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NASA Contract NAS 5-302

PROJECT APOLLO

A Feasibility Study of an Advanced Manned Spacecraft and System

FINAL REPORT

VOLUME IV. ON-BOARD PROPULSION

Book 2 — Appendix P-A

[redacted]

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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GENERAL ELECTRIC

MISSILE AND SPACE VEHICLE DEPARTMENT

A Department Of The Defense Electronics Division

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APPENDIX F

MODEL SPECIFICATION FOR THE APOLLO PRESSURE-FED PROPULSION SYSTEM AJ10-133

LIST OF TABLES

1. SCOPE

1.1 Scope--This specification covers requirements for the Aerojet-General AJ10-133 propulsion system.

1.2 Classification--The Model AJ10-133 (Apollo) pressure-fed propulsion system consists of ablation-cooled plastic rocket thrust chamber assemblies, propellant (oxidizer and fuel) system, pressurization system, and interconnecting plumbing. Each thrust chamber is rated at 6,000 lb (max) nominal thrust in vacuum with a 35:1 expansion ratio (ϵ) exit cone. The propellants utilized, liquid oxygen (LOX) as the oxidizer and liquid hydrogen (LH_2) as the fuel, are injected into the thrust chamber at a nominal static instantaneous mixture ratio of 5.0:1 by weight of oxidizer to fuel. The propellants are pressure-fed to the thrust chamber by use of helium to expell the liquid oxygen and gaseous hydrogen to expell the liquid hydrogen.

Vehicle attitude corrections are accomplished in response to appropriate electrical signals supplied from sources outside the propulsion system. During powered flight, pitch and yaw control is accomplished by gimbaling of the thrust chamber assemblie. During coasting flight, control is accomplished by means of a generate attitude control system not considered a part of the propulsion system specified herein.

The propulsion system includes automatic starting, restarting, shutdown, and performance monitoring provisions.

2. APPLICABLE DOCUMENTS

2.1 The following specification forms a part of this specification except as modified here:

SPECIFICATION

Military

MIL-E-5149	Engines, Rocket, Liquid Propellant General Specification for

2.1.1 Unless otherwise specified, the following specifications, of the issue in effect on date of invitation for bids form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military

JAN-A-669	Anti-seize Compound, White Lead Base
MIL-T-5542	Anti-seize Compound, Oxygen Systems
MIL-E-6872	Soldering Process, General Specification for Aircraft Electrical and Electronic Equipment
MIL-P-25508	Propellant Oxygen
MIL-E-8189	Electronic Equipment, Guided Missile, General Specification for
MIL-W-16878	Wire, Electrical, Insulated, High Temperature
MIL-I-26600	Interference Control, Requirements, Aeronautical Equipment
MIL-P-27201	Propellant, Hydrogen

2.2 The applicable publications listed in the following bulletin form a part of this specification:

PUBLICATIONS

Air Force-Navy Aeronautical Bulletin

No. 343M dated 3 December 1959	Specifications and Standards Applicable to Aircraft Engines and Propellers, Use of

2.2.1 Unless otherwise specified the following publications of the issue in effect on date of invitation for bids, form a part of this specification to the extent specified herein.

PUBLICATIONS

Military

Handbook 5	Strength of Metal Aircraft Elements

Air Force Ballistic Missile Division Exhibit

58-10	Reliability Program for Ballistic Missile and Space Systems

2.3 Unless otherwise specified, the following Aerojet-General specification of the issue in effect on date of invitation for bids, form a part of this specification to the extent specified herein.

SPECIFICATIONS

AGC-44027	Heliu, Gas, Grade A

3. REQUIREMENTS

3.2 Mockup--One full scale mockup shall be prepared for examination and approval as soon as the contractor has established the installation features of the engine. Any changes required by the using service shall be subject to negotiation.

3.2.1 Propulsion system changes--The rocket propulsion system installation drawing(s) shall be submitted to the Apollo prime contractor for approval. The prime contractor shall be notified of changes, to the rocket propulsion system affecting installation weight or performance, which are made after approval of the installation drawing.

3.3 Performance characteristics--The propulsion system performance characteristics shown in Table 1 are determined using the propellants specified in 3.3.9.1 an d are on the terms and standard conditions defined in this model specification.

3.3.1 Propulsion system operation regimes

3.3.1.1 Altitudes and temperatures--The propulsion system shall be designed to start, operate, and shutdown satisfactorily throughout all pressure altitudes and ambient air temperature encountered during vehicle flight.

3.3.1.1.1 Static exposure

(a) The propulsion system shall be designed to start, operate and shutdown satisfacotrily after static exposure for hours at a maximum ambient temperature of

(b) The propulsion system, in an unserviced condition, shall be without detrimental effects.

(c) The propulsion system shall be designed to start, operate, and shutdown satisfactorily after static exposure for days at a minimum ambient temperature

(d) The propulsion system shall be designed for continuous storage, in the unserviced condition, for one year minimum.

3.3.1.2 Attitudes--The rocket propulsion system shall start, operate, and shutdown satisfactorily in any attitude, provided a net positive acceleration parallel to the propulsion system longitudinal axis exists immediately prior to and during the starting transient.

3.3.1.3 Propulsion system life--The propulsion system shall be capable of multiple up to 17 restarts with accumulated duration limited only by the capacity of the propellant tanks.

3.3.2 Ratings--The performance ratings of the propulsion system are based on operation in vacuum and are defined in Table 1. The ratings are further based on the use of propellants conforming to the requirement specified in 3.3.9.1, and on the use of an exhaust nozzle having an expansion ratio of 35:1.

TABLE 1

PROPULSION SYSTEM PERFORMANCE RATINGS
IN VACUUM (STEADY-STATE)

Parameter	Units	Values
Total impulse, I_t, minimum	lb-sec	3.38×10^6
Thrust, F (total)	lb	24,000
Instantaneous mixture ratio $\dot{w}_o/\dot{w}_f$ (static)		5.0
Instantaneous specific impulse, I_{sp}, nominal	lb-sec/lb	430

3.3.3 Estimates--Estimated performance curves shown in Figures 1 through 13 form a part of this specification.

3.3.3.1 Altitude performance--Not applicable - system designed for vacuum operation.

3.3.4 Components--Curves shown in Figure 1 through 9 form a part of this specification. These data are based on the nominal rated conditions and performance parameters described in 3.3.2 and 3.3.3.

3.3.4.1 Thrust chamber--Operation characteristics of the thrust chamber are shown in the following figures:

Figure 4	Estimated Thrust and Thrust Coefficient vs Chamber Pressure (Vacuum Operation) (not available)
Figure 5	Estimated Specific Impulse vs Mixture Ratio
Figure 6	Estimated Thrust and Chamber Pressure vs Time
Figure 7	Estimated Chamber Pressure vs Time (Starting Transient)
Figure 8	Estimated Nominal Thrust vs Time (From Command and Automatic Shutdown Signal)
Figure 9	Estimated Thrust and Chamber Pressure vs Time (Propellant Exhaustion with FTCV and OTCV open)
Figure 10	Estimated Characteristic Exhaust Velocity vs Mixture Ratio
Figure 11	Estimated Propellant Flow Rate vs Time
Figure 12	Estimated Thrust Decay vs Time (From 10 percent to 0 percent Thrust) (not available)

3.3.4.1.1 Thrust chamber assembly performance data--The estimated nominal performance data in vacuum for the chamber assemblies are consistent with rated performance described in 3.3.2 and are shown in Table 2.

TABLE 2

ESTIMATED THRUST CHAMBER ASSEMBLY PERFORMANCE DATA IN VACUUM (STEADY-STATE)

Parameter	Units	Values
Thrust, F (per chamber)	lb	6,000
Thrust chamber pressure, P_c	psia	65
Instantaneous specific impulse, I_{sp}	lb-sec/lb	430
Thrust Coefficient, C_F		1.81
Total propellant flow rate, $\dot{w}_T$ (per chamber)	lb/sec	13.95

TABLE 2 (cont.)

Parameter	Units	Values
Mixture ratio, (Static) $\dot{w}_o/\dot{w}_f$		5.0
Fuel flow rate, $\dot{w}_f$	lb/sec	2.32
Oxidizer flow rate, $\dot{w}_o$	lb/sec	11.63

3.3.4.1.2 Thrust chamber configuration--The thrust chamber configuration is shown in Table 3.

TABLE 3

THRUST CHAMBER CONFIGURATION

Characteristics	Units	Values
Nozzle throat area, A_t	in^2	50.9
Nozzle throat diameter, D_t	in	8.05
Nozzle exit area, A_e	in^2	1782
Nozzle exit diameter, D_e	in	47.8
Nozzle expansion rate, A_e/A_t		35

3.3.4.2 Tanks -

3.3.4.2.1 Propellant systems--Operating characteristics of the propellant systems are shown in the following figures:

Figure 13 Thrust Chamber Pressure vs Propellant Tank Pressure (not available)

3.3.4.2.1.1 Propellant tank configuration--The propellant tank configurations are shown in Table 4. The propellant tank assembly consists of a spherical main fuel tank below which are suspended four spherical oxidizer tanks. The main fuel tank contains an inner fuel tank and cylindrical auxiliary (pressurization) fuel tank.

TABLE 4

PROPELLANT TANK CONFIGURATIONS

Characteristics	Units	Nominal Value
Total oxidizer tank volume	cu ft	103.2
Available oxidizer volume	cu ft	98.0
Ullage of total oxidizer volume	%	5 (nominal)
Oxidizer tank diameter (spherical)	in.	44
Total fuel tank valume	cu ft	303.0
Outer fuel tank volume	cu ft	173.0
Inner fuel tank volume	cu ft	116.5
Auxiliary fuel tank volume	cu ft	13.5
Ullage of total fuel volume	%	5 (nominal)
Fuel tank diameter, outer, (spherical)	in.	100
Fuel tank diameter, inner, (spherical)	in.	75

3.3.4.2.2 Pneumatic system--Operating characteristics of the pneumatic system are shown in the following figures:

Figure 11 Estimated Helium Tank Pressure vs Time (not available)

3.3.4.2.2.1 Helium tank configuration--Each of the two helium tanks is an 18-inch diameter sphere: the total volume of the tanks is 3.54 cu ft

3.3.4.2.2.2 Nitrogen tank configuration--Not applicable

3.3.4.3 Pumps--No propellant pumps are utilized.

3.3.4.7 Auxiliary fluid systems--Not applicable

3.3.5 Starting and restarting--The starting system consists of surface gap spark plugs, and provides for starts consistent with the propulsion system life cited in 3.3.1.3 under the conditions cited in 3.3.1.1 and 3.3.1.2, entitled "Altitudes and Temperatures" and "Attitudes" respectively.

3.3.5.2 Starting sequence--The propulsion system operating time sequence is shown in the following figure:

Figure 12 Time Sequence Diagram (not available)

The sequence for starting shall be as follows:

3.3.5.2.1 Flight operation--

3.3.5.2.1.1 General--Independent of vehicle attitude, upon application of power to the propulsion system, the following events occur:

a. A normally closed shutoff valve in the helium pressurization lines is actuated open at fire switch thereby allowing pressure regulated helium to pressurize the oxidizer tank and the auxiliary fuel tank.

b. Propellants from the aforementioned tanks are transferred to the settling rocket which is started prior to the main thrust chamber assemblies.

c. Helium and hydrogen are heated in the settling rocket heat exchanger and returned to pressurize the oxidizer tank and fuel tank respectively.

d. When the main propellant tanks reach operating pressure the following events occur:

(1) Spark plugs energized and the main oxidizer valves are actuated open.

(2) 0.1 sec later the main fuel valves are actuated open.

e. The spark plug ignition system is de-energized at receipt of signal from combustion chamber pressure sensing instrumentation.

3.3.5.2.2 Ground operation--The sequence for ground starting and steady-state operation shall be the same as for flight operation (see 3.3.5.2.1) with the following exception:

a. Application of power to the flight unit shall be through a fire switch on the ground control system.

3.3.5.2.3 Restart--The restarting sequence of operations shall be the same as that of 3.3.5.2.1.1.

3.3.6 Command shutdown--Command shutdown is initiated by removal of power from the propulsion system which closes the main propellant valves.

3.3.7 Malfunction--An analysis of pertinent malfunction conditions anticipated in service usage shall be prepared and a report submitted to the procuring activity prior to preliminary flight rating tests.

3.3.8 External power--

3.3.8.1 Electrical power--All electrical components shall operate satisfactorily in accordance with Specification MIL-E-8189 (see 2.1.1) with 20 to 30 vdc for starting, operating, and shutdown for both start and restart. The estimated dc electrical loads of the propulsion system are shown in the following figure:

Figure 13 Estimated Electrical Current vs Time (not available)

3.3.9 Propellants and fluids--

3.3.9.1 Propellants--The propellants supplied to the propulsion system shall meet the following requirements:

(a) Oxidizer--Liquid oxygen in accordance with Specification MIL-P-25508.

(b) Fuel--Liquid hydrogen in accordance with Specification MIL-P-27201.

3.3.9.1.1 Propellant properties--Propellant properties are shown in the following figure:

Figure 14 Propellant Specific Gravity vs Temperature (not available)

3.3.9.2 Pressurizing gas--The pressurizing gas applied to the propulsion system shall meet the following requirements:

(a) Helium, Navy, Grade A, in accordance with AGC 44027.

(b) The helium shall have a maximum dew point of -76°F at ambient pressure.

3.3.9.3 Lubricants--

(a) Lubricating grease, pneumatic; In accordance with Specification MIL-L-4343. This grease shall be used for assembly and lubrication of parts handling helium.

(b) Anti-seize compound, white lead base: In accordance with Specification JAN-A-669. This compound shall be used as thread lubrication in helium applications.

3.3.9.3.1 Consumption--The amount of lubricants consumed during a full-duration operation is negligible.

3.3.9.5 Fluid leakage--Propulsion system external or internal fluid leakage which impairs or endangers functioning of the propulsion system or vehicle shall not be permitted. Permissible leakage rates shall be as follows: (not available).

3.3.10 Control--

3.3.10.1 Accuracy--The controls shall be such that the propulsion system shall operate within the limits described in 3.3.2 entitled "Ratings".

3.3.10.1.1 Mixture ratio--The mixture ratio shall be within safe operating limits at full thrust and during thrust increase and decrease. Mixture ratio limits at rated conditions are specified in Table 1. (not available)

3.3.10.1.2 Thrust chamber pressure--The thrust chamber pressure shall be in accordance with Table 2. (not applicable) Thrust variation during starting and shutdown shall not exceed the limits specified in 3.3.10.3.

3.3.10.2 Thrust--

3.3.10.2.2 Increase--The time interval in the starting sequence from the start signal to 10% chamber pressure shall not exceed 1.1 sec. The time interval in the starting sequence from the start signal to 90% chamber pressure shall not exceed 1.4 sec. Estimated chamber pressure versus time from application of power shall be shown in Figure 5.

3.3.10.2.3 Decrease--The time interval for thrust decay shall be as follows:

(a) The time interval for thrust decay from receipt of the shutdown signal to 10% chamber pressure, in a command shutdown sequence from rated thrust, shall be 0.25 ± .025 sec. The total impulse developed during a command shutdown, from rated thrust to 10% of rated thrust in vacuum, shall be 1150 ± 10% lb sec.

3.3.10.3 Stability--The transient starting chamber pressure shall not be greater than 125% of the nominal rated chamber pressure shown in Table 2. Instantaneous chamber pressure oscillations shall not exceed ± 5% during the period of effective steady-state operation. The average operating chamber pressure shall not vary more than ± 3 percent during static test.

3.4 Environmental and load factors--

3.4.1 Environmental conditions-- The propulsion system shall be designed to suffer no detrimental effects during storage or after exposure in the empty condition to extreme temperature, vibration, humidity, rain, sand and dust, salt spray, and fungus. External protection may be provided to meet the requirement.

3.4.1.1 Temperature-- The propulsion system, under field storage conditions, shall not suffer any detrimental effects when exposed to the temperature conditions described in 3.3.1.1.1.

3.4.1.2 Vibration-- The propulsion system shall withstand vibration loadings as encountered in normal usage without deterious effects or impairment of its serviceability.

3.4.2 Flight and ground loading conditions--

3.4.2.1 Aircraft rocket engine--(not applicable)

3.4.2.2 Aircraft launched missile rocket engine--(not applicable)

3.4.2.3 Missile rocket propulsion system--

3.3.2.3.1 Flight loading conditions--The propulsion system shall resist flight loading conditions as follows:

(a) The propulsion system shall withstand the forces result- from all cirtical combinations of load factors, interal pressures, air loads, and accelerations as specified below. The system shall be designed to withstand limit loads without excessive deformation such as would degrade the performance of the system, and shall be capable of sustaining ultimate loads (equal to times limit load) without collapse or rupture.

(b) For design purposes, the yield strength shall be a minimum of 1.50 times the membrane stress resulting from the limit loads.

3.4.2.3.1.1 Flight loads--Preliminary design in-flight loads are shown in the following figure:

Figure 15 Maximum In-Flight Loads (not available)

Limit load factors to be used for the design of the various items, such as brackets and supports, not covered by other design conditions are as follows:

(a) +7.0 g parallel to the booster missile longitudinal axis.

(b) +2.0 g in any direction normal to the booster missile longitudinal axis.

3.4.2.3.2 Ground loading conditions--The propulsion system and its supports shall be capable of withstanding handling loads of 3.75 g in any direction without permanent deformation.

3.4.2.3.3 Allowable loads and material strengths--Allowable loads and material strengths shall be in accordance with Handbook 5. Strength of m materials not specified in the above reference shall be substantiated by tests or data. Probability allowable data shall be used on all structures except that, where single load path structure is involved, minimum graranteed allowable data shall be used.

3.4.2.3.4 Internal pressure--The minimum design burst pressure shall be 1.50 times the limit pressure. All components on the fluid systems, other than the tankage, shall withstand pressure. The tankage shall withstand a proof pressure of 1.1 times the limit pressure. All components of the fluid system shall withstand leak tests in accordance with the contractors drawings.

3.4.3 Limiting zone temperature--The maximum operating temperatures of components of systems which are limited are as follows:

3.4.3.1 Thrust chamber external surface limiting zone temperature--

The maximum ablative plastic thrust chamber external surface temperature shall not exceed 400°F. A heat shield may be used around the titanium extension.

3.5 Drawings and data--The following Aerojet-General drawings and data form a part of this specification.

Figure 19	AJ10-133 Propulsion System, Installation (not available)
Figure 20	AJ10-133 Propulsion System, Main Assembly (not available)
Figure 21	AJ10-133 Flow Diagram (not available)
Figure 22	AJ10-133 Electrical Diagram (not available)
Figure 23	Attitude Control System Schematic (not available)
Figure 24	Nozzle Location Schematic (not available)

3.5.3 Dry weight of the propulsion system-- The dry weight of the deliverable propulsion system shall not exceed 1413 pounds for the components listed in Table 5.

TABLE 5

ESTIMATED NOMINAL DRY WEIGHT SUMMARY

Item	Weight
Basic propulsion system	
Fuel tank, outer, with insulation and mounts.	312
Fuel tank, inner, with support cone.	80
Fuel tank, auxilliary	22
Oxidizer tank, with insulation and mounts	200
Helium tank and supports	104
Thrust chamber assembly with propellant valves and gimbal actuators	512
Settling jets	20
Structure	121
Lines, fittings, valves, electrical	42
TOTAL	1413

3.5.4 Overall dimensions--The overall envelope and dimensions are shown in the following figures:

Figure 22	AJ10-133 Propulsion System, Installation (not available)
Figure 23	AJ10-133 Propulsion System, Main Assembly (not available)

3.6 Components and systems--All components of the fluid systems, other than the tankage, shall withstand a proof pressure defined as 1.3 times maximum steady-state pressure. The tankage shall withstand a proof pressure of 1.1 times the limit load pressure. All components of the fluid system shall withstand leak tests in accordance with the contractor's drawings.

3.6.1 Propellant and other fluid systems - The propulsion system shall function satisfactorily under the conditions described in 3.3.1 when propellants and other fluids are supplied to the system at the temperatures, pressures, and flow rates specified within this specification.

3.6.1.1 Pump and drive assembly - (not applicable)

3.6.1.1.1 Turbine exhaust connection - (not applicable)

3.6.1.2 Propellant drains - Suitable drainage provisions shall be incorporated in the fluid system. Non-drainable fluids shall not constitute a safety hazard. The maximum amounts of fluids remaining in the system after drainage shall not exceed the following values:

Fluid systems	Maximum Quality Remaining (lb)
Propellant	
Oxidizer	(not available)
Fuel	(not available)

3.6.1.3 Lines and fittings - The lines shall be as short as practical and shall contain no collection traps which cannot be purged or drained. The minimum and maximum torque values shall be as specified on Drawing AND10064 for the sizes or types of lines listed. The torque values for other sizes or types shall be as specified on the contractor's drawings.

3.6.1.4 Filters -

3.6.1.4.1 Servicing filters - Fluids supplied to the propulsion system shall be passed through filters of the following sizes:

Helium	10 microns
Oxidizer	250 microns
Fuel	250 microns

3.6.1.5 Filler connections - Filler connections for like propellant systems shall not be interchangeable with those of any other propellant system.

3.6.2 Power control - The components required for control of the propellant system shall be as shown in Figure 24.

3.6.2.1 Preflight check - The preflight check procedure of the propulsion system shall be as outlined in the Field Procedures. It shall be concerned with, but not limited to, the following items.

(a) Pressurization of tanks
(b) Electrical functional test
(c) Electro-mechanical functional test
(d) Leakage test
(e) Integrated systems test
(f) Weight and balance
(g) Electrical systems test
(h) Propellant servicing
(i) Helium console checkout

The test support equipment utilized in performing these checks includes, but is not limited to, the following:

(a) Electro-mechanical checkout console

(b) Transducer simulator

(c) Leak dectector

(d) Launch control console

(e) 28-vdc power supply

(f) Leak rate unit

(g) Transducer ratio calibrator

(h) Administration van

(1) Gas regulator flow bench

(j) Helium pressurization console

(k) Propellant decontamination trailer

(l) Propellant servicing trailers

(m) Propellant emergency dump trailers

(n) Nitrogen pressurization console

(0) Handling trailer hoisting pivot

(p) Instrument van

(q) Shop van

(r) Supply van

(s) Drying and inert gas purging system

(t) Missile weather cover

(u) Relay and junction box

(v) Vacuum dehydration unit

(w) Lifting support (strong back)

3.6.2.1.1 External test connections - Noninterchangeable external test connections shall be provided for ground checking of significant test devices.

3.6.2.2 Indication -

3.6.2.2.1 Fittings - Fittings shall be provided on the propulsion system to permit indication of the following data during acceptance test.

(a) Fuel tank pressure
(b) Fuel injection pressure
(c) Oxidizer tank pressure
(d) Oxidizer injection pressure
(e) Helium tank pressure
(f) Thrust chamber pressure
(g) Regulator output pressure
(h) Fuel flow rate
(i) Oxidizer flow rate

3.6.2.2.2 Flight instrumentation - Instrumentation compatible with the telemetering system which is furnished by RCA shall be installed to monitor the following propulsion system parameters

	Item	Range
(a)	Fuel tank pressure	0-200 psia
(b)	Fuel injection pressure	0-200 psia
(c)	Oxidizer tank pressure	0-200 psia
(d)	Helium tank pressure	0-5000 psia
(e)	Auxiliary Fuel tank pressure	0-400 psia
(f)	Thrust chamber pressure	0-100 psia
(g)	Helium regulated pressure	0-400 psia
(h)	Oxidizer injector pressure	0-200 pdia
(i)	Cutoff signal	0-30 vdc

3.6.2.4 Interrelation with propulsion system - The sequence of control operations, interrelation of controls of the propulsion system, and the sequence of propulsion system operation shall be in accordance with 3.3.5. These relationships shall be as further illustrated in Figures 24, 25 and 26 (not available).

3.6.2.4.1 Performance selector - (not applicable)

3.6.2.5 Starting - The propulsion system shall have no performance selector and no ready condition time limits for starting, except the time of settling rocket firing prior to fire signal to the main thrust chamber.

3.6.2.5.1 Fixed thrust rocket engines - (not applicable)

3.6.2.5.2 Variable thrust rocket engines - (not applicable)

3.6.2.6 Control adjustment - Thrust range control adjustment shall be made by regulation of the propellant system pressures. Such regulation shall be accomplished by the use of orifices.

3.6.2.6.1 Thrust vector location - The effective thrust vector is defined as the line joining the geometric center of the throat and the geometric center of the 35:1 divergent nozzle exit line.

3.6.3 Electrical system -

3.6.3.1 Electrical power - All components using dc electrical power from vehicle power system shall function properly over an input range of 20 to 30 dc. No point in the dc electrical power system shall be grounded to the vehicle frame.

3.6.3.1.2 Plugs and receptacles - A nozzle grounding receptacle shall be provided for each propellant tank.

3.6.3.1.3 Installation - Specification MIL-E-8189 shall apply to the installation of components, relays, and similar electrical equipment using vehicle electrical equipment , except for the use of Teflon insulated wire as specified in 3.6.3.1.1.

3.6.3.1.4. Soldering - Soldering shall be in accordance with MIL S- 6872.

3.6.3.2 Radio interference - Electrical components shall not cause radio interference beyond the limits specified by MIL-I-26600. Electrical bonding shall be provided in accordance with MIL-B-5087.

3.6.3.3 Ignition proof - Electrical components shall not ignite any explosive mixture surrounding the equipment.

3.6.4 Ignition system - Ignition system shall consist of four spark plugs.

3.6.5 Lubrication system - No lubrication system is required in the propulsion system.

3.6.6 Thrust chamber assembly -

3.6.6.1 Propellant accumulation - (not applicable)

3.6.6.2 <u>Assembly</u> - The thrust chamber assembly shall include the thrust chamber and controls such as the oxidizer and fuel thrust chamber valve and thrust chamber valve pilot valve. Operating and performance parameters of the thrust chamber are described in 3.3.4.1.

3.6.6.3 <u>Thrust Alignment</u> - The alignment of the thrust chamber assembly with the vehicle shall be accomplished by adjusting the center reference point on the alignment fixture to within ______ inch of the effective thrust vector.

3.6.10 <u>Gimbal Actuation System</u> - The gimbal actuation system shall provide pitch, and yaw control during powered flight. This will be accomplished by servo-actuators serving as variable length links between each thrust chamber assembly and its supporting structure.

3.6.11 <u>Attitude control system</u> - Not applicable

3.6.12 Pneumatic system - The pneumatic system shall be utilized to pressurize the liquid oxygen tanks and the auxiliary fuel tank. The pneumatic system shall include the helium tanks, helium filling and disconnect valves and fittings, pressure regulator.

3.7 Fabrication--

3.7.1 Materials--

3.7.1.1 Quality--Materials used in the manufacture of the propulsion system shall be of high quality, suitable for the purpose and shall conform to the applicable specification in accordance with ANA bulletin No. 343. When temporary substitutions are used, the contractor's drawings shall specify the applicable government specification of the alternate material.

3.7.1.2 Critical materials--The use of critical materials shall be held to a minimum. The estimated weight of each of the following materials, based on the raw stock and finished parts, required in the construction of the propulsion system, shall be specified in subsequent revisions of this model specification.

(a) Chromium
(b) Cobalt
(c) Columbium
(d) Molybdenum
(e) Natural rubber
(f) Nickel
(g) Tungsten

3.7.2.3 Interchangeability--All parts having the same manufacturer's part number shall be directly and completely interchangeable with respect to installation and performance except that matched parts or selective fits will be permitted where required. Changes in manufacturer's part namber shall be governed by the drawing number requirements of MIL-D 5028. Interchangeability of delivered systems, insofar as attachment provisions for adding forward and aft body components are concerned, shall be privided. However, the interchangeability of joining or splicing provisions shall be the responsibility of the Using Agency.

3.7.2.4 Protective treatment - All parts shall be corrosion resistant or suitably protected.

3.7.3 Standards -

3.7.3.1 Parts - An, Jan, or MIL Standard parts shall be used where ever suitable for the purpose and shall be identified by standard part numbers. The use of nonstandard parts shall be acceptable only when standard parts have been determined to be unsuitable, except for electrical components. Use of nonstandard parts in electrical components shall be approved in accordance with MIL-E-8189.

3.7.4 Parts list - A parts' list for the system shall be prepared.

3.9 Reliability - All equipment shall be designed and constructed so that a ___ percent probability of successful operation of the propulsion system may be achieved in its intended environment. This is based on failure rates being within allowable limitations for the prescribed tests as related to the aforementaioned reliability.

4. QUALITY ASSURANCE PROVISIONS

4.2.1 Alternate test fluids - (not applicable)

4.2.2 Qualification tests - (not applicable)

4.2.3 Preliminary flight rating tests - Establishment of a perliminary flight rating for the propulsion system shall be predicated on compliance with Supplement A to this Appendix.

4.2.4 Acceptance tests - Acceptance of the propulsion system shall be predicated on satisfactory completion of tests in accordance with Supplement B to this Appendix.

4.2.5 Reliability monitoring program - The reliability of the propulsion system, subsystems, and components shall be continuously evaluated and monitored throughout the development, acceptance, and PFRT programs in accordance with Specification AFBM Exhibit 58-10. All tests performed on the propulsion system, subsystems, and components shall be noted on form AGC-02-52, Reliability Log, together with test duration, cycles, and data on any failure. Failure data shall be recorded on AFTO form 120.

5. PREPARATION FOR DELIVERY

5.2 Storage, shipment and delivery - The propulsion system components and accessories shall be prepared for storage and shipment on axhandling dolly. The seller shall furnish a packing list with each package. All parts, accessories, and components not installed on the system but shipped with it, shall be included on the packing list.

6. Notes

6.1 Intended use - This Aerojet-General liquid propellant, pressurized, rocket propulsion system, is intended for use as the propulsion module for the Apollo vheicle.

6.2 Symbols and definitiions -

6.2.1.46 Limit load - Applied or limit load is the anticipated maximum actual load to be established by a rational analysis of the design criteria.

6.2.1.47 Factor of safety - Factor of safety is an arbitrary multiplication factor on the limit load to provide a design margin of safety or reliability. When this factor is to be associated with the material yeild strength, it is designated as the yield factor of safety. When it is associated with the material ultimated strength, it is designated as the ultimate factor of safety.

6.2.1.48 Yield load - Yield load is the limit load times the yield factor of safety.

6.2.1.49 Ultimate load - Ultimate load is the limit load times the ultimate factor of safety.

6.2.1.50 <u>Yield margin of safety</u> - Yield margin of safety =

$$\frac{\text{Material yield strangth}}{\text{Stress at yield load}} - 1$$

6.2.1.50 Limit pressure - Applied or limit pressure is the anticipated maximum actual pressure to be established by a rational analysis of the design criteria.

6.2.2 Symbols - Symbols used in this specification are defined as follows: (not available)

SUPPLEMENT A TO APPENDIX F
PRELIMINARY FLIGHT RATING TEST PROGRAMS FOR THE AJ10-133 SPACECRAFT PROPULSION MODULE

I. GENERAL

The AJ10-133 spacecraft propulsion module will be certified for manned flight through concurrent two phase preliminary flight rating test program. The first phase will consist of a thrust chamber evaluation and the second phase will consist of overall propulsion module evaluation as discussed under the term "aircraft rocket engines" in MIL-E-6626A (ASG).

A. This two phase program will certify the thrust chamber and propulsion module for use in manned test flights.

B. At an intermediate point in the PFRT program the thrust chamber and propulsion module will have achieved non-manned rate of certifications as discussed under "remotely launched missile rocket engines" in MIL-E-6626A (ASG).

C. Additions to, and variations from, MIL-E-6626A (ASG) are discussed as they appear in this proposal.

II. PFRT PROGRAM

A. THRUST CHAMBER ASSEMBLY (MIL-E-6626 PARAGRAPH 4.3.3.2)

1. Each thrust chamber injector will be flow-tested with water at rated flow to determine the pressure drops and orifice coefficients at rated flow.

2. No coolant jacket calibration need be made as chamber is ablatively cooled.

3. Three full-duration firings will be made, one each, at 90% of minimum thrust, at 110% of maximum thrust, and at the nominal thrust.

II, A, PFRT Program (cont.)

The chamber will be installed on a horizontal stand, and thrust will be measured.

4. One full-duration test will be made at maximum thrust, following a five-hour exposure to the lowest anticipated flight temperature to demonstrate the resistance of the ablative chamber to thermal shock.

5. The thrust chamber assembly will be given an additional test to demonstrate resistance to humidity. It will be exposed to a humid environment in accordance with (6626 paragraph 4.2.1.8.2.2) and then inspected for evidence of corrosion or deterioration.

B. PROPULSION MODULE (6626 PARAGRAPH 4.2.1)

1. The complete propulsion module will be weighed as part of the acceptance test prior to this program.

2. All fluid systems will be tested for leakage in accordance with the model specification.

3. The propellant systems will be filled with water, in the normal servicing attitude, and then drained. The remaining fluid will be measured.

4. No vibration tests of the propulsion module will be conducted.

5. Nine full-duration calibration firings will be made at various thrust levels. Three each will be conducted at 90% of minimum thrust, 110% of maximum thrust, and at the nominal thrust level.

II, B, Propulsion Module (6626 Paragraph 4.2.1) (cont.)

6. One-hundred short-duration "Safety Limits" tests will be conducted at minimum thrust.

a. Forty tests (of 15 sec duration) will be made with the dc input voltage varied through a range specified in the model specification.

b. Sixty start-shutdown tests (of 15 seconds duration) will be made to demonstrate again the restart capability of the propulsion module. These firings will be conducted in five series of five tests each, with a 15-minute cooling period between firings.

7. Twenty-six additional full-duration firings will be conducted, nominal thrust. During each of these, the gimbal and force control systems will be operated by an electronic programmer simulating flight requirements. These additional firings will also satisfy the requirement of MIL-E_6626A (ASG) for thirty-five full-duration runs.

8. One-hundred thirty-nine test firings will be conducted during the PFRT pgrogram.

The total test duration will be about 12,300 seconds

III. HARDWARE REQUIREMENTS

One complete propulsion module and 49 ablative thrust chambers without nozzle extensions will be expended during the PFRT program.

SUPPLEMENT B OF APPENDIX F
SUPPLEMENT TO MODEL SPECIFICATION

[redacted]

GENERAL
ELECTRIC

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