVA parameters characterizing the selected thrust modes and the functional requirements imposed on RNS subsystems are summarized in Table 7.2-7.

The RNS startup operations are defined in Section 3.11 of Book 1. Evaluation of the startup operations has identified the need for a thrust hold at the throttle point during the NERVA startup ramp. Since the engine operates at full Isp, payload losses associated with the thrust hold are negligible. The thrust hold will provide time to complete propellant settling prior to prepressurization and increase the time available for prepressurizing the propellant module, thereby reducing pressurant demand from NERVA. The estimated thrust hold durations established in Section 3.11 of Book 1 are summarized in Table 7.2-7. The steady-state operating times associated with these were not increased to reflect the thrust hold duration.

Table 7.2-6
NERVA THRUST MODE REQUIREMENTS

Burn	Thrust Mode	Steady State Time (sec)	Thrust Hold Duration (sec)
TLI	Full thrust	1,750	51
Midcourse	Idle	500	
LOI-1	Full thrust	70	3
LOI-2	Throttle	25	<del></del>
LOI-3	Full thrust	160	0
TEI-l	Full thrust	82	0
TEI-2	Throttle	0	
TEI-3	Full thrust	43	0
Midcourse	Idle	250	
EOI	Full thrust	470	0

The integration and utilization of aftercooling propellant has a major impact on stage performance. Its implications are discussed in Section 3.13 of Book 1. Accurate N-body trajectory simulations were performed using the ANSC NERVA cooldown data to evaluate the performance implications of aftercooling. Whereas early RNS performance calculations neglected any potential payload gain from utilization of aftercoolant, the benefits have been established in this study. This amounts to a credit to the mission velocity resulting in 8.400 lb of payload delivered to lunar orbit. The amount of aftercoolant required represents a degradation of the Isp for the stage. It was established that there would be a potential additional payload gain of 23,500 lb if aftercooling with propellant could be eliminated entirely.

The current NERVA specifications contain an impulse tolerance of ±20,000 lb-sec. The impact of this tolerance on the translunar trajectory was determined in Section 3.14 of Book 1 for the trajectory simulations as corresponding

Table 7.2-7
REQUIREMENTS FOR NERVA THRUST MODES

	NERVA Parameters			RNS Functions			
NERVA Thrust Mode	Thrust (lb)	Flow Rate (lb/sec)	Isp (sec)	Propellant Settling	Feed System Chilldown	Prepressurization	Run Tank Refill
Full power	75,000	91.9	825	x	X	X	X
Throttle mode	45,000	55.1	825	X	x		
Idle mode	1,000	2.0	500				
Aftercooling	300	0.7	430				
X = Required							

to 0.6 percent of TLI impulse or less than 12-nmi lunar miss distance. Consequently, it is considered that the tolerance could be relaxed and should be related to the operating time and total impulse.

Evaluation of midcourse correction concepts indicated that multiple impulsive midcourse maneuvers or a single impulsive correction early in the trajectory are preferable to a single impulsive maneuver at the end of the cooldown phase. A simulation indicated that manipulating the vehicle attitude and cooldown impulse during cooldown thrusting is competitive with an impulsive midcourse correction. It is desirable to develop a method for predicting error early in the cooldown phase. This would permit implementation of a guidance policy to maximize the cooldown utilization as indicated during Phase II (Section 2.3.4, "Nuclear Flight System Definition Study - Final Report," Volume II, Part 2, MDC G0585, May 1970).

Whereas the nominal NERVA Isp is 825 sec the actual Isp obtained for the mission operations exclusive of idle mode burn is 790 sec. This imposes a substantial performance penalty as indicated. Therefore, it is desirable to reduce the amount of aftercoolant required by increasing the radiated power level from NERVA. The implications of this were discussed in Section 3.13.3 of Book 1.

Evaluation of the TLI trajectories with N-body trajectory simulations indicated that when using the aftercooling propellant for mission velocity, there is a critical period between 0.8 and 3.2 hours from ignition during which a vehicle abort could result in an earth impact trajectory. This is discussed in Section 3.13 of Book 1. This trajectory results from deflection of the vehicle by the lunar gravitational field. Failures which could lead to such a condition include loss of NERVA operation, loss of attitude control, and destruction of the RNS.

### 7.3 RNS/NERVA PHYSICAL INTERFACE

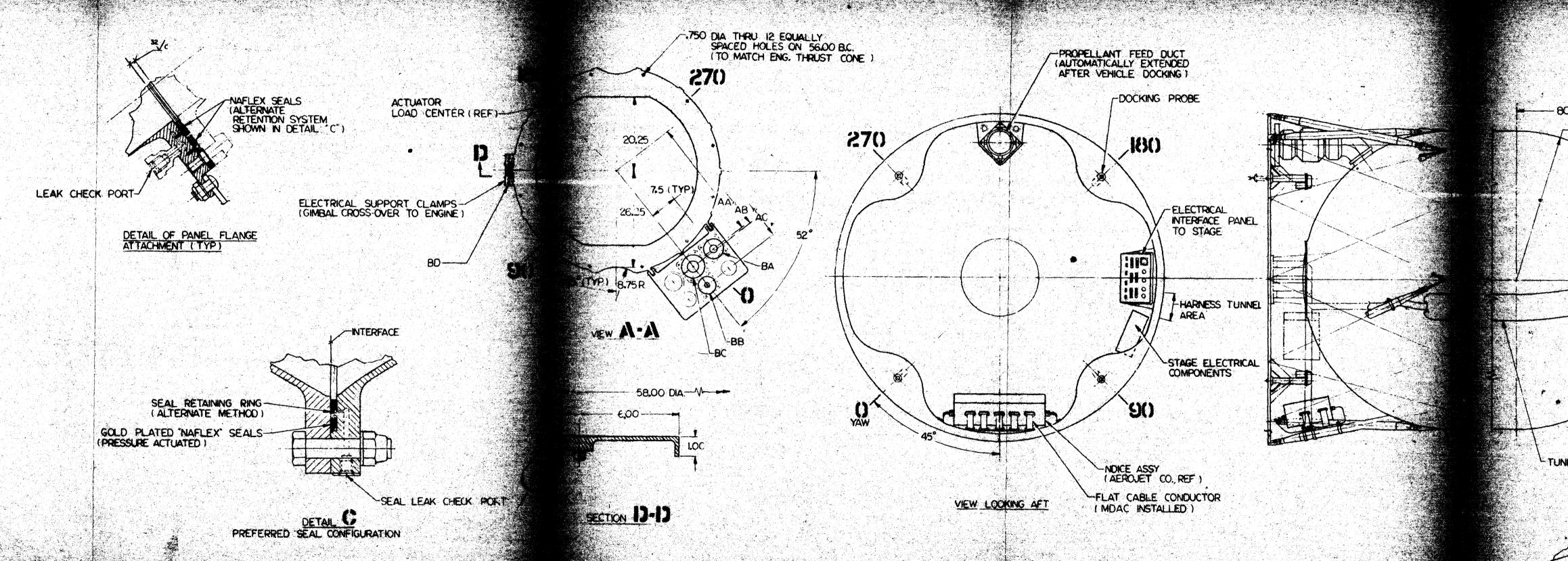
This section contains a physical description of the NERVA to RNS propulsion module interface. An interface control drawing documents this physical interface.

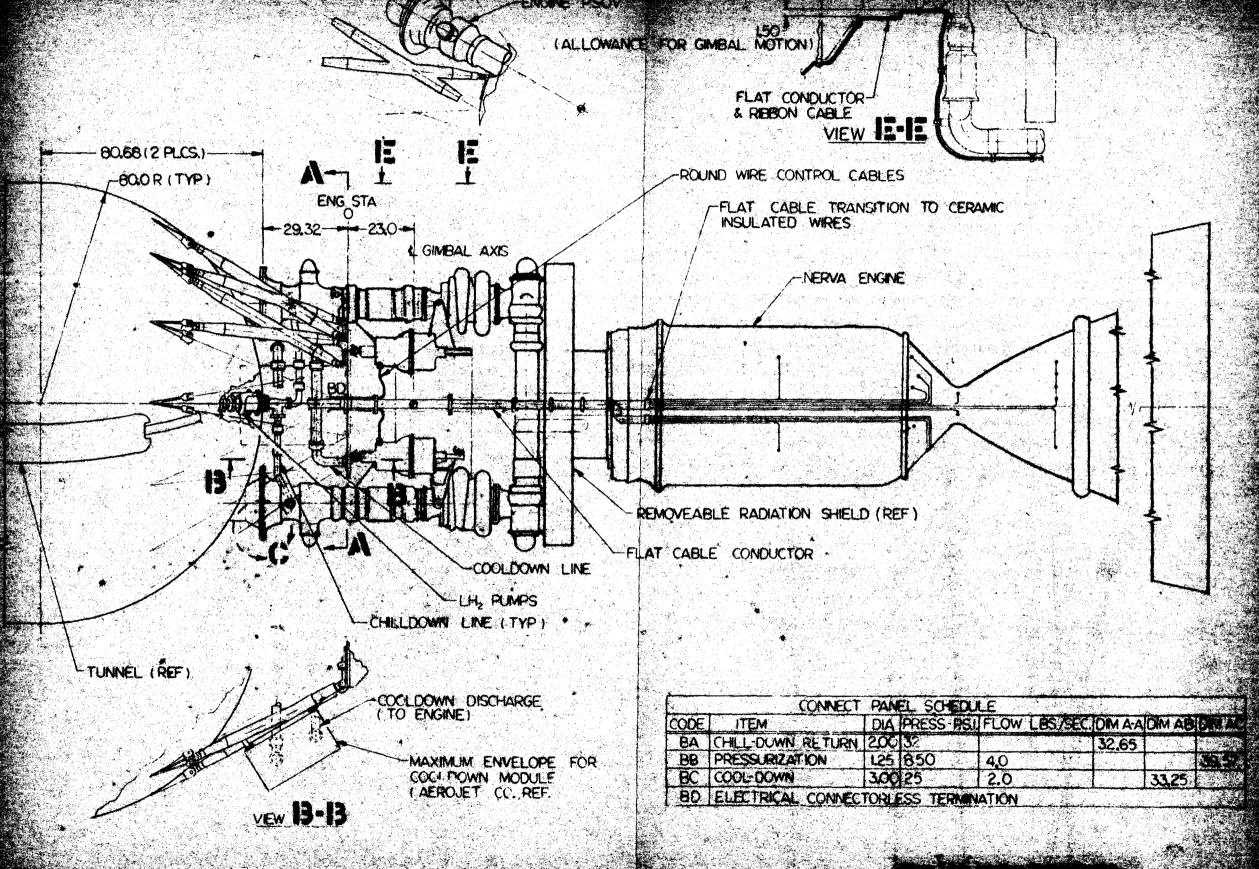
# 7.3.1 Interface Control Drawing

Figure 7.3-1 is the interface control drawing (ICD) for the NERVA engine to the propulsion module run tank. This drawing defines the structural, fluid, and electrical physical interfaces, based on ANSC Engine Layout Drawing 1137400C, 9 August 1970, and includes MDAC interface considerations. The main view shows the NERVA engine installed to the run tank. The structural interface occurs at station zero. This is a cut through the thrust structure. The fluid lines that cross this interface plane are the childown return line, pressurization line, and cooldown lines. These are located on the stage/ engine customer connect panel. The two main feed duct attachments are detailed in View C. For the electrical cross plane functions the flat cable routing is depicted. An end view of the propulsion module run tank is shown. This view shows the interface between the propulsion module and the propellant module in the RNS Class 1-hybrid. Depicted in this location are the probe/drogue docking system, the automatic feed duct deployment and coupling mechanisms, and the location of the automatic deployable electrical interface panel. The clocking and location of the harness tunnel area and the general arrangement of all of these subsystems are shown. This drawing will establish the dimensional compatibility between the NERVA engine and the stage.

#### 7.3.2 Structural

The structural attachment for the NERVA engine to the run tank thrust structure occurs at station zero, as shown on the ICD. This station plane is a cut through the thrust structure. The engine side of this interface contains the NERVA upper thrust structure, which is an integral part of the engine. The stage side of this interface consists of a tubular thrust structure which initiates at the run tank and terminates in a thrust frame. The interface ring shown is fabricated from a 7075-T73 aluminum plate stock. It has a 58-in. diameter at the interface plane and is basically a channel section 6 in. deep incorporating integrally machined lugs for attachment of the thrust structure struts. The interface is designed to pick up the 12 equally spaced 3/4-in. -diameter attach points on the 56-in-diameter bolt circle of the engine







upper thrust structure (UTS). This is a mastered hole pattern. In order to provide the most direct load path the thrust structure struts attach to the interface ring at these bolt locations. Cutouts are incorporated in the ring to provide clearance for the propellant inlet lines. This stage/engine attachment is a hard attachment, and, therefore, it is assumed that the engine supplied gimbal bearing, which is an integral part of the upper thrust structure and the engine lower thrust structure, will have provisions for alignment in two axes during installation.

The separation distance between the pole of the aft dome and the interface plane increased to 30 in. from 23 in. because the POSV's and their flanges increased in size. The strut configuration was tailored to provide clearance for the POSV's and the engine feed line. Separate fittings are welded in the tank bottom for attachment of the POSV's. These fittings incorporate a flange which has provisions for installation of the Naflex seals. The antivortexing, filtration screens are mounted to the interior surface of these fittings. In order to provide adequate thermal insulation between the run tank and the NERVA the thrust structure struts are fabricated from fiber glass. They are tapered and have a tubular cross-section. Titanium fittings containing self-aligning bearings are installed in the ends of the struts.

The customer connect pannel is attached to lugs machined in the closing frame of the thrust structure. It is stabilized by a truss that attaches to the titanium splice members of the thrust structure X-member subassemblies. It is designed to accommodate the gimbal loads induced by the propulsion lines that attach to it. The flat conductor and ribbon cable is also supported off the thrust structure closing frame. The support clamps are bolted to machined faces on the frame.

### 7.3.3 Fluid

The fluid interface will be described for the four basic stage subsystems: (1) propellant feed, (2) childown, (3) aftercooling, and (4) pressurization.

#### 7.3.3.1 Propellant Feed

The feed system from the run tank bottom to the NERVA turbopump inlet contains the engine supplied PSOV which is a 10-in. nominal diameter in-line poppet valve. An in-line duct from the PSOV discharge flange to the pump inlet is supplied by the engine manufacturer. The present design indicates that this duct has a section of untied bellows and two tied gimbals. These flexible elements are required to absorb the engine gimbal deflections. The current design deflection is ±3 degrees. In addition to the gimbal deflections, this ducting must absorb stage deflection requirements. These requirements are incurred by stage thermal deflections, manufacturing tolerances, tank pressurization deflections, and various load deflections that occur during NERVA operation. In the present design the physical interface is the bolted flange connection on the PSOV. This static connection utilizes a Marman type conoseal. The maximum flow of hydrogen at this interface is 91.9 lb/sec.

NERVA engine conditioning is accomplished by directing the chilldown pump discharge flow to two lines that tie from the chilldown pump discharge manifold, as shown in Figure 7.3-1. Each line injects flow forward into the NERVA pump inlet duct downstream of the closed PSOV. Check valving located at the injection points prevents surges and disturbances from being transmitted to the adjacent system. This chilldown ducting does not cross the gimbal plane. The present consideration is to inject the supply flow through a boss that is an integral part of the PSOV body casting. Chill flow proceeds through the NERVA pump inlet ducting, turbopump, and down to the pump discharge valves. Upstream of these valves a tap-off takes the return flow manifolded from both engine pumps to a common return line. This return line crosses the gimbal plane and contains three gimbal joints to provide for the required deflection. Return flow is introduced back into the tank via a set of quad-redundant shutoff valves at a location well removed from the chilldown pump location to prevent degrading fluid inlet condition. The interface drawing shows the chilldown supply duct which does not cross the gimbal plane. This duct will be stage supplied, and the interface for this system will be the bosses which are located on the PSOV's. A return duct is

required in conjunction with the chilldown conditioning system. This duct taps off from both engine main pump discharge manifolds to a single duct and must be returned to the tank. The engine must provide the pump tap-off manifolding and run a 2-in.-diameter return line back to the engine/stage customer connect panel. Since this line crosses the gimbal axis, gimbal provisions will be an engine requirement. At the customer connect panel the stage will provide a line lack to the run tank for the return of the chill-down conditioning fluid.

# 7.3.3.2 Aftercooling

The current NERVA design depicts a stage-mounted cooldown supply module located on the run tank lower thrust structure. The module receives hydrogen from the run tank and a single discharge line comes to the engine gimbal interface. Across the interface a three-gimbal doglegged duct provides for the gimbal deflections. This duct as presently conceived will be part of the NERVA engine.

Details of the engine supplied cooldown module are shown in View BB on Figure 7.3-1. This module, which is furnished by the engine manufacturer, contains the quad-redundant cooldown valves. It will be mounted on the stage side of the engine interface. In the position shown, the module is hard mounted to the tubular thrust structure. This module will obtain hydrogen from the run tank via a 3-in.-diameter cooldown supply line. A 3-in.-diameter duct will leave the module and run to the customer connect panel. Both legs of this duct—the tank tapoff and the module discharge leg to the customer connect panel—will be stage supplied. From the customer connect panel across the gimbal plane and on to the NERVA engine, this duct will be engine supplied.

The NERVA pressurization system requires that a single 1-1/4-in. nominal diameter line cross the interface plane. The configuration of this duct, flexible elements, and position are not defined by current Aerojet interface drawings.

This duct provides the run tank and propellant modules with expulsion pressurant that is tapped off from the engine turbopump discharge side. This duct, the cooldown supply duct, and the chilldown return line will all cross the interface at the engine-to-stage customer connect panel. View AA on Figure 7.3-1, a section through station zero of the structural interface, also depicts this customer connect panel. The hinge panel is attached to the thrust frame as shown. The stage will supply ducting from the run tank to the customer connect panel. Ducting from the panel to the NERVA engine will be engine supplied; this portion of the ducting run will have to absorb gimbaling deflection and other associated operational tolerances. In the right hand portion of the interface control drawing there is a table titled, "Connect Panel Schedule," which codes the customer connect panel fluid functions noted in View BB, with their function, duct diameter, pressure schedule, and flow rate.

It should be noted that all the fluid lines that interface from the NERVA engine to the stage must be reviewed with respect to heat-short thermal conditioning. The main feed inlet ducting is a primary concern, in view of the difficulties involved in defining insulation layup schemes which are compatible with the deflections required of these ducts. This problem also exists for the three other smaller cross-plane ducts.

### 7.3.4 Electrical

Physical interfaces between stage and engine electrical components exist in three locations on the RNS: (1) at the engine stage interface (Station 0.0), (2) at the forward end of the run tank, and (3) in the CCM.

The baseline Aerojet interface between the engine and stage consists of numerous connectors on a connector panel at Station zero which is mounted to the engine thrust structure. These connectors are located both internal and external to the thrust structure. This type interface is compatible with ground testing. However, there are two significant disadvantages for flight vehicles. The first is the extreme reliability penalty paid by the use of connector systems. The second is the interference problems caused by internally mounted connectors because of the envelope and routing restrictions.

The baseline interface arrived at in the RNS study allows for provision of 3,000 lines to cross this interface. The bulk of these lines represents instrumentation signals. The type of wiring that will cross the interface is anticipated to be a combination of flat conductor cable and round conductor wire in a ribbon configuration to be compatible with the parallel conductor system. To enhance reliability, the use of connectorless terminations is recommended at this interface. It is envisioned that once these connections are made at the point of engine run tank assembly, there will be no requirement to disassemble this interface; however, the use of connectorless termination does not preclude this disconnect should maintenance operations be required prior to launch.

NDICE components are located at the forward end of the run tank. These include a multiplexer and signal conditioning for the engine instrumentation and the decode for engine control functions. Stage wiring is routed along the side of the run tank to these modules where permanent or connectorless terminations are utilized to connect stage wiring to the NDICE components. These components interface with a dedicated data bus terminal and EDS wiring via stage wiring that terminates in an interface panel at the propulsion module interface. The latter wiring is largely represented by emergency control functions and the stage data bus.

The NDICE components located in the CCM interface with the interface wiring routed to the CCM/propellant module interface and via the data bus to the data management system. The use of permanent or connectorless terminations is recommended in this location also to enhance reliability.

#### 7.4 INTERFACE RECOMMENDATIONS SUMMARY

The preceding sections have contained an extensive discussion of the functional and physical interfaces between the stage and NERVA, including specific changes which are recommended. Also, the RNS design analyses and descriptions contain implicit NERVA interface considerations. These have been collected into Table 7.4-1, which provides a summary of recommended changes to the NERVA interface and identifies aspects of the interface which require future work.

Table 7. 4-1
NERVA INTERFACE RECOMMENDATIONS SUMMARY

Requirements	Recommended Interface
1. Mission operations	
1.1 Thrust mode	
Translunar injection Lunar orbit injection	Full thrust Full thrust
Transearth injection  Earth orbit injection	Full thrust Full thrust
Lunar orbit plane changes	Throttle (45,000 lb)
Midcourse correction Separation maneuver Rendezvous maneuver	Idle (~1,000 lb)  Idle (~1,000 lb)  Idle (~1,000 lb)  Establish minimum impulse tolerances and cooldown impact for idle mode.
1.2 Aftercooling	
Maximum performance	<ul> <li>(1) Total utilization of aftercooling impulse - no thrust nulling</li> <li>(2) Increase radiated power level for passive cooling (&gt;100 kw) - potential 24,000 lb or 22% increase of lunar orbit payload</li> <li>High temperature passive heat rejection from NERVA: at least 1,200 to 1,500°R</li> </ul>
Impulse tolerance and predictability	Relax ±20,000 lb-sec tolerance — corresponds to 0.6% of TLI impulse or <12 nmi lunar miss distance

Table 7.4-1 (Continued)

Requirements	Recommended Interface
	Future Work:
	(1) Relate tolerance to operating time or total impulse
	(2) Develop method for predicting error early in cooldown
	(3) Correlate performance to impulse tolerance
Trajectory correction	Regulate impulse for error correction
1.3 Abort	
Inject into safe orbit or trajectory	(1) Mutliple start capability: single emergency mode operation followed by cool- down and one or two idle mode operations
	(2) Remove constraint of 5-hour maximum cooldown
	(3) Determine impact of multiple emergency mode operations and increased Isp on external rescue requirements
2. Structures	
2.1 Engine attachment	
Transmit all engine, gimbal, and actuator loads to thrust structure.	(1) Current closing ring in ICD acceptable
Silucture,	Provide stage contractor with loads envelope for interface plane: shear, moment, and axial loads for all design conditions.
	Define bolt pattern tolerances

Table 7.4-1 (Continued)

Requirements	Recommended Interface
	(2) Distribute actuator loads uniformly to stage thrust structure
	Provide stage contractor with load envelope resulting from actuator operation
2.2 Engine Deflection	
5.7° maximum deflection: ±3° for TVC (square pattern) and ±1.5° misalignment	Decrease maximum deflection to reduce loads in intermodule structures
	Evaluate round pattern
	Evaluate misalignment requirements
2.3 Thrust structure configuration	
Locate struts to provide clearance for PSOV	Define angulation capability of feed duct for installation
2.4 Engine Alignment	
Lateral motions at interface plane to align engine and tank centerlines	Adjustable gimbal lateral alignment
2. 5 Acceptance test	Install GSE for PSOV and cool- down module to isolate tank and simulate operations
	Evaluate installation of flight assemblies for some tests
2.6 Customer connect panel	External to stage thrust structure
location	Provide stage contractor with loads envelope for all design conditions

Table 7.4-1 (Continued)

Requirements	Recommended Interface
2.7 Aftercooling bypass line support	Support from thrust structure closing ring  Provide stage contractor with loads envelope for all design conditions
3. Structural dynamics	
Propulsion module launch to orbit by space shuttle	(1) Stage provides lateral restraint and energy dissipation
Prevent excessive dynamic loading to NERVA — particularly on nuclear subsystem and gimbal actuators  Prevent excessive dynamic loading on stage	(2) Tentative ANSC attach points at nozzle throat and NERVA upper thrust structure  (3) Design gimbal actuators for flight and accommodate launch by restraint system  Future Work:  Establish dynamic environment for:  (a) Space shuttle cargo bay  (b) Phase IV selected alternate launch mode  Define support, restraint, and possible energy dissipation  Clarify dynamic load implications on nuclear subsystem

Table 7.4-1 (Continued)

Requirements	Recommended Interface
<ul><li>4. Thrust vector control</li><li>4.1 Engine gimbal capability</li></ul>	
Deflection: ±3 deg Rate: 0.25 deg/sec Acceleration: 0.5 deg/sec <sup>2</sup>	Review periodically as the RNS configuration and mission requirements evolve
4.2 Thrust vector alignment	Pretrim prior to restart — reduces attitude transient (essential for short burns). Define tolerance.
4.3 Attitude control during aftercooling	
Minimize attitude error impact on APS	Active trimming during aftercool- ing. Define tolerance.
4.4 Gimbal actuator dynamics	
Actuator transfer function	To be determined by stage contractor
5. Propellant management	
5.1 Propellant conditions	
(1) Startup and steady state: total pressure vs. flow rate specified by curve in ANSC letter 7410:1075 July, 1970 (includes 26 psia, 0 NPSP for steady state)	(1) Satisfactory - permits autogenous startup  Reduce steady state require- ment to 22 psia, 0 NPSP: stage weight savings of 2,400 lb
(2) Malfunction Mode: requires 2 psia increase of total pressure	(2) MDAC design based on no increase in total pressure—avoids 1,100 lb penalty  Revise malfunction mode requirement to no increase in total pressure

Table 7.4-1 (Continued)

Requirements	Recommended Interface
(3) Aftercooling: not specified, but originally was identical to steady state requirements	(3) Saturated liquid — avoids a pressurization system and >1,000 lb penalty  Permit mixed phase or vapor — would permit reduction of gaseous residuals (>2,800 lb)
5.2 Pressurant demand	
Steady state	0.58 lb/sec
Peak: during propellant tank	5.58 lb/sec
bootstrap prepressurization	Review peak demand as operations evolve
5.3 Thrust ramp	
Thrust hold at throttle point	(1) Integrate propellant settling with NERVA startup ramp
	(2) Stage commands to hold thrust at throttle and resume thrust buildup
	Future Work:
	Orbital experiments on propellant settling
5.4 Feed ducts	
Spacing	Acceptable — a tank sump is not required, and duct spacing does not affect LH <sub>2</sub> residual

Table 7.4-1 (Continued)

Require	ements	Recommended Interface
		Future Work:
		(1) Optimize pump spacing for radiation shielding
		(2) Review type of flexible element — stage contractor considers untied bellows unreliable
Coupling to st	age	Ground assembly only
Seal		Dual seal flange (metallic seal) with leak detection port — common throughout stage
		Flange location below PSOV or welded connection would reduce leakage into HPI
Thermal isola	ation of tank	(1) Stage HPI extend > 2 ft below PSOV, and possibly to turbopump
		HPI layup on flexible ducting is not state-of-the-art
		(2) Install duct HPI integral with tank blanket
	Evaluate alternate locations of PSOV and flange to accommodate HPI installation	
5.5 Other ducts		
Coupling, sea	al, and thermal	Analogous to feed duct
5.6 Customer con	nnect panel	
Stage supplied tank to panel; via ANSC coo	d ducts from aftercooling ldown module	Engine ducting shall absorb deflections below panel

Table 7.4-1 (Continued)

Requirements	Recommended Interface
5.7 Propellant cleanliness	
Limit erosion, contamination, and damage: ANSC used MIL-STD-1246A, Level 1,500; in addition, ANSC limits particulate matter accumulation to 220 gm	Stage will filter particles exceeding 25 microns  Review need for stringent ANSC cleanliness requirement
6. Feed system conditioning	
Provide saturated liquid in active portion of feed system prior to run tank refill and NERVA startup	Integrated stage/NERVA chilldown system as per MDAC concept: stage ducting to PSOV and PDKV for closed loop
	Future Work:
	(1) Review system requirements
	(2) Orbital experiments on zero-g boiling
7. External disk shield	
7.1 Baseline criteria	
10 rem to payload	2,900 lb, 3 zone
Payload attentuation = 3	Configuration/shield optimization
4.5° gimbal deflection	for new RNS concepts (alternative launch vehicles)
7.2 Alternate criteria:	
Same as above but with no payload attentuation factor	5,700 lb, 4 zone  Configuration/shield trade studies for all concepts

Table 7.4-1 (Continued)

Requirements	Recommended Interface
8. Astrionics and NDICE interfaces	
8.1 NERVA power level and conditioning	
Full thrust:	(1) Supplied by stage
2.3 kw nominal, 3.5 kw peak	Refine NERVA power requirements
Aftercooling:	(2) 28 ±4 vdc and inverters provided by stage
0.2 kw nominal (CCM), 1.0 kw peak	(3) Voltage reference by each contractor.
8.2 Power Source	
Stage + NERVA:	Supplied by stage. Baseline
317 kw-hr/round trip 1.2 kw nominal	system: fuel cells and secondary batteries, 785 lb total
8. 3 Data Management	
NERVA instrumentation monitored by NDICE	(1) Stage supplied serial data bus terminals dedicated to NDICE located at CCM and forward of run tank
	Establish NDICE traffic rates (0.5 $\times$ 10 <sup>5</sup> bits/sec for stage)
	(2) NDICE digitize to 10 bits
	(3) Hardline backup for EDS
Autonomous NDICE processor	Communicate with RNS processor via data bus
	Establish NDICE processor requirements
	Evaluate processor integration (2.5 $\times$ 10 <sup>5</sup> ops/sec for stage)

Table 7.4-1 (Continued)

Requirements	Recommended Interface
Transmission to ground	Stage compression and formatting of all data
8.4 Control	
NERVA control by NDICE	(1) Gimbal actuator control from stage N&G
	(2) Stage commands to NERVA include start, shutdown, hold thrust at throttle point, resume thrust buildup, etc.
	Establish command repertoire and format
	Evaluate feasibility of Isp trim signal
	(3) NDICE provide stage with continuous prediction of after-cooling impulse to permit use of heuristic algorithm by stage N&G
	Evaluate control of aftercool-ing impulse
	Evaluate performance sensitivity to impulse tolerance
Commands	(1) Stage supplied serial data bus terminals dedicated to NDICE located at CCM and forward of run tank
	(2) NDICE supply control logic encode and decode
	(3) Hardline backup for EDS

Table 7.4-1 (Continued)

Requirements	Recommended Interface
8.5 Cable and Connections 3,000 lines	<ul> <li>(1) Flat conductor and ribbon cable</li> <li>(2) Polyimide insulation</li> <li>(3) Connectorless terminations</li> </ul>