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5/28/2009

RELEASED

Global Precipitation Measurement (GPM)

Thruster Specification

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

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CHANGE HISTORY LOG

Sheet: 1 of 1

Rev Level	Description of Change	Approved By	Date Approved
Rev –	Initial release per GPM-CCR-0187	C. Carlisle	03/27/2009
Rev A	1.0 Scope Change last sentence From: In addition, one spare of each type of thruster and one spare valve will be required. To: In addition, one spare of each type of thruster will be required. Approved per GPM-CCR-272.	C. Carlisle	05/28/2009

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List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date

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1.0 SCOPE

This document establishes the performance, design, development, physical characteristics, and testing requirements for the Global Precipitation Mission (GPM) Core Spacecraft propulsion system thrusters, herein referred to as thruster(s) or unit(s). The propulsion system includes 12 thrusters for orbit insertion, stationkeeping, attitude control, and momentum unloading. Of the 12 thrusters, 4 will have 90-degree nozzles, and 8 will have straight nozzles. In addition, one spare of each type of thruster will be required.

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2.0 DOCUMENTATION AND DEFINITIONS

The following list represents documents that govern the design, construction, and testing of the thruster as referenced herein. If no revision or date is specified for the document, the latest issue at the time of contract release shall apply. In the event of a conflict between the GPM Thruster Statement of Work (SOW) (GPM-PROP-SOW-0019) and this specification, the SOW shall take precedence. When the requirements of any of the documents so referenced conflict with this specification, the requirements of this specification shall take precedence, with the exception of the SOW.

2.1 DOCUMENTS

2.1.1 MILITARY DOCUMENTS

AFSPCMAN 91-710v3	Air Force Space Command Manual 91-710, volume 3, Range Safety User Requirements Manual, Volume 3 – Launch Vehicles, Payloads, and Ground Support Systems Requirements (replaces EWR 127-1)
IEST-STD-CC1246D	Product Cleanliness Levels and Contamination Control Program
MIL-PRF-26536	Propellant, Hydrazine, High Purity
MIL-PRF-27401	Propellant, Nitrogen, Pressurizing Agent
MIL-PRF-27407B	Propellant, Helium, Pressurizing Agent
MIL-PRF-27415A	Propellant Pressurization Agent, Argon
MIL-STD-13OL	Identification Marking of U.S. Military Property
MIL-STD-462	Measurement of Electromagnetic Interference Characteristics
MIL-STD-889B	Dissimilar Metals
MIL-W-46132	Welding, Fusion, Electron Beam, Process for

2.1.2 FEDERAL DOCUMENTS

FED-STD-TT-I-735	Isopropyl Alcohol

2.1.3 NASA DOCUMENTS

JSC-SPEC-C-20C	Water, High Purity, Specification for

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GSFC-S-311-641	Switches, Thermostatic, General Requirements for
GSFC-X-673-64-lE	Engineering Drawing Standards Manual
GSFC-S-311-P-079	Procurement Specification for Thermofoil Heater
GSFC-S-311-P-018	Thermistor Specification
NASA-STD-5001	Structural Design and Test Factors of Safety for Space Flight Hardware
NASA-STD-8739.3	Soldered Electrical Connectors
NASA-STD-8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring
NASA-STD-8739.1	Workmanship Standard for Staking, Conformal Coating

2.1.4 GPM DOCUMENTS

Note: these documents will be provided upon request.

GPM-MECH-REQ-0012	GPM Core Spacecraft Mechanical Environmental Loads
GPM-PROP-SOW-0019	GPM Thruster Statement of Work

2.1.5 JAXA DOCUMENTS

JMR-002A	Launch Vehicle Payload Safety Standard (JAXA)
JERG-0-001	Technical Standard for High-Pressure Gas Equipment for Space Use (JAXA) (April 1, 2004)

2.1.6 OTHER DOCUMENTS

ASTM D1193-06	Standard Specification for Reagent Water
ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
ASTM-A511	Standard Specification for Seamless Stainless Steel Mechanical Tubing
AMS-QQ-S-763	Pressure Tubing Specification, Stainless Steel
EEE-INST-002	Instructions for EEE Parts Selection, Screening Qualification, and Derating
ISO 10012-ED1	Quality Assurance Requirements for Measuring Equipment

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2.2 DEFINITIONS

Flight Hardware: Any component intended to fly on the Observatory. This includes protoflight, follow-on, and flight spare hardware.

Protoflight Hardware: Flight hardware of a new design. Protoflight hardware is subject to a qualification test program that combines elements of prototype and flight acceptance verification. This program shall include the application of design qualification test levels and flight acceptance test durations.

Follow-On Hardware: Flight hardware built in accordance with a design that has been qualified either as prototype of as protoflight hardware. Follow-on hardware is subject to a flight acceptance test program.

Qualification Test: A test performed on non-flight hardware. The purpose of the test is to prove that a new design meets one of more of its design requirements. Qualification testing is performed at maximum expected flight levels plus a margin. Test durations are typically longer than for acceptance tests.

Protoflight Test: A test performed on flight hardware. The purpose of the test is to prove that a new design meets one of more of its design requirements. Protoflight testing is performed at maximum expected flight levels plus a margin. Test durations are typically the same as for acceptance tests.

Acceptance Test: A test performed on flight hardware. The purpose of this test is to prove that a particular flight unit has been manufactured properly. The design has already been proven during a qualification or protoflight test program. Acceptance testing is performed at maximum expected flight levels.

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3.0 REQUIREMENTS

3.1 DESCRIPTION

The thrusters shall produce thrust by the catalytic decomposition of hydrazine propellant as specified herein. The major components include the thruster chamber, catalyst bed, nozzle, thruster valves, mounting bracket, catalyst bed heaters, thruster valve heaters, and thermal sensors.

3.2 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

3.2.1 Thrust

The thruster will operate in a blowdown mode with an initial feed pressure of 400 psia and a final feed pressure of 100psia. The thruster shall operate safely at all feed pressures in this range. The nominal steady-state thrust shall be at least 13.3 N at end of life (EOL) at a feed pressure of 125 psia and shall not exceed 44.5 N at a feed pressure of 400 psia.The vendor shall provide thrust data for steady-state and pulse mode operation versus inlet pressure for nominal and ±3σperformance, including EOL performance. If the statistical ±3σperformance cannot be provided, the vendor shall demonstrate by analysis or test what the statistical confidence is in the nominal steady state performance.

3.2.2 Thrust Repeatability

Steady-state thrust and specific impulse for each thruster shall be predictable to within 5% at beginning of life (BOL).

3.2.3 Specific Impulse

The minimum vacuum steady-state specific impulse provided by the thruster shall be as shown in Table 3-1 for the corresponding inlet pressures. The vendor will provide specific impulse versus inlet pressure curves for nominal and worst case performance. If the statistical -3σ performance cannot be provided, the vendor shall demonstrate by analysis or test what the statistical confidence is in the nominal steady-state performance.

Table 3-1 -3σ Worst Case Steady-State Specific Impulse

Inlet Pressure (psia)	-3σ Worst Case Isp (s)
100	218.0
150	220.5
200	221.5
250	225.5
300	223.0
350	223.5
400	223.5

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3.2.4 Impulse Bit

The thruster shall be capable of operating in a pulsed mode with valve command pulse durations of 50 milliseconds (ms). The minimum impulse bit is defined as the area under the thrust-time curve for a given valve open pulse width. The impulse bit shall be repeatable to +/- 5% for any continuous firing duration of 1 second or greater with similar initial conditions. For any firing duration less than 1 second, the impulse bit shall be repeatable to +/- 25%.

3.2.5 Propellant Throughput

The minimum qualified throughput of the thrusters shall be 214 kg.

3.2.6 Thruster Duty Cycle

Thruster operation shall not have any duty cycle restrictions for on times between 50 ms and the firing duration defined in Section 3.2.14 at all inlet pressures and thermal environments specified herein.

There are two categories of expected duty cycles for the GPM mission. The two categories are described below and summarized in Table 3-2.

The first category is off-pulsing for attitude control during delta-V burns. In this mode, the thrusters will operate at either a 33%, 67%, or 83% duty cycle for several seconds immediately followed by a steady-state burn of several seconds.

The second category is for momentum unloading. In this mode, the thruster will operate at a 17%, 33%, or 67% duty cycle for periods of several seconds separated by non-firing periods of one second to several minutes.

Table 3-2 Thruster Duty Cycles

Category 1

On Time (s)	Off Time (s)	Pulse Mode Duty Cycle (%)	Number of Pulses	Steady-State Burn Time after Pulse Train (s)
0.1	0.2	33	10-50	≥3
0.2	0.1	67	10-50	≥3
0.25	0.05	83	10-50	≥3

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Category 2

On Time (s)	Off Time (s)	Pulse Mode Duty Cycle (%)	Number of Pulses	Non-Firing Time after Pulse Train (s)
0.05	0.25	17	3-10	≥1
0.1	0.2	33	3-10	≥1
0.2	0.1	67	3-10	≥1

3.2.7 Catalyst Bed Heater

The catalyst bed heater shall be designed to achieve operational catalyst bed temperature within 45 minutes of enabling from the worst-case minimum temperature.

3.2.8 Inlet Pressure

The thruster shall operate at any valve inlet pressure from 100 psia to the maximum expected operating pressure (MEOP) of 400 psia. The maximum exposure pressure for the thrusters in a non-operating condition with valves closed shall be 550 psia.

3.2.9 Propellant Temperature

The thruster shall operate at any propellant temperature between 12 and 40 °C.

3.2.10 Propellant

The thruster shall be qualified to operate with high purity grade hydrazine per MIL-PRF-26536E (with Amendment 1).

3.2.11 Pressurant Gas

The pressurant shall be gaseous nitrogen per MIL-PRF-27401, Grade B.

3.2.12 Leakage

3.2.12.1 External Leakage

Each thruster shall have an external leak rate of less than or equal to 1x 10^-6 scc/s GHe at the MEOP of 400 psia, with valves open and nozzle plugged.

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3.2.12.2 Internal Leakage

All thruster valve seats shall have an internal leak rate of less than or equal to 5 scc/h GHe at a test differential pressures of 25 psid, 400 psid, and the maximum differential pressure of 550 psid (400 psid MEOP + 150 psid latch valve back pressure relief).

3.2.13 Cleanliness

3.2.13.1 External Cleanliness

All thrusters shall be verified to be visibly clean highly sensitive with a blacklight inspection per JSC-SN-C-0005C upon delivery.

3.2.13.2 Internal Cleanliness

All thrusters shall be cleaned and verified internally clean to Level 100A per IEST-STD-CC1246, with the additional requirement that no metal particles are allowed above 25 microns.

3.2.14 Firing Duration

The thruster shall be capable of continuous steady-state firing durations of up to and including 3200 seconds.

3.2.15 Roughness

Chamber pressure oscillations shall not cause any damage to thruster or performance shortfalls during all modes of operation. The thruster shall not exhibit any occurrence of "spiking" (rapid isolated increases of chamber pressure caused by collection and detonation of undecomposed propellant) at any condition of feed pressure, temperature, etc. specified herein.

3.2.16 Proof and Burst Pressures

3.2.16.1 Thrusters

The thrusters shall have a proof pressure capability of not less than 1,500 psiaand a burst pressure of not less than 2,200 psia with valves open.

The thruster valves, when closed, shall be capable of withstanding a proof pressure of 1,500 psia, and the vendor shall demonstrate through a qualification program that each valve has a burst pressure of at least 2,200 psia.

3.2.16.2 Propellant Inlet Tubes

The interface tubes shall be capable of withstanding a proof pressure of 825 psia (1.5x maximum exposure pressure).The vendor shall demonstrate through a qualification program that each

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valve's interface tubes have burst pressures of 2,200 psia (4x maximum exposure pressure) at a minimum.

3.2.17 Cycles

3.2.17.1 Thermal Cycles

All thrusters shall be qualified for160thermal cycles. A single thermal cycle is defined as a temperature excursion from the below the thruster's minimum operational temperature to the maximum thruster operational temperature and back down below the minimum operational temperature.

The catalyst bed heater design shall be qualified to 160 cycles.

3.2.17.2 Valve Cycles

All thruster valves shall be qualified for 39,000 cycles.

3.2.18 Cold Starts

All thrusters shall be capable of surviving 10 cold starts with no more than 10% degradation in thrust. The cold start catalyst bed temperature shall be defined as 12 deg-C or lower.

3.2.19 External Pressures

The thruster shall be capable of surviving at all ambient external pressures from sea level to deep space with internal pressures as specified herein. Specification requirements for specific impulse, total impulse and thrust apply only to deep space environment.

3.3 PHYSICAL CHARACTERISTICS

3.3.1 Mass Properties

The thruster mass shall be less than 0.8 kg, including all thermal and electrical hardware. The mass shall be measured to within 0.05 kg. The center of mass shall be calculated and shall be labeled on the component interface drawing.

3.3.2 Envelope

The thruster assembly external dimensions, including mounting provisions, shall be within an envelope of 200mm x 120 mm x 90 mm for the thrusters with 90^0 nozzles and 200mm x 100mm x 90 mm for the thrusters with straight nozzles. This envelope shall not apply to the interface tube.

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3.3.3 Thrust Alignment

The centerline of the nozzle shall be perpendicular to the mounting flange for thrusters with straight nozzles and parallel to the mounting flange for thrusters with 90-degree nozzles to within ±0.25°. The position of the nozzle centerline as built shall be within ± 0.050 inches of the position as designed.

3.3.4 Thruster Valves

All thrusters shall have a dual-seat (series-redundant) propellant valve, with each seat able to be independently verified for leakage. Each seat shall be electrically operated independently and normally closed when unpowered.

3.3.5 Thruster Valve Heaters

Each thruster shall include heaters for the valves. The heaters shall have prime and redundant circuits, each of which incorporates series-redundant thermostats such that each circuit is single fault tolerant to overheating. Heaters and thermostats shall be provided by the vendor in accordance with GSFC specifications S-311-641 and S-311-P079. GPM Thermal will provide representative thermal environments to the vendor.

The heaters shall be sized for the worst-case cold thermal condition and shall have a maximum duty cycle of 70% at 27 V.

All thermal hardware shall be installed prior to acceptance testing.

3.3.6 Thruster Catalyst Bed Heaters

The thrusters shall include heaters to preheat the catalyst bed prior to thruster operation. The heaters shall have prime and redundant circuits. Each heater shall be operated independently.

3.3.7 Thruster Thermal Sensors

Each thruster shall include a total of 4 thermal sensors: 1 primary valve thermistor, 1 redundant valve thermistor, 1 primary catalyst bed platinum resistance temperature sensor (PRT), and 1 redundant catalyst bed PRT. The temperature sensors for the valve shall be thermistors that conform to GSFC specification S-311-P-018.

3.3.8 Mounting Flange

The thruster shall incorporate a mounting flange to attach the engine to the spacecraft mounting bracket, as per a Mechanical ICD provided by the vendor and approved by NASA/GSFC.

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3.3.9 Filter Integral to the Valve

The thruster shall incorporate a filter to protect the valve seats from contamination. The filter shall have a nominal rating of 25 micrometers or larger.

3.3.10 Propellant Inlet Tubes

The interface tubes shall be 304L stainless steel per ASTM-A511 or AMS-QQ-S-763. The interface tubes shall have the following dimensions: 0.2515±0.0015 inch OD, 0.028±0.003 inch wall thickness. The interface tube centerline shall be perpendicular to the centerline of the thruster valve body. The interface tube shall have a minimum length of 2 inches from the thruster body centerline.

3.4 ELECTRICAL REQUIREMENTS

3.4.1 Power Requirements

3.4.1.1 Thruster

The thruster shall meet all performance requirements with power input between 21 and 35 VDC.

3.4.1.2 Thruster Valve

All thruster valves shall be designed with a maximum current draw of 1.5 A over the specified operating voltage range. The maximum current draw shall be the total for both valve coils wired in parallel.

3.4.1.3 Valve Heater

All thruster valve heaters shall be designed with an operating voltage range of 23 – 35 VDC.

3.4.1.4 Catalyst Bed Heater

All thruster catalyst bed heaters shall be designed with an operating voltage range of 21 – 35 VDC, with a minimum resistance at temperature of 125 Ω per heater.

3.4.2 Survival of Anomalous Voltage

The thruster shall be designed to not be damaged by any voltage in the range of -5 to +40 VDC for an indefinite time period applied to the power input during anomalistic operations. No flight thruster shall be tested to this requirement.

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3.4.3 Wire

3.4.3.1 Insulation

The insulation resistance shall be greater than 100 MΩ when measured at 21 ± 10 ^{O}C with a potential of 500 ± 50 VDC applied between the shorted coil leads and the case.

3.4.3.2 Leads

All Power wires shall be Mil-W-22759/33-xx or MIL-W-81381 Twisted Pairs.All Signal wires shall be M27500xxSC Shielded Twisted Pairs, where xx is conductor AWG. Wire shall be sized appropriately for derated current capacityper Table 4A, Section W1 of EEE-INST-002.The minimum wire size (max gauge) for power and heaters shall be 22 AWG.The minimum wire size (max gauge) for signals shall be 24 AWG. Exceptions shall be approved by the GPM Electrical systems engineer.Length shall be >1 m. All wire shall be color-coded per component drawing.

3.4.4 Electrical Bonding to Ground

The thruster shall be electrically bonded to ground by direct contact over the entire mounting surface. The mounting surface shall be free of any non-conducting finishes.

3.4.5 Charging Mitigation

System impacts of the discharges from any unavoidable non-conductive surfaces shall be assessed and approved. If necessary, a waiver request will be submitted for each specific non-compliant application. The vendor shall supply a comprehensive list of non-conductive surfaces on the outside of the thruster.

3.5 THERMAL REQUIREMENTS

3.5.1 Thermal Interfaces

GSFC will provide representative thermal environments for the vendor to incorporate with their thermal model of the thruster assembly. This shall include both Radiative and Conductive interfaces. The models representative of the thruster thermal environment will be provided in Thermal Desktop format. Alternative formats may be proposed by the vendor if necessary.

The vendor shall deliver a thermal model of the thruster assembly comprised of no more than 50 nodes per thruster assembly. This model shall be capable of predicting heater powers for valves and catbed heaters as well as firing and non-firing thermal behavior. The model shall be provided in Thermal Desktop format. Alternative formats may be proposed by the vendor, but at a minimum, both Geometric Radiative and Thermal Network models must be provided.

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3.5.1.1 Conduction

The thermal control of the thruster assembly shall not rely on the Conductive interface to the spacecraft.

3.5.1.2 Radiation

The thermal control of the thruster assembly shall not rely on the Radiative interface to the spacecraft. The spacecraft blanket temperatures in the Radiative Field of View of the thruster assembly shall be maintained below 250°C. The vendor shall provide analysis and documentation demonstrating compliance with the blanket requirement stated above. The inclusion or exclusion of a heat shield shall be the vendor's responsibility.

3.5.2 Flight Interface Design Temperature Limits

The thrusters shall be capable of operation in a vacuum with temperatures defined in Table 3-3. The temperatures in Table 3-3 refer to the temperature of the thruster hardware interface and the thruster valves (except due to thruster firing when thruster valves are expected to exceed these temperatures). The temperature ranges are specific to the type of test being conducted. The Operational Temperature Range is the nominal expected orbital range for operating conditions as well as non-operating and non-firing conditions. The Acceptance Temperature Range is the range to be used for any acceptance test. The Qualification Temperature Range is the range to be used for protoflight testing.

Table 3-3 Temperature Limits

Operational Temperature Range[1]	Acceptance Temperature Range[2]	Qualification Temperature Range[3]
+12 ^{O}C to +40 ^{O}C	+7 ^{O}C to +45 ^{O}C	2 ^{O}C to +50 ^{O}C

[1] Nominal expected orbital range, for operating conditions, as well as non-operating and non-firing conditions.
[2] Test temperatures for flight units; conducted only on flight hardware for which the design has already undergone a qualification program.
[3] Maximum performance limits; test temperature for protoflight hardware if design is not previously qualified.

3.5.3 Ground Test Environment

The thruster valves shall be able to operate while powered in a lab environment with air temperature between +5 and +35 ^{O}C and relative humidity between 10 and 70%.

The thruster shall survive while unpowered with air temperatures of +5to +35 ^{O}C and relative humidity between 10 and 70%.

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3.6 MECHANICAL REQUIREMENTS

This section defines the limit loads, mechanical environments, and mechanical verification requirements of the GPM thrusters.

3.6.1 Random Vibration

The thruster shall demonstrate its ability to meet its performance requirements after being subjected to the following random vibration environment. These levels are to be applied at the GPM/thruster interface.

Table 3-4 Thruster Random Vibration Environment

	Acceptance	Qualification
Frequency (Hz)	ASD (g^2/Hz)	ASD (g^2/Hz)
20	0.013	0.026
50	0.08	0.16
800	0.08	0.16
2000	0.013	0.026
Overall	10.0 g_{rms}	14.1 g_{rms}

3.6.2 Static

The thruster shall demonstrate the capability to meet the mass acceleration curve in Figure 3-1 without any damage or degradation in performance.These design loads are intended to cover low-frequency dynamic inputs less than 100Hz, as well as static inputs on components and subsystems typically less than 100 kg. For components weighing less than 0.5 kg, a design limit load of 36 g shall be used. Loads are to be applied independently in each axis.

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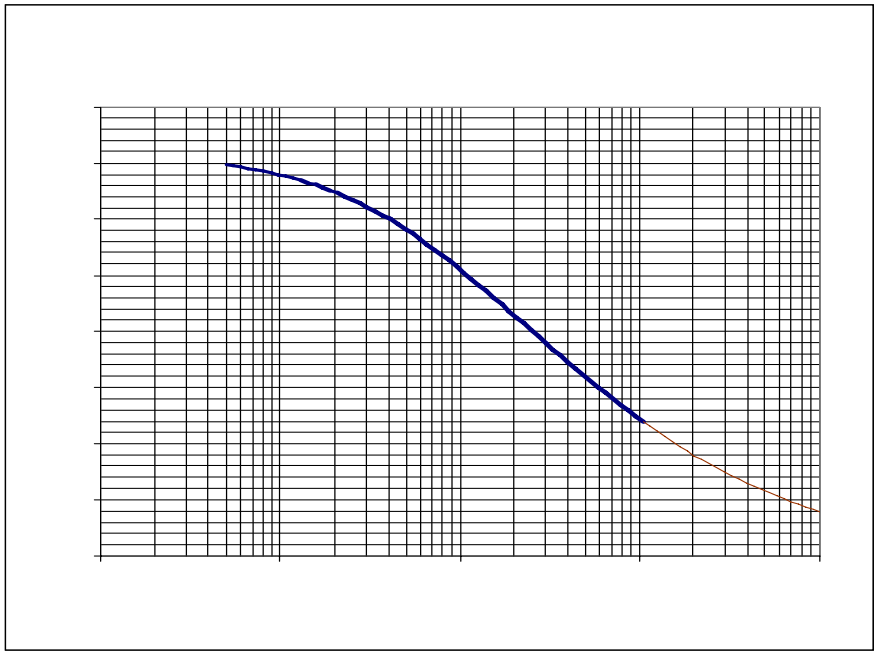

Figure 3-1 Mass Acceleration Curve

3.6.3 Swept Sine Vibration

The thruster shall demonstrate the capability to survive the swept sine levels given in Table 3-5 without any damage or degradation in performance.

Table 3-5 Swept Sine Input Levels

	Frequency (Hz)	Acceptance (g)	Qualification (g)
Axial	5-50	6.4	8.0
Lateral	5-50	6.4	8.0

3.6.4 Shock

The thruster shall be designed to withstand the shock environment Table 3-6 and Figure 3-2 without any damage or degradation in performance. Qualification may be shown based on prior testing of similar components.

Table 3-6 Shock Spectrum

Freq. (Hz)	Acceptance Level (Q=10)	Qualification Level (Q=10)
100 100-1430 1430-20000	24.4g +5.14 dB/oct. 2300 g	30.5 g +5.14 dB/oct. 2875 g

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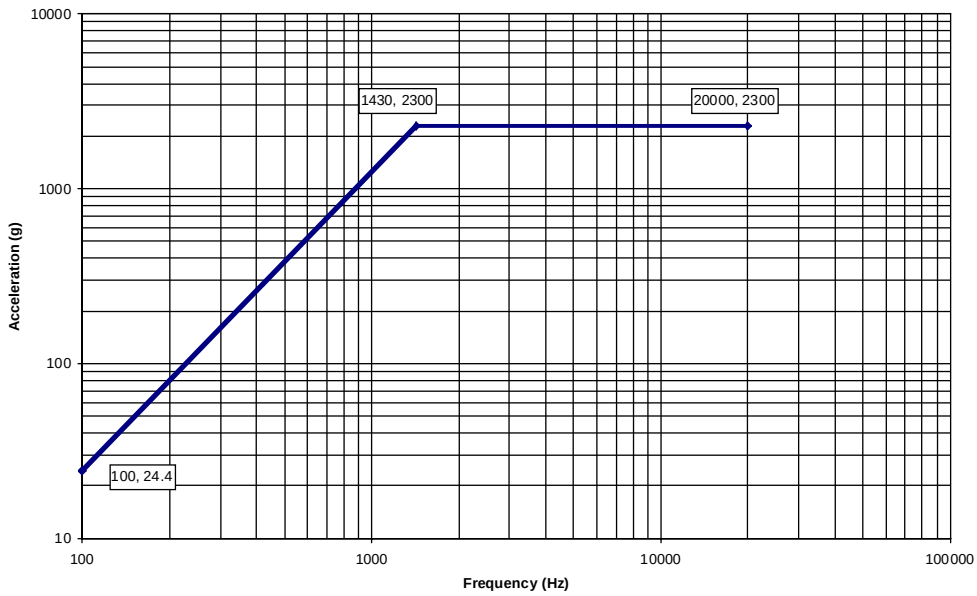

Figure 3-2 Shock Spectrum

3.6.5 Frequency Requirement

The thruster shall have a fundamental frequency greater than 100 Hz when hard mounted at its spacecraft interface.

3.7 RADIATION REQUIREMENTS

The vendor shall confirm that none of the materials in the valve are EEE parts and that they are not susceptible to radiation damage.

3.8 MATERIALS, PARTS, AND PROCESSES

3.8.1 Materials

The thrusters shall function within specification after exposure to propellant for a 5-year duration. Materials compatibility compliance per KSC-KTI-5211, MSFC-HDBK-527F, or AIAA-SP-085-1999 will be submitted for all component piece parts, hardware, lubricants, soft goods, etc. that may come into contact with the propellant.

3.8.1.1 Material Compatibility

The thrusters shall be fabricated with materials that are compatible with all fluids described below:

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- Hydrazine per MIL-P-26536E (with amendment 1), High Purity Grade
- Deionized water per JSC-SPEC-C-20
- Isopropyl alcohol per FED-STD-TT-I-735, Grade A
- Nitrogen per MIL-PRF-27401, Grade B
- Helium per MIL-PRF-27407B
- Argon per MIL-PRF-27415A Amendment 1
- Xenon, research grade

3.8.1.2 Design for Demise Materials

All thruster parts exceeding the following thresholds shall be identified: (i) individual parts with a melting point exceeding 1000 deg-C and any linear dimension exceeding 0.20 m; (ii) individual parts with a mass greater than 3.0 kg of stainless steel alloys, 1.0 kg of titanium alloys, 1.0 kg of beryllium alloys, 10.0 kg of aluminum alloys, or 1.0 kg of any material with a melting point greater than 1000 deg-C.

3.8.1.3 Test Fluid Dewpoint

All test gases shall be dried to a dewpoint of -51 deg-C. If water is used for testing or flushing purposes, the thrusters shall then be dried to -51 deg-C dewpoint.

3.8.1.4 Fungus Inert

The thrusters shall not contain materials that are nutrients for fungus per Table 4-1 of MIL-HDBK-454, unless approved by the GPM Project.

3.8.1.5 Thin Film Flammability

The propulsion subsystem shall not use thin films that are prohibited by KSC-KTI-5212.

3.8.1.6 Stress Crack Corrosion

The propulsion subsystem shall not use metals that are susceptible to corrosion in ground and flight environments per MSFC-HDBK-527F and MIL-STD-889.

3.8.1.7 Lubricants

All lubricants shall be identified. Lubricants shall be compatible with hydrazine. All lubricants shall contain no silicones. If the use of silicones cannot be avoided, a low outgassing silicone shall be selected, and approval shall be obtained from GSFC for its use. Area may need to be sealed or masked depending on quantity and location.

3.8.1.8 Welding

All welds shall be performed and inspected according to a vendor procedure approved by NASA/GSFC.

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3.8.1.9 Bi-Metallic Joints

All procedures and inspection processes for bi-metallic joints shall be approved by quality assurance and materials engineers for the GPM Project.

3.8.1.10 Outgassing

The Contractor must meet an outgassing rate with a numerical number of 1.3 x 10-10 g/cm2/s using a temperature-controlled quartz crystal microbalance (TQCM). Materials and processes must be approved by the GPM Materials Assurance Engineer (MAE) for usage or application in space-flight hardware. The TQCM shall be maintained at -20C throughout the test to measure total outgassing of volatile outgassed condensables without the influence of water vapor. The TQCM must have a representative view of the hardware, preferably a vent.

The following test data shall be collected and delivered to GSFC: Chamber configuration (i.e. chamber size, use of shrouds, TQCM location, cold finger/scavenger plate locations (if used), and general test setup), TQCM readings, hardware temperature, chamber/shroud temperature, TQCM temperature, and pressure. If the Contractor's vacuum chamber uses a shroud to elevate and sustain an item's temperature for bake-out, background TQCM measurements shall be conducted before the bake-out with chamber in bake-out configuration in order to determine flight hardware contribution. If the Contractor uses a bake-out box, the chamber shall feature a shroud held at temperatures below the TQCM reading so as not to interfere with it, otherwise the bake-out box shall feature a coldplate near the bake-out box vent to collect contaminants that would otherwise interfere with the TQCM readings. Provision shall be made to measure effectiveness of pump system. This is necessary to relate TQCM deposition rates to source outgassing rates. In addition, the chamber configuration, cold finger data, and TQCM results shall be delivered to Goddard.

3.8.2 Interchangeability

Each component shall be directly interchangeable in form, fit, and function with other components of the same part number.

3.8.3 Identification and Marking

The thrusters shall be marked in accordance with MIL-STD-130L, and shall include but not be limited to the following:
1) Vendor Part Number
2) Vendor Name
3) Vendor Serial Number
4) Contract Number

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3.9 RELIABILITY

The thruster shall have an overall reliability greater than 0.99 (allocated).

3.10 REQUIRED GSE

The following ground support equipment (GSE) shall be provided:

- Twelve (12) contamination covers
- Twelve (12) nozzle plugs (with AN interface)
- Twelve (12) alignment plugs (self-aligning)

3.11 LIFETIME

3.11.1 Storage Life

The thrusters shall be capable of being stored on the ground for 5 years in the ambient environment specified herein with no degradation in performance and no maintenance required.

3.11.2 Mission Life

The thrusters shall be designed for a 3-year mission life after a 60-day on-orbit checkout period.

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4.0 VERIFICATION REQUIREMENTS

The vendor shall provide a qualification test report to demonstrate qualifications for all requirements in this document. Any discrepancies shall be clearly documented and rationale for a delta-qualification will be given.

An acceptance test program shall be conducted by the vendor to verify that all of the requirements of this document have been met. The vendor shall provide a verification matrix defining the method of verification. Verification methods include inspection, analysis, test or a combination of these techniques.

4.1 INSPECTION

Verification by inspection includes visual inspection of the physical hardware, a physical measurement of a property of the hardware, or the documentation search demonstrating hardware of an identical design has demonstrated fulfillment of a requirement.

4.1.1 Visual Inspection

Visual inspection of the physical hardware by a customer appointed qualified inspector.

4.1.2 Physical Measurement

Physical measurement of hardware property (i.e. mass, dimensions, etc.) demonstrating the hardware meets specific requirement.

4.1.3 Documentation Search

Verification of requirements based on similarity shall include supporting rationale and documentation and shall be approved by the NASA/GSFC Contracting Officer's Technical Representative (COTR).

4.2 ANALYSIS

Verification of performance or function through detailed analysis, using all applicable tools and techniques, is acceptable with NASA/GSFC COTR approval.

4.3 TEST

Represents a detailed test of performance and/or functionality throughout a properly configured test setup where all critical data taken during the test period is captured for review.

Performance parameter measurements shall be taken to establish a baseline that can be used to assure that there are no data trends established in successive tests that indicate a degradation of

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performance trend within specification limits that could result in unacceptable performance in flight.

4.4 TEST RESTRICTIONS

4.4.1 Failure During Tests

The test shall be stopped if equipment fails during testing in cases where this failure will result in damage to the equipment. Otherwise, the test shall be completed to obtain as much information as possible. No replacement, adjustment, maintenance, or repairs are authorized during testing. This requirement does not prevent the replacement or adjustment of equipment that has exceeded its design operating life during tests, provided that after such replacement, the equipment is tested as are necessary to assure its proper operation. A complete record of any exceptions taken to this requirement shall be included in the test report.

4.4.2 Modification of Hardware

Once the formal acceptance test has started, cleaning, adjustment, or modification of test hardware shall not be permitted.

4.4.3 Re-Test Requirements

If any event, including test failure, requires that a thruster be disassembled and reassembled, then all tests performed prior to the event must be considered for repeat. If the unit has multiple copies of the same build, then all units must be examined to determine if the problem is common. If all copies require disassembly for repair, then each must receive the same test sequence.

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4.5 REQUIRED VERIFICATION METHODS

The following measurements, tests, environments, and inspections are required for each thruster to provide assurance that the thruster meets specified performance, functional, environmental, and design requirements. Each test or demonstration is described below.

a. Weight and Envelope Measurements
b. Initial Alignment
c. Proof Pressure
d. Functional Tests
e. Gas Flow Impedance Test
f. Shock Test (if necessary)
g. Loads Test (Prototype/Protoflight only)
h. Random Vibration
i. Sine Vibration
j. Thermal Cycling
k. Alignment (if necessary)
l. Pre-Hot Fire Functional Tests
m. Hot Fire Tests
n. Final Alignment
o. Final Functional Tests
p. Final Gas Flow Impedance Test
q. Cleanliness (Internal and External)

4.5.1 Weight and Envelope Measurement

Measurement of the weight and envelope of the thruster shall be made to show compliance with specified requirements and provide accurate data for the mass properties control program.

4.5.2 Alignment

The alignment of the centerline of the nozzle shall be compared to the mounting bracket surface.

4.5.3 Proof Pressure Test

The thruster shall be pressurized to the level described in Section 3.2.16 for no less than 1 minute at ambient temperature. The proof pressure test shall not cause evidence of external leakage or permanent deformation with both thruster valve seats open.

4.5.4 Functional Tests

The thruster shall be tested to demonstrate compliance with performance requirements. A functional test shall be conducted at the beginning and end of each acceptance test. Functional tests are done periodically during or following the thruster environmental testing in order to

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show that changes or degradation to the thruster have not resulted from any tests, handling, transporting, or faulty installation. Functional tests shall include leakage, valve response time (open and close), and the resistances of all the circuits at a minimum.

4.5.5 Gas Flow Impedance

A gas flow impedance test shall be performed at atmospheric pressure with an inlet pressure of 10 psig (24.7 psia). The test shall be performed using GHe. The gas flow rate shall be recorded during the test. The test shall be conducted at the beginning and end of each acceptance test.

4.5.6 Loads Verification

Structural design loads shall be applied to prototype or protoflight hardware. There is no requirement to strength test flight hardware that has already been strength tested through a prototype or protoflight program (i.e., there is no "acceptance level" strength test requirement for flight hardware).

Structural Loads testing can be verified by performing either a fixed frequency Sine Burst test, a series of static loads pull tests, or, if approved, analysis.

No permanent deformation may occur as a result of the loads test, and all applicable alignment requirements must be met following the test. Units that require alignment will have an alignment check following loads testing. A performance test will be conducted to verify that no damage occurred due to the loads test.

4.5.6.1 Sine Burst

A simple Sine Burst test following the random vibration test in each axis is a convenient method to conduct a structural loads test. This test applies a ramped sine input at a sufficiently low frequency such that the test item moves as a rigid body. An analysis is required to show that a base drive Sine Burst test will not cause over-test or under-test in some areas of the structure. Duration: 5 cycles of full level amplitude.

4.5.6.2 Static Pull

Static pull tests are another method to perform loads testing and can be applied at flight interfaces in a static test facility. The loads can be applied either as thruster loads applied simultaneously, or the single resultant vector load can be applied to the test point. Strain gages are generally positioned around the test point to verify deflection predictions from the analytical model. Test Duration: 30 seconds.

4.5.6.3 Analysis

If appropriate development tests are performed to verify accuracy of the stress model, stringent quality control procedures are invoked to ensure conformance of the structure (materials,

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fasteners, welds, processes, etc.) to the design, and the structure has well-defined load paths, then strength qualification may be accomplished on metallic parts (except beryllium) by a stress analysis that demonstrates that the hardware has positive margins on yield at loads equal to 2.0 times the limit load, and positive margins on ultimate at loads equal to 2.6 times the limit load. Such alternative approaches shall be reviewed and approved on a case-by-case basis. The vendor shall contact the NASA/GSFC COTR to seek approval.

4.5.7 Random Vibration

The thruster shall be subjected to a random vibration test along each axis to the appropriate levels and durations shown in the mechanical requirements section. The test item shall be mounted to the test fixture as it would be mounted to the SC. A functional test shall be performed before the start of testing and after a test in each axis.

The Test Duration shall be 1 minute per axis for Acceptance and Protoflight Tests and 2 minutes per axis for Prototype Tests.

Prior to the test, a survey of the test fixture/exciter combination will be performed to evaluate the fixture dynamics and the proposed choice of control accelerometers.

4.5.8 Sine Vibration

The thruster shall be subjected to a swept sine vibration test along each axis to the levels in section 3.6.3. The sweep rate shall be 4 octaves/minute for Acceptance and Protoflight Tests and 2 octaves/minute for Qualification Tests. The test item shall be mounted to the test fixture as it would be mounted to the SC.

4.5.9 Sine Sweep

A low-level Signature Sine sweep shall be conducted on each thruster before and after vibration testing in each axis. This test is a tool to verify no change in structural integrity from testing and to verify the primary resonant frequency.

4.5.10 Thermal Cycle Test

The thermal cycle test, shown in Figure 4-1, is performed to verify workmanship of heater installation, wiring, temperature sensors, and valve operation. The thermal cycle test shall be performed on the thruster valve only.

The valve shall be cycled from +7 to +45 °C. The valve will be cycled 8 times with a minimum of 4 hour soaks at each plateau. Any key parameters shall be tested at each plateau, including temperature sensors, valve tests, or any other important health parameters.

These tests shall be performed before hot fire testing.

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Thermal cycle testing shall be performed with the thruster valve mounted in a manner which thermally simulates its attachment to the spacecraft structure, including heat shield. The unit shall be sufficiently instrumented to ensure measurement of realistic unit maximum and minimum temperatures. The vendor shall submit instrumentation quantity and locations for approval by NASA before the testing is conducted.

Thruster valve and temperature sensor electrical performance will also be verified for minimum, maximum, and nominal voltages at minimum and maximum temperatures and during temperature transitions.

Thruster valve and temperature sensor functional tests or performance tests will be conducted during the hot and cold soaks. Immediately following the thermal vacuum cycling will be the bakeout phase to eliminate volatiles. See Figure 4-1.

Soak time at each temperature: 4 hours. Run Performance Test during soak.

Number of complete cycles:
Prototype Unit: 8 full cycles, start and end on hot cycle. Include min, max and nominal bus voltages. Use Qualification temperatures as the "test temperature."

Protoflight Unit: 8 full cycles, start and end on hot cycle. Include min, max and nominal bus voltages. Use Qualification temperatures as the "test temperature."

Flight / Copy / Spare Unit: 8 full cycles, start and end on hot cycle. Include min, max and nominal bus voltages. Use Acceptance temperatures as the "test temperature."

Minimum Bus Voltage: 21V
Nominal Bus Voltage: 31 V
Maximum Bus Voltage: 35V

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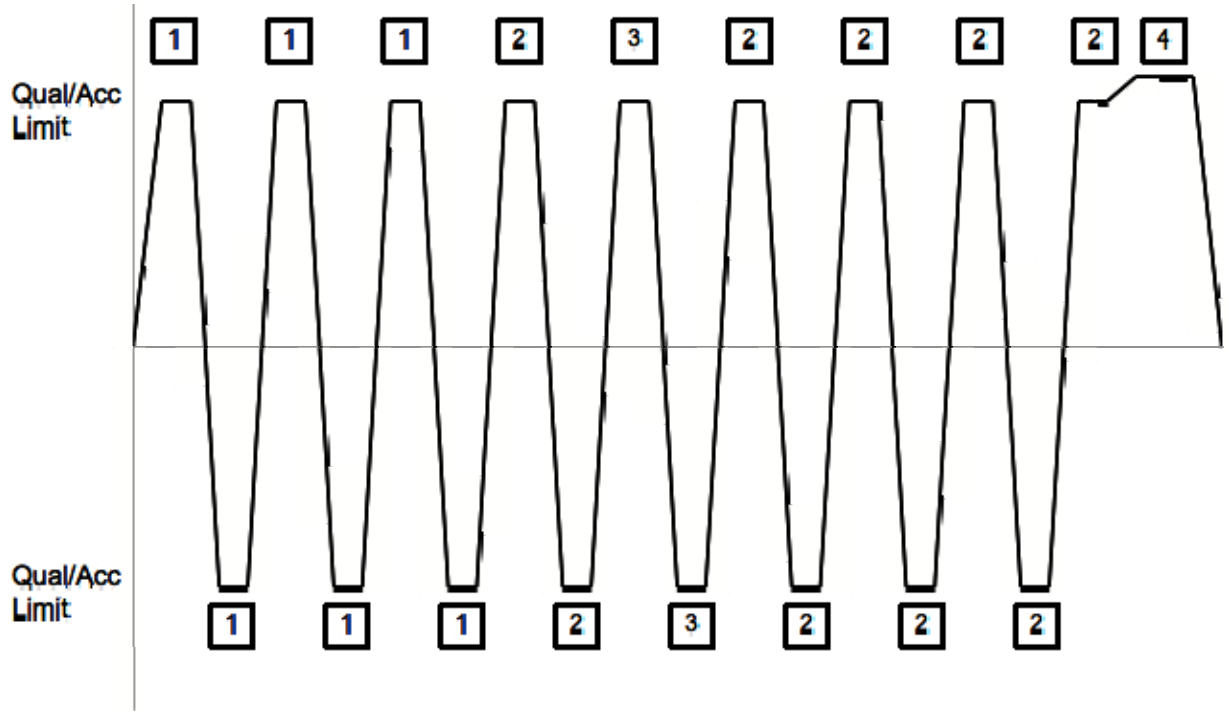

1 = Soak at test temperature 4 hours, run performance test, voltage = 21 V
2 = Soak at test temperature 4 hours, run performance test, voltage = 31 V
3 = Soak at test temperature 4 hours, run performance test, voltage = 35 V
4 = Bakeout phase

Figure 4-1 Thermal Vacuum Profile

4.5.11 Hot Fire Test

The vendor shall generate a test matrix for the hot fire testing based on the expected thruster duty cycles in Section 3.2.6 and other requirements herein. The test matrix shall be approved by NASA/GSFC prior to testing.

The hot fire testing shall be conducted with an initial ambient temperature of 20±5ºC unless otherwise specified. The thruster shall be exposed to vacuum conditions, and vacuum shall be maintained throughout the test. The following shall be recorded during the test:

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- Ambient Pressure
- Propellant temperature at multiple positions upstream of the valves (positions to be agreed upon with the NASA/GSFC COTR)
- Temperature of the mounting interface
- Chamber temperature
- Valve temperature
- Propellant flow rate
- Thrust
- Specific Impulse (steady-state and pulsed)
- Impulse Bit
- Chamber pressure
- Catalyst bed heater voltage
- Catalyst bed temperature
- Valve voltage and current
- Nozzle temperature

4.5.12 Cleanliness

The internal and external cleanliness of the thruster shall be shown to be in compliance with Sections 3.2.13.1 and 3.2.13.2 of this document.

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5.0 VERIFICATION MATRIX

5.1 VERIFICATION REQUIREMENTS

All requirements of this specification shall be met by method(s) agreed to by the vendor and NASA.

5.2 VERIFICATION MATRIX

The following abbreviations apply to the test method and test category used in the verification matrix.

1) Test Method
   a) NA-Not Applicable
   b) I-Inspection
   c) A-Analysis
   d) D-Demonstration
   e) T-Test

	Requirement	Compliant	Method					Comments
		(Y/N)	N/A	I	A	D	T	
3.1	Description							
3.2	Functional and Performance Requirements							
3.2.1	Thrust							
3.2.2	Thrust Repeatability							
3.2.3	Specific Impulse							
3.2.4	Impulse Bit							
3.2.5	Propellant Throughput							
3.2.6	Thruster Duty Cycle							
3.2.7	Catalyst Bed Heater							
3.2.8	Inlet Pressure							
3.2.9	Propellant Temperature							
3.2.10	Propellant							
3.2.11	Pressurant Gas							
3.2.12	Leakage							
3.2.12.1	External Leakage							
3.2.12.2	Internal Leakage							
3.2.13	Cleanliness							
3.2.13.1	External Cleanliness							
3.2.13.2	Internal Cleanliness							
3.2.14	Firing Duration							

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3.2.15	Roughness							
3.2.16	Proof and Burst Pressures							
3.2.16.1	Thrusters							
3.2.16.2	Propellant Inlet Tubes							
3.2.17	Cycles							
3.2.17.1	Thermal Cycles							
3.2.17.2	Valve Cycles							
3.2.18	Cold Starts							
3.2.19	External Pressures							
3.3	Physical Characteristics							
3.3.1	Mass Properties							
3.3.2	Envelope							
3.3.3	Thrust Alignment							
3.3.4	Thruster Valves							
3.3.5	Thruster Valve Heaters							
3.3.6	Thruster Catalyst Bed Heaters							
3.3.7	Thruster Thermal Sensors							
3.3.8	Mounting Flange							
3.3.9	Filter Integral to the Valve							
3.3.10	Propellant Inlet Tubes							
3.4	Electrical Requirements							
3.4.1	Power requirements							
3.4.1.1	Thruster							
3.4.1.2	Thruster Valve							
3.4.1.3	Valve Heater							
3.4.1.4	Catalyst Bed Heater							
3.4.2	Survival of Anomalous Voltage							
3.4.3	Wire							
3.4.3.1	Insulation							
3.4.3.2	Leads							
3.4.4	Electrical Bonding to Ground							
3.4.5	Charging Mitigation							
3.5	Thermal Requirements							
3.5.1	Thermal Interfaces							

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3.5.1.1	Conduction							
3.5.1.2	Radiation							
3.5.2	Flight Interface Design Temperature Limits							
3.5.3	Ground Test Environment							
3.6	Mechanical Requirements							
3.6.1	Random Vibration							
3.6.2	Static							
3.6.3	Swept Sine Vibration							
3.6.4	Shock							
3.6.5	Frequency Requirement							
3.7	Radiation Requirements							
3.8	Materials, Parts, and Processes							
3.8.1	Materials							
3.8.1.1	Material Compatibility							
3.8.1.2	Design for Demise Materials							
3.8.1.3	Test Fluid Dewpoint							
3.8.1.4	Fungus Inert							
3.8.1.5	Thin Film Flammability							
3.8.1.6	Stress Crack Corrosion							
3.8.1.7	Lubricants							
3.8.1.8	Welding							
3.8.1.9	Bi-Metallic Joints							
3.8.1.10	Outgassing							
3.8.2	Interchangeability							
3.8.3	Identification and Marking							
3.9	Reliability							
3.10	Required GSE							
3.11	Lifetime							
3.11.1	Storage Life							
3.11.2	Mission Life							

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APPENDIX A: ABBREVIATIONS AND ACRONYMS

A	Amps
BOL	Beginning of Life
C	Celsius
CCB	Configuration Control Board
CG	Center of Gravity
cm	Centimeter
CM	Configuration Management
CMO	Configuration Management Office
COTR	Contracting Officer's Technical Representative
CVCM	Collected Volatile Condensable Mass
dB	Decibels
EEE	Electrical, Electronic, and Electromechanical
EOL	End of Life
g	Gravity acceleration at the Earth's surface
GHe	Gaseous helium
GPM	Global Precipitation Measurement
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
Hz	Hertz
ICD	Interface Control Document
in	Inches
Isp	Specific Impulse
JAXA	Japanese Aerospace Exploration Agency
kg	Kilograms
m	Meter
MEOP	Maximum Expected Operating Pressure
MGSE	Mechanical Ground Support Equipment
ms	Milliseconds
N	Newton
NASA	National Aeronautics and Space Administration
OD	Outer Diameter
PRT	Platinum Resistance Temperature Sensor
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
psid	Pounds per Square Inch Differential
psig	Pounds per Square Inch Gauge
QA	Quality Assurance
rms	Root Mean Square
s	Seconds

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SC	Spacecraft
SOW	Statement of Work
scc/s	Standard Cubic Centimeters per Second
scc/h	Standard Cubic Centimeters per Hour
TBD	To Be Determined
TBR	To Be Refined
TML	Total Mass Loss
V	Volt
VDC	Volts Direct Current
W	Watts
°	Degree
Ω	Ohm

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