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NUCLEAR SHUTTLE SYSTEMS DEFINITION STUDY PHASE III

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PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
UNDER CONTRACT NAS8-24715
MSCF DRL-197, LINE ITEM 3

LMSC
SPACE SYSTEMS
DIVISION

FINAL REPORT

VOLUME VIII

RNS TEST PROGRAM REQUIREMENTS-NRDS

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA

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FOREWORD

This report presents the results of the Nuclear Shuttle Systems Definition Study, Phase III performed by the Lockheed Aircraft Corporation under Contract NAS 8-24715. This documentation represents the submittals identified under MSFC DRL-197, Line Items 3, 5, 6 and 7. This phase of the subject study was performed under the technical direction of Mr. C. C. Priest, PD-SA-P, George C. Marshall Space Flight Center.

The report is published in a total of eight volumes:

Volume I	Executive Summary
Volume II	Concept and Feasibility Analysis
Part A	System Evaluation and Capability
Part B	Baseline System Definition
Part C	Systems Engineering Documentation
Volume III	Program Support Requirements
Volume IV	Cost Data
Volume V	Schedules, Milestones, and Networks
Volume VI	Reliability and Safety Analysis
Volume VII	RNS Tank Pressurization Analyses
Volume VIII	RNS Test Program Requirements - NRDS

The Lockheed study manager was Mr. C. D. McKereghan, Dept. 69-01, Space Systems Division of Lockheed Missiles and Space Company.

The principal contributors to the performance of this study were:

Mr. F. Friedlaender	Systems Analysis
Mr. C. V. Hopkins	Development Planning
Mr. P. I. Hutchinson	Mission Capability and Flight Safety
Mr. C. E. Vivian	Operating and Development Requirements
Mr. B. G. Wong	Systems Design

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Section 1

INTRODUCTION

This report presents the overall test requirements for the Reusable Nuclear Stage/NERVA integrated systems testing at the Nuclear Rocket Development Stations (NRDS), Jackass Flats, Nevada. The intent of this activity was to provide direct support to MSFC in their participation in the preliminary engineering and design of the Engine/Stage Test Stand (E/STS-2) complex at NRDS. As the final RNS design configuration has not been selected, major emphasis was directed toward evaluating the impact on facility design and operation as related to the various candidate concepts. Unique test stand requirements related to specific configurations were identified. Most notable is the impact on the various test article envelopes and weights on design of the test stand umbilical tower, support, and fluid requirements.

The various concepts considered were developed by McDonnell Douglas (MDAC), North American Rockwell (NAR), and Lockheed Missiles & Space Company (LMSC) in concurrent Phase A activities for the systems difinitions of the Reusable Nuclear Shuttle. Basically, the concepts used in the development of these requirements are as follows:

- McDonnell Douglas -- Hybrid Tank Concept, as presented in "Second Interim Briefing, Nuclear Shuttle Definition Study, Phase III, MDC G0747, dated 16 Dec 1970, Contract NAS 8-24714
- North American Rockwell -- Single Tank 8-Deg. Half-Angle, as described in "Second Interim Revision - Phase III," PDS 70-644, dated 16 Dec 1970, Contract NAS 8-24716
- Lockheed Missiles & Space Company
  - a. Single-Tank (15-Deg Angle Cone) Concept, as reported in Vol. III, "Nuclear Flight System Definition Study, Phase II," LMSC-A986223, dated 1 May 1970
  - b. "Second Interim Briefing, Phase III," LMSC A981482, dated 17 Dec 1970, Contract NAS 8-24715

Previous test facility support analyses, documented in LMSC-A682848, "Stage Test Stand Nuclear Environmental Analysis" and LMSC-681841, "NGTM, Its Ground Support Equipment and NRDS Facilities Requirements," were reviewed for applicability to the previously discussed reusable shuttle concepts. Specific analyses from these prior studies relating to in-flight environment simulation, GTM design, test operational sequences, service system requirements, stage test requirements, instrumentation and control, GSE, radiation and thermal environment during and after test, personnel access, remote handling requirements, and interface definitions were reviewed and utilized wherever they were applicable.

The requirements and descriptions developed in this activity are presented in six sections. Section 2 describes the NRDS test program, which includes hot firing systems testing. These tests will demonstrate that the integrated propulsion systems are compatible and fully qualified for development flight operations. This test program covers NRDS tests of the propulsion systems under normal and malfunction operating modes in a restrained vertical downward firing configuration.

Section 3 describes the various study contractor's (NAR, LMSC, MDAC) basic RNS envelopes which were used to estimate to NRDS test article weights using these basic configurations and previously established criteria from LMSC-A681841, "Nuclear Ground Test Module, Its Ground Support Equipment, and NRDS Facilities Requirements." Functional systems schematics are also presented.

The ground support equipment necessary to support the servicing of the various RNS test article concepts in pre-test, test, and post-test operations is presented in Section 4. Basically, this equipment was developed under the previously referenced study. This equipment was reviewed and revised to incorporate any new requirements.

Section 5 describes the real-time quick-look, bulk data acquisition and processing requirements for the RNS NRDS ground test program. The measurements to be taken for the purpose of controlling the tests and to be obtained to determine performance were developed and categorized. Tabulation of these measurements by location (according to umbilical) and frequency response rates are also presented.

Section 6 describes the basic fluid requirements for servicing the various RNS concepts. The configurations reviewed were the NAR 8-deg half-angle conical bottom tank, the MDAC Class 1 Hybrid and the LMSC modular and single tank (15-deg half-angle cone) concepts. In addition to total fluid requirements, separate calculations and requirement for both the MDAC Hybrid and LMSC Propulsion Module concepts were performed as final test philosophy might require only the propulsion module as a test article in the NRDS test program.

Section 7 defines the nuclear flight environments for the NAR, MDAC, and LMSC concepts, NRDS environment simulation requirements and philosophy, and the post-test residual activation environment.

The initial delivery hardware flow, transportation, and handling requirements are presented in Section 8. This section describes the basic philosophy for fabrication and assembly of the large 33-ft tank concepts and the relatively small 15-ft diameter tank concepts. The sequence of events during this initial delivery is presented in functional flow diagrams. In addition, the transporter, handling fixtures, and support cranes are described.

Section 2

NRDS TEST PLAN

2.1 INTRODUCTION AND SUMMARY

This test program includes hot firing systems testing at NRDS to demonstrate that the propulsion systems are fully qualified for development flight operations. The test program covers NRDS tests of propulsion systems in a restrained, vertical, downward firing configuration. The basic tank structure will be of heavier than flight weight gages and will be designed to withstand the test environment and handling loads. The groundrules used in the development of this test program are as follows:

- o NERVA engine development and prequalification for flight tests will have already been accomplished.
- o All vehicle components and subsystems will have been previously qualified for flight.
- o Only those tests that require a hot firing NERVA engine (or are required for baseline data) will be conducted at NRDS.
- o A test article assembly, modification, and maintenance facility will be provided at NRDS.

To satisfy all of the NRDS test objectives the basic plan has been divided into 4 test series. These test series are separated into a number of runs as follows:

(1) Test Series 1 - Baseline and Compatibility Demonstration (1 run)
(2) Test Series 2 - Normal Mode Demonstration (4 runs)
(3) Test Series 3 - Malfunction Mode Demonstration (5 runs)
(4) Test Series 4 - Flight Readiness Demonstration (4 runs)

The specific variables and functions that will be controlled for each test series are presented in matrix form in various tables discussed in the description of each test series. Test profiles are presented in terms of mass flow, pressures, total impulse, thrust, etc. The sequence of events and relationship of these parameters are shown in Figs 2-1 and 2-2.

2.2 OBJECTIVES

The overall goals of the NRDS test program for the RNS are to obtain an operating history of the integrated propulsion system, determine if there are any undiscovered or unpredicted interactions, and to increase the level of confidence that the RNS flight test will be successful. To obtain these goals, the following primary test objectives are established:

A. Operational

(1) Demonstrate adequacy of flight standard and emergency operating procedures.
(2) Demonstrate restart operation of integrated vehicle.
(3) Demonstrate extended duration operation of integrated vehicle.
(4) Demonstrate integrated operation under pulse-cooling demonstration.
(5) Demonstrate integrated operation under multiple-burn demonstrations.
(6) Demonstrate integrated prelaunch checkout and flight operational sequence.
(7) Obtain reliability data on all equipment and contribute to reliability confidence level growth.
(8) Demonstrate assembly and re-assembly capability of vehicle/engine interface.
(9) Verify predicted results from cold flow tests and analytical studies.
(10) Determine the effects of combined radiation/cryogenic environments on vehicle material and components.
(11) Provide launch crew and ground maintenance personnel training.
(12) Verify launch peculiar ground support equipment performance.

B. Propellant Management

(1) Demonstrate propellant feed system chilldown procedures.
(2) Demonstrate the capability to deliver LH_2 at required pump inlet conditions including temperature, pressure, liquid/vapor ratio, etc. during all phases of operation.
(3) Demonstrate control of propellant vortexing during dynamic, hot-firing conditions.
(4) Determine propellant temperature/pressure profiles during test.
(5) Verify liquid-level sensing and control system operation and accuracy.
(6) Determine nuclear heating of propellant during NERVA engine operation.

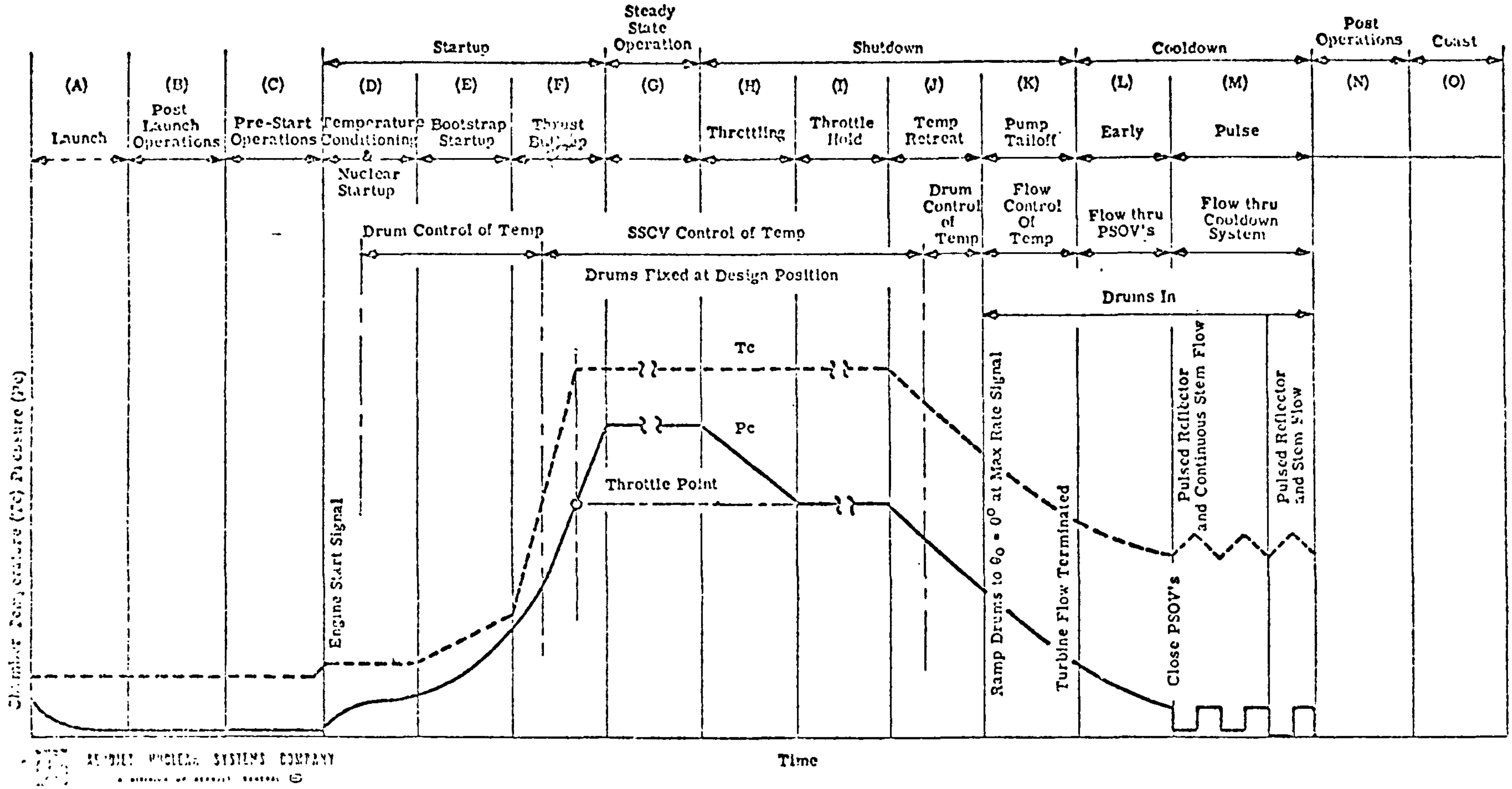


Fig 2-1 - NERVA Engine Operation Phases

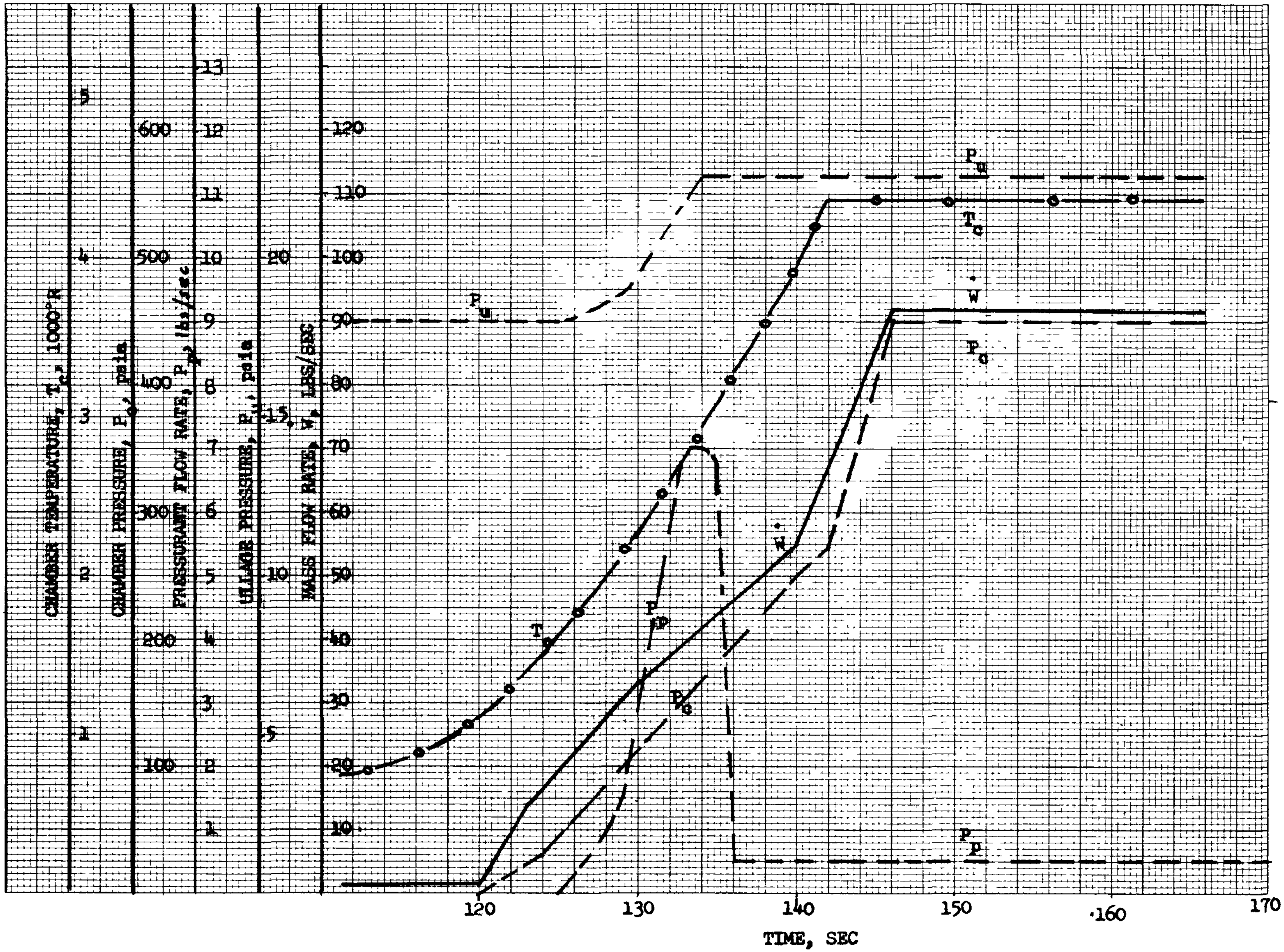


Fig. 2-2 RNS Start Transient

C. Astrionics

(1) Verify electrical subsystem operation.
(2) Verify safety subsystem operation.
(3) Verify telecommunication subsystem operation.
(4) Demonstrate guidance and control subsystem operation integrated with engine gimbal subsystem.
(5) Verify integrated engine programmer operations.
(6) Verify adequacy of the data management system including on-board checkout after succeeding hot tests.

D. Engine

(1) Demonstrate engine chilldown and startup integrated operation.
(2) Demonstrate engine shutdown transient integrated operation and cooldown.
(3) Verify engine/stage interface operation.
(4) Verify engine gimbaling procedures.
(5) Demonstrate transitions to and operations in the malfunction mode and the emergency mode.

E. Pressurization and Venting System

(1) Demonstrate pressurization and feed system operation.
(2) Demonstrate the pressurization system ability to maintain the required pump suction head (NPSH).
(3) Demonstrate the ability to perform in the selected start mode.
(4) Determine optimum system performance characteristics.
(5) Demonstrate flight vent system operation.
(6) Demonstrate ground vent system operation.

F. Component Control

(1) Verify capability of the component (valves, etc.) control system to provide integrated system operations.
(2) Verify response time for component activation.

2.3 OPERATIONAL PLAN SUMMARY

The Test Control Center will be the program control point from which all cold-soak, cold-flow, prefiring, captive-test firing, and post-firing tests of the integrated system will be directed, controlled, and monitored. In addition, when the test article and/or engine transporter enters the E/STS area, the control center will assume responsibility for monitoring transporter activites.

The test article without engine will be brought from its preparation area to the test stand via the transporter, erected, and placed on the test stand by a mobile crane as described in detail in the Transportation and Handling Section. All umbilical connections will be made and checked out. At this juncture, the engine will be transported to the test stand by the EIV and aligned and mated with the propellant tank thrust structure. The engine poison system will be removed, the duct cover retracted remotely, and the remainder of the facility prepared for test as required. If an additional visual engine check is required after or during checkout of that system, the engine compartment will be entered and the inspection and/or minor repairs accomplished. In the event a defective component is detected on the Test Article, minor maintenance will be performed on the stand if radiation levels permit. However, major maintenance will require replacement of the engine poison system, disconnect of the umbilicals, removal of the engine, which is returned to E-MAD, and removal of the test article from the stand. In this event, the environmental enclosure will be removed and the propellant tank to the MAM building.

After a successful checkout of all facility, GSE and test article systems, purging operations will be begun. Continuous gaseous helium purge will be introduced into the area between the stage skirt and the tank bottom to ensure that GH_2 does not accumulate. At the same time, the area between the outer circumference of the stage's skirt and the facility shield will be purged continuously with GN_2 to prevent air from entering into the engine compartment.

The stage will be filled with LH_2 and the test program will commence. After the test has been completed, the reactor will be shut down and the cooldown period will begin. Post-firing tests will be conducted during cooldown, which requires from 2 to 17 days. During the early phases of the propulsion module cooldown period, a portion of the nuclear measurements dosimetry will be removed remotely.

Some of the NERVA cooldown will be accomplished by the RNS Test Article; however, the bulk of the fluids required for engine cooldown will be supplied by the facility. The return of the engine transporter will be timed to coincide with the proper cooldown cycle. Once the engine has been removed from the test stand, the remaining nuclear foils and dosimetry will be removed from the tank bottom. Decontamination operations will begin and all equipment in the Test Control Center will be readied for the next test.

2.4 TESTING SEQUENCE AND DESCRIPTION

The initial integrated systems test program will include four test series using a single NERVA engine as follows:

- o Test Series 1 - Baseline and Compatibility Demonstration
- o Test Series 2 - Normal Mode Demonstration
- o Test Series 3 - Malfunction Mode Demonstration
- o Test Series 4 - Flight Readiness Demonstrations

2.4.1 Test Series 1 - Baseline and Compatibility Demonstration

This test series will be a liquid hydrogen cold soak and cold flow using an engine simulator instead of the NERVA engine. The main purpose of this test series is to obtain baseline data in the insulation system performance and to validate the NRDS test complex and test article in preparation for hot tests. The overall test objectives for this include:

- o Verify that the facility is functionally ready to begin hot systems tests.
- o Determine the compatibility of the test article, the facility, GSE and operational procedures.
- o Verify that the test article is functionally ready to begin hot systems tests.
- o Obtain baseline data on the test article; such information as boiloff rates, pressure drop vs flow rate constants, temperature profiles, component response times, etc.

Although these tests are not intended to satisfy any specific primary test objectives, they will provide confidence and data that will support the attainment of specific test objectives, as follows:

A.7 Obtain reliability data on all equipment and contribute to reliability confidence growth.

A.9 Verify predicted results from cold flow tests and analytical studies.

A.10 Determine the effects of combined radiation/cryogenic environments on vehicle material and components.

A.11 Provide launch crew and ground maintenance personnel training.

A.12 Verify launch crew and ground maintenance personnel training.

B.1 Demonstrate propellant feed system chilldown procedures.

B.2 Demonstrate the capability to deliver LH_2 at required pump inlet conditions including temperature, pressure, liquid/vapor ratios, etc., during all phases of operation.

B.3 Demonstrate control of propellant vortexing during dynamic, hot-firing conditions.

B.4 Determine propellant temperature/pressure profiles during test.

B.5 Verify liquid-level sensing and control system operation and accuracy.

B.6 Determine nuclear heating of propellant NERVA engine operation.

E.6 Demonstrate ground vent system operation.

F.1 Verify capability of the component (valves, etc.) control system to provide integrated system operations.

F.2 Verify response time for component activation.

Test Series 1 - Operations

Pre-test Operations. After partial checkout of the assembled test article less engine, it is transported to the test stand and erected in a vertical attitude. Facility and GSE connections are made to the module. After assembly and checkout at E-MAD building, the engine is transported to the test stand and mated to the test article. At this point in the pretest operations sequence, the test article is in a simulated launch configuration, and procedures in many instances are similar to preflight activities at the launch site. The following sequential operations will incorporate prelaunch procedures and be evaluated to the fullest extent practical:

- o Functionally check facility and GSE support systems.
- o Functionally check Test Article vent, pressure, and pneumatics systems.
- o Functionally check engine.
- o Functionally check electrical and electronic systems (communications, guidance, power, programmer, etc.)
- o Leak-check tank, pressure, vent, and engine systems with helium mass spectrometer.
- o Check out test article data acquisition and data channel systems calibrations.

The run sequence will start with the filling of the propellant tank to the full test article leading and held for a period not less than 2 hours. This 2-hour cold soak period will demonstrate thermal compatibility of all systems as well as provide propellant boiloff performance. Following the cold soak period the propellant will be expelled from the test article tank at simulated engine full flow rate. This cold flow phase of the run will include expulsion with facility LH_2 make up simulating multitank vehicle operation followed by single-tank expulsion to run out. RNS test article electrical and pressurization requirements will be supplied by GSE.

A detailed inspection of the tank will be performed at the conclusion of the test to ascertain structural and thermal integrity of all components and the tank. All discrepancies will be analyzed and explained and/or understood. Portions of the run or the complete run may be repeated as necessary.

Specifically the following operations will be accomplished:

- o Functional check of test article, components, subsystems and systems.
- o Helium leak checks of propellant tank, propellant transfer/feed systems, and pressurization systems.
- o Continuity and load checks of electrical controls of vehicle and GSE systems.
- o Calibrations and functional checks of instrumentation, data acquisition, and monitoring equipment.

- Propellant systems pretransfer purging to eliminate condensables and reactive gases (N_2 & O_2) from internal systems that will contain LH_2.
- Load test article tankage with LH_2 per loading techniques simulating launch loading.
- Two hours cold soak of the vehicle with a full tank of LH_2 to demonstrate propellant tank and insulation integrity, permitting data acquisition on steady-state boil-off conditions. During this test, the LH_2 topping control by facility services will be observed, as will the test article and the ground pressurization and vent system.
- LH_2 expulsion - multi-tank simulation.
- LH_2 expulsion - single tank to run out.
- Propellant systems post-test purging-inerting to eliminate combustable gas from tank internal systems (GH_2).
- Helium leak check to verify no leakage occurred due to thermal cycle.
- Visual inspection to check for such items as insulation system damage.
- Data reduction/analysis/review and discrepancy analysis.

2.4.2 Test Series 2 - Normal Mode Demonstration

The primary purpose of this test series is to verify the compatibility of the integrated NERVA and test article and to discover any latent interaction between the systems. As such, it is desirous to cycle the RNS/NERVA systems as frequently as possible to obtain data in the critical stage operational phases, i.e., startup and shutdown transients, cool down. During these critical phases the propulsion system components, i.e., feedline valves, pressurization valves and regulators etc., are cycling and fluids (LH_2 propellant and GH_2 pressurization) are required in increasing and decreasing quantities at the interfaces, as shown in Fig 2-2. These tests will verify the NERVA and RNS systems capability to perform together as required.

The overall test objectives for this series include the following:

- Demonstrate programmable total impulse control
- Demonstrate autogenous (bootstrap) tank pressurization
- Determine fluid/thermal characteristics
- Verify instrumentation and data acquisition

The applicable specific detailed test objectives are as follows:

A.2 Demonstrate restart operation of integrated vehicle.

A.4 Demonstrate integrated operation under pulse-cooling demonstration.

A.5 Demonstrate integrated operation under multiple-burn demonstrations.

A.6 Obtain reliability data on all equipment and contribute to reliability confidence level growth.

A.8 Demonstrate assembly and re-assembly capability of vehicle/engine interface.

A.9 Verify predicted results from cold flow tests and analytical studies.

A.10 Determine the effects of combined radiation/cyrogenic environments on vehicle material and components.

A.11 Provide launch crew and ground maintenance personnel training.

B.1 Demonstrate propellant feed system chilldown procedures.

B.2 Demonstrate the capability to deliver LH_2 at required pump inlet conditions including temperature, pressure, liquid/vapor ratios, etc., during all phases of operation.

B.3 Demonstrate control of propellant vortexing during dynamic, hot-firing conditions.

B.4 Determine propellant temperature/pressure profiles during test.

B.5 Verify liquid-level sensing and control system operation and accuracy.

B.6 Determine nuclear heating of propellant during NERVA engine operation.

C.5 Verify integrated engine programmer operations.

D.1 Demonstrate engine chilldown and startup integrated operation.

D.2 Demonstrate engine shutdown transient integrated operation and cooldown.

D.3 Verify engine/stage interface operation.

E.1 Demonstrate pressurization and feed system operation.

E.2 Demonstrate the pressurization system ability to maintain the required pump sunction head (NPSH).

E.3 Demonstrate the ability to perform in the selected start mode.

E.4 Determine optimum system performance characteristics.

E.6 Demonstrate ground vent system operation.

F.1 Verify capability of the component (valves, etc.) control system to provide integrated system operations.

F.2 Verify response time for component activation.

Test Series 2 - Operations. A definition of each run in the test series is shown in Table 2-1. As can be seen, the various runs are conducted at a variety of LH_2 saturated conditions. The pressurant requirements for each initial propellant condition is also different to satisfy the demands imposed by the NERVA for NPSH, as shown in Fig. 2-3. This test series will provide performance data in the complete spectrum of anticipation initial LH_2 saturation condition and pressurant requirements.

Each run is comprised of three continuous cycles. The steady state run times are approximations for planning purposes. The actual times are regulated by the total impulse requirements. As can be seen, the total impulse requirements vary with each cycle in a test run, but are repeated for each run. This will demonstrate that controllable and predictable integrated vehicle performance can be obtained.

The stage will provide all cooldown fluids during the test run. These cooldown periods will occur at the end of each cycle and will last for approximately 200 seconds prior to recycling to steady state condition. After the last cycle cooldown test period, the facility will provide the proper cooldown services. A run schedule for test series 2 is shown in Table 2-2.

Thrust vector control is verified on runs 2 through 4 by introducing error signals to the guidance system which results in thrust chamber gimbal action.

Runs 1, 2 and 3 will simulate multitank operation by the addition of LH_2 into the test article tank from a facility source. Run 6 supplies LH_2 to the engine from only the test article tank and is operated to run out simulating a single vehicle tank operation.

Table 2-1

TEST SERIES 2 - MATRIX
NORMAL OPERATING MODE

Run No.	P_{sat}(psia)	P_u(psia)	Time (sec)	Total Impulse (10^7 lb-sec)	W (lb/sec)	Thrust (lb)	Gimbal
1	18	22.5	200	1.5	91.7	Full	No
	18	22.5	100	0.75	91.7	Full	No
	18	22.5	70	0.5	91.7	Full	No
2	20.0	23.0	200	1.5	91.7	Full	Yes
	20.0	23.0	100	0.75	91.7	Full	
	20.0	23.0	70	0.5	91.7	Full	
3	22.5	22.5	120	-	~ 2	Low	Yes
	22.5	24.0	200	1.5	91.7	Full	Yes
	22.5	24.0	100	0.75	91.7	Full	No
	22.5	24.0	70	0.5	91.7	Full	No
4	26.0	26.0	200	1.5	91.7	Full	Yes
	26.0	26.0	100	0.75	91.7	Full	No
	26.0	26.0	70	0.5	91.7	Full	No

2.4.3 Test Series 3 - Malfunction Mode Demonstration

The main purpose of this test series is to demonstrate the integrated operation of the NERVA and RNS systems with the NERVA engine operating in the malfunction mode, i.e., one of the two pumps fails to operate. The overall test objectives for this series are similar to those of test series two for the systems operating in imposed malfunction modes. These overall test objectives are:

- o Demonstrate programable total impulse control malfunction modes.
- o Demonstrate autogeneous (bootstrap) tank pressurization-malfunction modes.
- o Determine fluid/thermal characteristics.
- o Verify instrumentation/data acquisition.

The applicable specific and detail primary test objectives for this weries are as follows:

A.1 Demonstrate adequacy of flight standard and emergency operating procedures.

A.2 Demonstrate restart operation of integrated vehicle.

A.3 Demonstrate extended duration operation of integrated vehicle.

A.4 Demonstrate integrated operation under pulse-cooling demonstration.

A.5 Demonstrate integrated operation under multiple-burn demonstrations.

A.6 Demonstrate integrated prelaunch check out and flight operational sequence.

A.7 Obtain reliability data on all equipment and contribute to reliability confidence level growth.

A.8 Demonstrate assembly and re-assembly capability and contribute to reliability confidence level growth.

B.2 Demonstrate the capability to deliver LH_2 at required pump inlet conditions including temperature, pressure, liquid/vapor ratios, etc., during all phases of operation.

B.3 Demonstrate control of propellant vortexing during dynamic, hot-firing conditions.

B.4 Determine propellant temperature/pressure profiles during test.

Table 2-2 TYPICAL TIME LINE - TEST SERIES 2 - RUNS 1, 2, 3 & 4

EVENT	EVENT TIME, SECS	RUN ELAPSED TIME, SECS
Engine Preconditioning	120	120
Engine Boostrap) - Startup	5	125
Tank Presurization) - Startup	12	132
Thrust Buildup) - Startup	21	146
Steady State	200	346
Ramp Down) - Shutdown	4	350
Throttling & Hold) - Shutdown	30	380
Temperature Retreat) - Shutdown	11	391
Pump Tail-off) - Shutdown	~ 250	641
Cool Down	~ 250	891
2nd Cycle		
Start Up	26	917
Steady State	100	1017
Shut Down	~320	1337
Cool Down	~275	1612
3rd Cycle		
Start Up	26	1638
Steady State	70	1708
Shut Down	~330	2038
Cool Down	~300	2338
Cool Down From Facility	--	> 2338

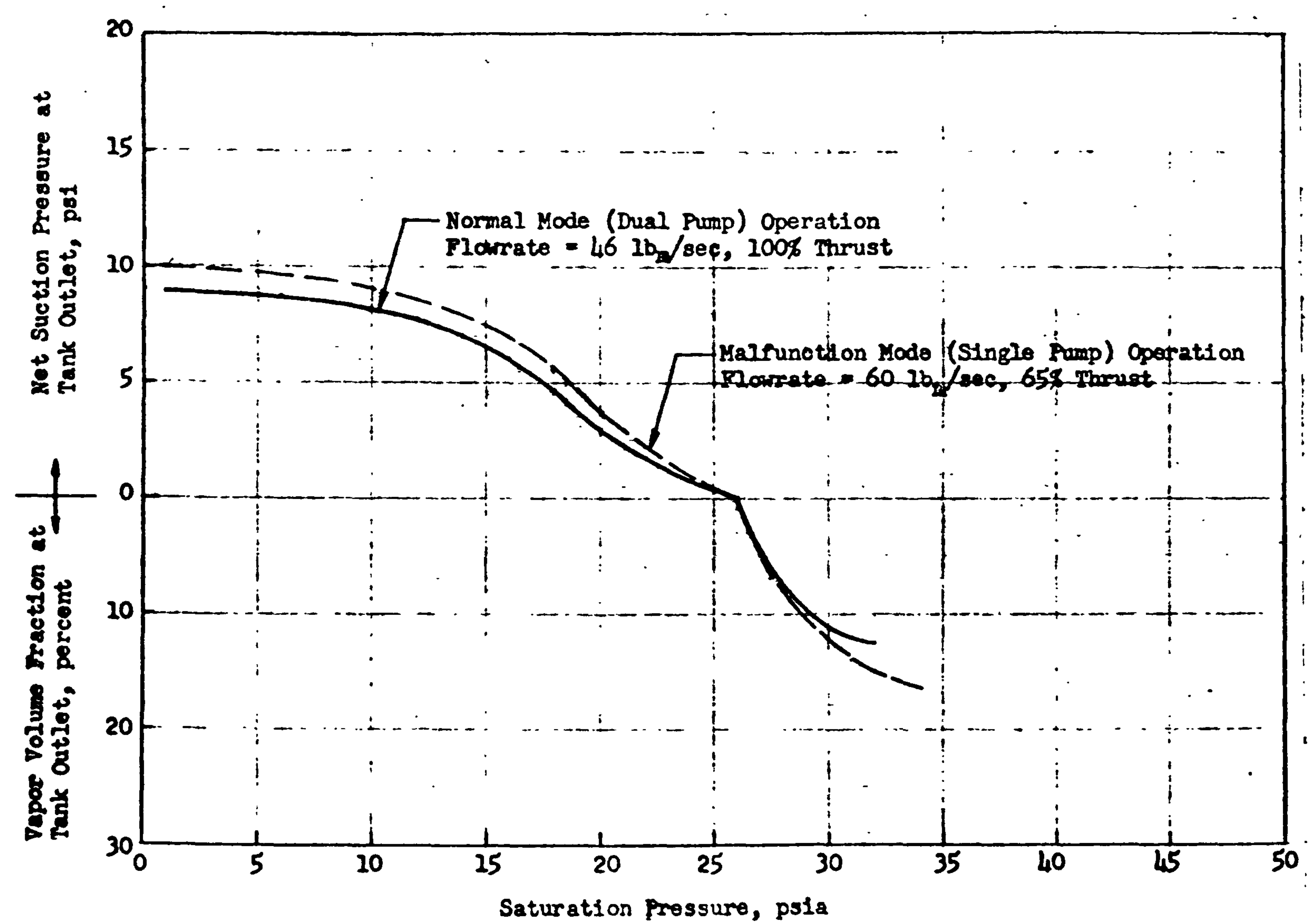


Fig. 2-3 NERVA NPSP Requirements

C.1 Verify electrical subsystem operation.

C.2 Verify safety subsystem operation.

C.3 Verify telecommunication subsystem operation.

C.4 Demonstrate guidance and control subsystem operation integrated with engine gimbal subsystem.

C.5 Verify integrated engine programmer operations.

C.6 Verify adequacy of the data management system including on-board checkout after succeeding hot tests.

D.5 Demonstrate transitions to and operations in the malfunction mode and the emergency mode.

E.1 Demonstrate pressurization and feed system operation.

E.2 Demonstrate the pressurization system ability to maintain the required pump sunction head (NPSH).

E.3 Demonstrate the ability to perform in the selected start mode.

Test Series 3 - Operations. This test series consists of five operational runs. Table 2-3 describes the characteristics of each run and run cycle required to satisfy the primary test objectives.

The significant item varied during this test series is the point of occurance of the malfunction. An analysis of the critical phases of the operating sequence results in occurrence of malfunction in the start transient and during the steady state condition being critical. For example, the first run shown in Table 2-3 experiences a failure during the early phases of startup (about 12 sec after startup begins). Full thrust is never attained, and to meet the targeting objectives the system must adjust run times, flow rates, etc. To obtain continuity, the total impulse requirements, established in Test Series 2 for each run cycle is used for these tests. A time line analysis for Test Series 3, Run 1, is shown in Table 2-4.

Run 2 of Test Series 3, Malfunction Operating Mode, will demonstrate the capability of the integrated systems to adapt to a malfunction after reaching a steady state status, i.e., flow rates will be reduced from 91 lb/sec to 60 lb/sec, thrust is reduced to 60. As shown in Table 2-3, the same targeting objectives are utilized. A time line analysis for test run is shown in Table 2-5.

Table 2-3

TEST SERIES 3 - MATRIX - MALFUNCTION OPERATING MODE

Run No.	P_{sat}, psia	P_u, psia	Time, sec	Total Impulse, 10^7 lb-sec	W, lb/sec	Thrust, lbs	Gimbal
1	18	24	310	1.5	60	65%	Yes
	18	24	125	0.75	60	65%	No
	18	24	85	0.50	60	65%	No
2	18	23→24	< 310	1.5	92 → 60	100 → 65%	No
	18	24	125	0.75	92 → 60	100 → 65%	No
	18	24	85	0.5	92 → 60	100 → 65%	No
3	22.5	24 → 25	< 310	1.5	92 → 60	100 → 65%	Yes
	22.5	24 → 25	1800	---	92 → 60	100 → 65%	No
4	26	26	< 310	1.5	92 → 60	100 → 65%	Yes
	26	26	1800	---	92 → 60	100 → 65%	No
5*	--	--	200	1.5	92	Full	No
	18	24	100	0.75	92	Full	No
	18	24	70	0.50	92	Full	No

* New or replaced engine

Table 2-4

TIME LINE - TEST SERIES 3 - RUN 1

EVENT	EVENT TIME, SEC.	RUN ELAPSED TIME SEC.
1st Cycle		0
Engine Preconditioning	120	120
Startup	20	140
Steady State	310	450
Shut Down	~250	700
Cool Down	~250	950
2nd Cycle		
Startup	20	970
Steady State	125	1090
Shut Down	~320	1415
Cool Down	~275	1690
3rd Cycle		
Startup	20	1710
Steady State	85	1795
Shut Down	330	2125
Cool Down	300	2425
Cool Down From Facility	--	> 2425

Table 2-5

TIME LINE - TEST SERIES 3 - RUN 2

EVENT	EVENT TIME, SEC.	RUN ELAPSED TIME, SEC.
1st Cycle		
Preconditioning	120	120
Start Up	26	146
Steady State	300	446
Shut Down	~250	696
Cool Down	~250	946
2nd Cycle		
Start Up	26	972
Steady State	115	1087
Shut Down	~320	1407
Cool Down	~275	1682
3rd Cycle		
Start Up	26	1708
Steady State	75	1783
Shut Down	~330	2113
Cool Down	~300	2413
Cool Down From Facility	--	> 2413

The important parameters in Runs 3 and 4, Test Series 3, include a long duration run in the malfunction mode.

The malfunction will occur after steady state conditions are established in each test run cycle. Table 2-6 presents a typical time line analysis for Runs 3 and 4. These runs will demonstrate the capability of the integrated systems to perform in the malfunction mode for an extended period.

Run 5 will demonstrate system failures during the shutdown transients. A time line analysis for this run is shown in Table 2-7. For all runs total impulse will be programmed for a value identical to Test Series 2.

2.4.4 Test Series 4 - Flight Readiness Demonstration

The purpose of this test series is to demonstrate the flight readiness of the integrated systems for the flight test program. The module systems and subsystems will be exactly the same in design and production as those of the flight article (LH_2 tank, skirts and insulation will be the only exception). All vehicle pretest operations will simulate prelaunch operations. Checkout activities will only be to the level planned for prelaunch checkout. The overall test objectives for this series are as follows:

- o Demonstrate that integrated systems operate as predicted under typical flight mission programming.
- o Verify that operating procedures (prelaunch checks, LH_2 loading, calibration, etc.) are adequate for flight operation.
- o Demonstrate in flight engine replacement.

<u>Test Series 4 - Operations</u>. The parameters of the specific test runs are depicted in Table 2-8. Test Runs 1 and 2 are identical except at different LH_2 saturated conditions $P_{sat.}$ Test Run 3 is identical to Test Run 1 except that after Test Run 2 the engine is removed and a new or same engine is replaced, the integrated systems are checked out and a full extended duration run is conducted. Test Run 4 provides the final demonstration of the integrated systems performance in a malfunction mode. Time line analyses are presented in Tables 2-9 and 2-10.

Table 2-6

TYPICAL TIME LINE - TEST SERIES 3 - RUNS 3 & 4

EVENT	EVENT TIME, SEC.	RUN ELAPSED TIME, SEC.
1st Cycle		
Preconditioning	120	120
Start Up	26	146
Steady State	300	446
Shut Down	~ 250	696
Cool Down	~ 250	946
2nd Cycle		
Start Up	26	972
Steady State	1800	2772
Shut Down	~ 350	3122
Cool Down	~ 478	3600
Cool Down From Facility	---	> 3600

Table 2-7

TIME LINE - TEST SERIES 3 - RUN 5

EVENT	EVENT TIME, SEC.	RUN ELAPSED TIME, SEC.
<u>1st Cycle</u>		
Preconditioning	120	120
Start Up	26	146
Steady State	200	346
Shut Down	250	596
Cool Down	250	846
<u>2nd Cycle</u>		
Start Up	26	872
Steady State	100	972
Shut Down	320	1292
Cool Down	275	1567
<u>3rd Cycle</u>		
Start Up	26	1593
Steady State	70	1663
Shut Down	330	1993
Cool Down	300	2293
Cool Down From Facility	---	> 2293

Table 2-8

TEST SERIES 4 - MATRIX

FLIGHT READINESS DEMONSTRATION

Run No.	P_{sat}(psia)	P_u(psia)	Time (sec)	Total Impulse (10^7 lb-sec)	W (lb/sec)	Thrust (lb)	Gimbal
1	18	22.5	1800	16.5	91.7	Full	Yes
2	20	23	1800	16.5	91.7	Full	Yes
3*	18	22.5	1800	16.5	91.7	Full	Yes
4	20	24	2400	16.5	92 - 60	100 - 65%	Yes

* New or Replaced Engine

Table 2-9

TYPICAL TIME LINE - TEST SERIES 4 - RUNS 1, 2 and 3

EVENT	EVENT TIME, SEC.	RUN ELAPSED TIME, SEC.
Begin Chilldown	--	0
Preconditioning	120	120
Start Up	26	146
Steady State	1800	1946
Shut Down	~ 250	1996
Cool Down	~ 400	2396
Cool Down From Facility	---	> 2396

Table 2-10

TIME LINE - TEST SERIES 4 - RUN 4

EVENT	EVENT TIME, SEC.	RUN ELAPSED TIME, SEC.
Begin Childown	--	0
Preconditioning	120	120
Start Up	26	146
Steady State	~ 2400	2546
Shut Down	~ 250	2796
Cool Down	~ 400	3196
Cool Down From Facility	---	> 3196

Section 3
TEST ARTICLE DESCRIPTION

3.1 INTRODUCTION AND SUMMARY

The objectives of this task were to review the latest RNS configurations recommended by the three study contractors and to develop the criteria and material thicknesses required for "battleship" test articles for NRDS hot firing tests. Considerable work has been previously accomplished for development of a 33-foot diameter test article (see Ref. 3-1). This report utilizes some of the basic material and criteria data from the Ref. 3-1 report to develop each test article configuration from the basic configuration detailed in Ref. 3-2, 3-3, and 3-4 reports. The data output is to provide sufficient information for facility planning activities at NRDS/E/STS-2 complex, but is limited in many areas to avoid specific designs subject to study program changes or where detail study contractor data is still lacking.

Three basic configurations were reviewed for this study. The following summarizes the dimensions and general flight vehicle RNS configuration used for this study.

The NAR configuration (Fig. 3-1) was derived from the Ref. 3-2 report.

For the LMSC test vehicle shown in Fig. 3-2, only the propulsion module is planned for hot firing test series use. The hot firing test duration will either be limited by the propulsion module LH_2 capacity or will be replenished from facility storage during the lengthened test runs. This configuration was based on data from the Ref. 3-3 report.

It is possible that the MDAC test article shown in Fig. 3-3 configuration could include just the small propulsion module as the LMSC configuration; however, the current design includes both tanks. These data were derived from the Ref. 3-4 report.

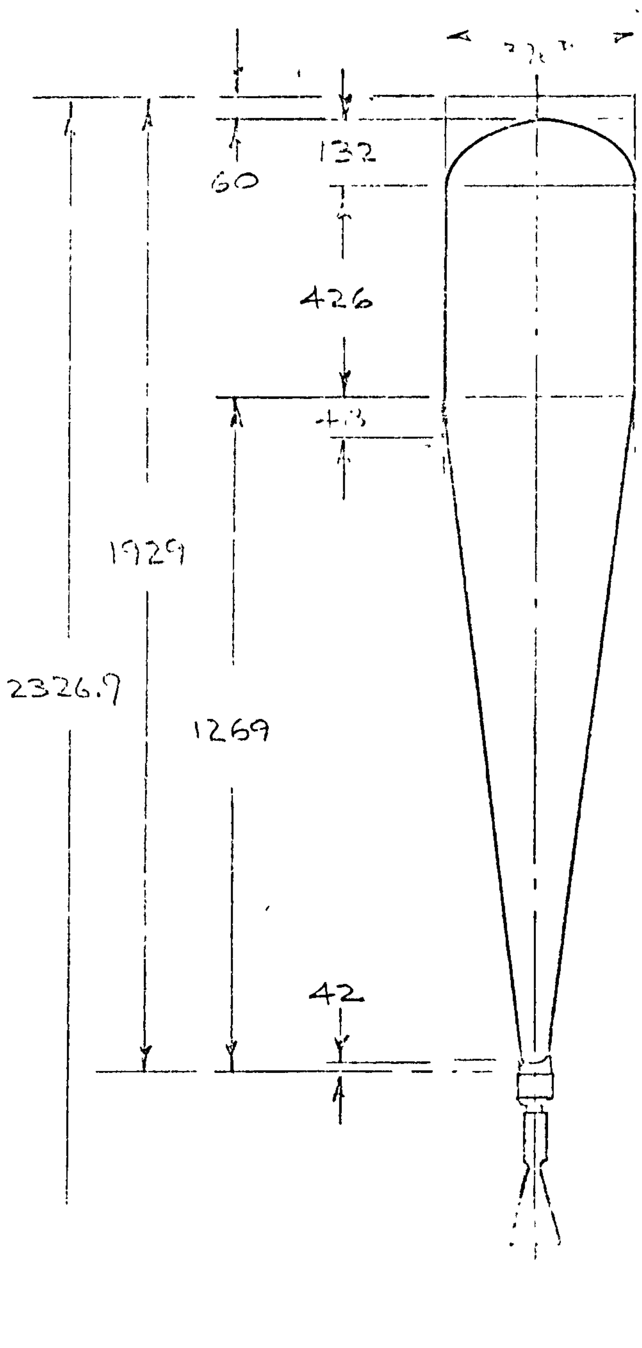


Fig. 3-1 NAR Single Tank Concept - 8-deg. Half Cone Angle
25-in. Cap Dome Radius

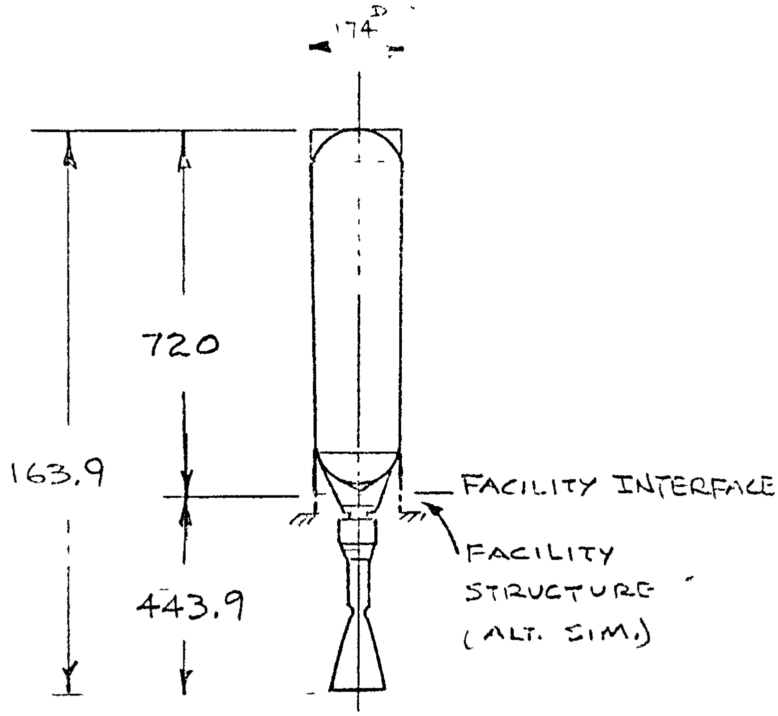


Fig. 3-2 LMSC Propulsion Module

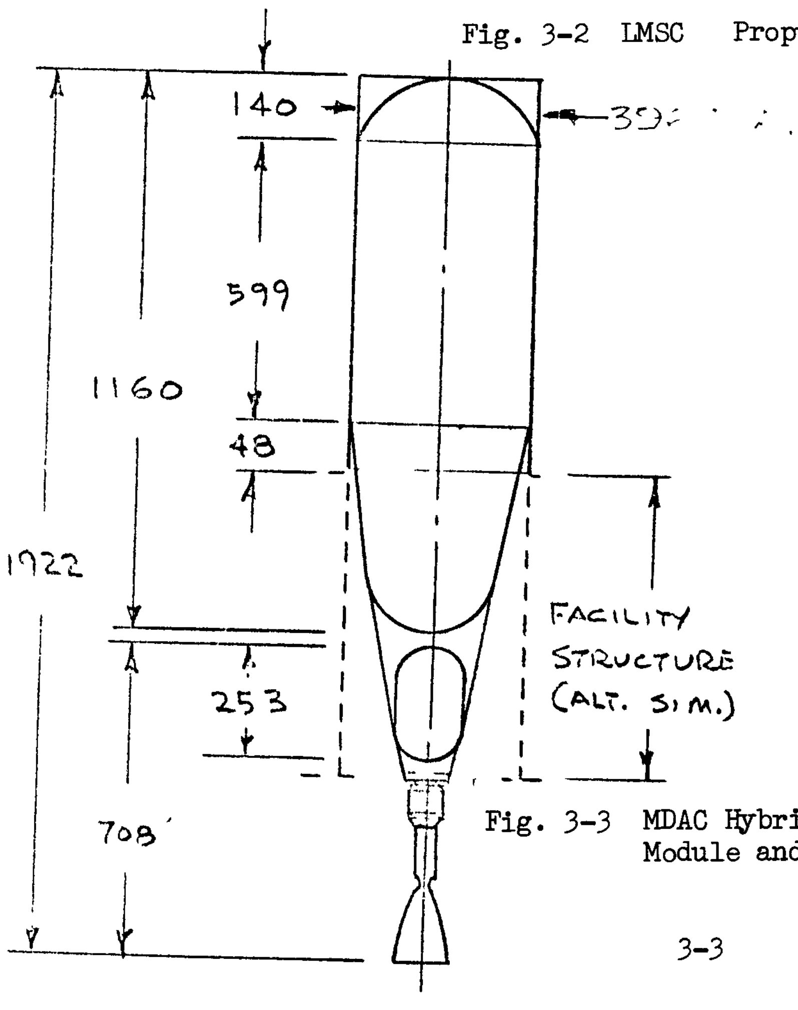


Fig. 3-3 MDAC Hybrid RNS - Propellant Module and Propulsion Module

3.2 MATERIALS

The basic material considered for fabrication of the test article structural components was aluminum. Various aluminum alloys are capable of handling cryogenic fluids, and most aluminum alloys have a residual activation life span significantly shorter than most materials used as cryogenic containers, such as stainless steel. For these two significant reasons, an aluminum alloy was used wherever possible. Stainless steel alloys were used only for those components that, by their configuration, environment, or availability, preclude the use of other materials. All structural components are fabricated from the selected aluminum alloy.

Four aluminum alloys were considered for fabrication of the test article structural components: 2219-T87, 5083-H 113, 5456-H321 (5456-H321 (5456-H343), and 6061-T6. Typical yield tensile strength F_{ty} and ultimate tensile strength F_{tu} (as welded) properties for these candidate materials are shown in Figs. 3-4 and 3-5. On the basis of these comparisons, the decision was made to eliminate 6061 alloy from further consideration.

The residual activation of the remaining candidate materials was calculated. The difference between 5083 and 5456 from a nuclear activation standpoint was so insignificant that these two alloys are considered as the same. Figure 3-6 presents a comparison of the total activation levels of Test Article constructed of 2219 and 5083 (5456) aluminum alloys. These alloys vary with respect to each other until a decay time of approximately 250 hours, at which time they maintain a relatively stable relationship.

In summary, 2219-T87 aluminum alloy is recommended at the material to be used for fabrication of the Test Article structural components for the following reasons:

- o Minimum weight because of its relatively higher strength at ambient and cryogenic temperature
- o Lower induced activity after approximately 150 hours
- o Welding and joining characteristics

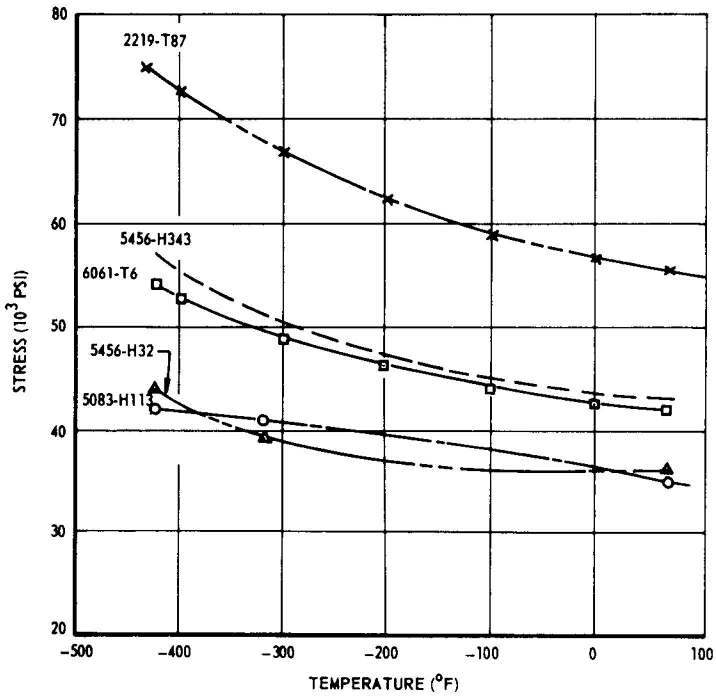


Fig. 3-4 F_{ty} Comparison for Various Aluminum

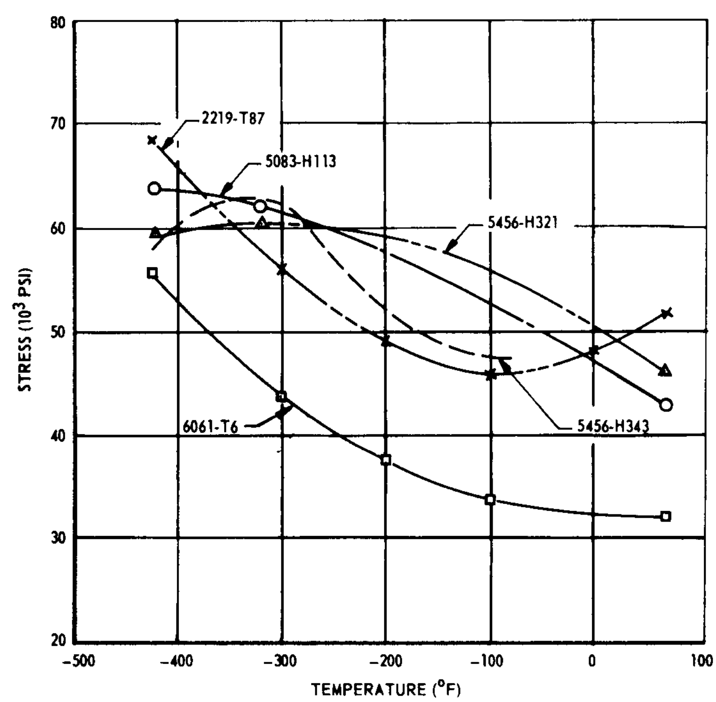


Fig. 3-5 F_{tu} (As Welded) for Various Aluminums

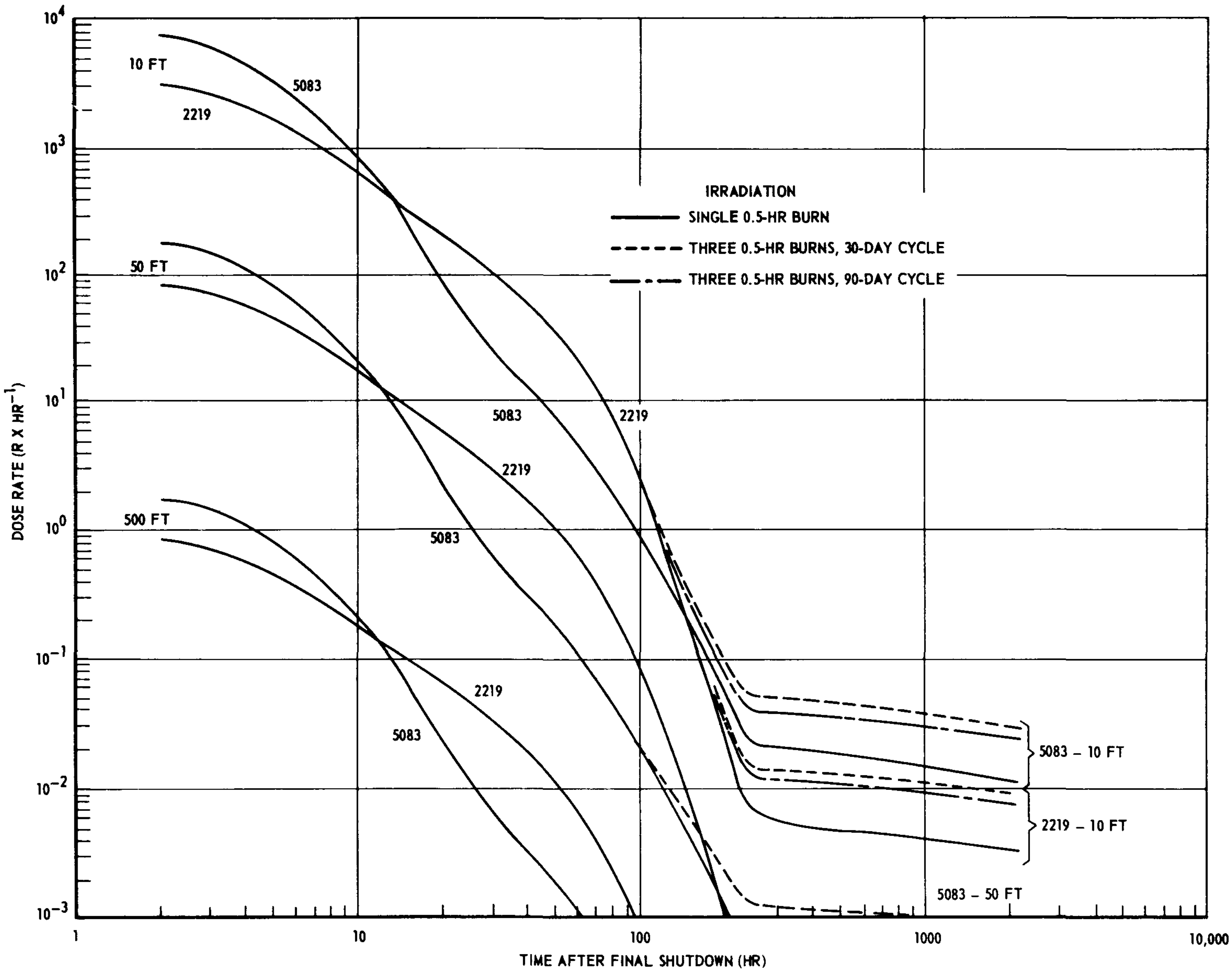


Fig. 3-6 Total Activation Dose Rates – 5083 and 2219 Aluminum

3.3 DESIGN CRITERIA

The following general criteria was utilized for the design of all test article configurations.

The propellant tank will be designed to sustain hoisting and land loads. The following criteria was used to establish the preliminary design configuration. No seismic or dynamic loads analysis was made for this preliminary design.

- Safety Factors

  Ultimate load = 2.0 x design limit load

- Hoisting

  1.5 g (lateral)
  1.5 g (longitudinal; hoisted at trunnions)
  1.5 g (longitudinal; supported at trunnions)

- Transporter (Land)

  1.5 g (vertical))
  0.5 g (longitudinal)) In combination
  0.25 g (lateral))

  1.5 g (vertical))
  0.5 g (longitudinal))
  0.25 g (lateral)) Combined with 60-mph side wind
  100-mph side wind

In addition, the test article structure is designed to withstand a 50-mph wind during an engine firing (zero psi in engine chamber, which results in a 13.75 psia collapse pressure), with an internal work pressure of 25.0 to 48.7 psia, and/or a 100-mph wind with tank in an empty unpressurized condition (requires forward stabilizer). Safety factors for vertical installation on the test stand are as follows:

- Propellant Tank
  Proof pressure = 1.3 x limit pressure
  Burst pressure = 2.0 x limit pressure
- Engine gimbal deflection = ±3 degrees
- Engine gimbal rate - 0.75 deg/second

The following specific propellant tank design pressures were utilized based on latest study contractor reports on the recommended configurations.

- o NAR - Max. operating design pressure = 27.5 psi
- o LMSC - Max. operating design pressure = 25.0 psi
- o MDAC - Max. operating design pressure = 32.0 psi

NOTE: NRDS - Average ambient pressure = 13.75 psia

NRDS - Altitude Simulator Capability = 6 psia to 0.3 psia
(Ref. Norman Engr. Report)

(Design propellant tank bottom for external pressure effect of 0.0 psia)

3.4 TEST ARTICLE CONFIGURATION AND WEIGHTS

Using the design criteria described in par. 3.3 and the various configurations described in par. 3.1, weights for each concept were developed. This section summarizes the results of those calculations and prevents applicable weight statements for each configuration analyzed. The weights presented in this section do not reflect the final recommendation by the various contractors. They are weights derived to satisfy the environments and handling loads that can be anticipated in the NRDS operations. These weights are conservative in nature and are intended for planning use only.

3.4.1 NAR 8° Conical Bottom Based Concept

Figure 3-7 presents the calculated tank membrane thickness for the reference NAR tank configuration. Figure 3-8 presents the pressure profile as developed by the operating pressures, hydrostatic head, and NRDS wind loads. The specifics of the design parameters of the configuration were taken from the Ref. 302 report, which is summarized in Table 3-1.

Note that the facility structure for the altitude simulation containment shields the cone from the prevailing wind loads. However, the aft skirt is influenced by this environment.

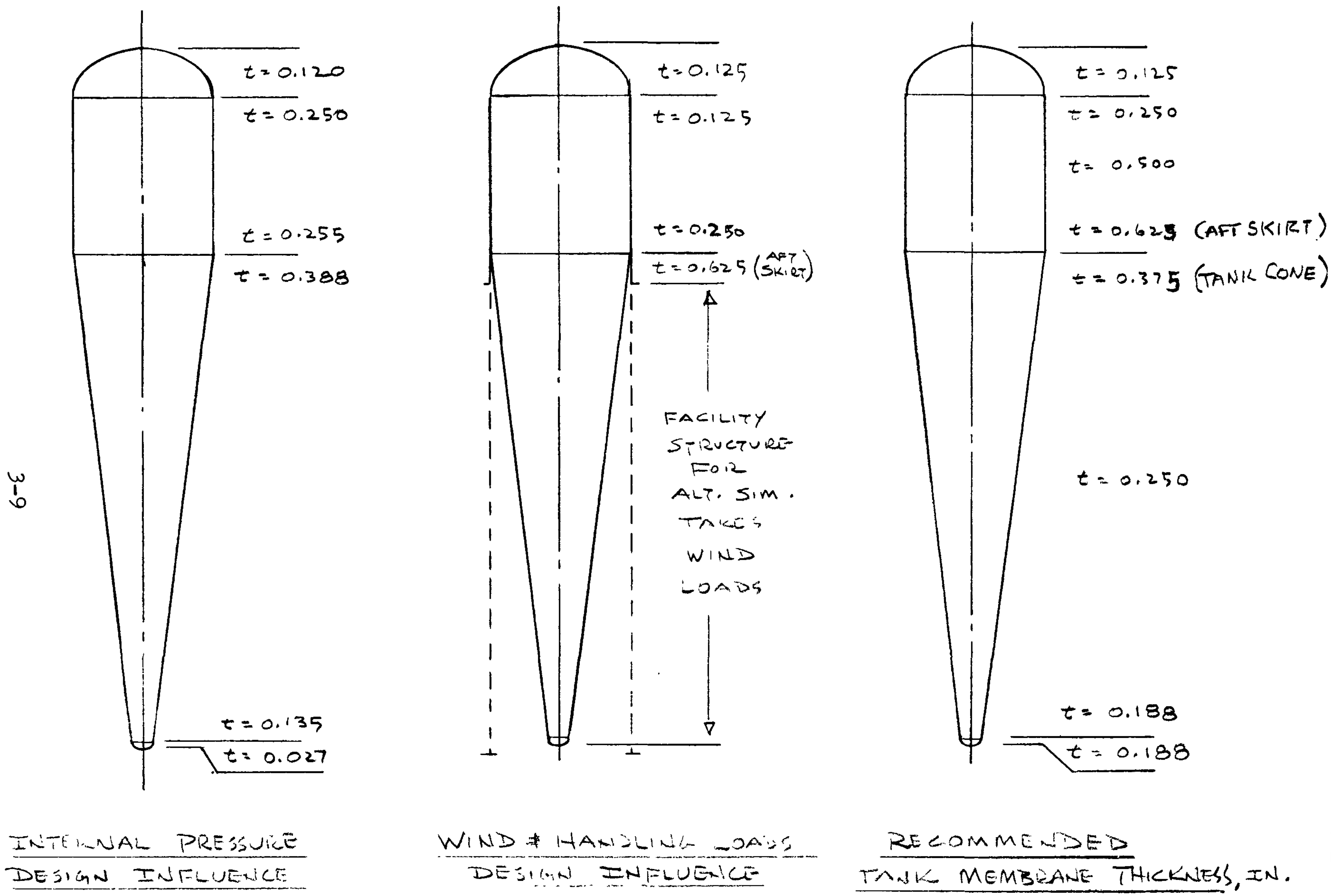


Fig. 3-7 Recap of Tank Membrance Thickness - NAR

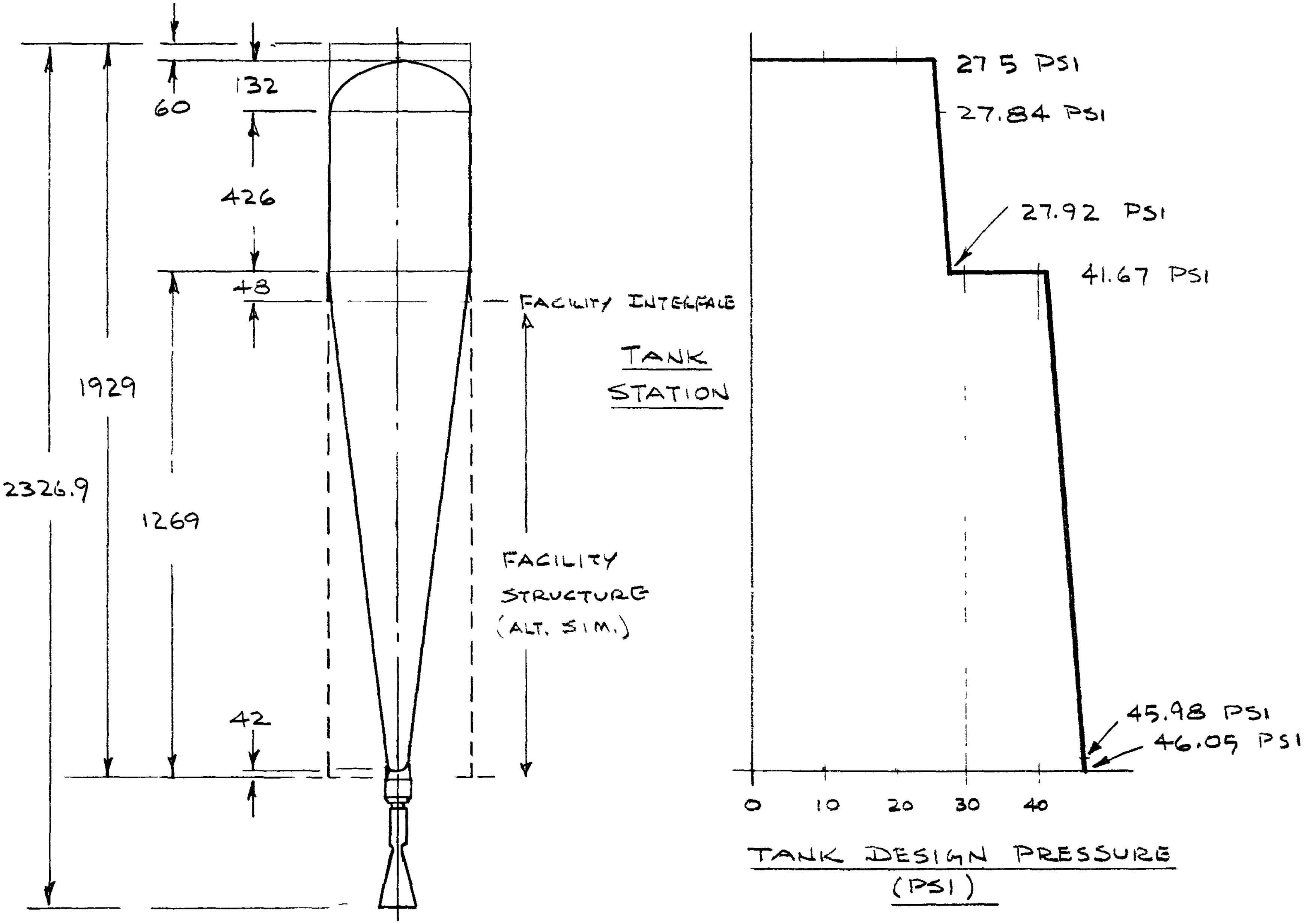


Fig. 3-8 NAR Test Tank Design Pressures NRDS Facility

Table 3.1

STUDY CONTRACTOR DATA
NORTH AMERICAN ROCKWELL (NAR)

Reference: Second Interim Revision -- Phase III, PDS 70-644, dated 16 Dec 1970

Item	Single-Tank, 8-Deg. Half Angle 25-Inch Cap Radius
LH_2 Propellant Loading	300,000 lb
Propellant Tank Dia.	33 ft
Tank Ullage	5%
Propellant Tank Design Pressure	27.5 psi
RCS Fuel Cell LOX/LH_2 Tanks	8 tanks, size not given, super critical O_2/H_2
Reaction Control Systems,	4600 lb O_2
Expendable Fluids	1200 lb H_2
Engine Cooldown	8,000 to 10,000 lb LH_2 (included in total LH_2 vehicle loading)
GN_2 for Purge Atmosphere During Transport	Quantity and pressure not stated
Reaction Control System GH_2/GO_2 With Gas Generator	O_2 storage pressure = 800 psia H_2 storage pressure = 500 psia
Reactant Supply for Fuel Cells	155 to 170 lb H_2 1240 to 1360 lb O_2 (no pressure stated)
Fluid Requirements	Quantities not stated
Insulation Protection System	Purge gas requirements not stated
Propellant Management	Passive stratification or destratification

A summary of the weights of the various test article segments is presented in Table 3-2.

Table 3-2

TEST TANK WEIGHTS SUMMARY - NAR

Basic Structure (skirts, tank, support cylinder)	=	65,829 lb
Functional Systems (components and lines)	=	13,200 lb
Engine and Thrust Structure	=	28,248 lb
Insulation	=	8,030 lb
Umbilicals, Instrumentation and Control Equipment	=	5,000 lb
Environmental Enclosure	=	1,500 lb
Dry Weight	=	121,807 lb
LH_2 (Fully Loaded, 5% ullage)	=	300,000 lb
Total Weight*	=	421,807 lb

* Does not include NERVA Test Engine

3.4.2 LMSC Modular Tank Based Concept

Figure 3-9 presents the calculated tank membrane thickness for the reference LMSC configuration. Figure 3-10 presents the pressure profile as induced by the combination of operating pressure hydrostatic head and wind loads. The basic criteria used for this configuration were derived from the Reference 3-3 document, which is summarized in Table 3-3. A summary of the weights of the LMSC Propulsion Module Test Article is presented in Table 3-4.

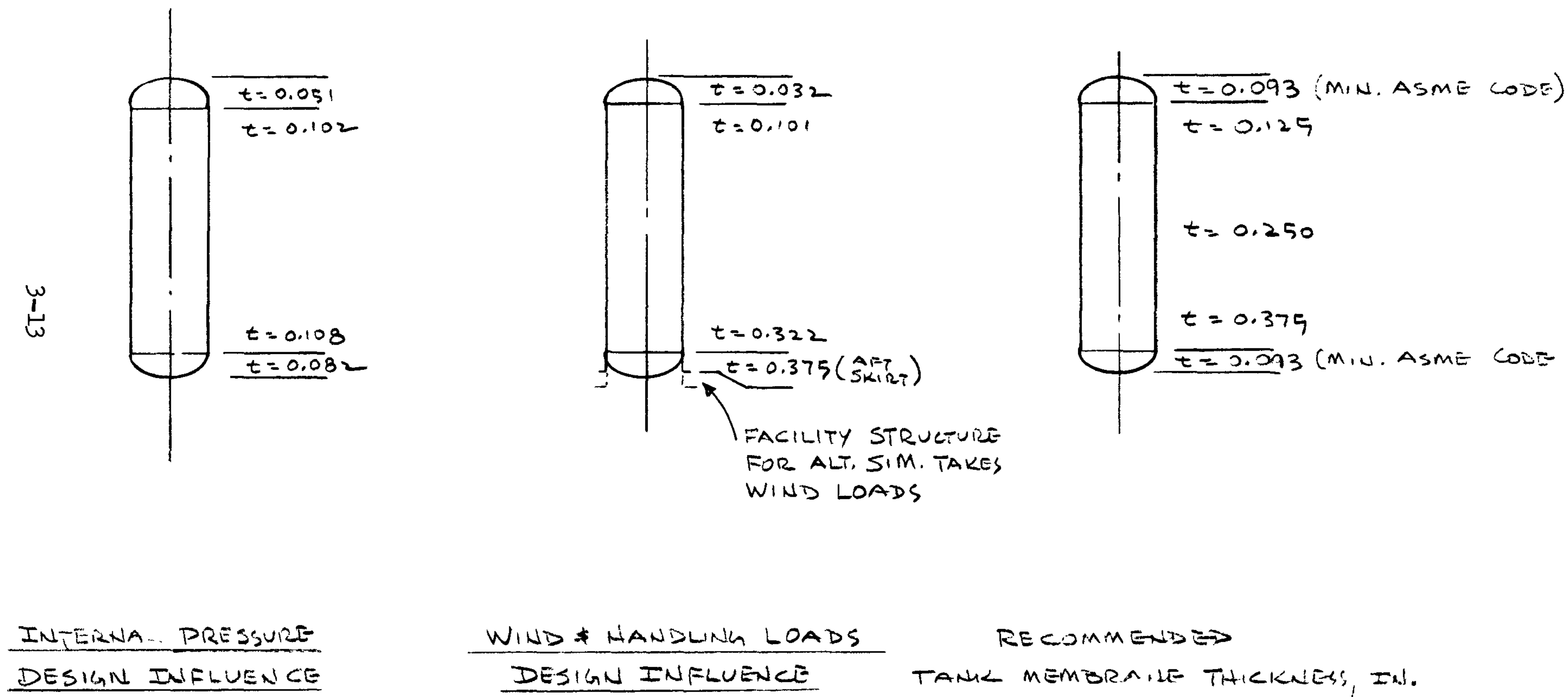


Fig. 3-9 Calculation of Tank Membrane Thickness-
LMSC Propulsion Module

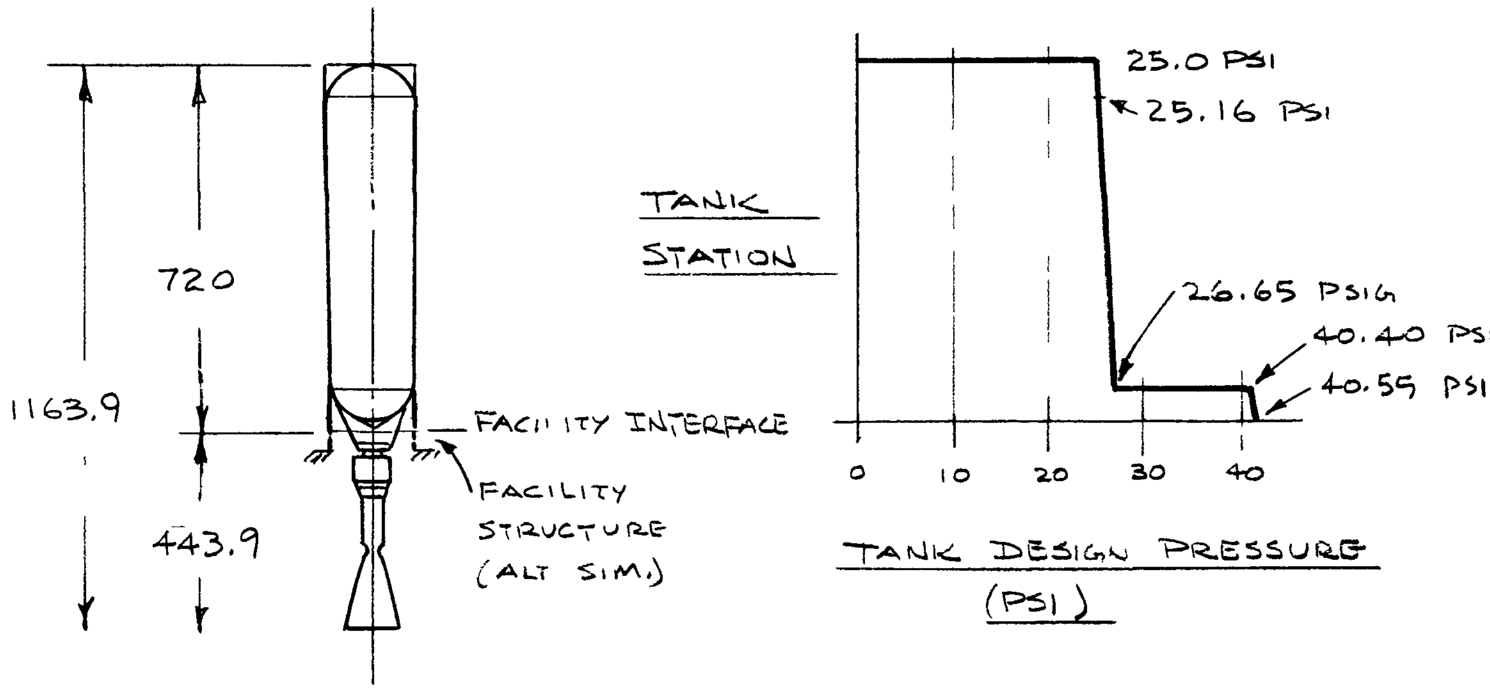


Fig. 3-10 LMSC Test Tank Design Pressures

Table 3-3

STUDY CONTRACTOR DATA

LOCKHEED MISSILES & SPACE CO. (LMSC)

Reference: Volume II - Nuclear Flight System Definition Study, Phase II LMSC-A968223 dated May 1, 1970,
Aug 70 Progress Report - Nuclear Shuttle System, Phase III, LMSC-A976254

ITEM	SINGLE TANK	MODULAR-7-TANK (15 Ft x 60 In D)
Initial Propellant Loading, LH_2	300,000	269,427
Initial Saturation Pressure	18.0 psia	18.0 psia
Operating Pressure	25.0 psia	25.0 psia
Vent Pressure	25.1 psia	25.1 psia
Propellant Tank Volume	67,720 ft^3	Propulsion Module = 8,880 ft^3 Propellant Module = 9,190 ft^3
Ullage Volume	5%	Propulsion Module = 5% Propellant Module = 5%
Propellant Weight	300,000	Propulsion Module = 37,371 lb Propellant Module = 38,676 lb

Table 3-4

TEST TANK WEIGHTS SUMMARY - LMSC

ITEM		WEIGHT(lb)
Basic Structure (Skirts, Tank, Support Cylinder)		11,218
Functional Systems (Components and Lines)		2,000
Engine and Thrust Structure		28,248
Insulation		2,000
Umbilicals, Instrumentation and Control Equipment		2,000
	Dry Weight	45,466
LH_2 (Fully Loaded, 5% Ullage)		37,371
	Total Weight*	82,837

* Does not include NERVA test engine

3.4.3 MDAC Hybrid Tank Based Concept

Figure 3-11 and 3-12 present the calculated tank membrane thickness for the MDAC propulsion and propellant tank hybrid concept. The specific criteria used for these calculations were derived from the Reference 3-4 document, which is summarized in Table 3-5.

Both tanks were assumed to be "battleship" configurations. Flight safety factors could be applied to the small propulsion tank if desirable. However, the structure would still be heavier than flight.

A summary of weight for the MDAC configuration is presented in Table 3-6.

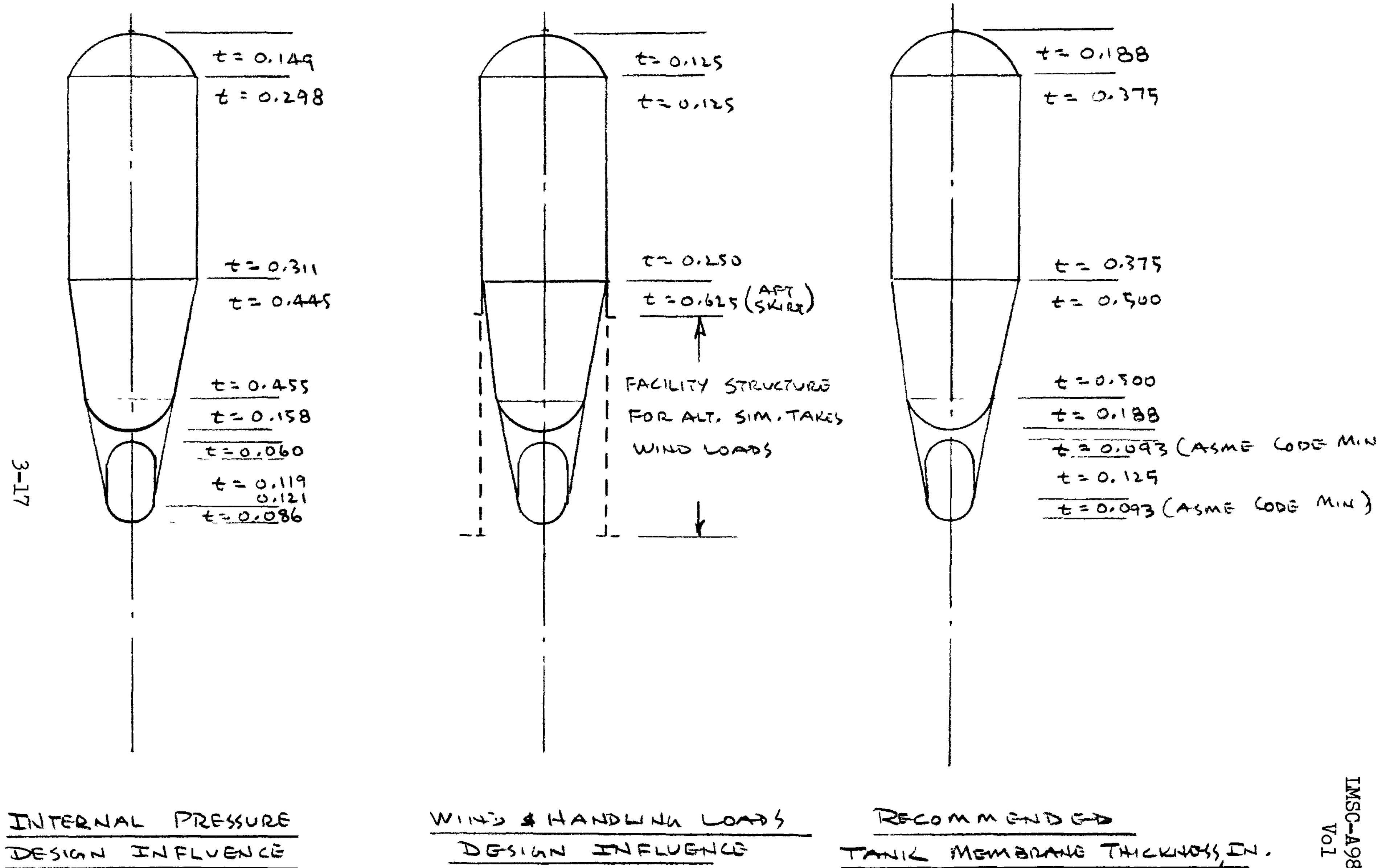


Fig. 3-11 Calculated Tank Membrane Thickness - MDAC

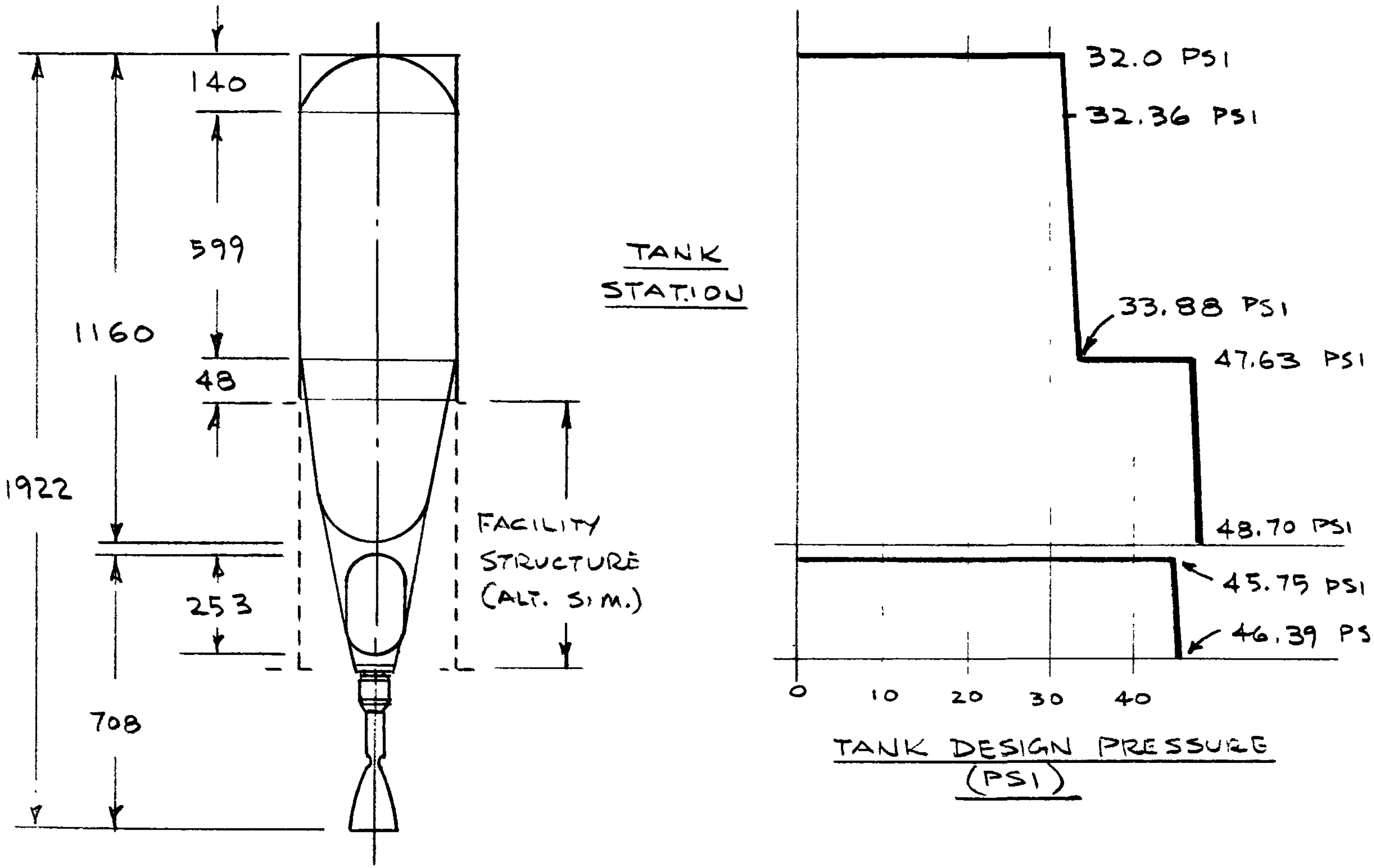


Fig. 3-12 MDAC Test Tank Design Pressures

Table 3-5

STUDY CONTRACTOR DATA
McDONNELL DOUGLAS CORP (MDC)

ITEM	RNS -- CLASS I HYBRID
LH_2 Propellant Loading	291,300 lb LH_2 Propellant Module, 9,700 lb LH_2 Propulsion Module
Propellant Tank Ullage	5% (Propulsion Module not stated) 5% (Propulsion Module not stated)
Propellant Tank Design Pressure	Propellant Module: 28.0 psi Propulsion Module: 26.5 psi
Propellant Tank Diameter	33 ft (Propellant Module) 160 in. (Propulsion Module)
Propellant Tank Weight	19,450 lb (15-deg. half angle) 24,760 lb (8-deg. half angle)
LOX & LH_2 Weights Fuel Cell Reactants	Not stated
Initial Saturation Pressure of LH_2	Not stated
Pressurant Gas (GH_2) Flow Rate	Not stated
Propellant Feed Line	Propellant Module: 12-in. dia. line Propulsion Module: 8-in. dia. line (2)
NERVA Engine After-cooling pressure	Not stated
LH_2 Fill Line Size, 4" dia.	Propellant Module - Separate line, diameter not stated Propulsion Module - use flight feed line 12 in. dia.
LH_2 Fill Time	Not stated
LH_2 Fill Line Location	Forward skirt area of propellant module
LH_2 Drain System	Through expulsion of propellant tank fill line disconnect
Propellant Tank Pressurization System	NERVA bleed, separate re-pressurization expulsion and control
Ground Vent & Relief	Field connection to flight vent system, size not stated

Table 3-5 (cont)

ITEM	RNS -- CLASS I HYBRID
Flight Vent	Quad redundant pilot-operated solenoid valves, pressure sensor controlled, size not stated
Prelaunch Boiloff (at max. surface temperature)	Not stated
Surface temp. range at Launch	Not stated
Insulation Protection Systems Purge	Not stated
APS Systems, Cryogenics	1130 lbs total propellant LO_2 & LH_2 quantities not stated
Propellant Tank Volume	Propellant Module 71,590 ft^3 Propulsion Module
Auxiliary Propulsion System	GH_2 (qty not given)

Table 3-6

TEST TANK WEIGHT SUMMARY - MDAC

ITEM	WEIGHT (LB)
Basic Structure* (Skirts, Tank, Support Cylinder)	68,134
Functional Systems (Components and Lines)	11,000
Engine and Thrust Structure	28,248
Insulation	9,000
Umbilicals, Instrumentation and Control Equipment	5,000
Environmental Enclosure	1,500
Dry Weight	122,822
LH_2 (Fully Loaded, 5% Ullage)	300,000
Total Weight**	422,882

* Includes both tanks

** Does not include NERVA test engine

3.5 TEST ARTICLE FUNCTIONAL SYSTEMS

The MDAC and NAR concepts will feature a "full-up" systems approach for the NRDS test article. However, the LMSC modular concept will not require full-up systems located on-board the test article. The primary goals of the NRDS test program are to determine the compatibility of the RNS/NERVA interfaces and to discover any latent interaction. As the primary interface is with the propulsion system, it is necessary to provide a propulsion module with the interacting data management, power, control, etc., interfaces as would exist in the flight system. As these latter functional interfaces are primarily across a data bus, these functional systems need not be located on the test stand, but could be located in the umbilical tower or test centers. Some of these systems could be simulated if the interface characteristics were maintained. Figures 3-13, 3-14, 3-15, 3-16, 3-17 and 3-18 present how this division will be made.

3.6 UMBILICALS

The test article will be equipped with two umbilicals, one in the forward area and one in the aft skirt. Although these items have not been completely defined, the layouts of the umbilicals shown in Figs. 3-20 and 3-21 are typical of the size and oayout of the umbilicals to be used. In addition, the services are identical to those required. Line sizes may vary; however, the general layout and overall size is adequate for planning purposes.

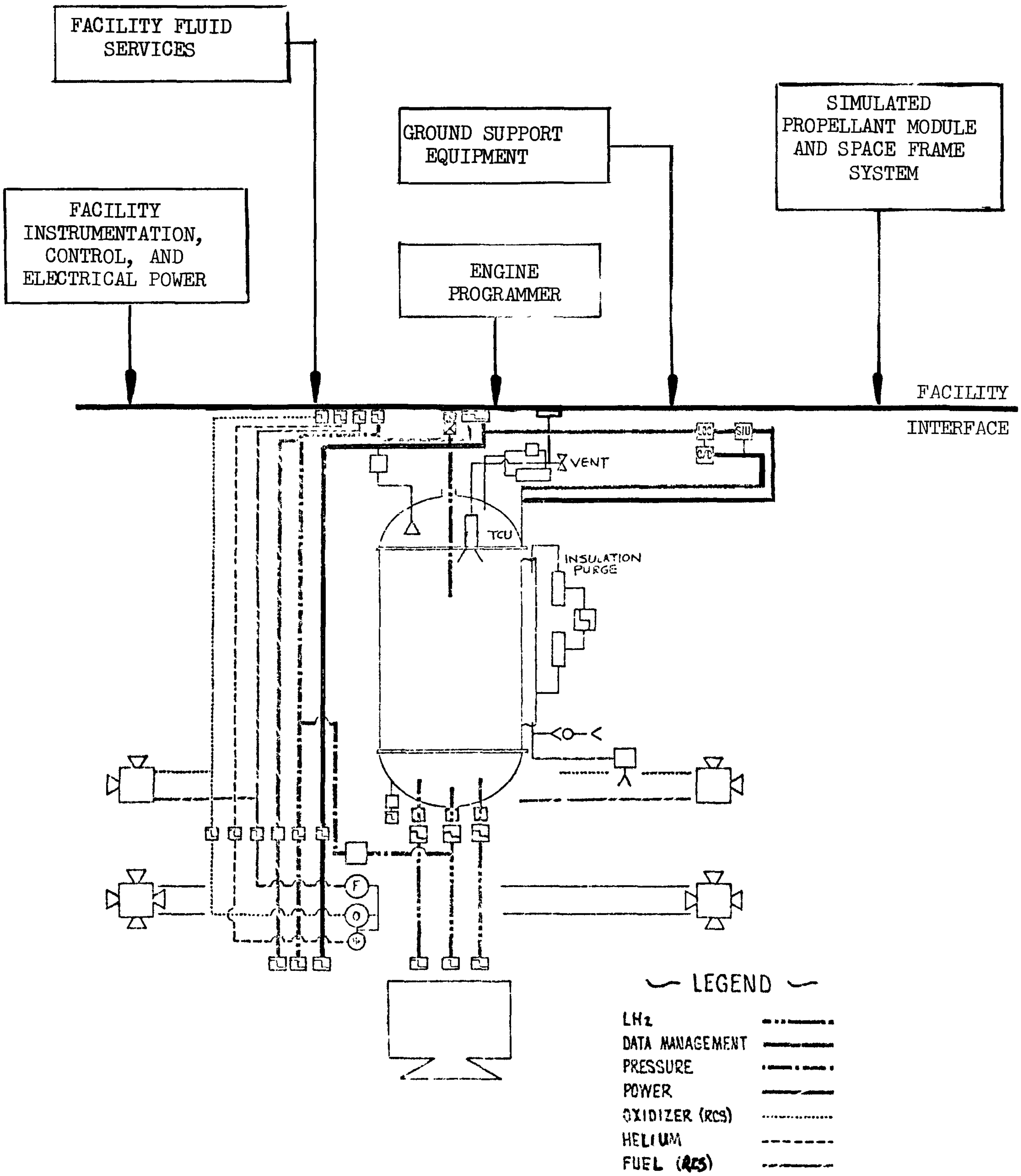


Fig. 3-13 NRDS Test Article Functional System Schematic

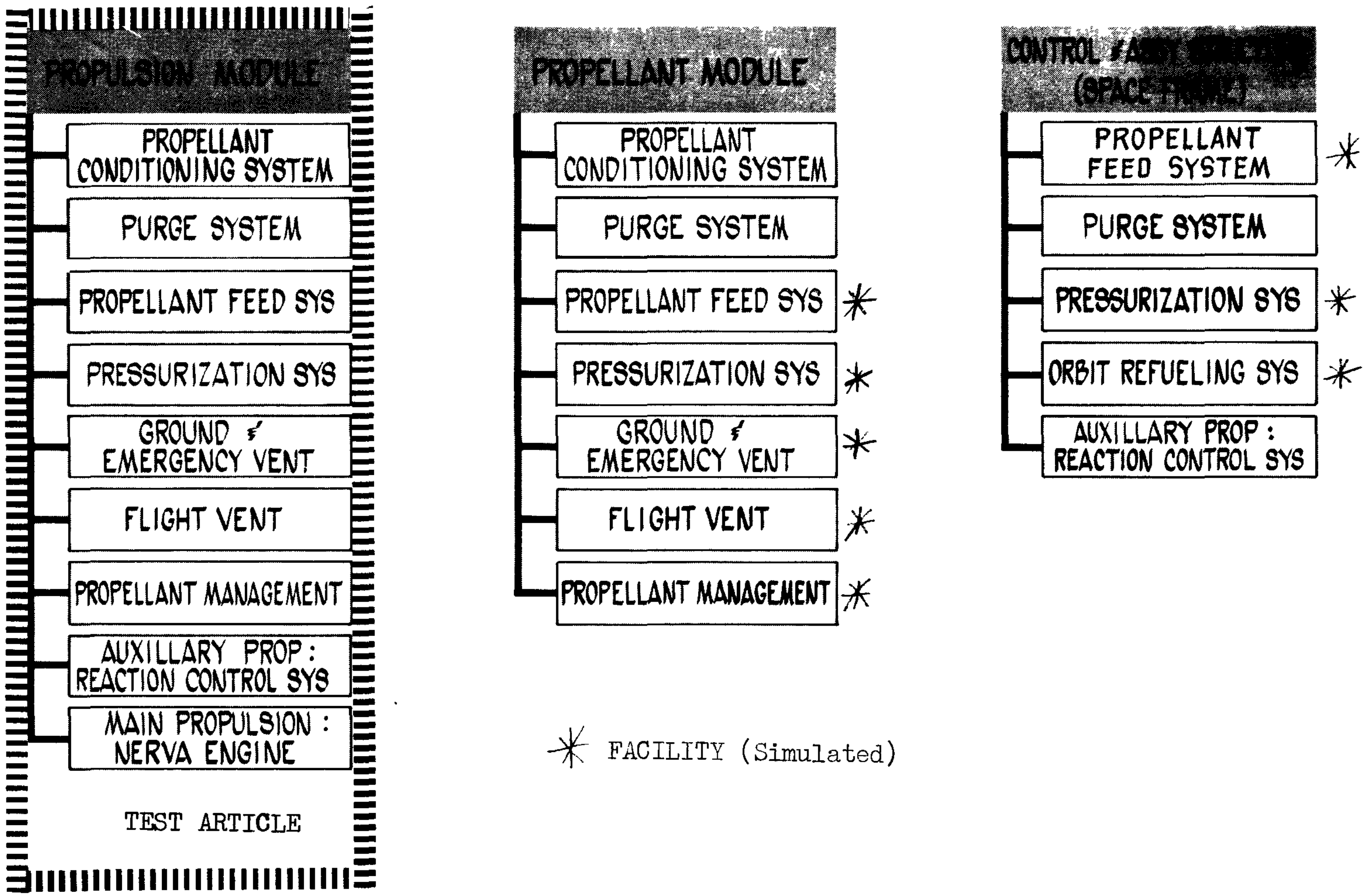


Fig. 3-14 Propulsion System Definition

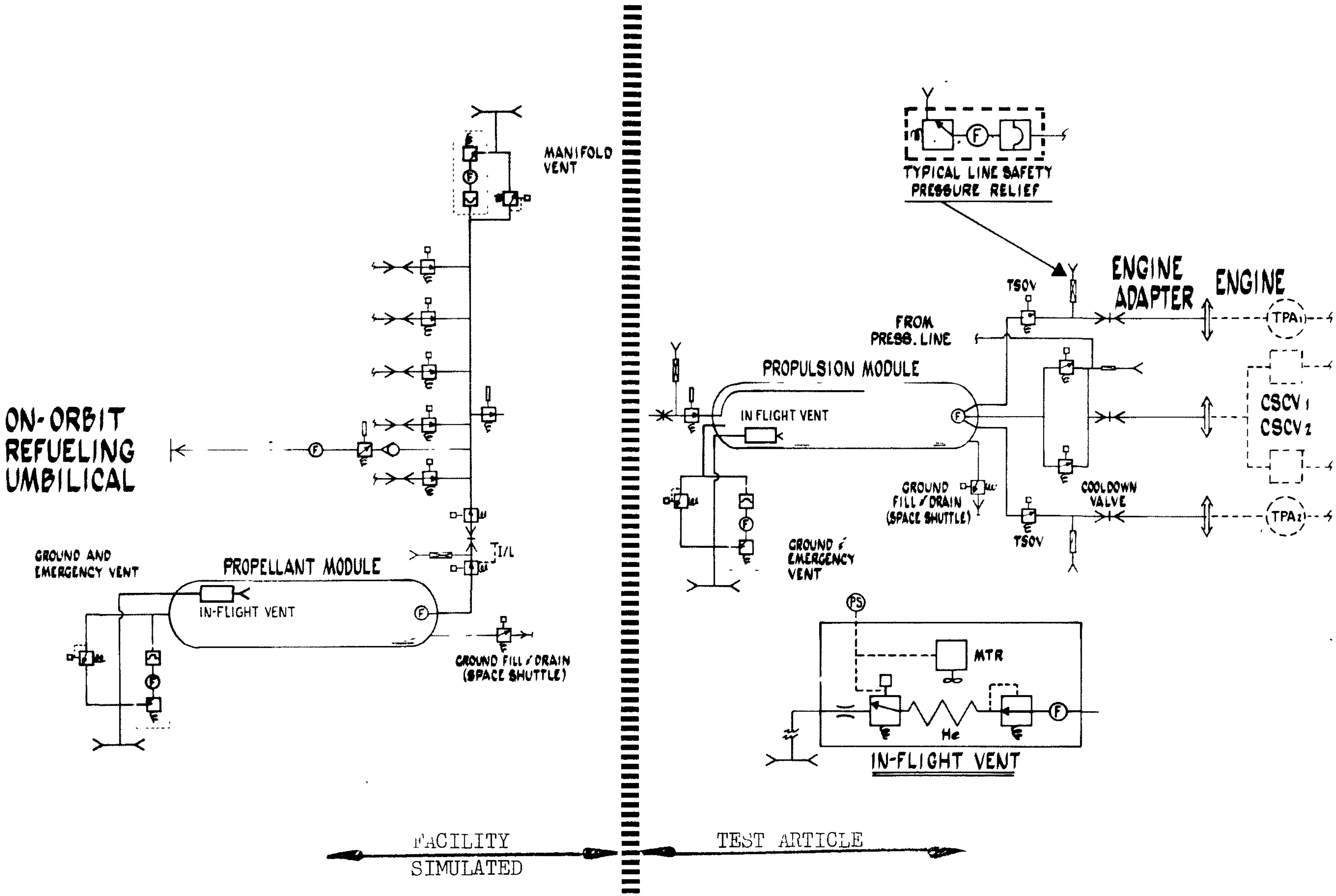


Fig. 3-15 Propellant Feed System

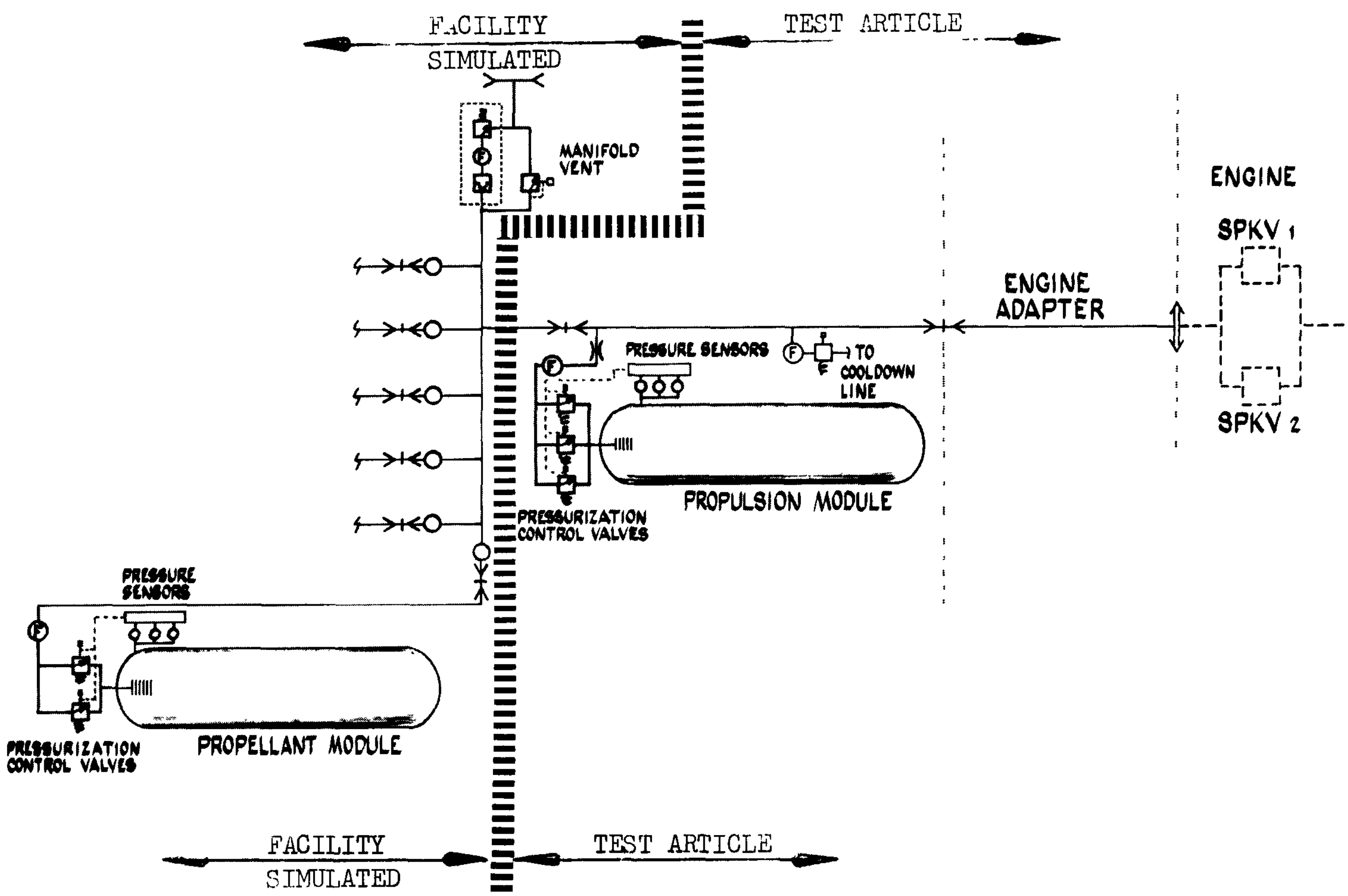


Fig. 3-16 Pressurization System

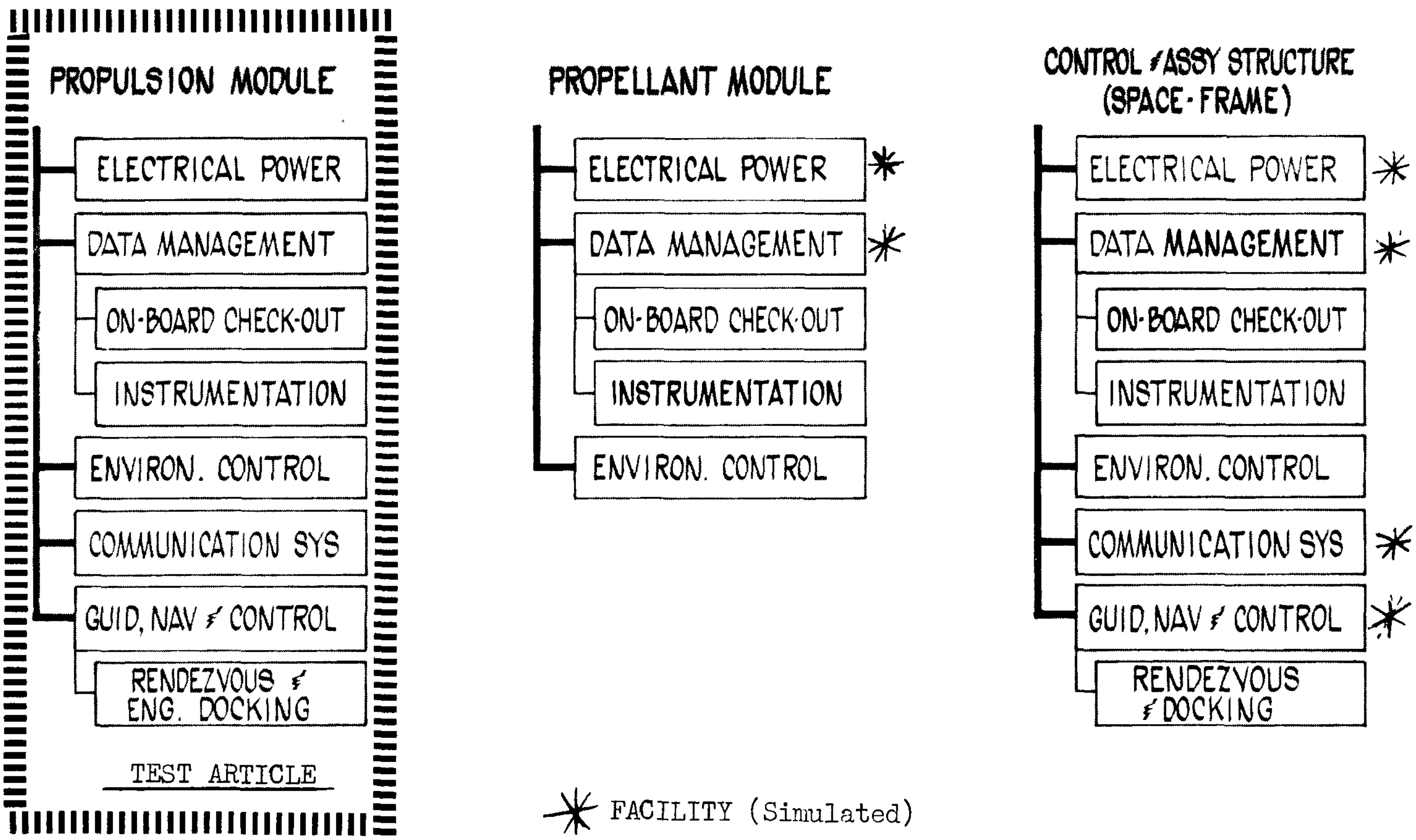


Fig. 3-17 Avionics System Definition

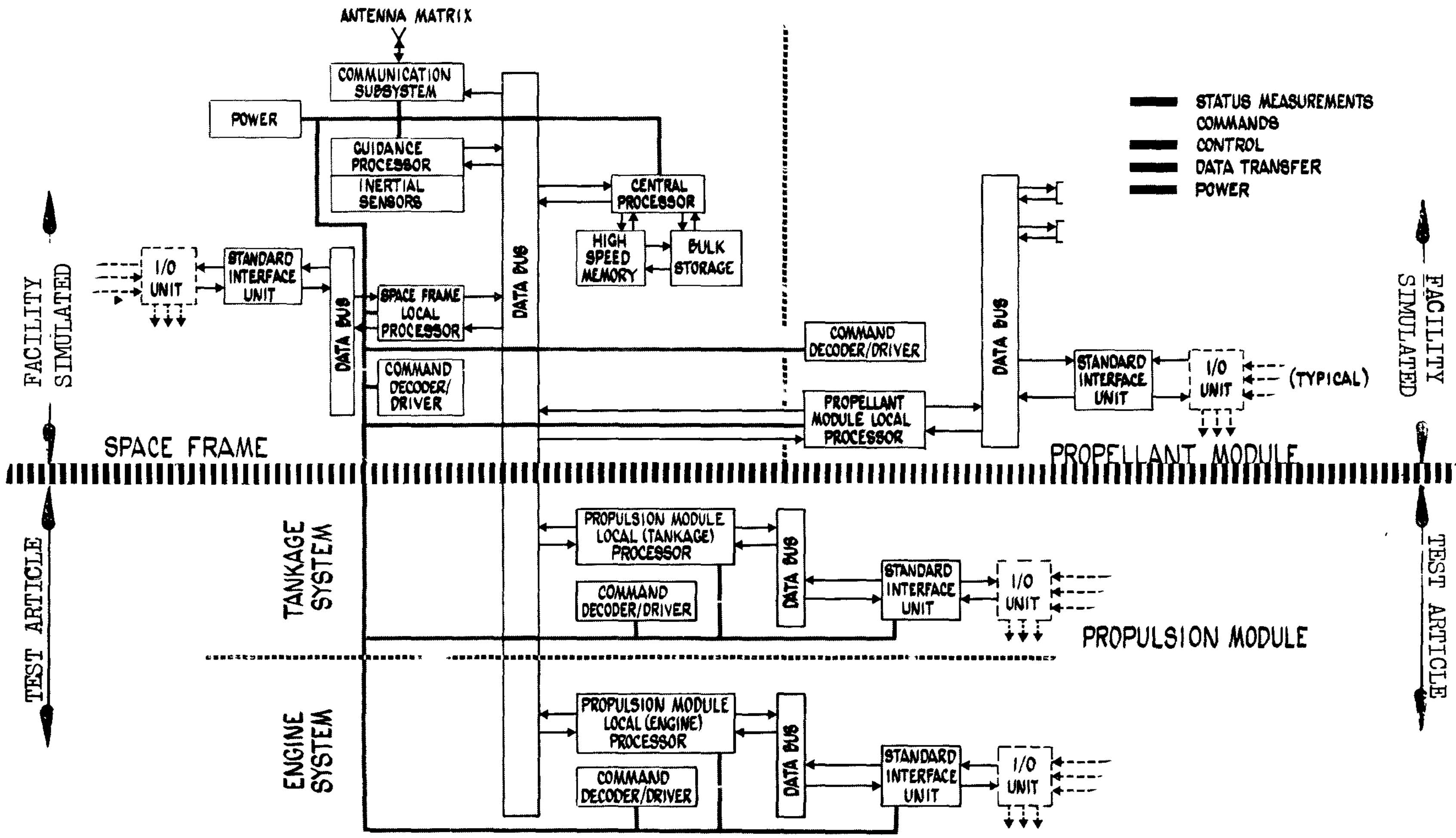


Fig. 3-18 Integrated Avionics System Schematic

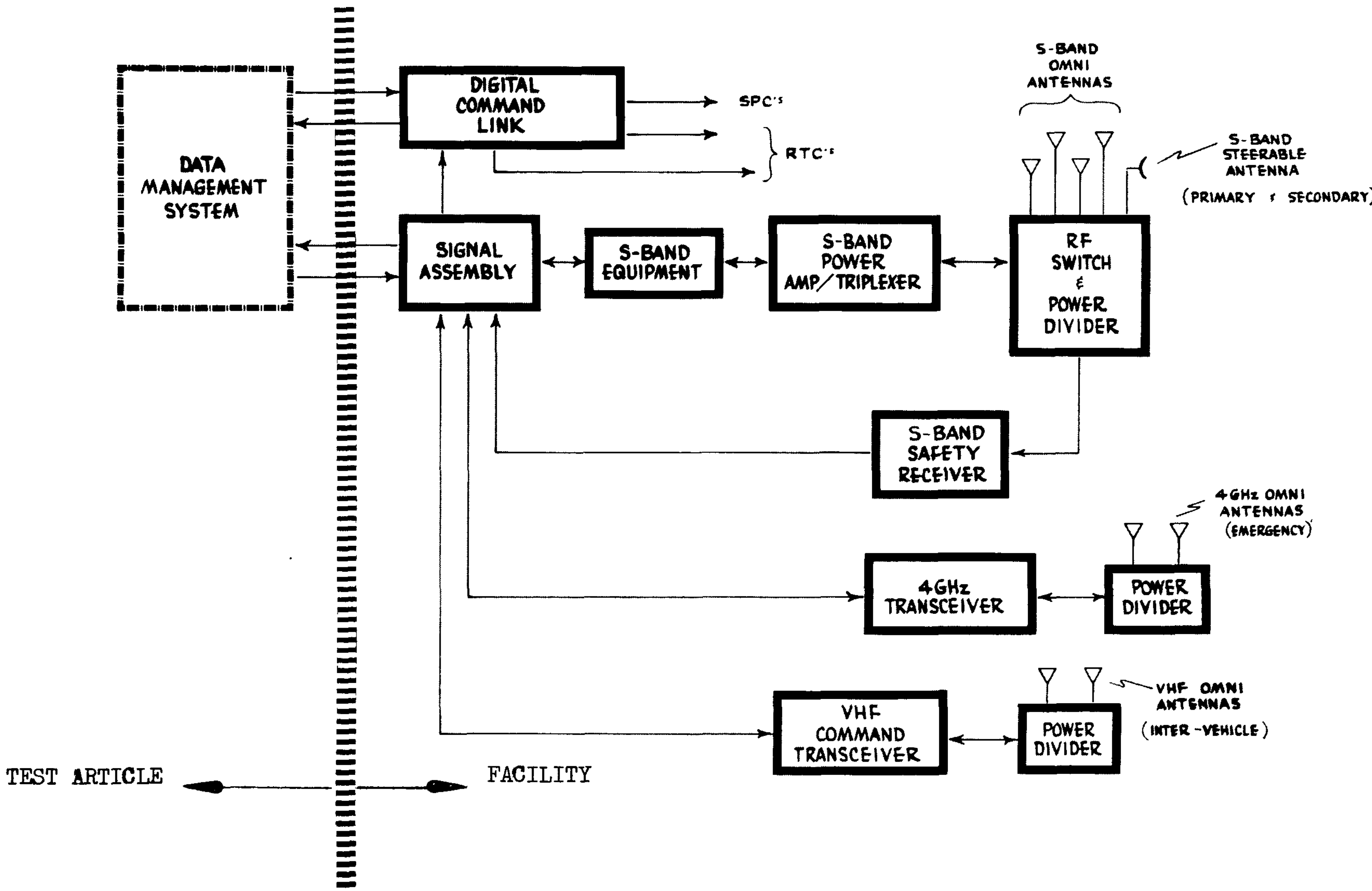
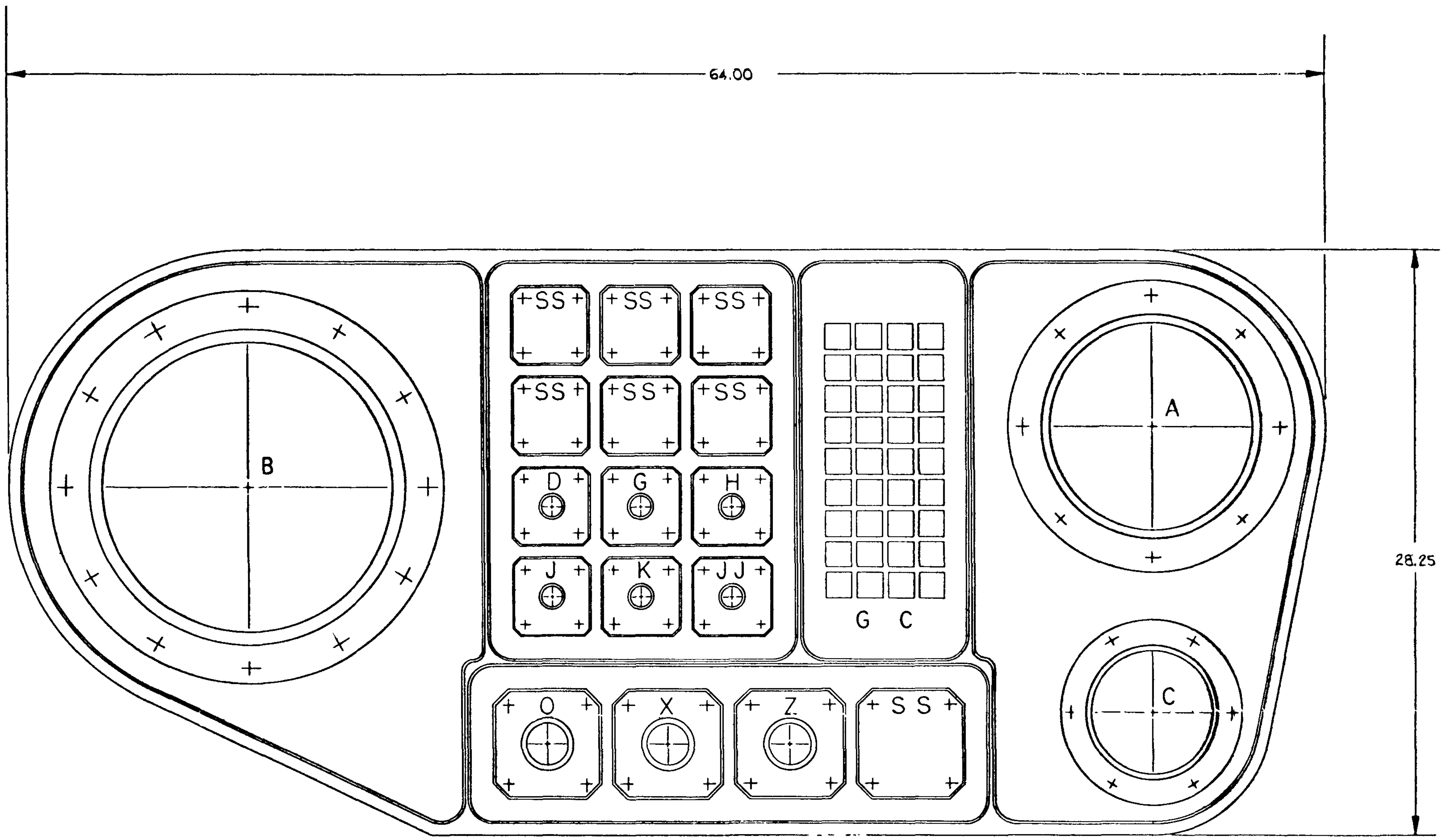


Fig. 3-19 Communications System



SYMBOL	DIA (IN)	FUNCTION
A	10	PROPELLANT TANK FLIGHT VENT
B	14	PROPELLANT TANK GROUND VENT
C	6	GROUND PRESSURIZATION
D	1	PNEUMATIC AND ACCUMULATOR TANK PURGE
G	1	GROUND VENT CONTROL AND PURGE
H	1	PNEUMATIC TANK FILLAND DRAIN
J	1	ACCUMULATOR TANK FILL AND DRAIN
K	1	PNEUMATIC TANK PRESSURE RELIEF
O	2	INSULATION PURGE
X	2	ENVIRONMENTAL ENCLOSURE PURGE
Z	2	INSULATION VACUUM
J J	1	AIR SUPPLY
S S	1, 2	SPARES (6-1, 1-2)
G C		CONNECTOR, ELECTRICAL (36)

Fig. 3-20 Forward Umbilical Services

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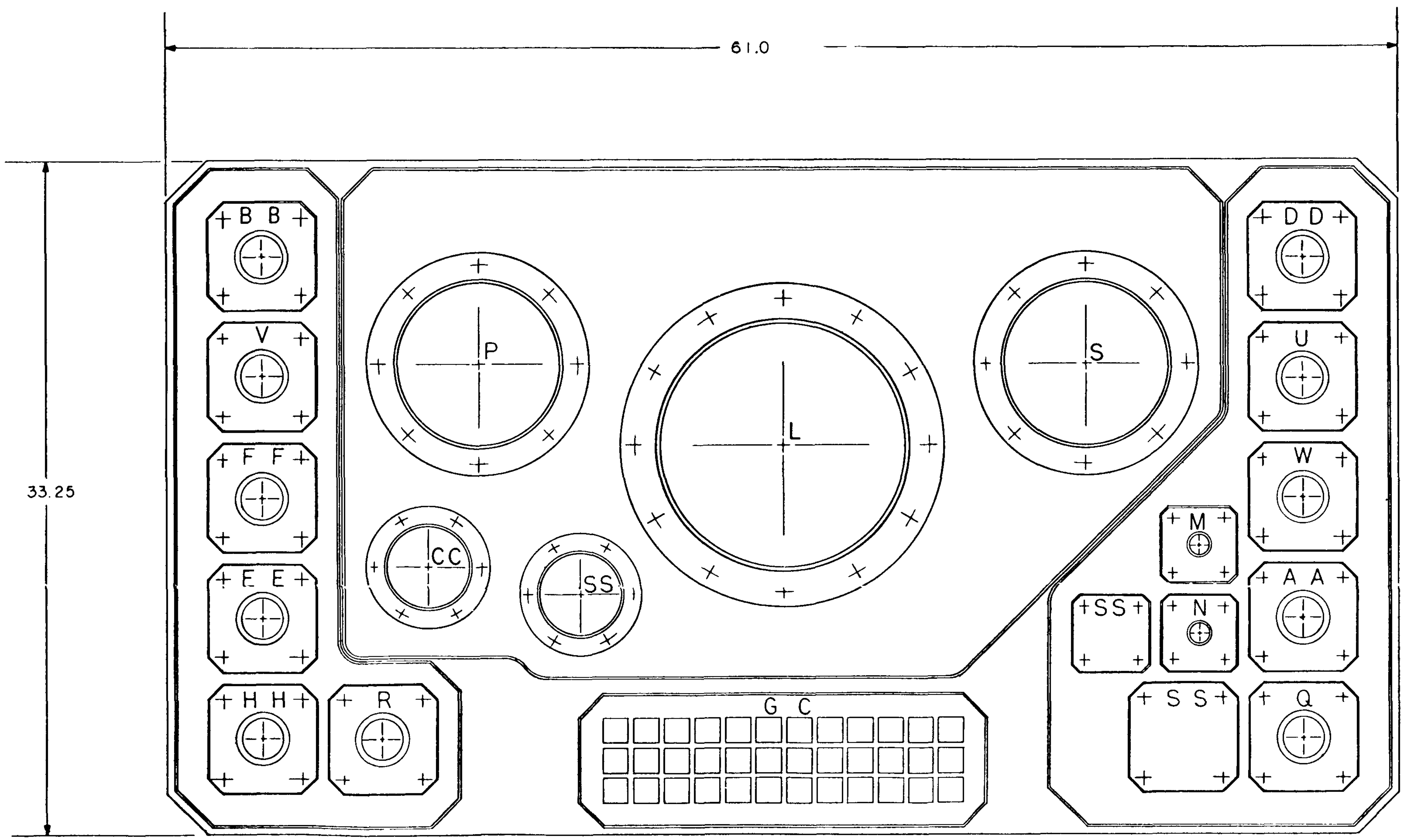

SYMBOL	DIA. (IN.)	FUNCTION
L	12	TANK FILL & DRAIN LH_2
M	1	ACTUATOR GROUND CONTROL SUPPLY GH_2
N	1	ACTUATOR CONTROL SCAVENGE & PURGE SUPPLY GH_2
P	8	ENGINE COMPARTMENT/DUCT PURGE SUPPLY GH_2
Q	2	ENGINE PURGE, SPECIAL PURPOSE
R	2	ENGINE ASSY. PURGE & COOLDOWN GH_2
S	8	ENGINE COOLDOWN, SUPPLY GH_2/LH_2 FLIGHT SIMULATION
U	2	ENGINE THRUST STRUCTURE/ENGINE FEED SYSTEM COMPARTMENT PURGE
V	2	ENGINE PNEUMATIC TANK FILL, DUMP & PURGE
W	2	PNEUMATIC SYSTEM LINE PURGE GH_e
AA	2	TURBINE INLET & EXHAUST PURGE GH_e
BB	2	PROPELLANT FEED LINE PURGE GH_e
CC	4	ENGINE COOLDOWN CIRCULATION VENT, LH_2
DD	2	O_2 DETECTOR
EE	2	H_2 DETECTOR
FF	2	INSULATION PURGE GH_e OR GN_2
HH	2	INSULATION VACUUM
SS	1, 2, 4	SPARE (1 EACH)
GC		CONNECTOR, ELECTRICAL (36)

Fig. 3-21 Aft Umbilical Services

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Section 4
GROUND SUPPORT EQUIPMENT

This section describes the ground support equipment (GSE) necessary to support the servicing of the various RNS Test Article concepts in pre-test, test, and post-test operations. Basically, the equipment described in this section were developed under Contract NAS 8-20007, LMSC 581841, "Nuclear Ground Test Module, Its Ground Support Equipment and NRDS Facilities Requirements." The equipment designed in the referenced report was reviewed and revised to incorporate any new requirements. There is little or no change in the basic GSE requirements for the current test program and test article designs.

Ground test operations of the test article with the NERVA engine requires that various fluid services and electrical power and signals be regulated and controlled. The GSE consists of mechanical service units, as shown in Fig. 4-1, and the electrical controls required for operation of the service units by the Test Control Center.

4.1 MECHANICAL GSE DESCRIPTION

The mechanical GSE systems diagram (Fig.4-1) reflects the equipment configurations considered for GSE. They are as follows:

- o Aft-Stage Pneumatic Service Unit
- o Forward-Stage Pneumatic Service Unit
- o Engine Simulation Service Unit
- o Umbilical Systems
- o Vacuum Service Unit
- o Air Conditioning Service Unit
- o Coldplate Coolant Service Unit

The aft and forward stage pneumatic service units provide GN_2, GH_2, and GHe services to the stage (includes engine), skirt enclosure, environmental cover,

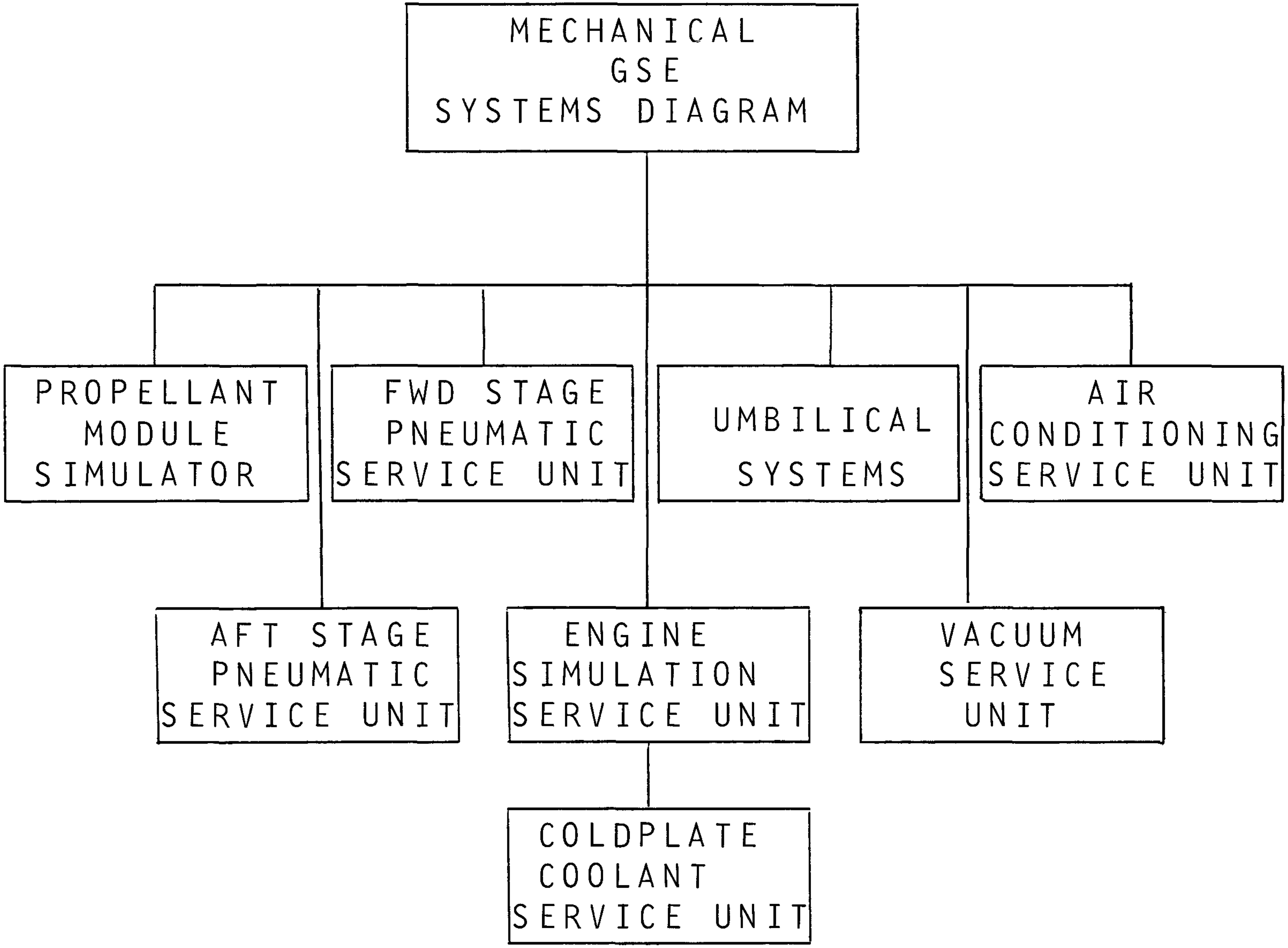


Fig. 4-1 Mechanical GSE Systems Diagram

and all purge requirements for LH_2 and GH_2 disconnects and electrical service terminals. Purge gas is also provided for the split-shield seals.

The engine simulation service unit provides cold flow test capability for Test Series 1 by simulating LH_2 flow and pressure drops across an engine. The facility LH_2 fill and drain system will be tested with this unit.

The umbilical systems include all the fluid and electrical services required to service the test article during test operations. Interfaces with the facility GSE and test article are shown with fluid flow rates.

The vacuum service unit controls the vacuum level required for insulation purge operations. It uses a facility-provided vacuum source. This service unit may not be required as progress is made on the insulation development program. LMSC recommends inclusion of this service unit as a requirement, but to be reviewed later. The air conditioning service unit controls the conditioned air being distributed to the environmental cover during periods when test personnel are working in the equipment section of the forward skirt area. It uses facility-provided precooled air and refrigerant supply.

A portable spray foam unit is required to make necessary insulation system repairs or modifications. This unit is regarded as a maintenance rather than a service unit and therefore is not listed in Fig. 4-1. The unit must be capable of operating while the test article is in the test stand, or in the maintenance building being reconfigured for a new test series.

4.2 FORWARD AND AFT STAGE PNEUMATIC SERVICE UNIT

The service unit design (Figs. 4-2 and 4-3) combines the pressurization, purge, vent, and control-gas functions in one console or equipment rack design located in the test stand near the aft portion of the stage.

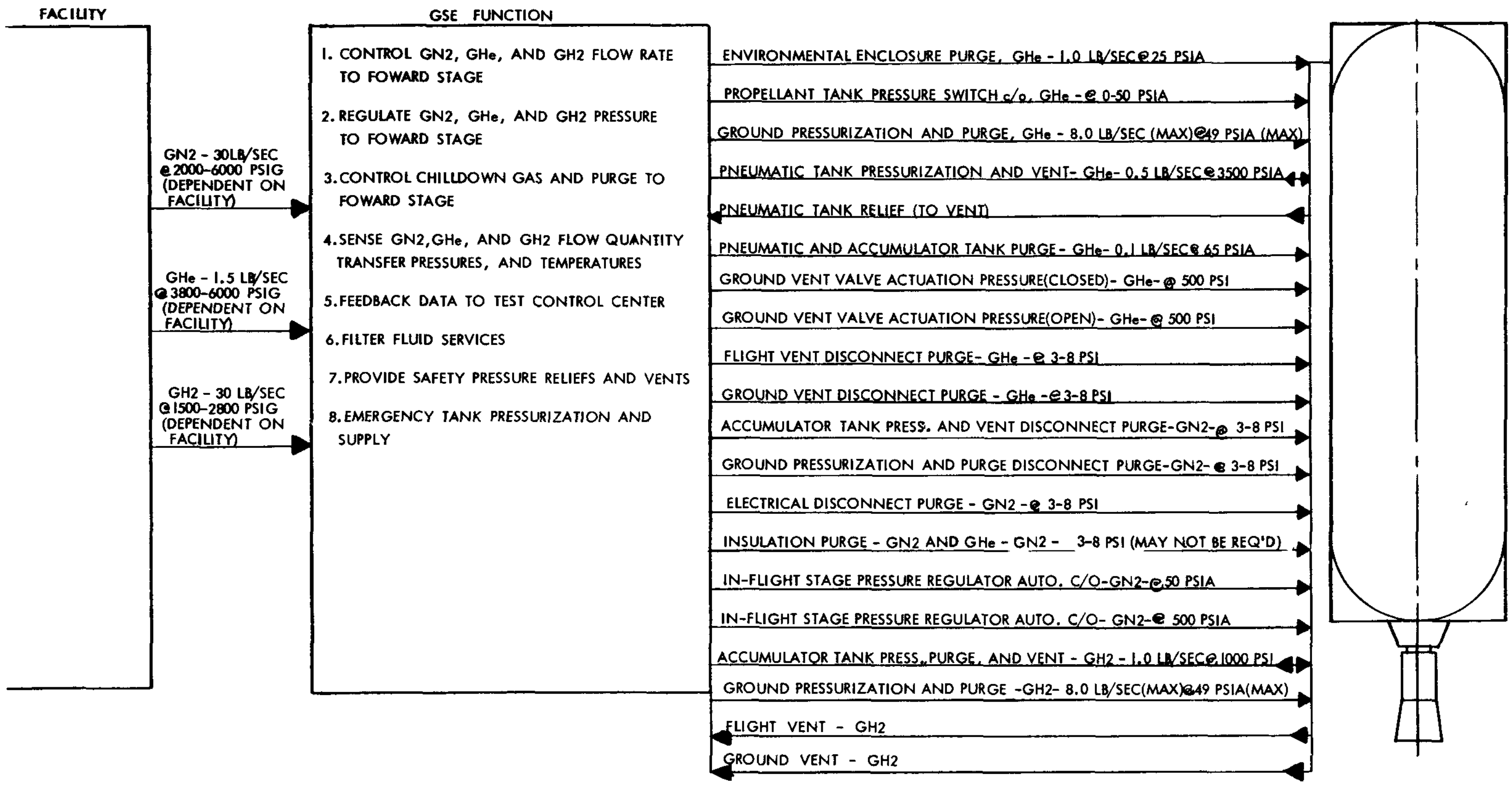


Fig. 4-2 Facility - GSE - Test Article Interfaces
Forward Stage Pneumatic Service Unit

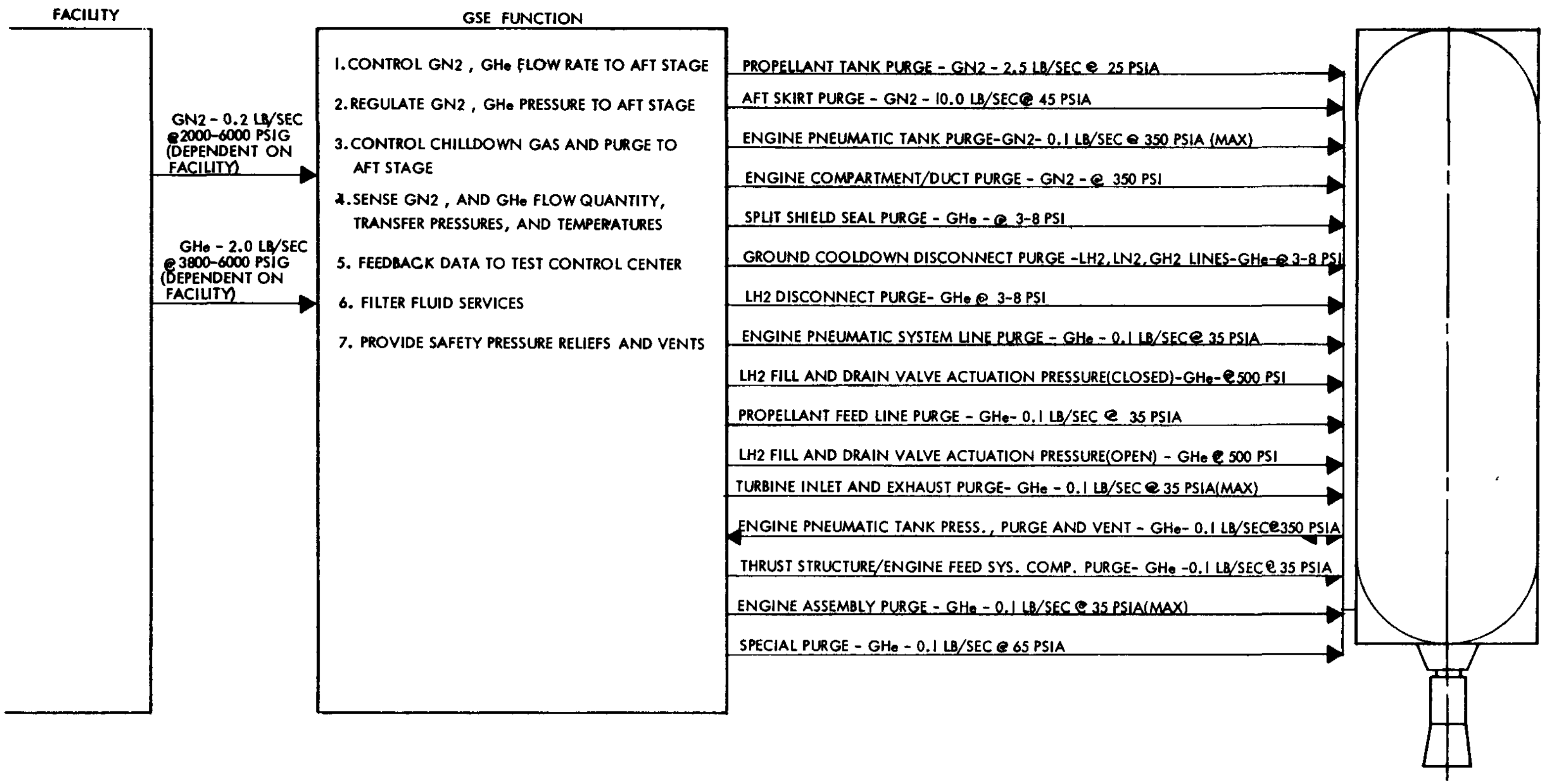


Fig. 4-3 Facility - GSE - Test Article Interfaces
Aft Stage Pneumatic Service Unit

The design is consistent with MSFC layout of pneumatic services for the stage in the test stand. It provides for some test stand controls and displays to facilitate test setup by test personnel, but retains operational control by the test-control center. Redundancy will be used for those components where single point failure can cause interruption of a test and recognizes that components such as solenoid control valves and regulators, in particular, require selective redundancy. To improve reliability of the system, the design uses manual set components, i.e., regulators and hand valves which can be set in the operating position during the pretest period. For test operations, the test control center then can activate solenoid shut-off valves to start gas flow at the proper pressure level.

A preset relief valve is located after every point where pressure is reduced in the line. A manual shutoff valve for bleeding the line is provided wherever gas can be trapped in the line at elevated pressures.

A pressure gage and pressure transducer is provided at each pressure level in a system. The pressure gage is provided for test personnel working in the area for test setups. The pressure transducer will allow remote monitoring. A gas filter is provided at both the inlet and the outlet disconnects of the service unit, thereby ensuring clean gas to the stage and reducing the probability of component failure caused by dirt.

4.3 ENGINE SIMULATION SERVICE UNIT

A requirement is foreseen for a service unit that will permit cold flow tests of the stage without a hot firing. The availability of such a unit will facilitate the planned development testing for investigation of propellant vortexing during rate flow conditions, associated baffling, and pre-valve pressure drop and feedthrough conditions.

At NRDS the use of this service unit will permit facility checkout of the LH_2 fill and drain systems and associated pressurization, dewar, and provide baseline data on the insulation systems, and vent control systems. This work can be accomplished prior to delivery of a hot-fire engine.

Schedule problems associated with late delivery of a hot-fire engine will be avoided by use of the service unit and will permit an independent checkout of the stage and the facility without the use of a hot-fire engine.

Additional design analysis is required before a recommended working schematic is available. The main design challenge is associated with simulating the engine turbopump.

4.4 AIR CONDITIONING SERVICE UNIT

The stage has an environmental enclosure over the test article that permits test personnel to work in the forward bay area. Ambient conditions in the NRDS area require cooling of the air within the cover to tolerable levels. The air conditioning service unit (Fig. 4-4) will provide this control.

Air flow control is regulated by pressure transducer sensors in the environmental enclosure, sending demand signals to the service unit controller which activate motorized dampers controlling flow of the precooled facility air to the service unit. Any overload of air can be bypassed back to the facility. The service unit will be remotely controlled by the test control center, but will have local override controls and displays to permit test operations personnel to conduct non-test operations. The service unit is expected to be used only when personnel are working in the test area. During stage test periods, when the propellant tank will be filled with LH_2, the air flow to the environmental enclosure will be shut off, and the enclosure will be filled with helium to prevent cryopumping.

4.5 VACUUM SERVICE UNIT

The insulation on the test article will be a closed-cell polyurethane foam system. It is recognized that a continuing insulation development program is

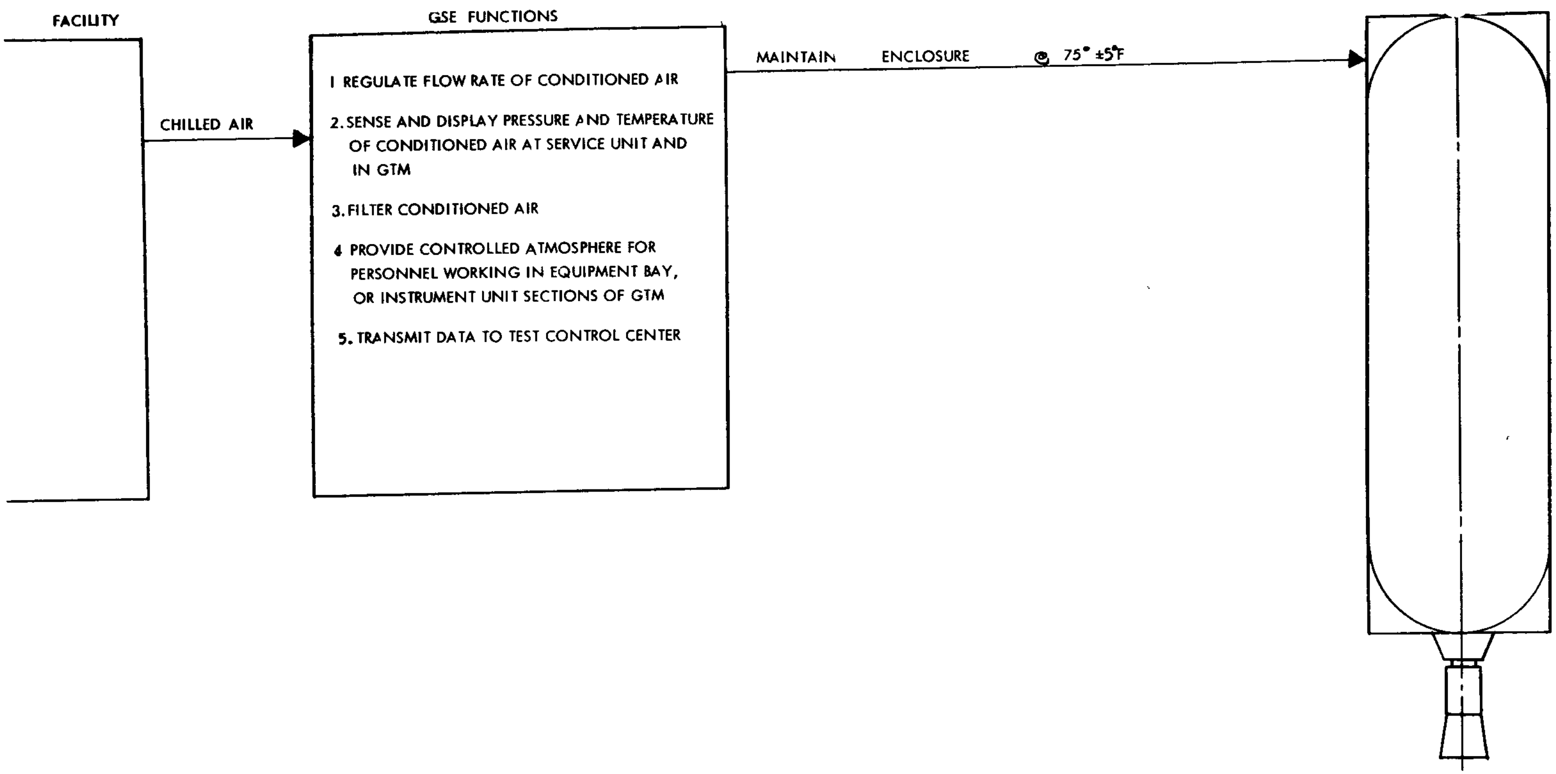


Fig. 4-4 Facility - GSE - Test Article Interfaces, Air Conditioning Service Unit

required to supplement work performed to date, and therefore it is recommended that the vacuum service unit be included as a GSE requirement, but to be reviewed later.

The design (Fig. 4-5) is based on the concept that the service unit controls the vacuum level to the insulation system, but that the facility provides the actual vacuum generating equipment. A fast (vacuum) pulldown valve (large diameter motorized gate valve) provides the capability to control the vacuum level to a rough pumping cycle for initial vacuum operations. A slow (vacuum) pulldown valve (smaller diameter motorized gate valve) provides the capability to control the vacuum level to that required at the end of the vacuum cycle. All operations will be remotely operated and monitored.

4.6 COLDPLATE COOLANT SERVICE UNIT

This service unit (Fig. 4-6) is required to maintain the coldplate coolant temperatures whenever electrical equipment is being operated. The coldplate coolant is recirculated through the service unit by a positive pressure pump using a three-way valve and flow controller to bypass any coolant back to the coolant reservoir. Coolant flow is determined by a differential temperature-sensing system and the coolant-flow controller.

The test control center can remotely monitor and change the controller settings. A closed loop conventional freon refrigerant system provides the thermal sink to remove heat in the heat exchanger from the coolant loop.

4.7 UMBILICAL SYSTEM

The functional flow diagrams (Fig. 4-7) indicate the umbilical required for each fluid service. The type of fluid, normal operating pressure, and the normal flow rate have been indicated.

Flow rates shown reflect previous figures concurred with by MSFC, NRDS, and Aerojet personnel.

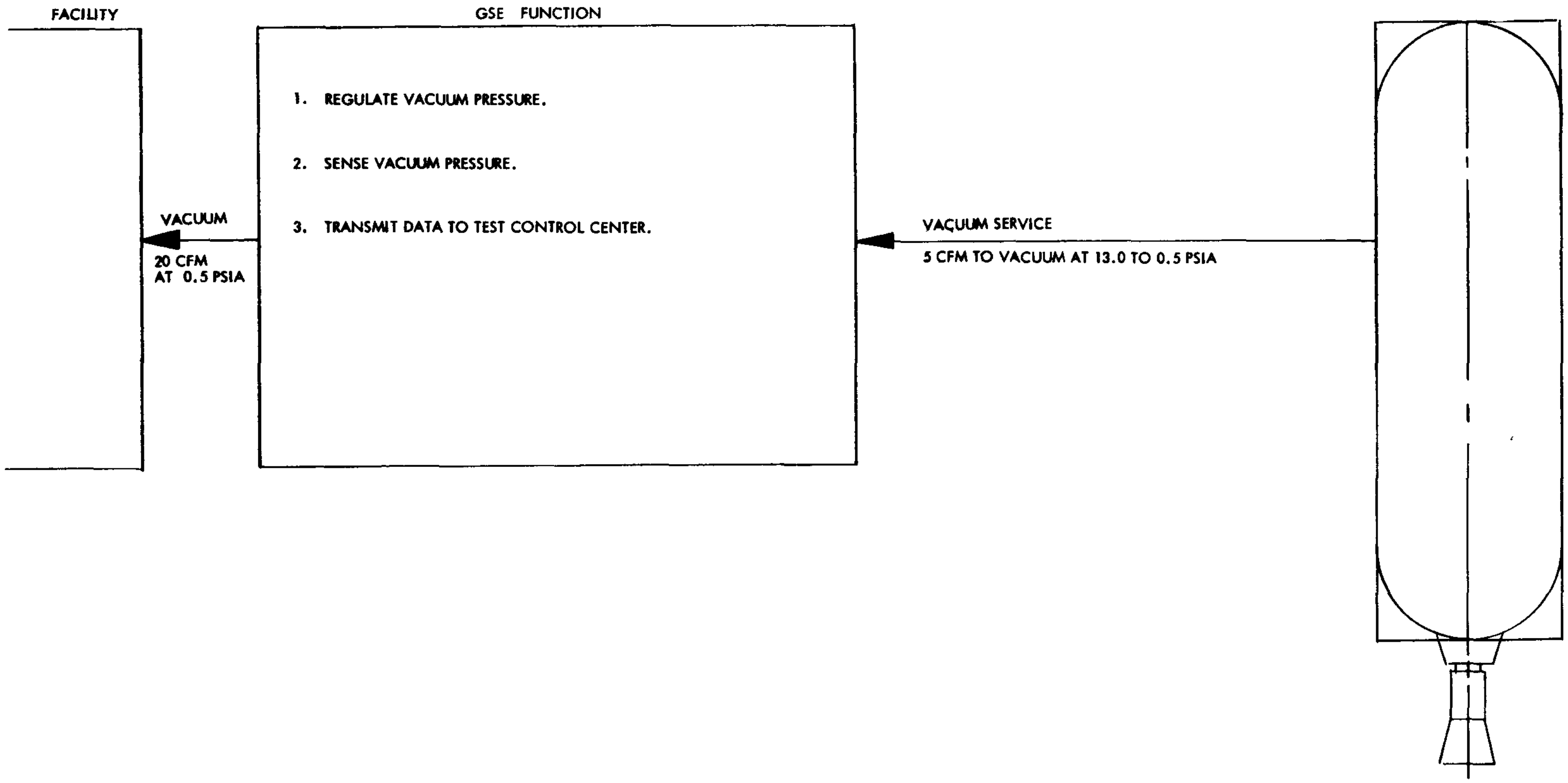


Fig. 4-5 Facility - GSE - Test Article Interfaces
Vacuum Service Unit

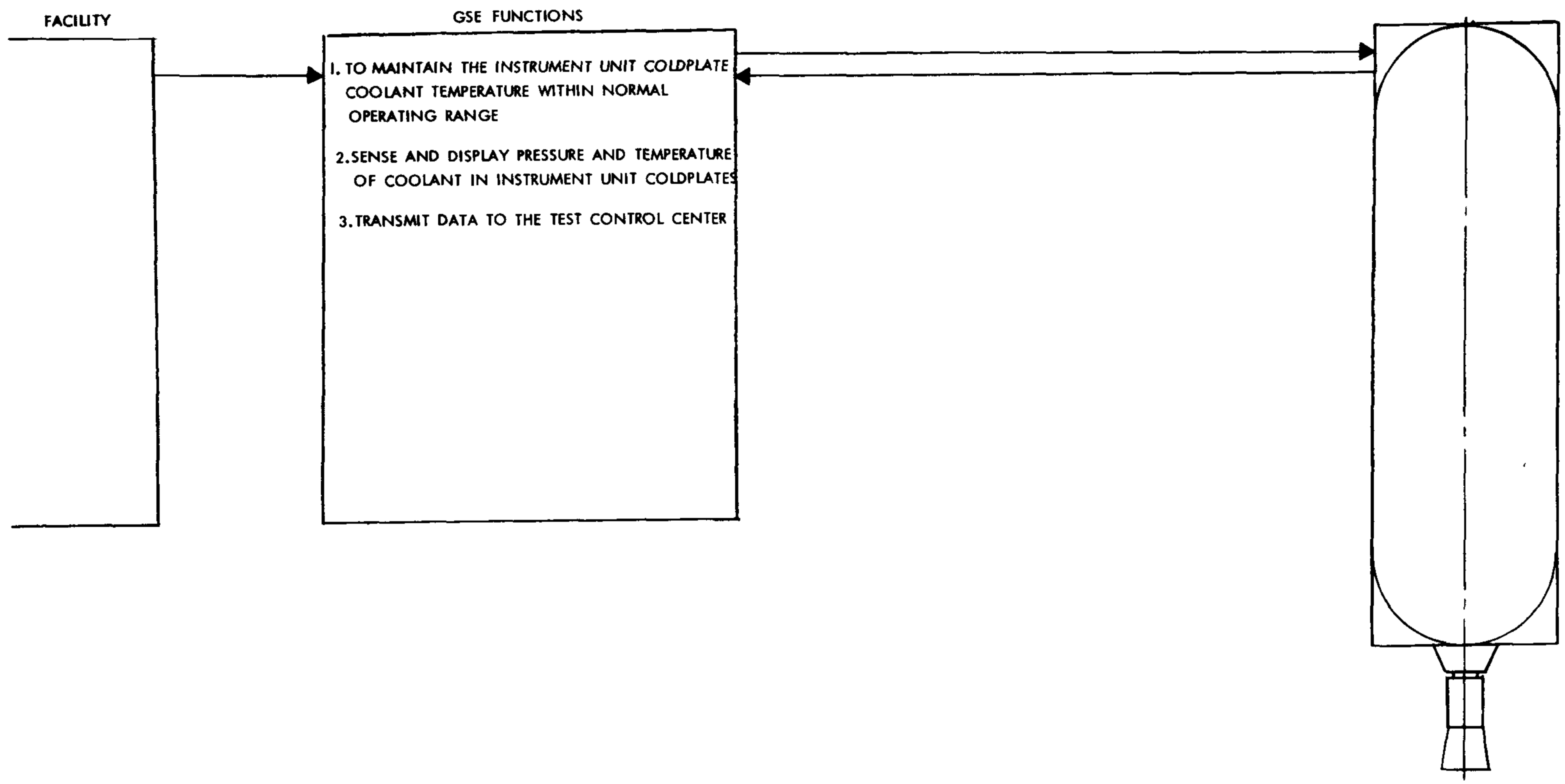


Fig. 4-6 Facility - GSE - Test Article Interfaces
Coldplate Coolant Service Unit

A description of the umbilical requirements and the relationship between the various fluid service connectors is shown in Section 1 for the forward and aft umbilical plates.

4.8 PROPELLANT MODULE SIMULATOR

This unit will provide the liquid hydrogen supply to the test article (propulsion module) during the test runs. This unit will modulate control, condition the LH_2 to simulate the flow of LH_2 from the propellant module propellant manifold to the propulsion module in the RNS flight system.

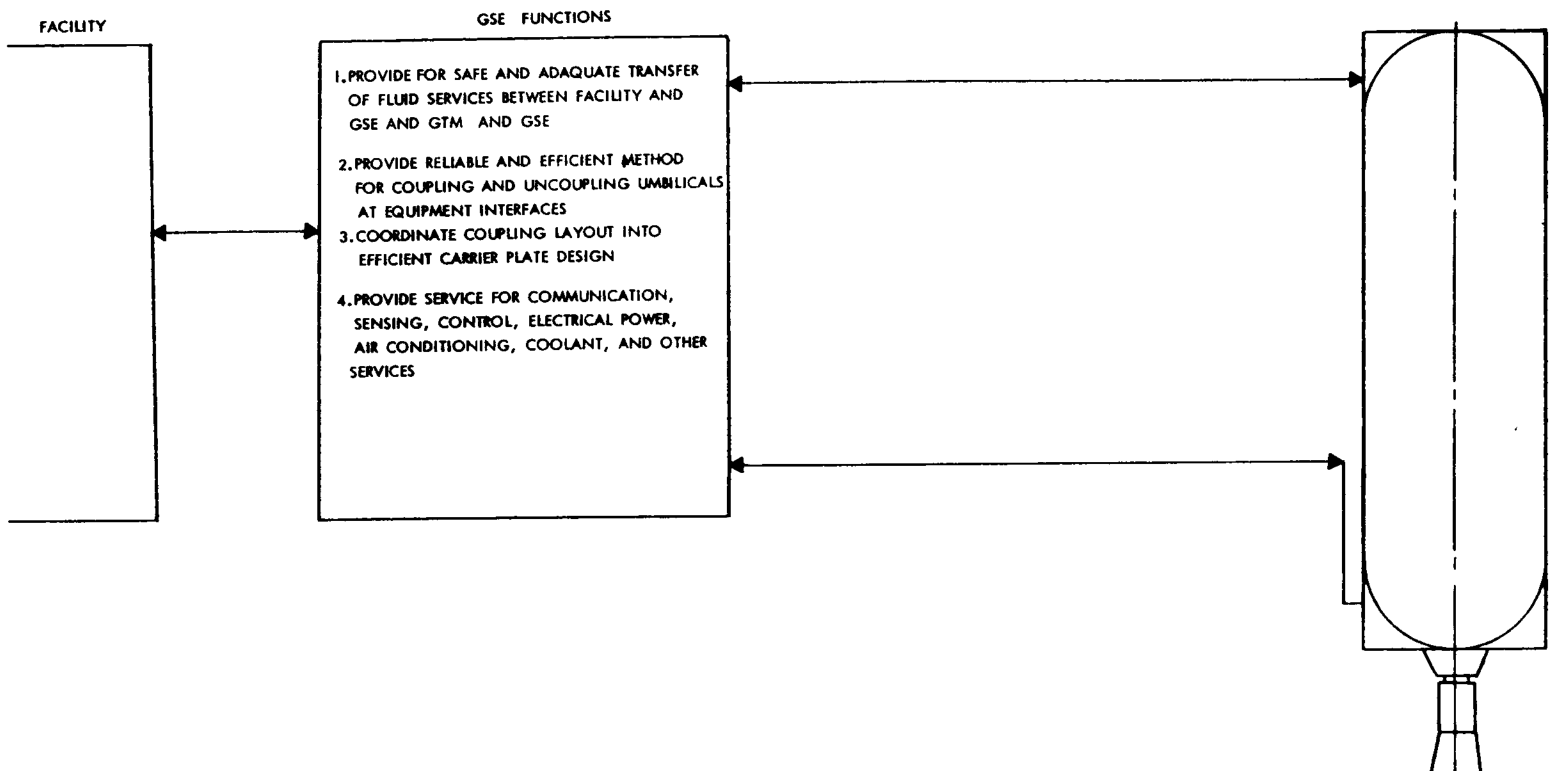


Fig. 4-7 Facility - GSE - Test Article Interfaces Umbilical Systems

Section 5

INSTRUMENTATION AND CONTROL

5.1 INTRODUCTION

This section describes the realtime, quick-look, and bulk data acquisition and processing requirements for the RNS NRDS ground test program. The measurement to be taken for the purpose of controlling the tests and to be obtained to determine performance were reviewed and categorized. Data acquisition and support are described and data analysis requirements are presented. To establish the realtime and data processing requirements, it was necessary to review the measurements that will be taken during the tests. The LMSC report, "Modular Nuclear Vehicle Study Phase IV, Nuclear Ground Test Module, Its Ground Support Equipment and NRDS Facilities Requirements," LMSC-681841, dated 14 October 1968, was used as the basis for estimating the quantity and characteristics of the measuring data. A series of tabulations were made and are included to provide background information.

Table 5-1 is a summary of the total number of measurements for both the flight and ground tests. The flight information has been included for future reference. The measurements have been tabulated by type and pertain to the ground/flight test articles only. Test stand, test area, and control center monitoring and control requirements have not been included in this task.

Table 5-2 lists the measurements as asigned by location according to the umbilical wiring. A 20-percent allowance for increasing the required measurements have been added.

Table 5-3 gives the measurements by location and includes the response rate requirements. The addition of monitors for the electronic equipment and provisions for event monitoring has also been included. The high frequency response measurements (i.e., acoustic and vibration) are noted separately.

Table 5-1

MEASUREMENTS FOR FLIGHT AND GROUND TESTS

Type of Measurement*	Ground Test			Flight Test		
	Vehicle	Engine	Total	Vehicle	Engine	Total
V	53	36	89	39	14	53
T	87	250	337	84	93	177
P	28	80	108	23	27	50
F	4	70	74	4	11	15
PO	4	50	54	--	50	50
S	66	110	176	66	48	114
N	28	40	68	28	9	37
LL	25	--	25	25	--	25
RPM	--	2	2	--	2	2
LEAK	--	4	4	--	--	--
X	4	--	4	4	--	4
SV	12	60	72	12	19	31
Totals	315	702	1017	268	273	541

* Symbols

V - Voltage, Signal
T - Temperature
P - Pressure
F - Flow
PO - Position
S - Strain
N - Nuclear
LL - Liquid Level
RPM - Rotation
LEAK - GH_2 Leak
X - Acoustic
SV - Vibration

NOTES

1. Information from LMSC-681841 Report, Engine Requirements should be reduced as test program develops.

Table 5-2

DIVISION OF MEASUREMENTS BY LOCATION*

Type	Forward	Aft	Engine	Total
V	44	24	43	111
T	68	35	300	403
P	20	13	96	129
F	5	--	84	89
PO	5	--	60	65
S	48	24	132	204
N	34	--	48	82
LL	30	--	--	30
RPM	--	--	3	3
LEAK	--	--	5	5
X	2	2	--	4
SV	2	12	72	86
Totals	258	110	843	1211

* 20% allowance for increase in measurements as requirements are finalized.

Table 5-3

REQUIRED FREQUENCY RESPONSE

Forward

Type	No.	SPS		Total SPS
V	22	@ 1.5	=	33
	10	@ 5	=	50
	8	@ 10	=	80
	4	@ 15	=	60
T	68	@ 1.5	=	102
P	20	@ 1.5	=	30
F	5	@ 5	=	25
PO	5	@ 1.5	=	8
S	48	@ 1.5	=	72
N	34	@ 5	=	170
LL	30	@ 1.5	=	45
				675

Aft

Type	No.	SPS		Total SPS
V	12	@ 1.5	=	18
	5	@ 5	=	25
	4	@ 10	=	40
	2	@ 15	=	30
T	35	@ 1.5	=	52
P	13	@ 1.5	=	20
S	24	@ 1.5	=	36
				221

Engine

Type	No.	SPS		Total SPS
V	21	@ 1.5	=	32
	10	@ 5	=	50
	8	@ 10	=	80
	4	@ 15	=	60
T	200	@ 1.5	=	300
	100	@ 5	=	500
P	50	@ 1.5	=	75
	32	@ 5	=	160
	8	@ 15	=	120
	2	@ 30	=	60
	4	@ 50	=	200
LEAK	5	@ 1.5	=	8
F	40	@ 1.5	=	60
	20	@ 5	=	100

Electrical Equipment

Type	No.	SPS		Total SPS
V	10	@ 1.5	=	15
T	10	@ 1.5	=	15
PO	20	@ 1.5	=	30
				60
	Events		=	16

High Frequency

Type	No.		Frequency
SV	2	@	30-3000 Hz
X	2	@	20-3000 Hz

High Frequency

Type	No.		Frequency
SV	10	@	30-3000 Hz
X	2	@	20-3000 Hz

Engine (contd.)

Type	No.	SPS		Total SPS
	10	@ 10	=	100
	5	@ 15	=	75
	5	@ 30	=	150
	4	@ 50	=	200
PO	40	@ 1.5	=	60
	15	@ 5	=	75
	5	@ 15	=	75
S	132	@ 1.5	=	200
N	30	@ 5	=	45
	12	@ 10	=	120
	6	@ 50	=	300
RPM	3	@ 50	=	150
				3161

High Frequency

SV 60 @ 30-3000 Hz

* Samples per second

Table 5-4

REALTIME MEASUREMENTS AND DATA RATES BY LOCATION

Type	Forward	Qty		SPS		Response (SPS)
V	Elect Equip	2	@	1.5	=	3
	Propellant Control	5	@	1.5	=	8
	Controls	4	@	15	=	60
T	Struct	4	@	1.5	=	6
P	Tanks & Lines	6	@	1.5	=	9
F	Lines	4	@	5	=	20
PO	Valves	5	@	1.5	=	8
S	Struct	4	@	1.5	=	6
N	Equip	2	@	5	=	10
LL	Tanks	30	@	1.5	=	45
		66				175
	Aft					
V	Controls	2	@	1.5	=	3
	Distributor	2	@	15	=	30
T	Structures	4	@	1.5	=	6
P	Lines	4	@	1.5	=	6
S	Structures	8	@	1.5	=	12
		20				57
	Engine					
V	Controls	2	@	15	=	30
T		10	@	5	=	50
P		4	@	50	=	200
F		4	@	50	=	200
PO		5	@	15	=	75
S		8	@	1.5	=	12
N		6	@	50	=	300
RPM		3	@	50	=	150
LEAK		5	@	1.5	=	8
		47				1025

Type	High Frequency	Qty		Range
SV	Fwd	2	@	70 to 3000
	Aft	2	@	30 to 3000
	Eng	4	@	30 to 3000
X	Fwd	1	@	20 to 3000
	Aft	2	@	20 to 3000
		11		

NOTE: The 30 LL measurements are comprised of the following

1-Capacitor probe approx 4 ft long at top of tank.
2-Capacitor proble approx 4 ft long at bottome of tank
3-Capacitor probe extending length of tank.
8-Optical point sensors or discrete capacitor sensors near top of tank.
8-Optical point sensors or discrete capacitor sensors near bottom of tank.
11-Optical or discrete capacitor sensors distributed throughout tank.

The primary measurements required for control and safety monitoring have been selected and are listed according to location. These are tabulated in Table 5-4 along with each required frequency response. The measurements listed in this table are the required realtime measurements and also indicate the data rate requirements.

Table 5-5 is a summary of the measurements and has been tabulated by type of measurement, classification of data, and frequency response. Notations have been included to explain the table and to point out some of the pertinent information. A discussion of the analysis of the acqusition, display, and processing requirements follows.

5.2 ANALYSIS OF DATA REQUIREMENTS

5.2.1 Realtime Data

The forward section (see Table 5-4) requires monitoring of 66 measurements. Of these, 30 pertain to the liquid level and are of the point sensor and capacitive probe type (see Table 5-4). These measurements can be grouped or multiplexed. For realtime display a maximum of 4 data channels will be required for the liquid level measurements. The aft section requires 20 realtime measurements. The engine monitoring demands faster response rates and also a fairly extensive survey; therefore, an allowance of 47 measurements is required.

A total of 105 realtime data channels is recommended. Displays for these can be in the form of indicator lights for valve positions (10); multiple channel X-Y plotters for pressure (14) with the two most critical independently displayed and equipped with alarms (audio/visual); strip charts for strain measurements (20); voltage meters with preset indicator limits (17); multiple channel X-Y plotter for temperature (18) with the 4 most critical independently displayed and equipped with audio and or visual alarms; dial gages for flow measurements (8); RPM meters for the 3 shaft measurements; and indicator lights and strip charts recorder for the liquid level (30)

Table 5-5

SUMMARY OF MEASUREMENTS BY FREQUENCY RESPONSE*

	Frequency Response - Samples per second (SPS)													
	1.5		5		10		15		30		50		Totals	
Type	Real Time	Bulk	Real Time	Bulk	Real Time	Bulk	Real Time	Bulk	Real Time	Bulk	Real Time	Bulk	Real Time	Bulk
V	9	65	--	25	--	20	8	10	--	--	--	--	17	121
T	8	313	10	100	--	--	--	--	--	--	--	--	18	413
P	10	83	--	32	--	--	--	8	--	2	4	4	14	129
F	--	40	4	25	--	10	--	5	--	5	4	4	8	89
PO	5	65	--	15	--	--	5	5	--	--	--	--	10	85
S	20	204	--	--	--	--	--	--	--	--	--	--	20	204
N	--	--	2	64	--	12	--	--	--	--	6	6	8	82
LL	30	30	--	--	--	--	--	--	--	--	--	--	30	30
RPM	--	--	--	--	--	--	--	--	--	--	3	3	3	3
LEAK	5	5	--	--	--	--	--	--	--	--	--	--	5	5
Totals	87	765	16	261	--	42	13	28	--	7	17	17	133	1161

* Does not include special measurements (i.e., events, vibration, acoustic).
** Measurement Symbols

- V - Voltage, Signal
- T - Temperature
- P - Pressure
- F - Flow
- PO - Position
- S - Strain
- N - Nuclear Radiation
- LL - Liquid Level
- RPM - Rotation
- LEAK - GH_2 Leak

TOTAL DATA REQUIRED

A - Real Time Data (maximum per second) - 133 measurements
87 x 1.5 + 16 x 5 + 13 x 15 + 17 x 15 = 1255

B - Bulk Data - 1161 measurements (maximum per second)
765 x 1.5 + 261 x 5 + 42 x 10 + 28 x 15 + 7 x 30 + 17 x 50 = 3331

C - Events - (maximum per second) - 16 discretes
Highest rate will be a total sequence in one second.

D - High Frequency Data (maximum number of channels)
All 14 required simultaneously - the assumption, that sufficient data has been acquired during engine testing, accounts for the reduction to 14

E - Timing
Clock signals will be required for correlating the data.

measurements. The output of each of the GH_2 leak detectors and the 8 radiation level detectors require continuous display and connection to an alarm system for alerting the operators of out of tolerance readings. Either automatic or manual cutoff controls can be implemented. The selection of this is to be determined.

In addition to displaying the essential realtime data, it will, of course, be necessary to record the data and to reference it to a time standard so that the "bulk" data can be correlated with the realtime data. Much of the data will be required in analog form. It is desirable to have the data recorded on tape for automatic analysis. The total number of samples per second from Table 5-4 is:

$$87 \times 1.5 + 16 \times 5 + 13 \times 15 + 17 \times 50 = 1255 \text{ sps}$$

For ease of analysis this should be converted to an 8- or 10- bit digital form. The recording of the realtime data would require a bit rate of less than 20 kilobits/sec.

The most effective way to handle the realtime data is to bring each measurement via hard wire from the umbilicals to the control center. These measurements should not be considered to be a part of the Digital Data System (DDS) instrumentation system. In addition to the hard wire lines, the realtime measurements should be multiplexed and digitized at the forward control center at the test stand and sent via coaxial cable to the control center for recording.

5.2.2 Bulk Data

The remainder of the measuring data, except for high-frequency acoustic and vibration, will be obtained in three different groups. One will be the measuring data assigned to the DDS, a second will be that required for the engine. and the third will be derived from the stage either as parallel redundant or supplemental to the DDS.

The DDS is to represent the flight type of data monitoring. The data from this system is suitable for direct recording, providing that it is not applied to a carrier (600KZ). If a carrier is used, a demodulator will be required. The signal level will require testing or study to determine the need for an amplifier at the forward control center. By careful selection of the monitoring points, the DDS recorded data will provide the quick-look data. It will be necessary to record a realtime clock signal with the DDS output for correlating the test data. It is recommended that a careful selection of the measurements be made and that the number be limited to about 240. Even though the recommended on-board electronics system has a longer capacity, the tapes containing the DDS quick-look data can be sent to the computer at the test site for immediate reduction and should be available for review ithin a few hours after a test run.

The remining bulk data (i.e., from the GTM and engine) is suitable for multiplexing either on the test stand or at the forward control center. The required frequency response (GTM, 675 + 221 + 60 = 956 sps; and the engine, 1710 sps from Table 5-5) is sufficiently low to permit converting into a digital form after multiplexing in the forward control center. A 10-bit conversion would provide sufficient accuracy and would require about a 32K bit rate. Again as noted for the DDS, a realtime clock signal will be required for data correlation.

5.2.3 Events

Although the events could be interleaved with the realtime and bulk data, it is recommended that this information be recorded separately. This, combined with a realtime clock signal, will form the basis for converting the data. The events will be designated from the operational test plan.

5.2.4 High-Frequency Data

Fourteen high-frequency measurements are required for determining the vibration and acoustic characteristics. It is recommended that each of these signals be brought out separately and recorded. A spectrum analyzer can be provided for visual monitoring during the test runs.

5.2.5 Timing

As noted with the description of the data, a realtime clock will be required. Signals from the clock on at least one-second intervals will be required for reference with each of the recorded data tapes.

5.3 DATA CONTROL AND PROCESSING

The total amount of data accumulated will be a function of the test operations planning. For the typical test run noted in Table 5-6, two extended periods of steady state operation are noted; the period from T-300 seconds and the period from T+55 to T+355. Also, the period of time during the system cool-down from T+405 to T+800 is relatively inactive from a data point of view. Lower sampling rates could be assigned during these times to reduce the total amount of data without jeopardizing the acquisition of performance information. This is left for the operation planning at this time.

Standard data reduction and analysis techniques are required. The formatting of the digital data is to be described and is to be in keeping with available programs at NRDS. All measurements, with the exception of the high frequency for the critical measurements. Analog data will back up the digital data for the more important realtime measurements. The analog data will be useful during the actual test run and will serve as redundant data for the post-test analysis.

Section 6
FLUID REQUIREMENTS

Preliminary planning for facilities in support of an engine/stage test complex at NRDS have been prepared by an architect engineer consulting firm and documented in (Ref. 3-5). The fluid requirements for RNS testing shown in Fig. 4-12 of the referenced report were generally derived from requirements of ground test of a ground test module. Extension of the nuclear flight vehicle studies in Phase II and Phase III effort have resulted in changes in vehicle configurations and fluid requirements which impact on NRDS complex facility planning. The intent of this section is to update the fluid requirements consistent with the published data available to date from the three RNS study contractors.

The task of developing these RNS fluid requirements was generally categorized into subtasks, as follows:

- Review published RNS study contractor documents regarding fluid requirements and vehicle configurations.
- Coordinate with test planning objectives.
- Calculate fluid requirements for four configurations (single tank -8° and 15° half-angle conical domes, hybrid, and modular).
- Review data with RNS study contractors and MSFC.
- Publish final data as fluid requirements in support of RNS testing at NRDS.

6.1 REVIEW OF CONTRACTOR DATA

The three RNS study contractor documents were reviewed to determine all reference fluid requirements peculiar to each stage design. The initial reference point was the final report of each contractor for the Phase II study, as these were the most detailed in design in the area of vehicle fluid management, insulation systems, structural details, and in subsystem design and components. In all cases, these final reports concluded with a baseline and one or more alternate design concepts. However, in most cases the alternate and baseline concepts for each contractor's "family" of vehicles held approximately the same LH_2 propellant loading. It is to be noted that each contractor's stated propellant loading is based on requirements for the referenced lunar mission. Each contractor stated LH_2 propellant loadings are considered as NRDS fluid design requirements. After the Phase II final report data were tabulated, a review was made of the Phase III interim briefing and monthly reports, and modifications and changes in Phase II final data were noted.

6.2 ASSUMPTIONS AND LIMITATIONS

This study of fluid requirements has been predicated on several assumptions which are necessarily tied into the overall test objectives of the RNS program at NRDS. The test objectives were concurrently coordinated between the three study contractors and MSFC; however, the following assumptions appear to be within the scope of overall test objectives as they relate to fluid requirements.

The fluid requirements should be planned on a "full up" flight vehicle design (as related to fluid requirements).

The test article may only be the propulsion module of either the MDC hybrid or LMSC modular design and therefore separate calculations have been made for these modules alone and are presented in Section 5. However, it is always assumed that when the propulsion module is the only flight hardware utilized, it will be tested in conjunction with one of several options such as:

- o A flight-type main propellant tank
- o A "battleship" run tank
- o Direct replenishment from the facility storage system

Each option has been assumed to result in the same operational run LH_2 fluid requirement, as it is assumed the test objectives require a "full up" flight vehicle (as related to fluid requirements).

The test objectives are basic demonstrations which will not exceed RNS fluid requirements of the referenced lunar mission.

Demonstration tests of engine cooldown modes will not exceed the flight vehicle propellant allocation for cooldown. Estimates for this quantity vary from the 8,000 to 10,000 lb stated by NAR to the estimate of 20,000 lb by LMSC. Demonstration tests are expected to require less than the LH_2 budget allocation but facility will provide standby cooldown for LH_2 in event of failure of the flight cooldown system. In addition, the facility will provide the GN_2 or GH_2 required for post-engine cooldown and these fluid requirements are not incorporated in this report. These data may be obtained from the engine contractor.

The maximum hold period of time for a full propellant tank during test is assumed to be 12 hours duration. Boiloff quantities have been estimated for the various RNS configurations, and it will be necessary to top the propellant tank during this hold period. It is assumed that the worst hold period would be from 8:00 a.m. to 8:00 p.m. on a summer day.

6.3 RNS REQUIREMENTS - GENERAL

The following propellant management and other fluid systems of the RNS require fluid services which will be more specifically identified later. At this phase of the study, each contractor is generally considering more than one configuration, and where contractor data are available they are given in the reference section.

Propellant Feed Systems. The propellant feed system shall deliver LH_2 from the storage facility at the required fluid conditions (pressure, temperature, and quality).

Purge System. The facility shall provide for nitrogen, helium and/or gaseous hydrogen purge systems to purge the tank and tank systems as required. The systems shall receive nitrogen and helium and/or gaseous hydrogen from a ground source.

Pneumatic Control System. The facility shall provide gaseous hydrogen/helium control pressure to fulfill the propellant tank system valve situation requirements.

LH_2 Emergency Drain System. Provisions shall be made to allow the installation of an emergency drain line from the propellant tank to meet test stand emergency drain requirements. Emergency drain of the propellant tank shall be by RNS pressure transfer through the fill line back to storage dewar. Emergency drain provisions shall be incorporated so that in event of noncapability to effect a pressure transfer, LH_2 may be gravity drained to the storage dewar. If dewar siting prevents a gravity transfer to the storage dewar a burn pond or gravel pit design is acceptable if the facility provides a low pressure drop drain line for emergency drain.

Propellant Fill, Replenishment and Drain Systems. The propellant fill, replenish, and drain systems shall provide the means to load and drain fuel to and from the propellant tank prior to start of test. If a run tank or "battleship" tank is to be used, the facility shall replenish propellant at a rate that will provide for a 30-minute full power engine test followed by a normal cooldown with sufficient propellant remaining to provide an adequate safety margin.

Vent System. The vent system shall be sized so that pressure does not exceed TBD psig.

6.4 CALCULATION

6.4.1 MDC Configuration

Two MDC configurations were reviewed: the RNS Class 1 single tank configuration and the RNS Class 1 hybrid which consists of a propellant and propulsion module. These configurations are shown in Fig 6-1.

Additional detail for a 15-deg half-angle single tank RNS configuration is shown in Fig 6-2.

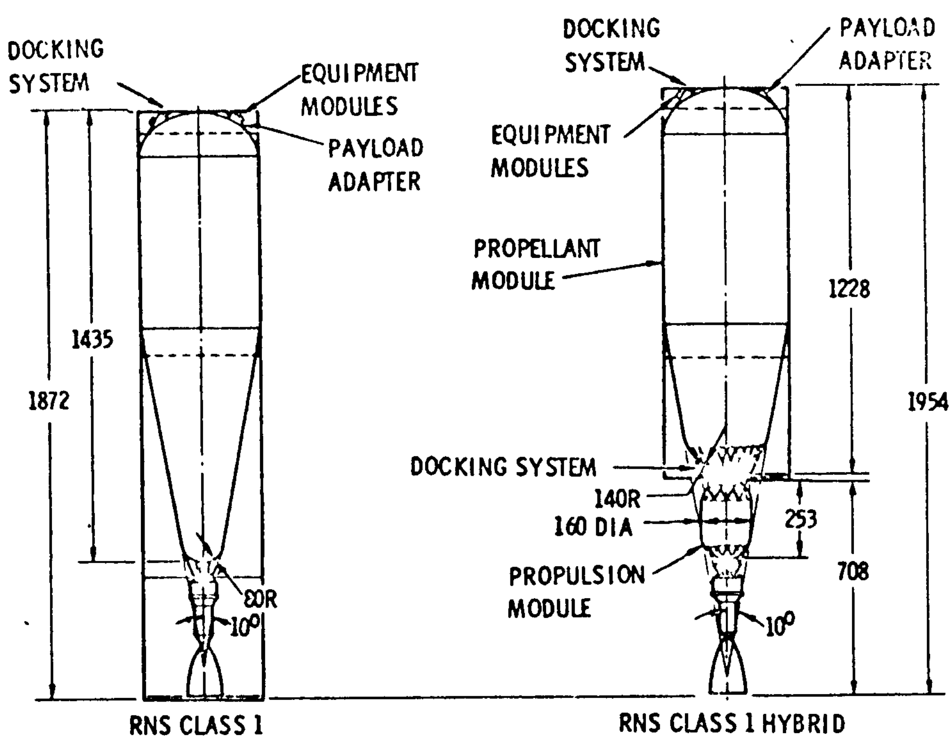


Fig 6-1 RNS Class 1 Configurations, 300,000 Lb LH_2

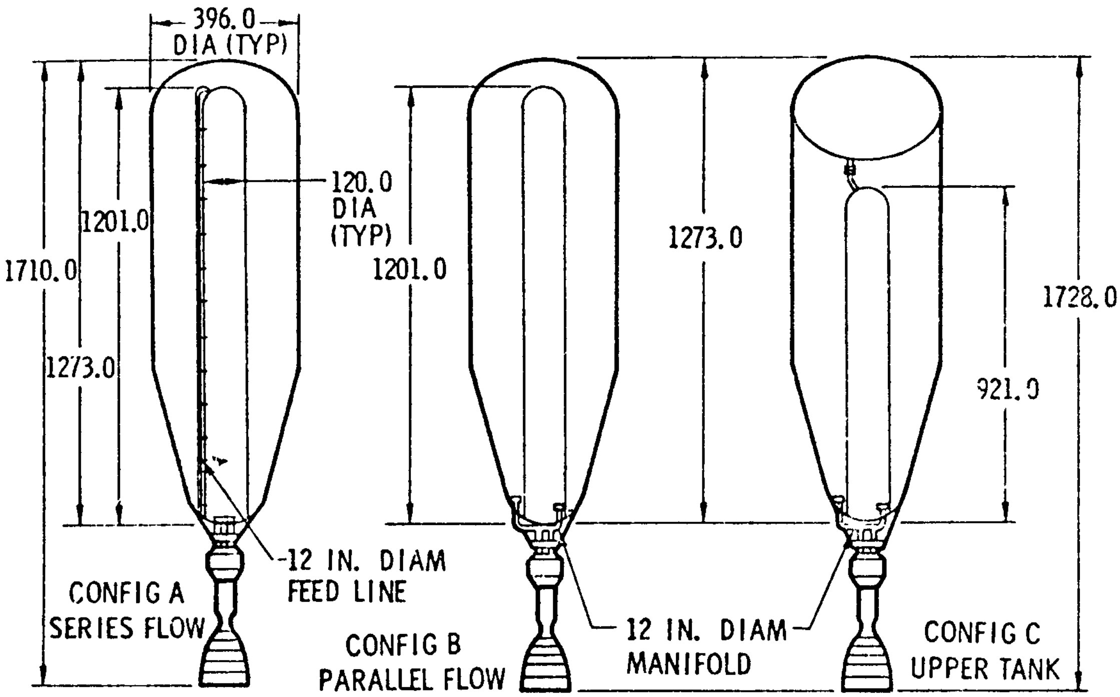


Fig 6-2 Initial RNS Internal Tank Configurations

The MDC reference data utilized for the following calculations is shown in Table 3-1. Based on these data the following calculations were made.

MDC Analysis

Propellant Module (Class 1 Hybrid and also RNS Class 1 Configuration propellant tank)

Given 291,300 lb LH_2 propellant load

Calculated volume $= \frac{291,300 \text{ lb}}{4.43 \text{ lb/ft}^3} = 67,756 \text{ ft}^3$ for LH_2

Given 5% ullage volume (of total)

$$\underset{(LH_2 \text{ vol})}{67,756 \text{ ft}^3} + \underset{(\text{ullage})}{0.05\ x} = X$$

Where X = total tank volume

$67,756 \text{ ft}^3 = 0.95\ x,\quad x = \underline{71,322 \text{ ft}^3 \text{ total volume}}$

Ullage vol $= 71,322 - 67,756 = \underline{3,566 \text{ ft}^3}$

Propulsion Module (Class 1 Hybrid

Given 9,700 lb LH_2 propellant load

Calculated volume $= \frac{9,700 \text{ lb}}{4.43 \text{ lb/ft}^3} = 2,190 \text{ ft}^3$ for LH_2

Assume 5% ullage volume (of total)

$$\underset{(LH_2 \text{ vol})}{2,190 \text{ ft}^3} + \underset{(\text{ullage})}{0.05\ x} = X$$

Where X = total tank volume

$2,190 \text{ ft}^3 = 0.95\ x,\quad x = 2,300 \text{ ft}^3$ total volume

Ullage vol $= 2,300 - 2,190 = \underline{110 \text{ ft}^3}$

Propellant Tank Childown - LH

Assume 1/6th qty of propellant tank (per GTM criteria - should be heat transfer calculation)

Propellant Module $= \frac{291,300}{6} = 48,550$ lb LH_2 for childown

Propulsion Module $= \frac{9,700}{6} = 1,616$ lb LH_2 for childown

Purge Gas Requirements - GH_2

Propellant Module (Class 1 Hybrid propellant tank)

Previous calculations total volume = 71,322 ft^3

Use 10 GH_2 vol changes = 71,322 x 10 = 713,220 ft^3

One ft^3 of GH_2 = 0.0052 lb

713,220 ft^3 x 0.0052 lb/ft^3 = 3,208 lb

Propulsion Module (Class 1 Hybrid)

Previous calculations total volume = 2,300 ft^3

Use 15 GH_2 vol changes = 2,300 x 15 = 39,500 ft^3

One ft^3 of GH_2 = 0.0052 lb

39,500 ft^3 x 0.0052 lb/ft^3 = 205 lb

For Hybrid Class 1 Design

Propellant Module (Class 1 Hybrid and also RNS Class 1 Configuration propellant tank)

Previous calculations total volume = 71,322 ft^3

Use 6 GN_2 vol changes - 71,322 x 6 = 427,932 ft^3

One ft^3 of GN_2 = 0.072 lb

427,932 ft^3 x 0.072 = 30,811 lb

Propulsion Module (Class 1 Hybrid)

Previous calculations total volume = 2,300 ft^3

Use 9 GN_2 vol changes = 2,300 x 9 = 20,700 ft^3

One ft^3 of GN_2 = 0.078 lb

20,700 ft^3 x 0.072 = 1,440 lb

For Hybrid Class 1 Design, then, total propellant and propulsion module purge gas required = 32,400 + 1,621 = 34,021 lb.

6.4.2 Calculation - NAR Configurations

Two NAR configurations were reviewed: the baseline Phase II single tank and the conical tank which evolved in the Phase III report. Fig 6-3 shows the baseline configuration during Phase II activities.

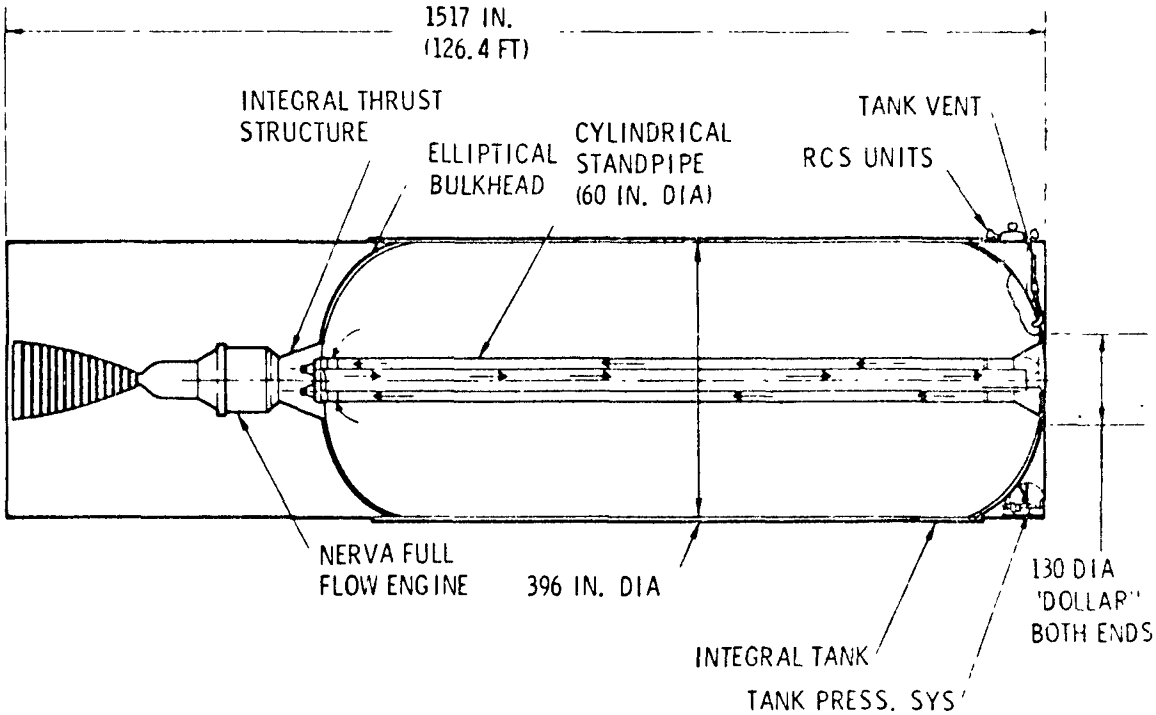


Fig 6-3 Initial Phase II Baseline Configurations

Fig 6-4 depicts the latest Phase III configurations under consideration and the conical single-tank configuration is utilized for calculations in this report. The reference data for the following calculations are shown in Table 3-1. Fig 6-5 is the recommended Phase III configuration and represents the basis for current plan.

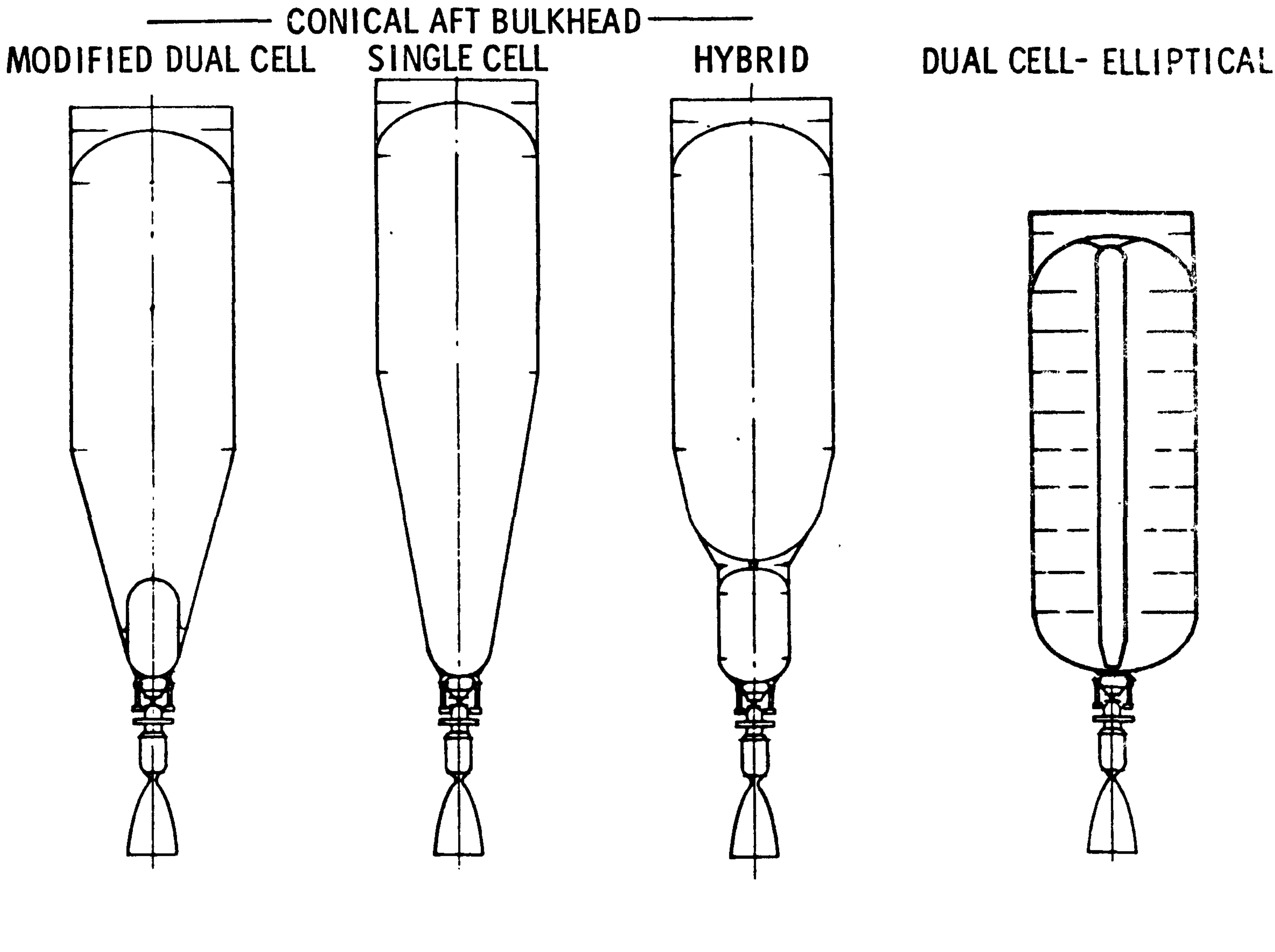


Fig 6-4 Current Phase III Configurations

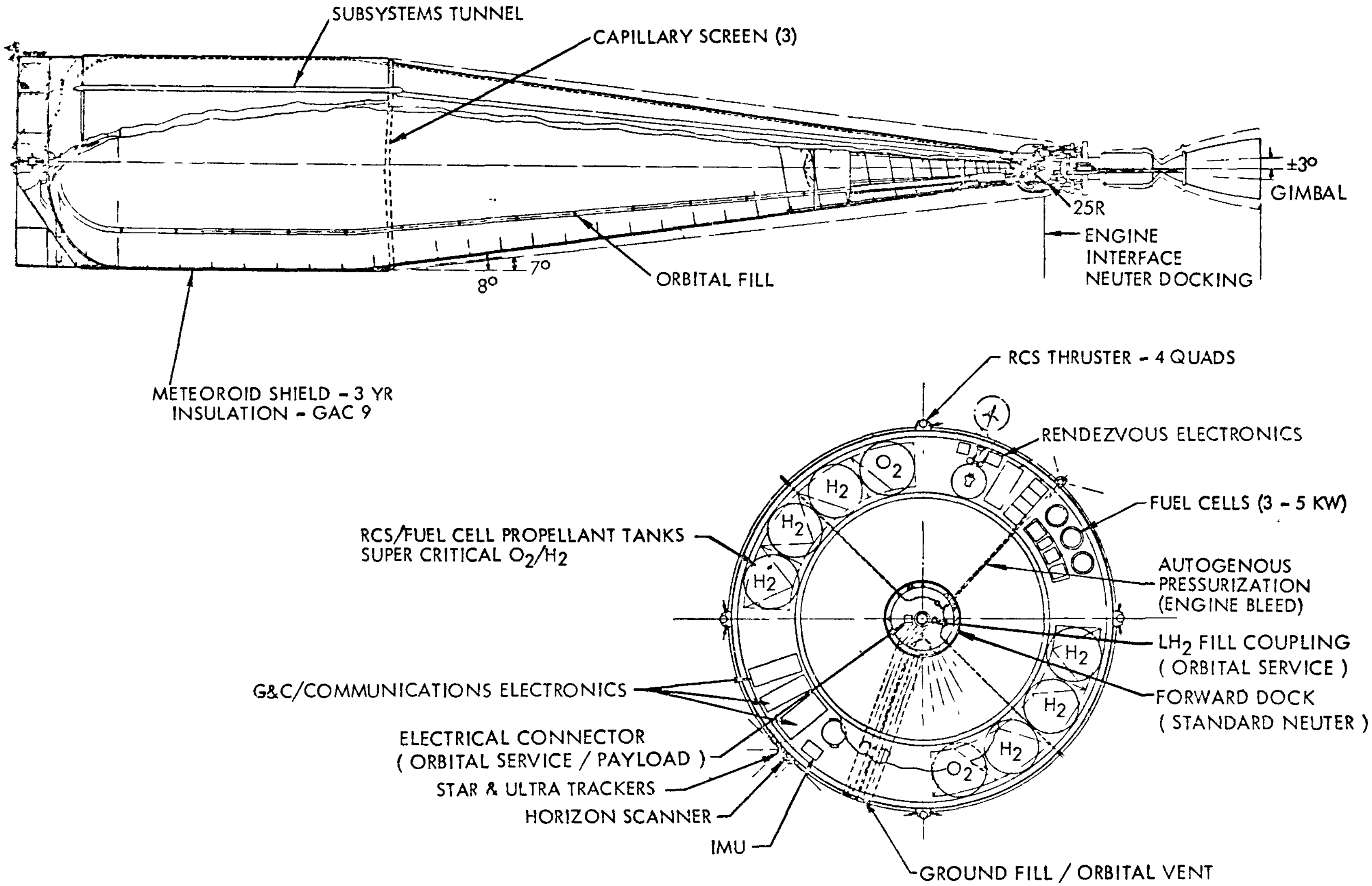


Fig 6-5 Recommended RNS Configuration and Subsystems

Propellant Tank Load = 300,000 lb (Phase III - first Interim Review)

Calculated volume = $\frac{300,000 \text{ lb}}{4.43 \text{ lb/ft}^3}$ = 67,720 ft^3 for LH_2

Given 4% ullage volume (of total) — 67,720 (LH$_2$ vol) + 0.05 x (ullage) = X

67,720 ft^3 = 0.95 x, x = 71,284 ft^3 total volume

Ullage volume = 3,584 ft^3

Propellant Tank Chilldown - LH_2

Assume 1/6th qty of propellant tank

Propellant tank = $\frac{300,000}{6}$ = 50,000 lb LH_2

Purge Gas Requirements - GH_2

Propellant Tank

Previous calculations total volume = 71,284 ft^3

Use 10 GH_2 vol changes = 71,284 x 10 = 712,840 ft^3

One ft^3 of GH_2 = 0.0052 lb

712,540 ft^3 x 0.0052 = 3,706 lb

Purge Gas Requirements - GN^2

Previous calculations total volume = 71,284 ft^3

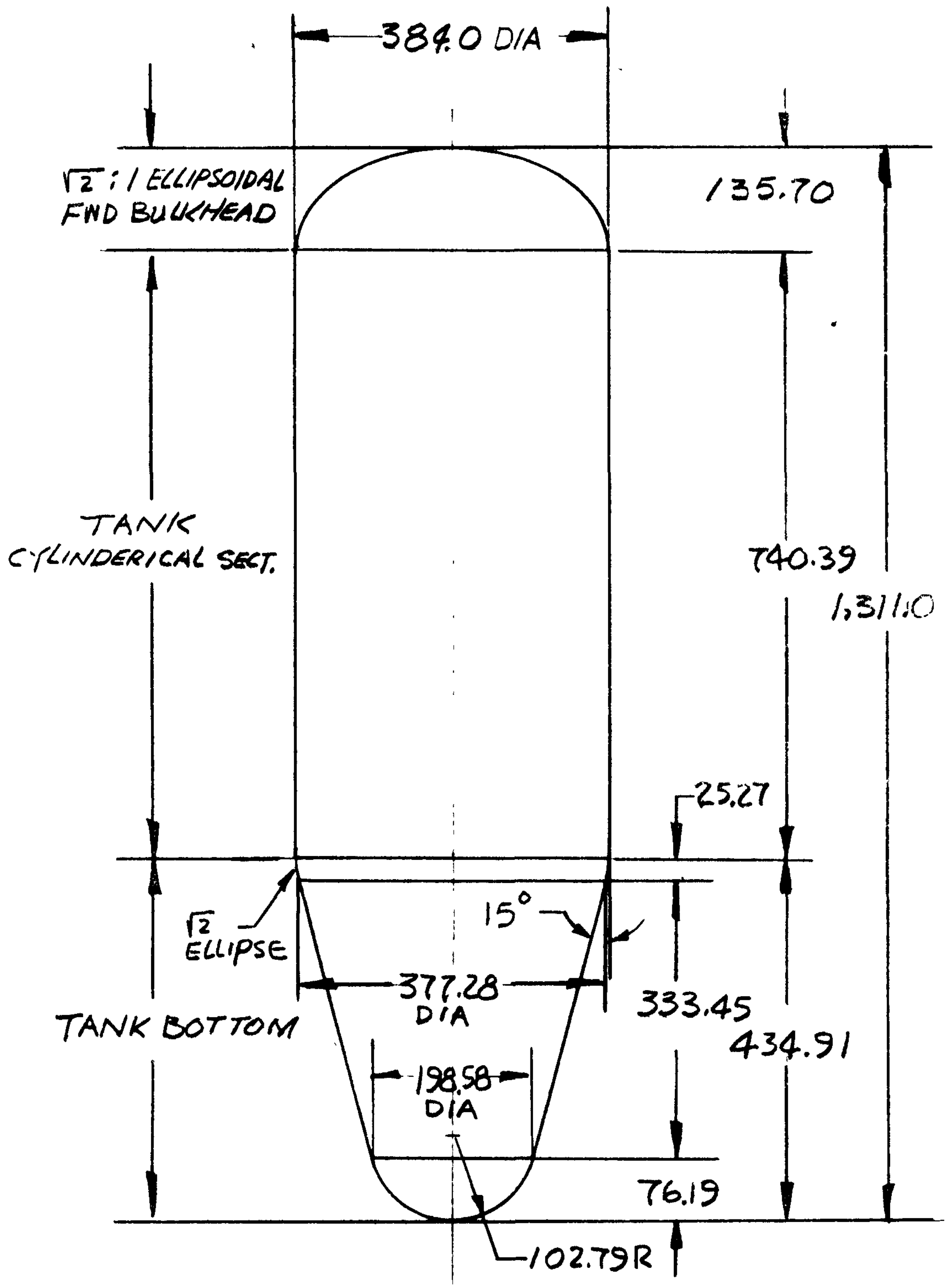
Use 6 GN_2 vol changes = 71,284 x 6 = 427,704 ft^3

One ft^3 of GN_2 = 0.072

427,704 x 0.072 = 30,795 lb

6.4.3 Calculations - LMSC Configuration

Two configurations were reviewed for this study. The single tank module with a 15-deg half-angle and a propellant loading of 300,000 lb LH_2 is shown in Fig 6-6. The baseline modular configuration of 7 modules of 15' dia x 60' length is shown on Fig 6-7 with two alternate tank configurations which were not reviewed.



300K Tank Basic Dimensions

PROPELLANT WT. = 300,000 lbs
TANK VOL. INCL. 5% ullage
PROPELLANT VOL. = 67,720.0 ft^3

Fig 6-6 Single Tank

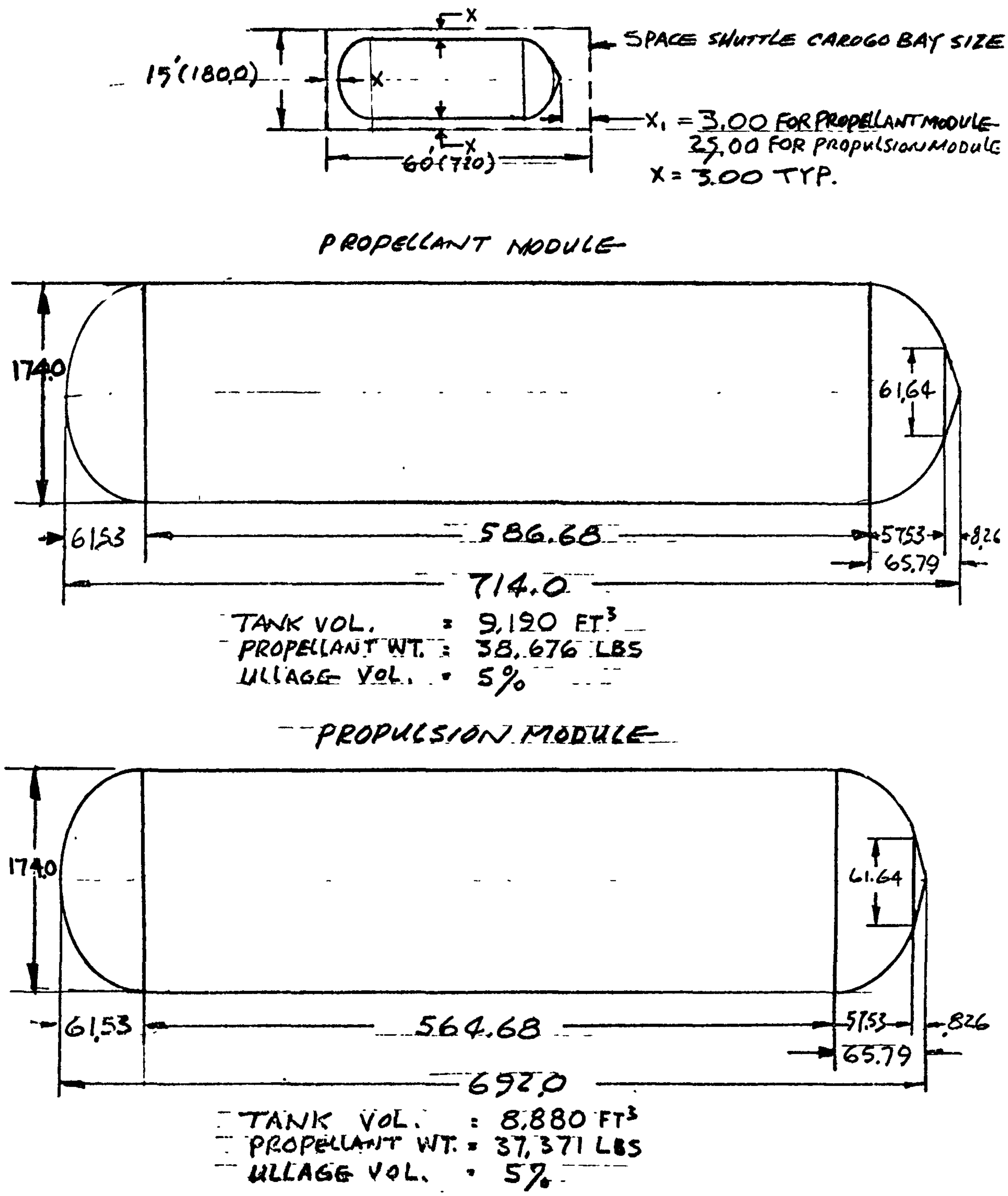


Fig 6-7 7 Tank Concept (270K LN_2)

The LMSC reference data utilized for the following calculations is shown in Table 3-3.

Chilldown - LH_2

Propulsion Module

Assume 1/6th qty of propellant tank

LH_2 required in propulsion module = 37,371 lb

LH_2 required for chilldown = $\frac{37,371}{6}$ = 6,228 lb

Propellant Module

Assume 1/6th qty of propellant tank

LH_2 weight in propellant module = 38,676 lb

Each propellant module LH_2 required for chilldown = $\frac{38,676}{6}$ - 6,446 lb

Total chilldown = 6,446 lb x 6 modules = 38,676 lb (total)

Purge Gas Requirements - GH_2

Propulsion Module

Previous data total volume = 8,880 ft^3

Use 15 GH_2 vol changes = 8,880 ft^3 x 15 = 133,200 ft^3

One ft^3 of GH_2 = 0.0052 lb

133,200 ft^3 x 0.0052 lb/ft^3 = 693 lb

Propellant Module

Previous data total volume = 9,190 ft^3

Use 15 GH_2 vol changes = 9,190 x 15 = 137,850 ft^3

One ft^3 of GH_2 = 0.0052 lb

137,850 lbs x 0.0052 lb/ft^3 = 717 lb

For 6 propellant modules GH_2 purge gas = 717 x 6 = 4302 lb

<u>Purge Gas Requirements</u> - GN_2

<u>Propulsion Module</u>

Previous data total volume = 8,880 ft^3
Use 9 GN_2 vol changes = 8,880 ft^3 x 9 = 79,920 ft^3
One ft^3 of GN_2 = .078 lb
79,920 ft^3 x .078 lb/ft^3 = 6,220 lb

<u>Propellant Module</u>

Previous data total volume = 9,190 ft^3
Use 9 GN_2 vol changes = 9,190 x 9 = 82,710 ft^3
One ft^3 of GN_2 = 0.072 lb
82,710 ft^3 x 0.072 lb/ft^3 = 5,955 lb
5,955 x 6 propellant modules = 35,730 lb

6.5 SUMMARY - TABULATION OF DATA

The summary of the RNS configurations fluid requirements is shown in Table 6-1. The configurations reviewed were the NAR 8-deg half-angle single tank, the MDC RNS Class 1 single tank and the RNS Class 1 hybrid and the LMSC modular and 15-deg. For both the RNS Class 1 hybrid and the LMSC modular, separate calculations and requirements are shown for the propulsion module, as final test philosophy might require only the propulsion module for some portion of the test program.

Table 6-1

FLUID REQUIREMENTS SUMMARY

Vehicle Configuration	Fluid Type	Fluid Pressure (psia)	Fluid Temperature Max/Min (°R)	Flow Rate (lb/sec)	Operational Quantity (lb)	Fluid Cleanliness
LMSC Single Tank (Ref.) 15° Half Angle	LH_2 (slow fill)	26.25	38	10.0	300,000	MSFC-SPEC-164
	LH_2 (fast fill)	26.25	38	100.0		"
	Topping (12-hr hold)	16	38	0 to 5.0	10,000	"
	GH_2 (tank chill-down)	26.25	35.6	0.3	50,000	"
	GH_2 (tank purge)	15.25	530/	2.5	3,000	"
	GH_2 (tank purge)	15.25	530/	2.5	25,000	"
NAR Single Tank (8° half angle, 25 in. cap radius)	LH_2 (slow fill)	27.5	38	10.0	300,000	MSFC-SPEC-164
	LH_2 (fast fill)	27.5	38	100.0		"
	Topping (12-hr hold)	16	38	0 to 5.0	TBD	"
	LH_2 (tank chill-down)	27.5 psi max	38	0.3	50,000	"
	GH_2 (tank purge)	15-25 psi max	530/	2.5	3,706	"
	RCS propellant 7,100	TBD	TBD	TBD	4,600 O_2 1,200 H_2	"
	Fuel cell reactants LO_x LH_2 1500		TBD	TBD	155-170 H_2 1240-1360 O_2	"

Table 6-1 (Con't)

Vehicle Configuration	Fluid Type	Fluid Pressure (psia)	Fluid Temperature Max/Min(^{o}R)	Flow Rate (lb/sec)	Operational Quantity (lb)	Fluid Cleanliness
MDC Hybrid	LH_2 (slow fill)	28 psi max	38	3.0	300,000	MSFC-SPEC-164
	LH_2 (fast fill)	28 psi max	38	3.0		"
	LH_2 (topping)	16 psi	38	0 to 5.0	TBD	"
Propellant Tank	LH_2 (tank chill-down)	28 psi max	38	0.3	50,000	"
	GH_2 (tank purge)	15-25 psi max	530/	2.5	3,990	"
	GN_2 (tank purge)	15-25 psi max	530/	2.5	3,240	"
	LH_2 (slow fill)	26.5 psi max	38	3.0	9,700	MSFC-SPEC-164
	LH_2 (fast fill)	26.5 psi max	38	3.0		"
	LH_2 (topping)	16 psi	38	0 to 5.0	TBD	"
Propulsion Tank	LH_2 (tank chill-down)	26.5 psi max	38	0.3	1,616	"
	GH_2 (tank purge)	15-25 psi max	530/	2.5	205	"
	GN_2 (tank purge)	15-25 psi max	530/	2.5	1,490	"

Table 6-1 (Con't)

Vehicle Configuration	Fluid Type	Fluid Pressure (psia)	Fluid Temperature Max/Min(^{o}R)	Flow Rate (lb/sec)	Operational Quantity (lb)	Fluid Cleanliness
Propulsion Module Only	LH_2 (slow fill)	25.5 psi max	38	10.0	37,371	MSFC-SPEC-164
	LH_2 (fast fill)	25.5 psi max	38	100.0		"
LMSC Modular	LH_2 (topping)	16 psi	0 to 5.0		TBD	"
	LH_2 (tank chilldown)	25.5 psi max	38	0.3	6,228	"
	GH_2 (tank purge)	15-22 psi max	530/	2.5	693	"
	GN_2 (tank purge)	15-22 psi max	530/	2.5	5,754	"

Section 7
NUCLEAR REQUIREMENTS

7.1 INTRODUCTION

The primary function of the NRDS complex is to provide ground test facilities that enable full-scale test firing of the nuclear ground test article. The environments to which this test vehicle is subjected should be reasonably close to that encountered by the Reusable Nuclear Shuttle (RNS) during typical operational sequences.

The environments expected to be encountered during flight for each general RNS concept are presented in summary form. Since environments tend to be dependent upon tank geometrics, which are presently in a state of evolution, the environments presented are representative, and are not meant to suggest definitive data for RNS configurations.

7.2 GAMMA ENVIRONMENT

Gamma radiation environments which are generally representative of levels for each class of RNS vehicle have been estimated. These data provide the baseline, (i.e., flight), environments for establishing allowable test stand perturbations. In all data the NERVA model is that described in the May 1969 Common Radiation Analysis Model, in which the internal reactor shield weight is approximately 3300 pounds. No external shields have been included in any of the estimates in this discussion. Limited data are given for tank bottom radiation levels, which are of primary importance in test stand considerations. These numbers are sensitive to configuration details such as bulkhead contour and engine separation distance, still being altered in the system definition. Typical environments at the top of the flight system, as a function of propellant residual, are included for general information only, since the presence of the atmosphere will have a major effect on this parameter during captive test.

Representative tank bottom gamma dose rates for each of the selected configurations are presented in Table 7-1. Tank top gamma dose rates representative of a single-cell configuration consisting of a tank with an 8-deg. half-cone angle, 25-in. cap radius, and a nominal propellant capacity of 300,000 lb are shown in Fig. 7-1 as a function of drain time. Gamma dose rates for the cluster configuration are shown in Fig. 7-2 and include dose rates above both the propulsion and propellant modules. Total nominal propellant capacity for the cluster configuration is approximately 270,000 lb. Hybrid tank configuration dose rates are presented in Fig. 7-3, and are representative of the Class 2 RNS configuration with nominal propellant capacity of 300,000 lb.

Table 7-1 Tank Bottom Dose Rates

Configuration	Average Dose Rate (rads/hr)	Max Dose Rate (rads/hr)
Single Cell	4×10^4	2.1×10^5
Cluster	2×10^5	2.5×10^5
Hybrid	7×10^5	1×10^6

7.3 NEUTRON ENVIRONMENT

Neutron environments at the tank top for each configuration are somewhat difficult to present because of their dependence upon tank geometrics. Therefore, representative top tank neutron dose rates are presented for comparative purposes only, and are not meant to reflect those expected in the final RNS configuration.

For example, a maximum neutron dose rate on the order of 3000 Rem/hr might be encountered on axis at the top of the propulsion modules for the cluster configuration. Dose rates at the top of the propellant module would be insignificant because of the interposed propellant module.

Tank top neutron dose rate for a single-cell configuration would be on the order of 200 Rem/hr. Tank top base rates for the hybrid configuration would

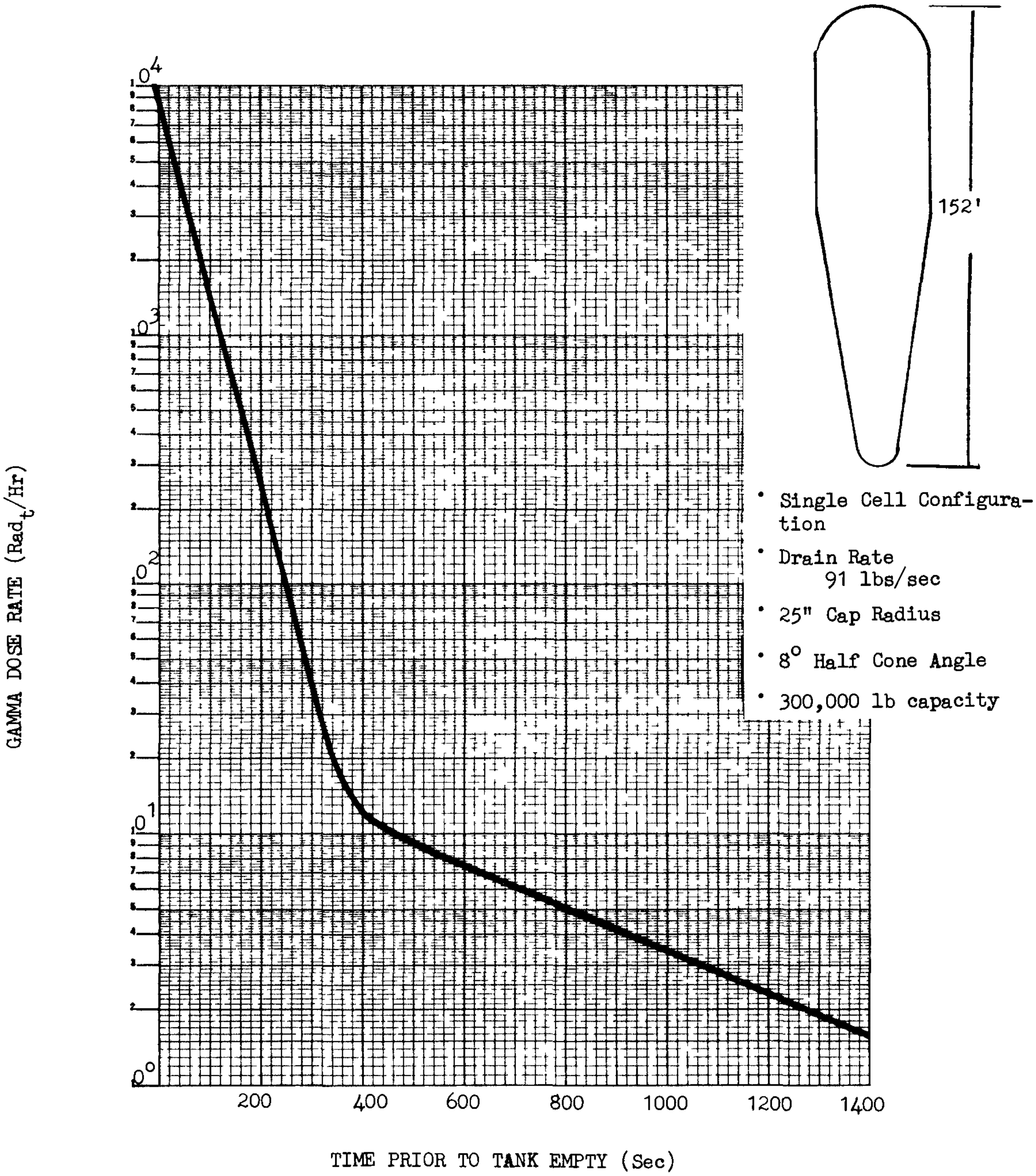


Fig. 7-1 Top of Tank Dose Rate 8-deg Single-Cell Configuration

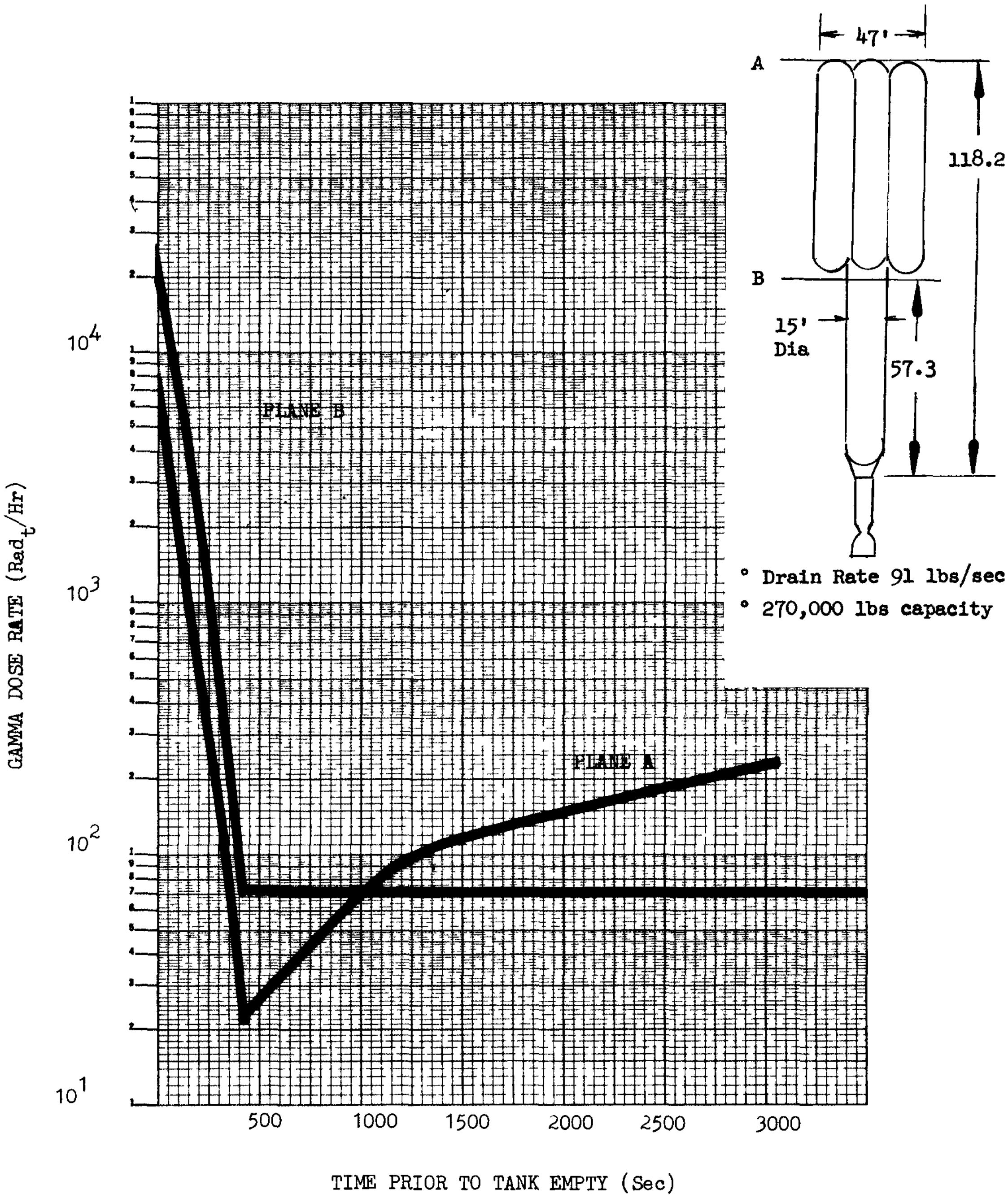


Fig. 7-2 Top of Tank Dose Rate, Cluster Configuration

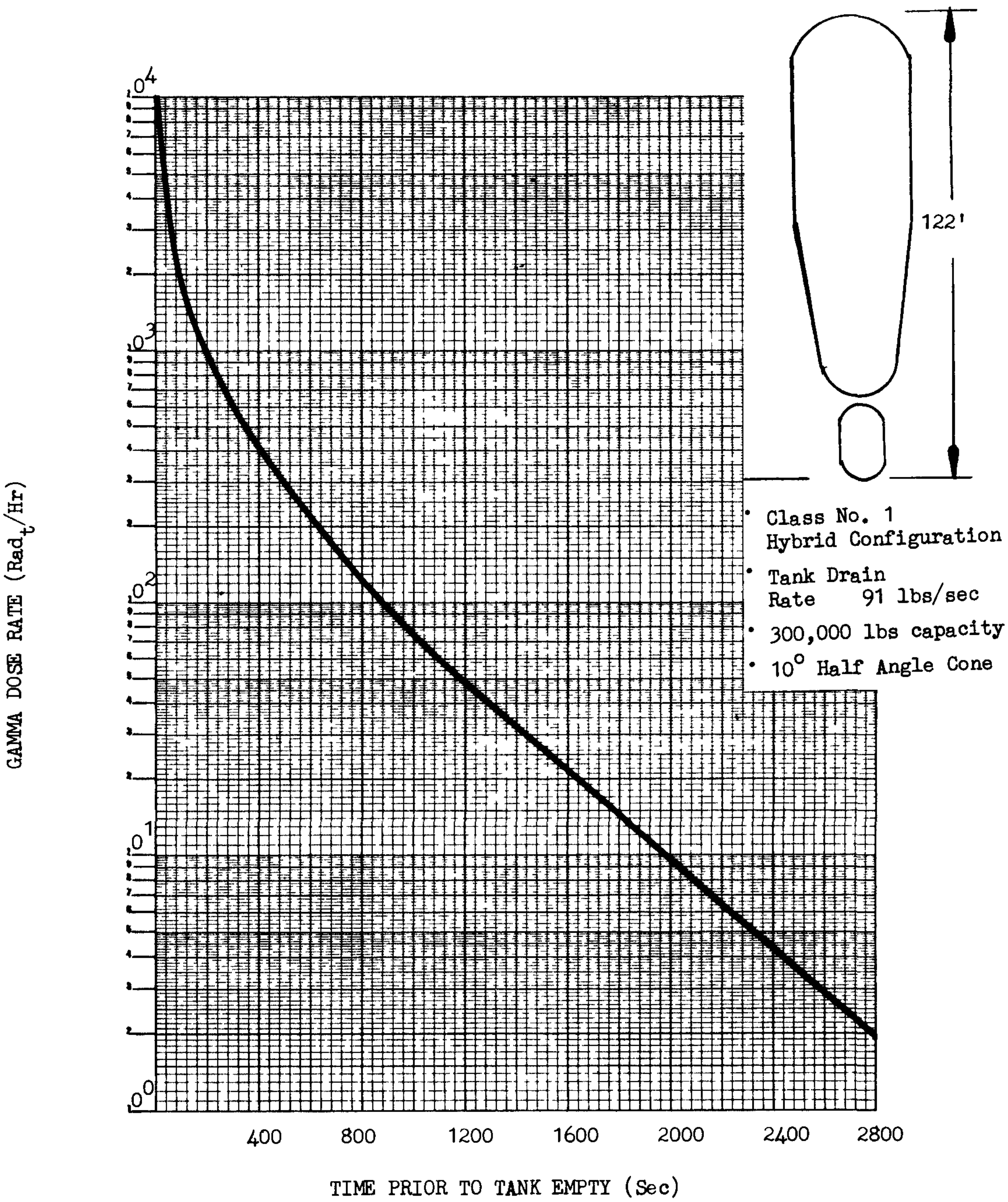


Fig. 7-3 Top of Tank Dose Rate,
Hybrid Configuration

be similar to those for the single-cell tank. In all the aforementioned cases, maximum neutron dose rates are given at the tank empty state, and would be insignificant as propellant quantity is increased only slightly.

7.4 ENVIRONMENT SIMULATION

Previous studies relating to simulation of flight nuclear radiation environments during captive testing have generally been concerned with modules to be used for one mission with an engine operating cycle which might reasonably be closely duplicated in test. Operating profiles for an RNS designed to perform 10 round-trip lunar missions involving 4 to 8 full-power burns per mission at widely separated times, may not be closely approximated in static test. For this reason it is concluded that accumulation of realistic integrated radiation doses to vehicle components will not be an objective of the captive test program. Radiation effects tests, both for component development and for qualification, must be performed at special test facilities in which the following effects to stage equipment may be studied:

- Integrated radiation effects
- Influence on radiation effects test results from long annealing periods between engine operations
- Radiation rate effects including heating
- Synergistic effects from vacuum and extreme termperatures

Previous studies (Ref. 3-1) have shown that point-to-point environmental simulation in the stage/engine interface and tank bottom areas probably cannot be feasibly achieved for current PVARA internal shield weights. However, evaluation of current radiation levels in these areas, for all configurations and without regard for additional shielding, does not reveal any points at which intensities are near critical values for damage or heating. Consequently, it is concluded that the facility design constraint should be placed on deviations of the total energy entering the tank rather than on spatial distributions. Total energy entering the tank should not exceed flight levels by more than a factor of 2. Both direct radiation from the PVARA and radiation scattered from the test facility walls into the test article must be considered in determining incident energy fluxes. While a point-to-point simulation is not required for captive test, attempts should be made in facility and facility shield design to achieve a spatial distribution of incident energy fluxes in the tank bottom region which reasonably resembles the flight distribution. Cases in which test radiation flux exceeds flight flux by more than a factor of 10, particularly for gamma radiation, should be critically examined and minimized. It is anticipated that such control may be achieved by judicious selection of facility internal shield concepts. No consideration is required for simulation of flight environments at the top of the test article.

7.5 RESIDUAL ACTIVATION LEVELS

The gamma dose rates arising from the neutron activation of a test article (modular concept) has been calculated at axial detector locations at Station 46 and at a second point 20 feet below Station 46 for times of 50, 100, 200, and 500 hours following an irradiation history consisting of nine 400 second irradiation periods followed by four 1800 second irradiation periods with a 30 day interval between each irradiation period. These gamma dose rates in units of milli-tissue rads/hr are as follows:

Times after Final Irradiation	50 hr	100 hr	200 hr	500 hr
At Station 46	1600.	151.	25.5	17.0
At 20 feet below Station 46	60.6	5.53	0.86	0.605

From these data it appears that it is safe with the exercise of normal precautions for an individual to venture into the vicinity of the second detector point after only a few days following the final irradiation, whereas a waiting period of a week or so will be required before the dose rate at the first detector point dimenishes to a comparable level.

The effects of fewer irradiation periods has been accessed by comparing the dose rates at 50 and 500 hours following the 1st, 9th, and 10th irradiation periods to those following the 13th irradiation period. The ratios of these dose rates are as follows:

Time after Irradiation Period	50 hr	500 hr
1st/13th	0.223	0.049
9th/13th	0.225	0.273
10th/13th	0.995	0.550

At 50 hours following an irradiation: Cu-64 with a half life of 12.8 hours is the predominant radiation source; Na-24 with a half life of 15 hours is also significant; all other source terms combined account for less than 5 percent of the dose rate. With 30 days between irradiation periods there is no buildup of these significant sources. This is examplified by comparing the dose rate after the 1st irradiation period with that following the 9th irradiation period. The jump in the dose rate following the 10th irradiation period shows that the dose rate is nearly proportional to the length of the irradiation period which increased from 400 to 1800 seconds.

At 500 hours following an irradiation the dose rate is dominated by isotopes with half lives greater than a few hundred hours. There is a considerable buildup of these sources from previous irradiations. This is shown by comparing the dose rates following the 9th irradiation period to that following the 1st irradiation period or by a comparison of the 13th to the 10th. The effect of buildup is of greater significance with the shorter irradiation periods.

From an operational standpoint fewer irradiation periods will significantly reduce the waiting time for entry into the area following an irradiation. This is especially true when the longer lined isotopes are withholding entry.

Section 8
TEST ARTICLE FABRICATION, TRANSPORTATION, AND HANDLING

8.1 NRDS TEST ARTICLE FABRICATION AND ASSEMBLY

Other studies by MSFC and RNS study contractors have shown the need for a "battleship" test article at NRDS, configured and simulating to the maximum degree the physical and operational characteristics of the flight RNS. Calculations have been made of the gross design parameters for four test article configurations using the following latest study contractor recommended designs:

- MDAC Class I Hybrid RNS Propulsion and Propellant Modules
- LMSC Modular RNS - Propulsion Module
- LMSC Single Tank - 15 deg Half-Cone Angle, 103 in. Cap Dome Radius
- NAR Single Tank - 8 deg Half-Cone Angle, 25 in. Cap Dome Radius

The objective of this task was to establish the major functional efforts required to produce the test article, recognizing the distinctly different design of the three configurations and the limitations they might impose on manufacture and, in particular, the transportation modes.

8.1.1 Basis for Task Analysis

The following points were utilized as a basis for establishing test article flow patterns.

- Maximum use of flight-type hardware, including structural members and tanks (where NRDS operational conditions permit such usage) in order to optimize test data application to the flight RNS
- Maximum off-site (from NRDS) manufacture and checkout of the test article utilizing existing facilities, design, and manufacturing know-how and test equipment applicable to the RNS program

- o Use of existing transportation facilities, or those contemplated for the RNS flight program, but not specially developed for the test article, i.e., special roads for large (33-ft dia) tank clearance
- o Use of the NRDS test facility for in-place modifications of the test article (unless of an extensive nature) to minimize tank article handling once the facility-test article integration tests have been accomplished
- o Use of the NRDS test facility for in-place installation of the polyurethane foam sandwich wall insulation systems for all test article configurations to minimize cracking and/or separation from the tank membrane as a result of transportation and/or handling forces.

8.1.2 Analysis

Figure 8-1 flow diagram depicts the planned sequence for the test article from design through NRDS system integration tests for the three large-diameter (33-ft) tank configurations. These configurations are comparable, on the general basis that transportation to NRDS of a fully-configured test article requires special roads or road modifications from West Coast areas, and consideration from other areas of the country is impractical. The available transportation modes, transportation time schedules, and cost data have been previously detailed, but suffice it to say it would require several million dollars currently; and when projected four or five years hence would be greater; and the opportunity may not even exist because of additional state road construction and changing vehicle codes. For this reason, the Fig. 8-1 analysis assumes that it would be more advantageous to expend funding in a NRDS assembly and maintenance building facility. The NRDS offsite effort is therefore confined to the fabrication and assembly of test article segments that can be readily transported by existing carrier systems to NRDS, wherein practical complete and functionally checked systems will be used to minimize test article checkout problems at NRDS. This concept, therefore, imposes on NRDS the requirement for a field assembly and maintenance building with capability of welding large tank segments, necessary welding and assembly tooling, overhead cranes, pneumatic and/or hydrostatic proof test facilities, and system checkout equipment for various levels of testing required for subsystem through final test article checkout prior to test stand installation.

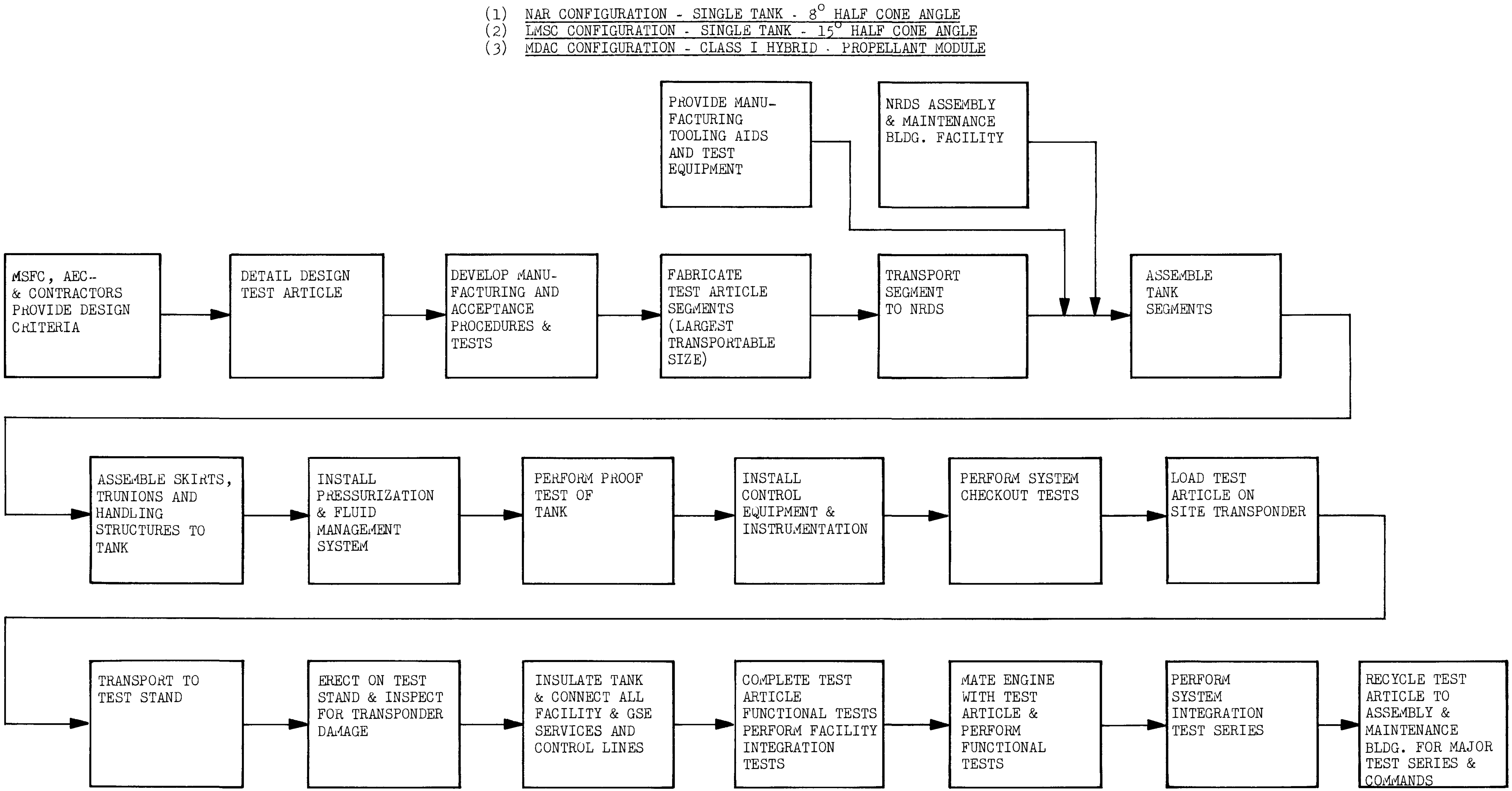


Fig. 8-1 NRDS Test Article Flow Diagram for Single Tanks

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A special NRDS site transporter will be required to transport each configuration. In particular, the NAR 8-deg half-angle cone tank needs considerable structural support to prevent excessive bending forces during the horizontal transport mode.

All 33-ft tank configurations are envisioned with a trunion box beam in the aft skirt area with a reinforced lift ring on the forward skirt for erecting the test article into the stand. Several possible methods have been proposed for lifting the test article into the test stand, i.e., test stand gantry cranes, mobile cranes, or combinations of both. However, in any case the capability has always been shown to handle the long tank configurations provided proper structural support is given to the test article during the rotational life from the horizontal transporter.

Once installed on the stand, the operations envisioned will be to connect all fluid, electrical, and instrumentation service lines and safety systems. The polyurethane foam sandwich installation on the exterior tank membrane wall will be made at this time to ensure that the bond of urethane foam will be as integral as possible without damage from handling or transport forces. After all test article and facility systems are independently checked, they will be checked for integration and verification of the safety systems. Final operations are the installation of the NERVA engine with interface checkouts planned. The test article is then ready for running the final integrated test to demonstrate total system (test article, engine, facility, and ground control station) readiness for conducting the planned test series.

After each test series is conducted, it is planned to leave the test article in the stand (after engine removal) to become radioactively cool enough to work on. All minor modifications to the test article systems are to be accomplished in the test stand area. Major changes may require recycling the test article to the Assembly and Maintenance building, as shown in Fig. 8-2.

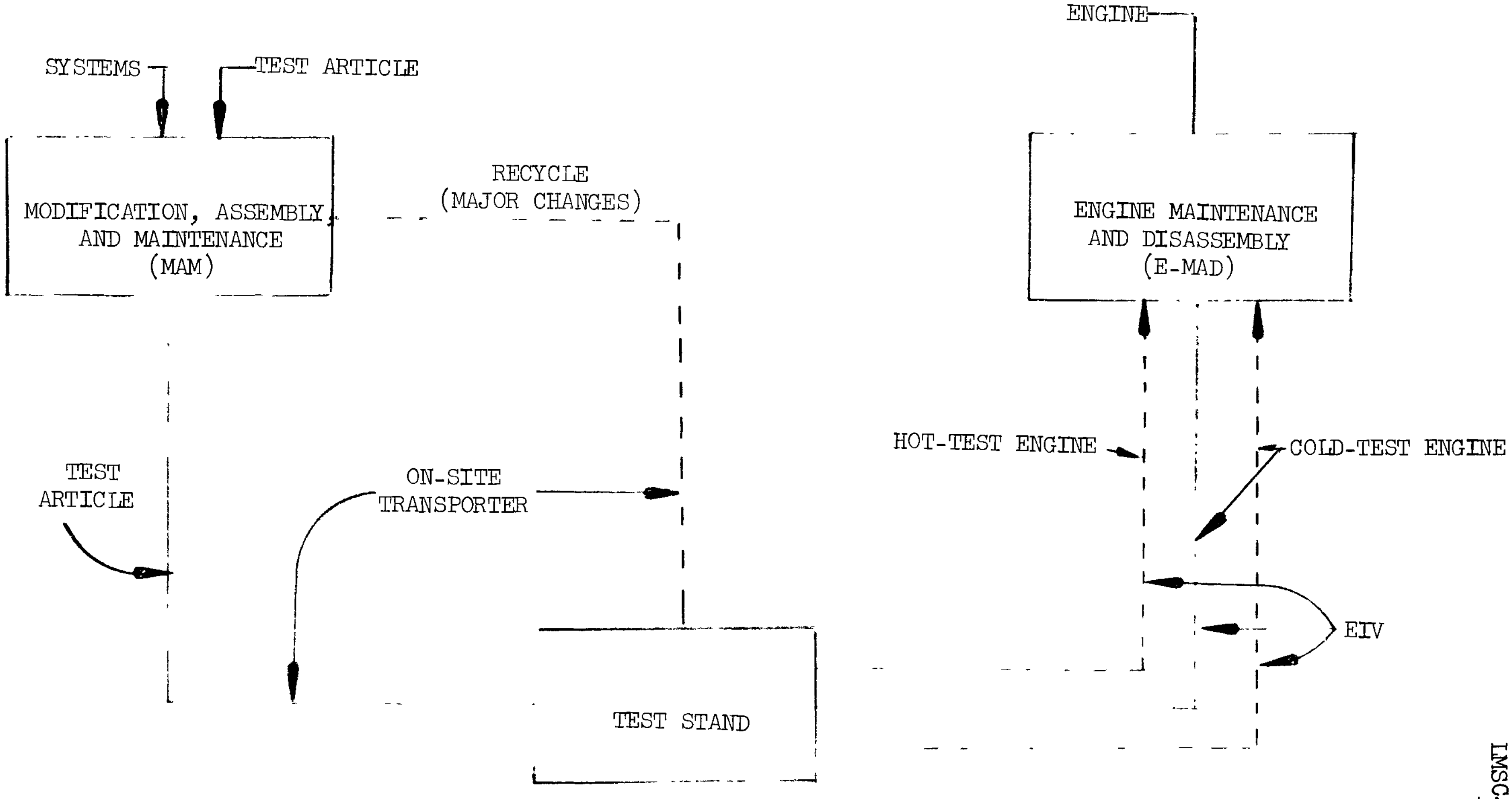

Fig. 8-2 Sequence of Test Article Operations

The operational sequence for the LMSC propulsion module and the MDAC propulsion module is shown in Fig. 8-3, and it differs from Fig. 8-1 in that the test articles are essentially completely manufactured and tested off-site (from NRDS) and shipped by air and/or road to NRDS. At NRDS they are directly loaded on the site transporter for delivery to the test stand and subsequent mating to the facility, or in the MDAC case to the propellant module. Installation of the foam insulation, again, is planned for the test stand area. Integration of test article, engine, facility, and ground control station takes place as with the larger 33-ft tank operation.

Again, after each test series is conducted it is planned to leave the test article on the stand for any minor modifications; however, major changes may require recycling to a maintenance facility such as was shown in Fig 8-2. The requirements for this facility are of a lesser complexity than those envisioned for support of the large (33-ft) diameter test articles, and it is possible to envision that all major rework on the MDAC or LMSC propulsion module be performed at the original fabrication facility, thereby eliminating the need for a special maintenance building at NRDS for these configurations.

8.1.3 Conclusions

- Two separate and distinct test article flow sequences evolve because of differences in physical size of the test article.
- The 33-ft diameter configurations will be fabricated in the largest transportable segments at an off-site (from NRDS) facility.
- Transport of the segments for the 33-ft diameter test article will be by air and road networks currently available, and not special road networks. No large aircraft capabilities for 33-ft diameter articles are envisioned for the 1974-75 time period.
- An assembly and maintenance building with large tank welding, processing, testing, and checkout capabilities will be required at NRDS for final assembly of the large diameter test articles.
- The MDAC and LMSC propulsion modules will be essentially completely fabricated, assembled, and tested at an off-site (from NRDS) facility.

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(1) LMSC MODULAR TANK CONFIGURATION - PROPULSION MODULE
AND
(2) MDAC CONFIGURATION - CLASS I HYBRID - PROPULSION MODULE

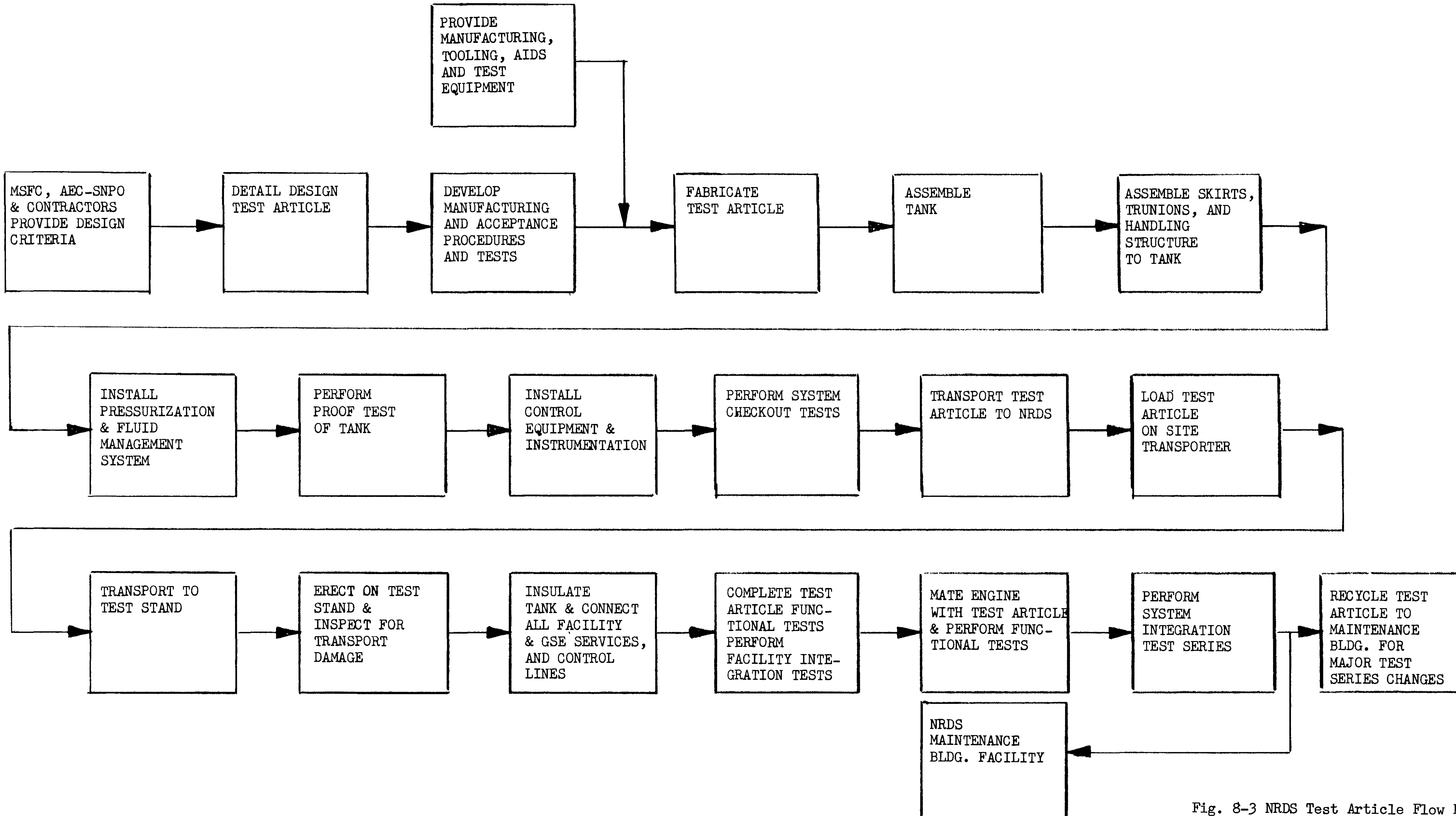

Fig. 8-3 NRDS Test Article Flow Diagram for Propulsion Modules

- o Transportation of the MDAC and LMSC propulsion modules will be by air and/or road network planned for transportation of the flight article.
- o The MDAC and LMSC propulsion modules require a less complex NRDS maintenance facility (as compared to the large-diameter test articles) and the program managers could exercise the option of not performing any major rework at NRDS. Shipment can be made directly to the original fabrication facility, thereby avoiding the need for a special building at NRDS for these two test article configurations.

8.2 ROAD TRANSPORTER

The present test program envisions the use of only one test article, whatever the selected configuration. For economical reasons, the modification of existing Saturn vehicle transportation equipment, wherever possible, is desirable. The S-II vehicle transporter (see Fig. 8-4) is 33-ft in diameter and approximately 955 in. in length. Considerable modification would have to be made to accommodate the full NAR 8-deg conical bottom configuration (1929 ins. in length). It is conceivable that this configuration will require a new transporter. It is reasonable to assume that the MDAC propellant tank (1150 ins.) would require only minor modification. The LMSC 15-ft-dia module would require an adaptation for a smaller diameter. The length (60-ft) is compatible with the current transporter design.

A forward and aft handling ring are used to support the propellant tank within the transporter frame. These handling rings support the test article at hard-faced contact pads on the tank ring construction. The aft handling ring is of special construction, acting as a trunnion support member for test article erection at the test stand or MAM building. If a second handling crane will be available at NRDS for handling the test article, the road transporter need not incorporate a trunion design. Wheel loadings for this transporter must meet the highway department limitations within the states traveled. Special highway requirements for exterior lighting, overhangs, etc., would be met by provision for specific equipment as required by the state highway departments.

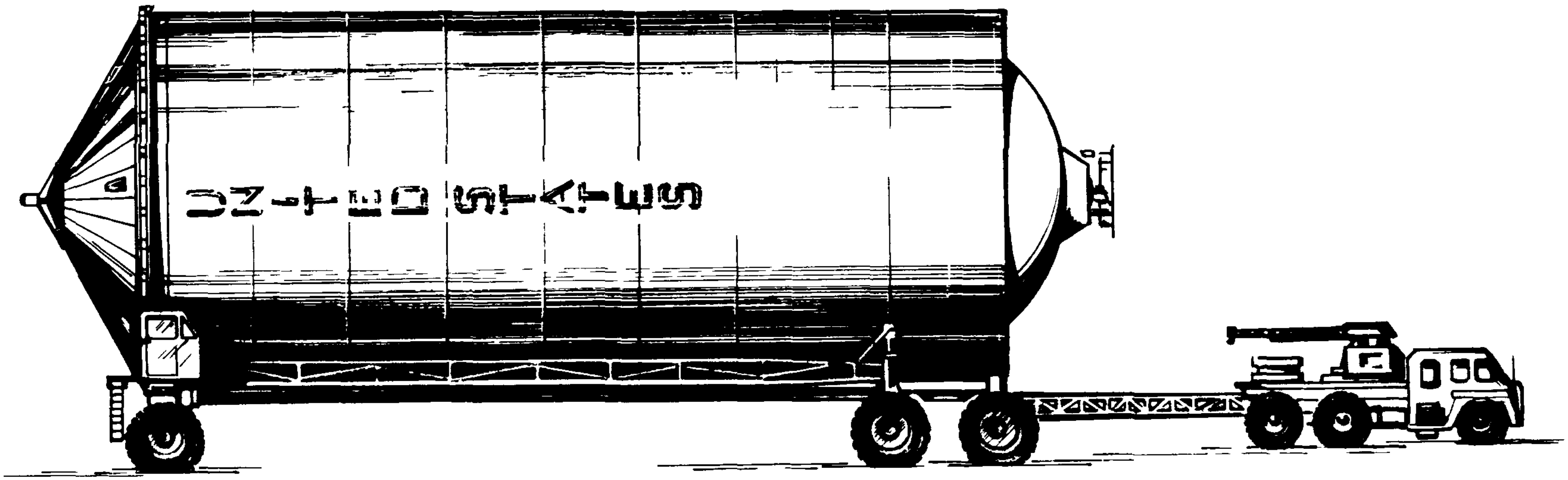

Fig. 8-4 Road Transporter

Further analysis by a road route survey would indicate specific areas of design requirements, but is not a part of this study.

The road transporter can also be utilized at NRDS to move the test article (without engine) to and from the MAM and the test stand complex, as shown in Fig. 8-2. An analysis of the NRDS on-site transportation and handling requirements indicates a special on-site transporter, which could also be utilized in the MAM building as a holding fixture, would be desirable, but generally would impose other considerations on the facility. A special on-site transporter would generally be regarded as a railroad track-guided vehicle, rather solid in its construction. The necessary railroad track construction would impose facility layout and economic requirements on location of the test complex and MAM constructions. The railroad construction would be necessary if the program requirements dictated a remote servicing type of capability for the test article (due to radiation levels). The present program is based on sufficient schedule time allowances for cooling of the test article to take place in the test stand area until safe radiation levels are reached for handling. It is therefore proposed to use the road transporter as the on-site transporter, since the present schedule allows for this type of phasing. Other program requirements may dictate schedule conflicts, but within the NRDS test program there do not appear to be any. The common usage of the transporter permits full application of the forward and aft handling rings and other associated equipment.

8.3 TEST ARTICLE LIFTING FIXTURE

It is proposed to place the test article (without engine) in the test stand using a portable crane. A lifting fixture is required to attach to the forward skirt ring construction to distribute the lifting loads uniformly through the tank construction. Regardless of tank diameter, the lifting fixture shown in Fig. 8-5 is an appropriate configuration. This fixture would match bolt to the forward skirt ring, and lifting loads would be

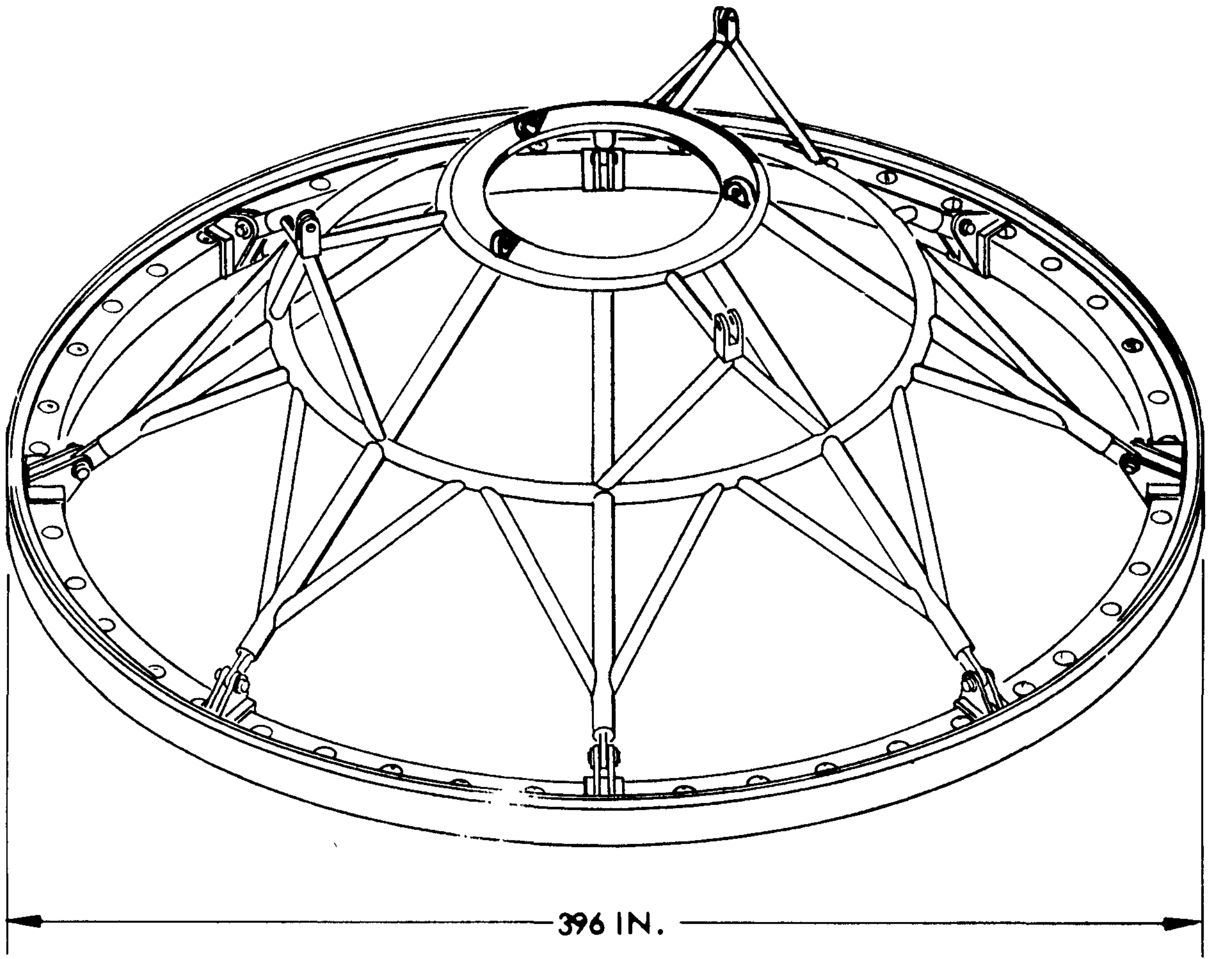

Fig. 8-5 Test Article Lifting Fixture

transmitted through the strut construction to three (3) lifting points. The strut construction has been found to be efficient and relatively light in weight for the loads carried.

8.4 PORTABLE CRANE

If two portable handling cranes will be available at NRDS for handling the test article, then the road transporter need not incorporate a trunion design.

The test article will be transported in the horizontal position in the transporter to the test stand complex. The transporter will be located as close as possible to the test stand, allowing for clearance for the portable crane to maneuver the test article. The lifting fixture will be attached at the test stand site. The portable crane will be used for this operation. With the lifting fixture in place, the portable crane will lift the forward end from the transporter, causing the test article to rotate about the aft handling ring trunion (Fig. 8-6). The transporter aft support structure will be modified as required to permit this rotation, of, if too costly, a separate rotating fixture will be provided at the test stand area.

A standard commercial 150-ton capacity portable crane, equipped with a special boom to allow free movement during the lift, will be used. A boom length of 175-ft is sufficient for this operation. The topography and elevations above ground level of the test stand structure are required to accurately determine the boom length. The portable crane will be used for installation of the IU and the environmental enclosure and other heavy items of equipment. After each test series the portable crane will be used to remove the test article or its components as required.

8.5 SPECIAL HANDLING EQUIPMENT

Within the MAM building it is expected that a special holding fixture will be available. This fixture will support the test article using the forward and aft handling rings. Rollers will be incorporated into the fixture to allow

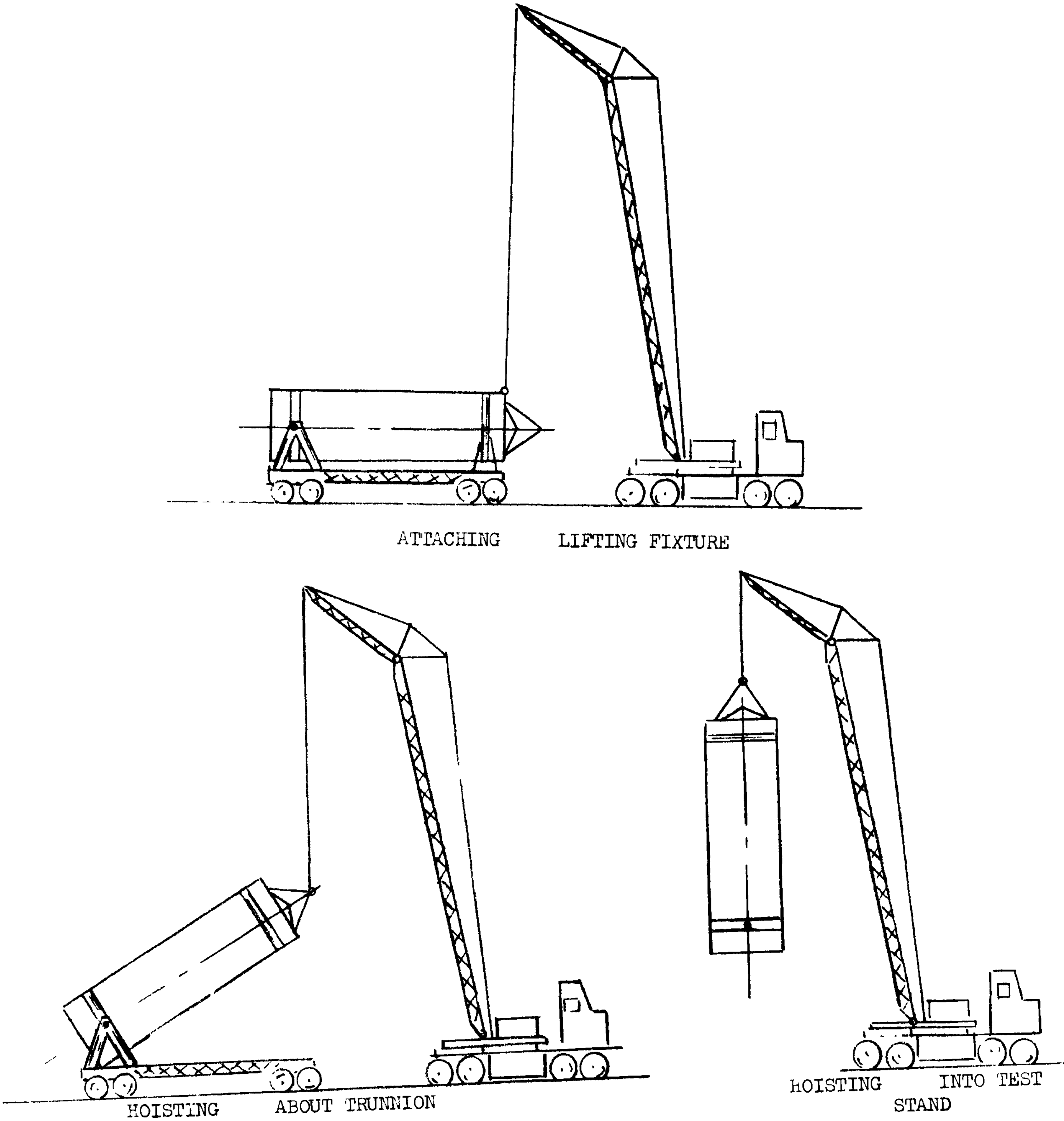

Fig. 8-6 Portable Crane Utilization

rotation on the fixture on the handling rings. This feature will facilitate inspection of the insulation system and provide ready accessibility to all areas. It is expected that this fixture will have rollers, or be rubber-tired, to allow it, along with the test article, to be rolled into and out of the MAM.

The environmental enclosure is expected to remain in the general test stand areas; however, a transportation dolly will be required as its assembly probably will be accomplished in the MAM building area. Also during the test program, reconfiguration of the test article between test series will require movement of the enclosure from the test stand immediate area to facilitate handling operations. The enclosure should be structurally designed to be self-supporting when lifted by the portable crane for installation.

A rubber-tired wheel dolly is recommended to transport the enclosure and the design should be similar to other transportation dollies used to move large-diameter interstage sections for the Saturn Program.

Special ladders, lights, and support fixtures are also required for working, transporting, and handling. Their requirements will be listed as the program proceeds in more detail.

REFERENCES

3-1 LMSC 682842, Nuclear Ground Test Module, Its Ground Support Equipment and NRDS Facilities Requirements, dated 14 October 1968.

3-2 Volumes I, III, IV, and V, Nuclear Flight Vehicle Systems Definition Study, Phase II Final Report, SD 70-117, dated August 1970.

3-3 Volume II - Nuclear Flight System Definition Study, Phase II, LMSC-A968223, dated 1 May 1970.

3-4 Volumes I and II - Nuclear Flight System Definition Study, Phase II Final Report, MDC G0585, dated May 1970.

3-5 Norman Engineering Report, "Engine/Stage Test Stand (E/STS 2) FEI Part I Specification," F007-CP-090232EA.