

GPM GSFC CMO

May 28, 2009

RELEASED

Global Precipitation Measurement (GPM) Project

Thruster Statement of Work



National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

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CM FOREWORD

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CHANGE HISTORY LOG

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Rev Level	Description of Change	Approved By	Date Approved
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1.0 Introduction

1.1 *General Information*

The National Aeronautics and Space Administration (NASA), the Earth Observatory Systems Program Office (EOS) and the Global Water and Energy Cycle (GWEC) program have the stated mission to design, develop, integrate, launch, and operate the Global Precipitation Measurement (GPM) Core Observatory.

The GPM Mission is an international partnership mission to understand global precipitation and its impacts. The GPM Core Observatory is a primary member of a multi-member constellation of satellites that provides precipitation science data for processing and distribution. Carrying both a dual frequency radar instrument and a passive microwave radiometer, the Core Observatory will serve as a calibration standard for the other members of the GPM spacecraft constellation. GPM is scheduled to launch in 2013 into a Low Earth orbit (LEO) with a mission life of three years.

This document defines the work to be performed for Contractor design, development, fabrication, and delivery of the GPM thrusters, from here on referred to as the thrusters.

1.2 *General Requirements*

The Contractor shall provide the facilities, personnel, services, tools, equipment, and materials necessary to deliver the following hardware and thermal design per the requirements specified in the GPM Thruster Specification (GPM-PROP-SPEC-0023):

- Eight (8) flight thrusters with straight nozzles
- Four (4) flight thrusters with 90-degree nozzles
- One (1) spare thruster with straight nozzle
- One (1) spare thruster with 90-degree nozzle

The contractor shall generate a matrix listing each section in this statement of work reflecting either compliance or non-compliance. Areas of non-compliance need to be addressed by the contractor showing how they plan to meet the requirement(s) or why it will remain non-compliant.

1.2.1 Option 1

The Contractor shall provide the facilities, personnel, services, tools, equipment, and materials necessary to deliver the following hardware and thermal design per the requirements specified in the GPM Thruster Specification (GPM-PROP-SPEC-0023):

- One (1) spare thruster valve

1.3 Applicable Documents

All applicable and reference documentation identified in this document shall apply in the situations where they are specifically referenced. In the event of a conflict between the SOW and the specification, the SOW shall take precedence. See Appendix C for referenced documents.

2.0 Management, Reporting, Documentation and Reviews

2.1 Management and Reporting

The contractor shall designate a single individual who will be given full responsibility and authority to manage and administer all phases of the work specified by the contract and ensure that all objectives are accomplished within schedule and cost constraints.

The contractor shall designate and identify by name a single individual who shall serve as a point of contact with the GSFC Contracting Officer Technical Representative (COTR) for all technical aspects of the thruster contract.

The contractor shall provide for managing all resources, controlling schedules, managing all engineering, manufacturing and procurement activities, configuration management, Quality Assurance, documentation control, and distribution.

The contractor shall prepare and present to the NASA/GSFC COTR monthly status via telecon and a written report. The report shall be a summary presentation of the period's progress, problem areas, and activities on-going and planned. The contractor shall generate a detailed schedule for the program that includes all significant activities that could impact the final hardware delivery schedule and program budget. This schedule shall include

- hardware and component procurement, fabrication, assembly, and test
- required analyses
- all required documentation
- other items deemed critical by the contractor or NASA GSFC

The contractor shall manage this program in accordance with the agreed upon schedule and shall immediately report to the NASA COTR any deviation from the schedule which has the potential to delay thruster deliveries or impact the program budget. The contractor shall show the program progress against this schedule in the monthly progress report.

2.2 Documentation

The contractor shall ensure the generation and delivery of all documentation as called for in the Contract.

In addition to that documentation specifically called for in the Contract, upon request by the NASA/GSFC COTR, the contractor shall make available a copy of any document or data

generated during this contract performance for review by the GSFC at either the contractor's facility or via the internet. This includes, but is not limited to, technical reports and memorandums, drawings, schematics, studies, analyses, parts and materials data, test data, alerts, etc.

The contractor shall also provide, upon request by NASA, those documents related to the thruster and its components that are relevant in assessing the safety and operational capability of the thruster for performing the GPM mission. Such documents could include, but are not limited to, qualification reports from past test program, failure analyses reports related to previous fabrication, assembly, test or on-orbit anomalies, or any other such documents which would assist NASA in assessing the mission capability and safety of the thruster.

2.3 Reviews and Meetings

2.3.1 Design Conformance Review (DCR)

The Contractor shall organize and present a Design Conformance Review to a GSFC Review Team at the Contractor's facility on a date defined in the contract. This review shall demonstrate overall conformance of the requirements specified in the GPM Thruster Specification GPM-PROP-SPEC-0023 and this Statement of Work. This review shall cover programmatic, technical, test and verification, and quality assurance topics. This review shall also provide an opportunity to review drawings and all analyses required to be approved before the start of fabrication.

The contractor shall provide an agenda to GSFC prior to the review. The contractor shall provide to GSFC a Design Conformance Review Presentation Package and all other required deliverable data two weeks prior to the review. Refer to section 3.2.3 for the list of required deliverable data.

Review minutes shall be prepared and, as a minimum, shall include attendance, action items, action item accomplishment responsibility and agreements. All items shall be in sufficient detail to be self-explanatory. A Design Conformance Review Report shall be prepared following the review and, as a minimum, contain meeting notice, agenda, review meeting minutes described above and responses to all recommendations and action items.

2.3.2 Pre-Environmental Review (PER)

The contractor shall organize and conduct a Pre-Environmental Review (PER) at the contractor's facility before the environment test program begins. This review shall demonstrate overall conformance of the requirements specified in the GPM Thruster Specification GPM-PROP-SPEC-0023 and this Statement of Work for this phase of the procurement. This review shall cover programmatic, technical, test and verification, and quality assurance topics. This review shall also provide an opportunity to review test plans and procedures and all analyses required to approve the testing of the hardware. The contractor shall provide an agenda to GSFC prior to the review.

2.3.3 Pre-Ship Review (PSR)

The Contractor shall hold a Pre-Ship Review at the contractor's plant at the completion of verification tests and prior to shipment of the hardware to GSFC. A PSR shall be held prior to the delivery of each hardware item. The contractor shall provide an agenda to GSFC prior to the review. A Data Delivery Package (reference 3.2.4) shall be presented for review at each PSR.

2.3.4 Technical Interchange Meetings (TIM)

The contractor shall plan for up to seven (7) informal, face-to-face technical interchange meetings to be held at the contractor facilities. These TIMs shall support review and coordination of technical issues including, but not limited to, parts, test plans, test procedures, software changes, design modifications, and design analyses. The TIM meeting notice shall be seven (7) calendar days in advance of each meeting.

2.4 Notification to NASA/GSFC Contracting Officer (CO) and Contracting Officer Technical Representative (COTR)

The contractor shall notify the NASA/GSFC Contracting Officer Technical Representative at least seven (7) calendar days in advance of all mandatory hardware inspections, test activities, and deliveries at either the Contractor's or a sub-Contractor's facility to allow timely participation by the NASA/GSFC Quality Assurance personnel.

3.0 Engineering

3.1 General Requirements

The contractor shall perform analyses of the technical and environmental requirements specified in the GPM Thruster Specification GPM-PROP-SPEC-0023 to ensure compliance of the hardware fabrication and to assemble the documentation necessary to ensure its usability by NASA/GSFC users.

3.2 Engineering Documentation

The system engineering analyses of the detailed design and subsequent fabrication and assembly, test, and inspection of the thrusters shall result, as a minimum, in the following technical documentation, as required in the Contract. Contractor format is suitable for this documentation.

3.2.1 Interface Control Document (ICD)

The Contractor shall provide a document or documents that defines, in detail, all performance, functional, environmental specifications, and all electrical and mechanical interfaces.

3.2.2 Drawing Package

The contractor shall provide a drawing package that includes, but is not limited to:

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ELECTRICAL: assembly and interface drawings

MECHANICAL: assembly and interface drawings. Include a STP file for electronic use.

3.2.3 Design Conformance Review Presentation Package

The contractor shall provide a Design Conformance Review Presentation Package prior to the manufacturing program. The Design Conformance Review data package shall address all program management, design, analysis, manufacturing, test, and quality assurance activities outlined in this SOW and the GPM Thruster Specification GPM-PROP-SPEC-0023 in sufficient detail to ensure that the proposed design conforms to all requirements and is ready for fabrication to begin. At a minimum, the design package should cover the following areas:

- Program Management
- Quality Assurance
- Electrical, Mechanical, and Environmental specifications
- Parts, including stress analysis
- Detailed architectural block diagrams for the different deliverable units
- Manufacturing flow with inspection points
- Facilities
- Verification test plan (Including Performance Test Description)
- Materials and Processes
- Thermal analyses
- Mechanical/Structural analyses
- Electrical Worst-Case analyses
- Failure Modes Effects Analysis
- Flight Heritage
- Verification Matrix
- Performance Analysis (preliminary)
- Thruster Operational Constraints Document (preliminary)
- Preliminary hot fire test matrix (final matrix due at PER)

3.2.4 Data Delivery Package

The Data Delivery Package shall be made available for review during pre-ship reviews for each of the different hardware deliverables. This package shall also be delivered with each end item with the level of detail required of that item. The package should be comprised of, but not limited to, the following data:

- As-Built vs. As Designed Parts List, (includes serialization/revisions)
- Final Drawing Package (including rework instructions, if any)
- Critical Parameters Trend Data,
- Problem/anomaly reporting (complete copies of report)
- Deviations/Waivers/open items/nonconformances and their dispositions,
- Class I MRBs (complete copies of reports)
- List of Materials and Processes used,
- Log of total operating time,
- List and status of all identified Life-Limited Items,
- Verification matrix, test data and reports (including qualification test report)
- Flight connector mate/demate log (Flight Unit only)
- Photograph Documentation (Pre-Closure and Closed)
- Certificate of Conformance
- Results of the Final Comprehensive Performance (Acceptance) Test.
- List of Open Items with reason for item(s) being open and proposed closure date
- Contamination Control Plan
- Fracture Control Plan
- Performance Analysis (final)
- Thruster Operational Constraints Document (final)

3.2.5 Verification Test Plan

A Verification Test Plan shall be generated by the contractor to perform verification tests identified in the GPM Thruster Specification GPM-PROP-SPEC-0023. Verification tests must demonstrate acceptable performance over the specified range of performance requirements, measure performance parameters and reveal inadequacies in manufacturing and assembly such as workmanship or material problems.

The plan should state the purpose of each test, state acceptance criteria, describe in detail the test method and instrumentation, and give the sequence of the tests. The plan should include a test matrix summarizing all tests that will be performed on the thrusters.

This plan shall be a contractor controlled document and shall indicate all changes made after the initial approval by the GSFC. After verification test plan approval, no changes shall be made without written NASA GSFC COTR approval.

3.2.6 Verification Test Procedures

The contractor shall generate Verification Test Procedures. The verification procedures shall be step-by-step instructions for performing tests outlined by the Verification Test Plan. The procedures should define the environmental conditions for the tests, required equipment and facilities, test constraints, use of diagnostic or performance test software, operating conditions, tolerance on all input stimuli, data to be recorded and pass/fail limits. Test procedures shall also include Safe-to-Mate procedures to verify that GSE can safely be mated to interfaces and that interfaces are safe to accept mating with the GSE.

Verification test procedures shall be contractor controlled documents and shall indicate all changes made after the initial release for review to NASA.

3.2.7 Contamination Control Plan

The Contractor shall furnish their Contamination Control Plan to GSFC for review.

3.2.8 Fracture Control Plan

The Contractor shall furnish their Fracture Control Plan to GSFC for review.

3.2.9 Qualification Test Report

The contractor shall provide the qualification test report to show that the design is qualified for flight.

3.2.10 Thruster Operational Constraints Document

The contractor shall supply a document that provides GSFC with at least the following information to prevent unintentional damage to the flight hardware: maximum water and gas flow rates for testing, maximum and minimum storage temperature and humidity, compatible fluids, allowable pressurization and depressurization rates, valve pull-in and drop-out voltage, maximum hot fire temperature, and maximum exposure temperatures and pressures. This report shall also document any operational modes or keep-out operational zones for the thruster that should be prohibited to preclude damage to the thruster or operations that could lead to unsafe or anomalous operation.

3.3 Thermal Analysis

The vendor thermal analysis must show that the thruster components are within operating and non-operating temperature limits. Heaters shall be sized and soak back temperatures calculated. The report should consider failure mode operation for the valve and catalyst bed heaters and identify any operational or environmental conditions that could result in unsafe or anomalous thruster operation.

The results of these analyses shall be summarized in a Contractor-format for the Thermal Analyses Report, which shall be provided for review as per the contract schedule.

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. The vendor may propose an alternative format with approval by the NASA GSFC COTR. At a minimum, both Geometric Radiative and Thermal Network models must be provided.

3.4 Structural Analysis

A Structural Analysis shall be performed on the Flight Unit structure to ensure the capability to withstand and survive launch and ascent loads. The effects of any thermal inputs shall be reflected in the analyses as appropriate. The results of these analyses shall be summarized in a Contractor format Mechanical Analyses Report that will be provided to the NASA GSFC COTR for review.

4.0 Hardware Manufacture

4.1 Thrusters

The Contractor shall manufacture and test hardware to meet the requirements of the GPM Thruster Specification GPM-PROP-SPEC-0023.

4.2 Ground Support Equipment (GSE)

The vendor shall provide the following:

- Protective covers to prevent incidental damage to the thrust chamber and nozzle during I&T
- A cover to keep contamination out of the nozzle
- An alignment fixture for measuring the alignment of the thruster's nozzle on the spacecraft. The fixture shall make use of mirrors for optical measurement of the nozzle orientation to within $\pm 0.1^\circ$. The design shall be approved by NASA
- A test plug (with 0.25" male AN fitting) for valve testing purposes that seals against the nozzle such that valve leakage and flow testing may be performed.

5.0 Quality Assurance

5.1 General Requirements

5.1.1 Quality Assurance Plan/Manual

The contractor shall implement a Quality Management System that meets the intent of the requirements of American National Standards Institute (ANSI)/ISO/ American Society for Quality (ASQ) Q9001 (1994 or 2000 version) or equivalent. GSFC shall be notified of any changes to the QA program.

5.1.2 Surveillance of the Contractor

The work activities and operations of the contractor, subcontractors, and suppliers are subject to evaluation, review, survey, and inspection by GSFC representative.

The contractor shall provide the GSFC representative with documents, records, equipment, and workings areas within their facilities that are required by the representative to perform their overview activities.

5.1.2.1 Government Source Inspection

The Government may elect to perform inspections at a supplier's plant. The following statement shall be included on all procurement documents: "All work on this order is subject to inspection and test by the Government at any time and place".

The Government quality representative who has been delegated NASA quality assurance functions on this procurement shall be notified immediately upon contractor receipt of any supplier / subcontractor orders. The Government representative shall also be notified 48 hours in advance of the time that articles or materials are ready for inspection or test.

5.1.2.2 Contractor Source Inspection

The contractor shall ensure that its procurement documents impose the applicable requirements on subcontractors and other suppliers. The subcontractor and other suppliers shall in turn impose the requirements on their procurement sources.

The contractor shall perform source inspection at the subcontractor's or supplier's facilities in accordance with the procurement documentation or when one or more of the following conditions exist:

In process, end item controls, or tests that are destructive in nature prevent the developer from verifying quality after delivery to the developer's facility.

It is not feasible or economical for the contractor to determine the quality of procured articles solely by inspections or tests performed at the contractor's facility.

Qualification tests are to be performed by the subcontractor or supplier.

Products are shipped directly from the source to NASA, by-passing the contractor's inspection facilities.

5.1.2.3 Government Mandatory Inspection Points (MIPs)

The government or its representative will perform the following MIPs listed below. The government may request additional MIPs if a specific process prohibits inspection at a later time.

- Inspect 100% solder
- Inspect 100% crimps
- Inspect 100% conformal coating, staking, and potting
- Rework Inspection
- Pre-closure Inspection
- Pre-Ship Inspection / Data Review

NASA reserves the right, after review of the vendor's inspection points, to add mandatory inspection points to the manufacture of the thrusters.

5.1.3 Configuration Management

The contractor's Configuration Management (CM) system (available for review on request) shall control the design and hardware by means of drawings, specifications, and other documents and shall ensure all applicable changes are reviewed in a systematic manner to determine the validity and impact on performance, schedule and cost. The contractor's Configuration Management system shall have a change classification and impact assessment process that ensures Class I changes are forwarded to the CO for approval prior to release/incorporation. Class I changes are defined as changes that affect form, fit, function, external interfaces, or requirements as stated within this document and GPM Thruster Specification GPM-PROP-SPEC-0023.

All other changes are considered to be Class II changes and shall be controlled and dispositioned by the contractor. All Class II changes shall be provided monthly to the COTR for review purposes. NASA/GSFC reserves the right to review all Class II changes for technical content to ensure the proper classification has been assigned. Any flight item that is found to be non-compliant with the quality, workmanship, and performance requirements of the contract shall be dispositioned via a waiver or MRB, unless the affected item is reworked to restore compliance or is replaced with a fully compliant item. The contractor shall submit Waivers and MRB's to the COTR for final approval.

A Contractor QA representative shall be a member of the Configuration Control Board. The QA activities shall be defined in the Configuration Management Plan and described in detail in the QA Plan. Related portions of the plans shall be cross-referenced.

5.1.4 Anomaly Reporting

Reporting of hardware anomalies to the NASA/GSFC COTR shall begin no later than the first firing of the thrusters at the start of acceptance testing. The NASA GSFC COTR shall be notified within 24 hours of each anomaly.

The Contractor's processes for review, disposition and approval of anomaly reports shall be described in their quality plan/manual or provided as a supplement document. In addition, the contractor's anomaly reporting document shall describe the members of the Material Review Board (MRB) and Failure Review Board (FRB). The MRB and FRB shall include GPM GSFC participation. These processes shall ensure that positive corrective action has been taken to preclude recurrence and that appropriate audits and tests are performed to verify the implementation of the corrective action.

The contractor shall routinely inform the GPM Project of MRB and FRB meeting schedules and agendas with sufficient notice to permit GPM Project participation if desired by GPM.

At the contractor's facility, NASA/Government representatives may participate in MRB/FRB activities as deemed appropriate by Government management or contract.

The NASA GSFC COTR reserves disapproval rights on MRB and FRB decisions. To assure process consistency, the contractor shall provide the GPM Project on-line access to their GPM anomaly-reporting database.

The Contractor shall provide, as part of the monthly report, a list of all open anomaly reports and a separate list of the anomaly reports closed during the month. For each reported anomaly or nonconformance, there shall be a report that documents the investigation and engineering analysis needed to determine the cause and corrective actions to disposition the nonconformance, and identify any closed problem reports that do not have a definitive cause or corrective action. Reports shall be submitted to the NASA GSFC COTR for review and approval of the disposition.

The supplier shall establish and maintain documented procedures to ensure product that does not conform to specific requirements is prevented from unintended use or installation. This control shall provide for identification, documentation, evaluation, segregation (when practical), disposition of nonconforming product, and for notification to the functions concerned.

5.2 System Safety Requirements

The contractor shall supply detailed descriptions of the design, test, operation and inspection requirements for all flight hardware and materials, ground support equipment, and their interfaces necessary for a valid identification, assessment, control and mitigation of documented hazards. This includes technical information concerning hazardous and safety

critical equipment, systems, operations, handling and materials. For all identified hazards, the contractor shall also document hazard controls, verifications and tracking methods.

The contractor shall provide technical support to the GPM Project for safety working group and technical meetings as necessary in conjunction with TIMs.

5.2.1 Safety Variance

The contractor shall submit safety waivers or deviations to the GPM Project and other appropriate authorities for review and disposition. A Safety Variance documents a safety requirement that cannot be met and the rationale for approval of a waiver, exception, or deviation as defined in NPR 8715.3. Note: a variance may require Range Safety concurrence.

5.2.2 Mishap Reporting and Investigation

The contractor shall report mishaps, incidents, and close calls per NPR 8621.1, "NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping." Mishaps, incidents, and close calls shall be reported to the Project CSO in accordance with, and to facilitate compliance with the Section 1.5 Notification and Reporting Requirements of NPR 8621.1.

5.2.3 Safety Package

The contractor shall submit a Safety Package that includes, at a minimum, the following items.

5.2.1.1 Safety Assessment Report

The contractor shall submit a Safety Assessment Report (SAR) to be used to document a comprehensive evaluation of the mishap risk being assumed prior to the testing or operation of the thruster, including associated Ground Support Equipment (GSE). The SAR will be provided to GPM Project Safety as an input to their preparation of the Safety Data Package (SDP), which is one of the media through which missile system prelaunch safety approval is obtained.

All hardware shall comply with the applicable requirements of JMR 002, Launch (Vehicle Payload Safety), AFSPCMAN 91-710 (Range Safety User Requirements), NPR 8715.3 (NASA General Safety Program Requirements), and JERG-0-001 (Technical Standard for High-Pressure Gas Equipment for Space Use). Additionally, the contractor shall meet applicable safety requirements of NASA-STD-8719.9 Standard for Lifting Devices and Equipment.

5.2.1.2 Verification Tracking Log

The contractor shall document, implement, and maintain a Verification Tracking Log (VTL). The VTL provides documentation of a Hazard Control and Verification Tracking process as a closed-loop system to ensure that safety compliance has been satisfied in accordance with

applicable launch range safety requirements. The Verification Tracking Log (VTL) shall track the status of hazard controls and verify each as either closed or open.

5.2.1.3 Orbital Debris Assessment Safety Data

The contractor shall support or provide safety data for development of the Project's Orbital Debris Assessment (ODA). The ODA ensures NASA requirements for post mission orbital debris control are met in accordance with NPD 8715.6 NASA Procedural Requirements for Limiting Orbital Debris Generation and NSS 1740.14 Guidelines and Assessment Procedures for Limiting Orbital Debris.

The contractor shall provide thruster design data (e.g. dimensioned drawings of the entire structure, materials, mass & dimensions for components) to support the Project's Orbital Debris Assessment (ODA). In addition, the developer shall indicate the location of stored energy sources (if any) and assist the project in determining an approach for passivation.

5.2.1.4 Range Safety Forms

The contractor shall prepare a Material Selection List for Plastic Films, Foams, and Adhesive Tapes. The data will be submitted to Launch Range Safety for an assessment of flammability.

5.3 Reliability Requirements

The contractor shall prepare and conduct the following set of reliability analyses.

5.3.1 Failure Modes and Effects Analysis

The Contractor shall perform a Failure Modes and Effects Analysis (FMEA) in accordance with MIL-STD-1629, "Procedures for Performing an FMEA". The FMEA shall identify failures at the functional level and address attendant consequences. This analysis shall be provided to the NASA COTR for review.

5.3.2 EEE Parts Stress Analyses

The contractor shall supply information on all Electrical, Electronic, and Electromechanical (EEE) parts and devices as employed in the Flight Item to the NASA COTR. NASA will perform the analysis to verify conformance with the de-rating requirements of EEE parts per EEE-INST-002.

5.3.3 Worst Case Analyses

The contractor shall perform worst-case parameter analyses on performance critical or functional critical components for which excessive operating variations could compromise mission performance. The contractor shall identify the worst case analyses planned to assure the design meets critical performance and life requirements. Adequate margins in electronic circuits, optics, electromechanical devices, or other mechanical items (mechanisms) can be verified by analysis, testing or both. When verification by analysis is used, the analyses shall consider all parameters at worst-case limits and worst-case environmental conditions for the parameter or operation being evaluated. Similarly, when verification by testing is used, the

testing shall be conducted to provide as direct a measure as possible of the critical performance or function while the element is subjected to worst-case parameter variations. Elements that may warrant worst case analysis may include: control loops that require adequate phase and gain margin to operate properly, sensitive analog circuitry, power supply or switching circuitry, motor and actuator systems, electro-mechanical elements that require torque margin to operate over life and environmental variations.

5.3.4 Limited-Life Items

The contractor shall identify and manage limited-life items. Limited-life items include all hardware that is subject to degradation because of limited shelf life or expected operating times or cycles such that their expected useful life is less than twice the required life when fabrication, test, storage, and mission operation are combined.

The GPM Project COTR shall approve the use of an item whose expected life is less than twice the mission design life.

5.4 Ground Support Equipment (GSE)

Mechanical and electrical Ground Support Equipment (GSE) that directly interfaces with flight deliverable items shall be assembled and maintained to mitigate potential risk to flight hardware. Parts and materials selection and reporting requirements are exempted as long as deliverable flight item contamination requirements are not compromised. However, all GSE interfaces to flight hardware shall be flight quality (i.e. connectors, baseplates, etc.).

5.5 Design Verification Requirements

5.5.1 Verification Requirements

The Contractor shall implement a program to verify all requirements specified in the GPM Thruster Specification GPM-PROP-SPEC-0023.

The Contractor shall provide a verification matrix defining the method of verification for each specific requirement of this contract. Verification methods shall include:

Inspection: Designated as (I) and represents inspection of the physical hardware by a customer appointed qualified inspector for compliance.

Analysis: Designated as (A) and represents documentation of performance or function through detailed analysis using all applicable tools and techniques.

Test: Designated as (T) and 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.

In-process production evaluation tests, and environmental stress screening tests shall also be considered to be verification tests.

5.5.2 Analysis / Trending / Reporting Of Test Data

The Contractor shall properly record, maintain and analyze test information during the normal test program to assess performance and flight worthiness and to aid in the identification and analysis of flight hardware failures and problems.

The Contractor shall also perform trend analyses to track measurable parameters that relate to performance stability and repeatability. Selected parameters shall be monitored for trends starting at component acceptance testing and continuing through the system integration and test phases. These parameters will be compiled in a Trended Parameters List (TPL).

The reports will be delivered as part of the Data Delivery Package and presented at formal technical reviews as appropriate.

5.6 Workmanship Standards and Processes

5.6.1 Workmanship: Use of Alternate Workmanship Standards

GSFC recognizes that the contractor may have an established workmanship program equivalent to the specific standards cited herein. In these instances, the contractor may use existing standards upon review and approval by the GPM Project COTR. It must be established that the developer's workmanship program fully encompasses the specific requirements of this chapter. It is the contractor's responsibility to list all deviations from the baseline workmanship standards and to provide data supporting their position/rationale.

5.6.2 Training and Certification of Contractor Personnel

All personnel performing work on flight hardware requiring a prerequisite set of skills and competency shall be certified as having completed the required training, appropriate to their involvement.

5.6.3 Hardware Handling, Cleaning And Packaging

The handling of flight hardware shall be performed by qualified personnel in accordance with approved procedures that address cleaning, handling, packaging, tent enclosures, shipping containers, bagging, and purging. Compatible packaging shall be selected so that hardware is not contaminated or otherwise degraded during shipping or storage. All personnel working on flight hardware shall be certified as having completed the required training and competency certifications prior to handling any flight hardware. This includes, but is not limited to, workmanship, clean room and ESD awareness courses.

5.6.4 Electrostatic Discharge Control Requirements

The Contractor shall document and implement an ESD Control Program suitable to protect the most ESD-sensitive instrument components at all levels of assembly and integration in accordance with the requirements of ANSI/ESD S20.20.

All personnel who manufacture, inspect, test or otherwise process electronic hardware or who require unescorted access into ESD protected areas shall be certified as having completed the required training, appropriate to their involvement prior to handling any electronic hardware.

5.6.5 Workmanship Requirements

The following workmanship standards shall apply to soldered assemblies, harnessing and materials selection.

5.6.5.1 Workmanship Requirements

The following workmanship requirements shall apply:

- Hand Soldering Assemblies: NASA-STD-8739.3, Soldered Electrical Connection
- Crimping, Wiring, and Harnessing: NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring;
- Titanium and Titanium Alloy Bar and Forging Stock: MIL-T-9047G
- Test Requirements for Space Vehicles: MIL-STD-1540B
- Metallic Materials and Elements for Aerospace Vehicle Structures: MIL-HDBK-5J

5.7 *EEE Parts Requirements*

5.7.1 General

Flight Unit parts shall be selected and processed in accordance with the requirements of EEE-INST-002, "INSTRUCTIONS FOR EEE PARTS SELECTION, SCREENING, QUALIFICATION, AND DERATING". All application notes in EEE-INST-002 will apply.

The minimum acceptable EEE part grade available for Flight Unit use on GPM is Class 2 with 100% Particle Impact Noise Detection (PIND) screening for cavity bodied devices and a sample Destructive Physical Analysis (DPA). This assumes that the radiation hardness requirements and system reliability goals are also being met. This would include parts costs, test costs, risk of test failures and reliability differences between both classes. The contractor shall maintain a EEE Parts Identification List and shall review proposed parts with the GPM COTR.

5.7.2 Custom Devices

In addition to the applicable requirements of EEE-INST-002, custom microcircuits, hybrid microcircuits, MCM, ASIC and other non-standard application unique devices planned for Flight Unit shall be subjected to a parts-level design review (with GSFC participation). The

design review shall address, at a minimum, de-rating of elements, method used to certify acceptable reliability, assembly and materials processes, methods for assuring adequate thermal matching of materials, and screening and qualification requirements.

5.7.3 Plastic Encapsulated Microcircuits (PEMs)

The use of Plastic Encapsulated Microcircuits is discouraged in the Flight Unit. However, when use is necessary to achieve unique requirements that cannot be found in hermetic high reliability microcircuits, plastic encapsulated parts, must meet the requirements of NASA GSFC EEE-INST-002. All PEM(s) require NASA/GSFC COTR review and concurrence. PEM usage shall be presented at the Design Conformance Review and TIMs, as applicable.

5.7.4 Radiation Hardness

All Flight Unit parts shall be selected to meet their intended application in the on-orbit GPM radiation environment as defined in the GPM Thruster Specification GPM-PROP-SPEC-0023. The radiation environment consists of two separate effects: total ionizing dose (TID) and single-event effects (SEE). If there are any radiation sensitive components or parts, then the Contractor shall document the radiation hardness assessment for each part with respect to both effects and include this assessment as part of the Design Conformance Review Presentation Package. Test plans and reports for parts that require radiation testing shall be submitted to the NASA/GSFC COTR for review.

5.7.5 Parts Age Control

Parts more than 5 years old require GPM COTR concurrence. Contractors shall present justification with inspection and test requirements.

5.7.6 GIDEP Alerts and Problem Advisories

Contractors shall keep sufficient selection and usage records for all flight parts and materials adequate to determine applicability of any issued Government Industry Data Exchange Program (GIDEP) alerts relevant to items used on GPM. The contractor shall review and disposition all GIDEP Alerts for relevancy and impact. In addition, the contractor shall review and disposition any NASA Alerts and Advisories provided to the developer by the GPM Project. Alert applicability, impact, and corrective actions shall be documented and status provided to the GPM Project on a monthly basis.

5.7.7 Reuse of Parts and Materials

EEE parts and materials, which have been installed in an assembly, and removed for any reason, shall not be used again for flight.

5.7.8 Part Notification of Failure

The contractor shall provide failure-reporting data to NASA/GSFC COTR within 72 hours of part failure determination.

5.8 *Materials, Processes and Lubrication Requirements*

5.8.1 Materials Selection Requirements

To qualify material for flight use, the material must meet the following applicable selection criteria, e.g.:

1. Outgassing
2. Corrosion Mitigation
3. Fastener integrity for structural applications
4. Environmental survivability
5. Process selection
6. Procurement
7. Welding
8. Fungus inert material
9. Corrosive metals
10. Interchangeability

Materials and processes shall comply with the requirements of the GPM MAR. Noncompliant materials require a Materials Usage Agreement (MUA) (see attachment). All materials and processes shall be defined by standards and specifications (including revision notation), be identified in the lists of materials and processes, and be submitted for GSFC review and approval. A sample format for the lists is attached, and contains fields for the required information. In addition to interim versions required prior to reviews, an As-Built Materials List (ABML) shall be included as part of the end item data package (EIDP). All related lists shall be provided in an electronically searchable format.

Pure Tin, Zinc, and Cadmium are not acceptable for flight use.

"Off-the-shelf hardware" for which a detailed materials list is not available and where the included materials cannot be easily identified and/or changed shall be treated as noncompliant.

5.8.2 Vacuum Outgassing of Polymeric Materials

All polymeric materials shall meet the general outgassing requirements of 1% maximum Total Mass Loss (TML) and 0.1% maximum Collected Volatile Condensable Materials (CVCM) when tested per ASTM E595. A material that exceeds these maximum limits shall be considered noncompliant. At the discretion of the GPM MAE, the user may be required to bring it into compliance via a bakeout, replace it with a different material, show that the material meets the SP-R-0022 requirements, or submit a MUA for its application. In the latter case, the MUA shall be reviewed against the GPM requirements by the MAE and disposed of by the GPM CSO. If outgassing tests are required due to a lack of existing relevant and current data, and data is not otherwise obtainable, the developer shall provide samples for testing.

5.8.3 Corrosion Mitigation

Materials used in structural applications shall be highly resistant to stress corrosion cracking according to MSFC-STD-3029 or MAPTIS-II. MUAs with the SCC evaluation form shall be required for those with moderate or low resistance to SCC, or those not listed in either reference. This requirement is not applicable to materials used in non-structural applications, such as EEE parts or modules.

To avoid electrolytic corrosion, the contractor shall not use dissimilar metals in direct contact unless protection against corrosion has been provided in accordance with MIL-STD-889. Variances from this policy must be submitted to the government for approval. In addition, metals shall be chosen to be resistant to corrosion, i.e. rated A or B as in Materials and Processes Technical Information System (MAPTIS-II), and be protected from corrosion using an acceptable process (MSFC-SPEC-250A).

5.8.4 Fasteners

The Contractor shall comply with the procurement and test requirements for flight hardware and critical GSE fasteners contained in the Goddard Space Flight Center Fastener Integrity Requirements Procedure and Guidelines (541-PG-8072.1.2A). Specialized fasteners shall be evaluated by GPM Procurement and M&P engineers to establish material, design, processing, and screening requirements appropriate to the GPM mission. These fasteners include custom manufactured fasteners, pyrotechnics, eyebolts, clevises, hooks, wire rope, turnbuckles, and those not specified in 541-PG-8072.1.2A.

5.8.5 Environmental survivability

Materials shall be selected to perform in the environments to which they will be exposed for their intended life-cycle exposure.

5.8.6 Process Selection

Materials and manufacturing process information shall be provided on the material list. Process specifications shall define process steps at a level of detail that ensures a repeatable/controlled process that produces a consistent and reliable product.

5.8.7 Procurement

Raw materials purchased by the Contractor and its developers shall be accompanied by a Certificate of Compliance and, where applicable, the results of nondestructive, chemical and physical tests. When requested, this information shall be made available to the NASA/GSFC COTR for review.

5.8.8 Welding

Welding shall be performed and inspected per vendor/NASA-approved procedure according to MIL-STD-2219A with Change 1. Control of weld filler material shall also be per vendor and NASA approval.

5.8.9 Fungus Inert Material

All materials used in the thrusters shall be fungus inert in accordance with MIL-STD-810F.

5.8.10 Corrosive Metals

All materials used in the thrusters shall be corrosion resistant or be treated to resist corrosive effects that may be introduced. Compatibility of corrosive media and adjoining materials shall be documented.

5.8.11 Interchangeability

Each thruster assembly shall be directly interchangeable physically and functionally with other items of the same part number.

6.0 Contamination Control Requirements

The contractor shall establish the specific cleanliness requirements to minimize performance degradation and delineate the approaches to meet the GPM Project requirements.

7.0 Handling, Storage, Packaging, Preservation, and Delivery

Products shall be stored, preserved, marked, labeled, packaged, and packed to prevent loss of marking, deterioration, contamination, excessive condensation and moisture, or damage during all phases of the program. Stored and stocked items shall be controlled in accordance with documented procedures and be subject to quality surveillance.

Contractor is responsible for providing an acceptable shipping container that protects the hardware appropriately.

While in a shipping container, the thrusters shall be wrapped in a non-ESD-generating vapor barrier with redundant maximum humidity indicators.

The shipping container shall also include shock and humidity indicators and shall be capable of prolonged shipping conditions. The Contractor shall document what action NASA GSFC is to take if the sensors are tripped when hardware arrives at the NASA GSFC receiving area. A copy of this document shall be included with shipping documentation.

By executing the act of product shipment, the supplier certifies that the product complies with all contract requirements. Prior to shipping, quality assurance personnel shall ensure that:

- Fabrication, inspection, and test operations have been completed and accepted.
- All products are identified and marked in accordance with requirements.
- The accompanying documentation (developer's shipping and property accountable form) has been reviewed for completeness, identification, and quality approvals.
- Evidence exists that preservation and packaging are in compliance with requirements.

- Packaging and marking of products, as a minimum comply with Interstate Commerce Commission rules and regulations and are adequate to ensure safe arrival and ready identification at their destinations.
- The loading and transporting methods are in compliance with those designated in the shipping documents.
- Integrity seals are on shipping containers and externally observable shock and humidity monitors do not show excessive environmental exposure.
- In the event of unscheduled removal of a product from its container, the extent of re-inspection and retest shall be as authorized by NASA or its representative.
- Special handling instructions for receiving activities, including observation and recording requirements for shipping-environment monitors are provided where appropriate.

The contractor's quality assurance organization shall verify prior to shipment that the above requirements have been met and shall sign off appropriate shipping documents to provide evidence of this verification. The contractor shall ship Freight On Board (F.O.B.) Destination. The contractor has the responsibility for any damaged incurred during shipment.

APPENDIX A: Abbreviations and Acronyms

ABBREVIATION/ ACRONYM	DEFINITION
ANSI	American National Standards Institute
ABML	As-Built Materials List
BBU	Breadboard Unit
BSP	Board Support Package
C&DH	Command and Data Handling
CDR	Critical Design Review
CM	Configuration Management
CO	Contracting Officer
COTR	Contracting Officer Technical Representative
CVCM	Collected Volatile Condensable Mass
DCR	Design Conformance Review
DPA	Destructive Physical Analysis
EIDP	End Item Data Package
ESD	Electrostatic Discharge
FMEA	Failure Modes and Effects Analysis
FRB	Failure Review Board
GEO	Geosynchronous Orbit
GPM	Global Precipitation Measurement
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
ICD	Interface Control Document
MAE	Materials Assurance Engineer
MAR	Mission Assurance Requirements
MIP	Mandatory Inspection Point
MRB	Material Review Board
MUA	Materials Usage Agreement
ODA	Orbital Debris Assessment
PEMs	Plastic Encapsulated Microcircuits
PER	Pre-Environmental Review
PIL	Parts Identification List
PIND	Particle Impact Noise Detection
PSR	Pre-Ship Review
PWB	Printed Wiring Board
QA	Quality Assurance
QCM	Quartz Crystal Microbalance
ROM	Read-Only Memory

ABBREVIATION/ ACRONYM	DEFINITION
SAR	Safety Assessment Report
SCC	Stress Corrosion Cracking
SCM	Software Configuration Management
S/C	Spacecraft
SDP	Safety Data Package
SEE	Single-Event Effects
SOW	Statement of Work
SUROM	Startup Read-Only Memory
TML	Total Mass Loss
TID	Total Ionizing Dose
TIM	Technical Interchange Meeting
TPL	Trended Parameters List
WVR	Waiver
VTL	Verification Tracking Log

APPENDIX B: GPM Material Usage Agreement Form

MATERIAL USAGE AGREEMENT (MUA)			USAGE AGREEMENT NO.:			PAGE OF			
PROJECT:		:	ORIGINATOR:				ORGANIZATION:		
DETAIL DRAWING		NOMENCLATURE		USING ASSEMBLY			NOMENCLATURE		
MATERIAL & SPECIFICATION					MANUFACTURER & TRADE NAME				
USAGE	THICKNESSES	WEIGHT	EXPOSED AREA	ENVIRONMENT					
				PRESSURE	TEMPERATURE	MEDIA			
APPLICATION:									
RATIONALE:									
ORIGINATOR:				PROJECT MANAGER:				DATE:	

APPENDIX C: List of Referenced Documents

Applicable Documents

All referenced documentation identified in the SOW shall apply in the situations where they are specifically referenced.

DOCUMENT NUMBER	TITLE	Revision/Date
GPM-PROP-SPEC-0023	GPM Thruster Specification	
541-PG-8072.1.2	GSFC Fastener Integrity Requirements	03/05/01
ANSI/ASQ9001-2000	Model for Quality Assurance Design, Development, Production, Installation, and Servicing	Aug 1991
NASA-STD-8739.3	Requirements for Soldered Electrical Connections	12/15/97
NASA-STD-8739.4	Requirements for Crimping Inter-connecting Cables, Harnesses, and Wiring	02/09/98
NASA-STD-8739.2	Workmanship Standard for Surface Mount Technology	08/31/99
S-311-M-70	Destructive Physical Analysis. Equivalent	1/7/91
NASA-STD-6001	Flammability, odor, off-gassing and compatibility requirements & test procedures for materials in environments that support combustion	2/9/98
MIL-STD-1629A	Procedures for Performing an FMEA	11/24/80
MSFC-STD-3029	Multiprogram/project common-use document guidelines for the selection of metallic materials for stress corrosion cracking resistance in sodium chloride environments	5/22/00

ASTM E-595	Standard test method for total mass loss and collected volatile condensable materials from outgassing in a vacuum environment	10/1/03
MIL-T-9047G	Titanium and Titanium Alloy Bar and Forging Stock	12/15/1978
MIL-STD-1540B	Test Requirements for Space Vehicles	10/10/1982
MIL-HDBK-5J	Metallic Materials and Elements for Aerospace Vehicle Structures	1/31/2003
MIL-STD-889B	Dissimilar Metals	
MSFC-SPEC-250A	General Specification for Protective Finishes for Space Vehicle Structures and Associated Flight Equipment	
NASA-STD-6016	Standard Materials and Process Requirements for Spacecraft	
GPM-SMA-REQ-0028	GPM Core Spacecraft Mission Assurance Requirements	
MIL-STD-2219A	Fusion Welding for Aerospace Applications	06/16/2008