# Ion Propulsion System (IPS)

# Information Summary for New Frontiers Missions

**January 2017**

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# 1.0 INTRODUCTION

This document serves as a guide to New Frontiers mission proposal teams. It describes the NEXT-C Project and the $10M incentive for two NEXT-C thrusters and two NEXT-C Power Processing Units (PPUs) in the New Frontiers 4 draft Announcement of Opportunity (AO). This document also provides background information on other subsystem components for information purposes. Proposers would have the ability to utilize any of these components if desired, but they would not be provided as government furnished equipment (GFE).

## 1.1 BACKGROUND

The NEXT ion propulsion system was developed under the NASA Science Mission Directorate In-Space Propulsion Technology (ISPT) project. The primary objective of the NEXT technology project was to significantly increase performance for primary propulsion to planetary bodies by leveraging NASA’s very successful ion propulsion program for low-thrust applications. The government/industry team completed the highest fidelity hardware planned, including a flight prototype model (PM) thruster, an engineering model (EM) power processing unit, EM propellant management assemblies, a breadboard gimbal, and control unit simulators. To transition this technology to flight applications, the Planetary Science Division of the NASA Science Mission Directorate initiated the project to build NEXT-C thruster and PPU flight hardware and provide as GFE to a future NASA mission and commercialize the hardware such that it is available for other users, such as New Frontiers.

NEXT is an advanced ion propulsion system oriented towards robotic exploration of the solar system using solar electric power. It is based on an evolutionary design that has strong heritage to the NSTAR (NASA’s Solar Electric Propulsion Application Readiness) ion propulsion system (IPS) that is currently flying on the Dawn spacecraft. Potential mission destinations that can benefit from a NEXT Solar Electric Propulsion (SEP) system include inner planets, small bodies, as well as outer planets and their moons when chemical or aerocapture approaches are used for orbit capture at the destination body. This range of robotic-exploration missions generally calls for ion propulsion systems with deep throttling capability and system input power ranging from 5 to 25 kW, as referenced to solar-array output at one Astronomical Unit (AU).

# 2.0 NEXT TECHNOLOGY DEVELOPMENT SUMMARY

The NEXT technology development project focused on those elements of an ion propulsion system that were most applicable to a range of mission concepts and had the greatest technology development risks. Figure 2.0-1 illustrates the NEXT technology project products in a representative, simplified, system configuration. This figure represents the subset of an overall ion propulsion system that the NEXT technology project team addressed. Appendix J of the “NASA Procedural Requirements (NPR) 7120.8 NASA Research and Technology Program and Project Managements Requirements” provides the definition of technology hardware maturity. Table 2.0-1 describes the various major subsystems of a flight ion propulsion system (IPS), and the hardware maturity (per NPR 7120.8) achieved on the NEXT technology project. This document retains the hardware maturity terminology used in prior NEXT publications.

Appendix A provides summaries of other products developed as part of the NEXT technology project. These are provided for information purposes only.

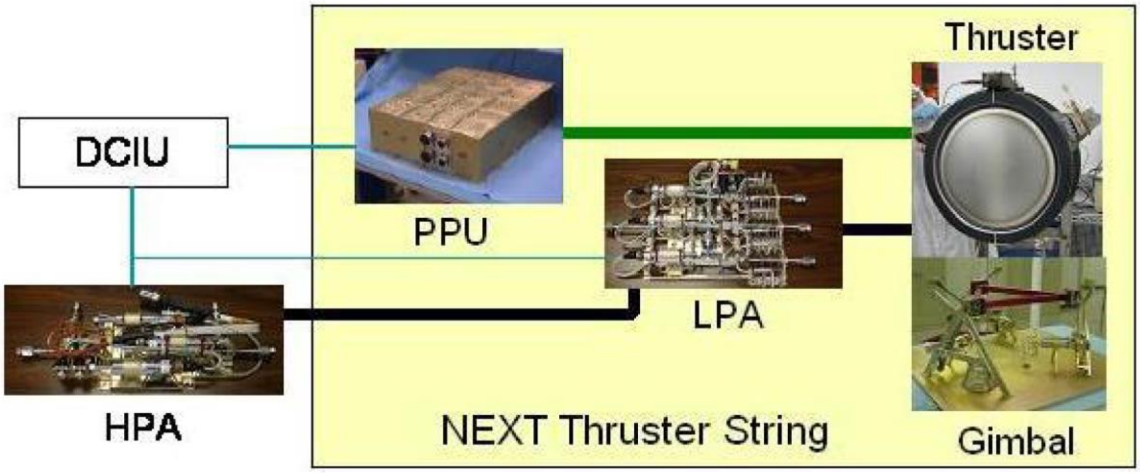


**Figure 2.0-1: NEXT ion propulsion system elements**

**Table 2.0-1: NEXT-based IPS Subsystems**

| IPS Subsystem | Function | NEXT Hardware Maturity Per NPR 7120.8 |
|---|---|---|
| Ion Thruster | Provide thrust | Engineering Unit |
| Power Processing Unit | Converts solar array power to thruster input power | Engineering Unit |
| Propellant Tank | Xenon storage | Not addressed on NEXT |
| High Pressure Assembly | Control xenon pressure to LPA | Engineering Unit |
| Low Pressure Assembly | Control xenon flow to thruster | Engineering Unit |
| Miscellaneous valves tubing and fittings | Xenon loading, isolation control, and purge flow | Not addressed on NEXT |
| Gimbal | Point thruster to desired vector | Brassboard |
| Control/Interface Unit | Control/data interface to spacecraft, PPU and xenon feed system | Simulator only, with brassboard xenon flow control cards |

## 2.1 NEXT PM THRUSTER

### 2.1.1 PM Thruster Summary

The NEXT ion thruster was developed through a two-phase approach during the NEXT technology project. NASA Glenn Research Center (GRC) developed the initial design concept and validated it through fabrication and test of five Engineering Model (EM) thrusters. GRC transferred the thruster concept to Aerojet for implementation in the PM thruster design and hardware. Aerojet delivered a prototype model (PM) thruster (equivalent to Engineering Unit per NPR 7120.8), and parts/sub-assemblies for a second thruster to NASA GRC. Key validation activities included performance acceptance testing, environmental analysis and testing, and life analysis and testing. The thruster was judged as TRL 6 in four independent TRL assessments. To preserve the demonstrated performance and lifetime capability, the PM thruster design is the baseline for the NEXT-C flight thruster development. Figure 2.1.1-1 shows the NEXT PM thruster operating during performance acceptance testing.

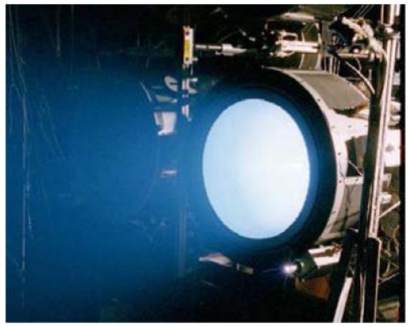

**Figure 2.1.1-1: NEXT PM thruster during performance acceptance testing**

### 2.1.2 PM Thruster Performance

Thrust and specific impulse are the primary measures of effective conversion of power and propellant to achieve the required mission velocity change (ΔV). Thruster performance is currently based on the NEXT Throttle Table 11 (TT11). This Throttle Table includes updates from the incorporation of extensive diagnostic test data and measured thrust generated in testing at The Aerospace Corporation, information gleaned from the thruster Long Duration Test, and assessment of operating margins. The key parameters of TT11 are summarized in Appendix B of this document. Additional detailed throttle table data is available upon request.

Extended Throttle Level (ETL) throttle points were characterized during testing at The Aerospace Corporation. The ETL points represent capabilities within the current thruster design and PPU output ranges that were not incorporated in testing during the technology-project-thruster-verification-test program. These points provide higher thrust-to-power capability, with operations at higher beam currents and propellant flow rates for some beam voltages. While performance verification of these points is extensive, thruster lifetime characterization has not been completed; therefore, they should be considered as having potential to provide increased capability (performance margin) for missions benefiting from high thrust-to-power, not as baseline capability. ETL summary parameters are provided in Appendix B of this document.

### 2.1.3 Thruster Lifetime

The NEXT thruster has a test-demonstrated mission life capability for throttle levels (TL) 1-40 exceeding 600 kg xenon throughput and 22.5 MN-s total impulse. Given thruster lifetime dependence on throttling strategy, application of the NEXT thruster life model by GRC against mission-specific throttle profiles provided by the mission should be accomplished to establish life margins for the intended mission applications. The values demonstrated during the execution of the Long Duration Test reflect the operational history of the test, and therefore, do not necessarily represent hard or firm maxima.

## 2.2 NEXT EM PPU

### 2.2.1 EM PPU Summary

The engineering model (EM) power processing unit (PPU) for the NEXT project is shown in Figure 2.2.1-1. This PPU is capable of processing from 0.5 to 6.9 kW of output power for operating the NEXT ion thruster. Its design includes many significant improvements for better performance over the state-of-the-art NSTAR PPU. The most significant difference is the beam supply that is comprised of six modules, and is capable of very efficient operation through a wide power and voltage range. The previously validated NSTAR PPU provided the basis for the low voltage power supplies. While EM PPU performance and functionality was successfully tested across a range of relevant operating conditions on both a thruster and resistive load, technical issues prevented completion of environmental testing; therefore, the PPU was judged as TRL 4 in three of the four independent TRL assessments. The NEXT-C flight PPU design was not constrained to the PPU design developed during the technology project, but the design is largely similar.

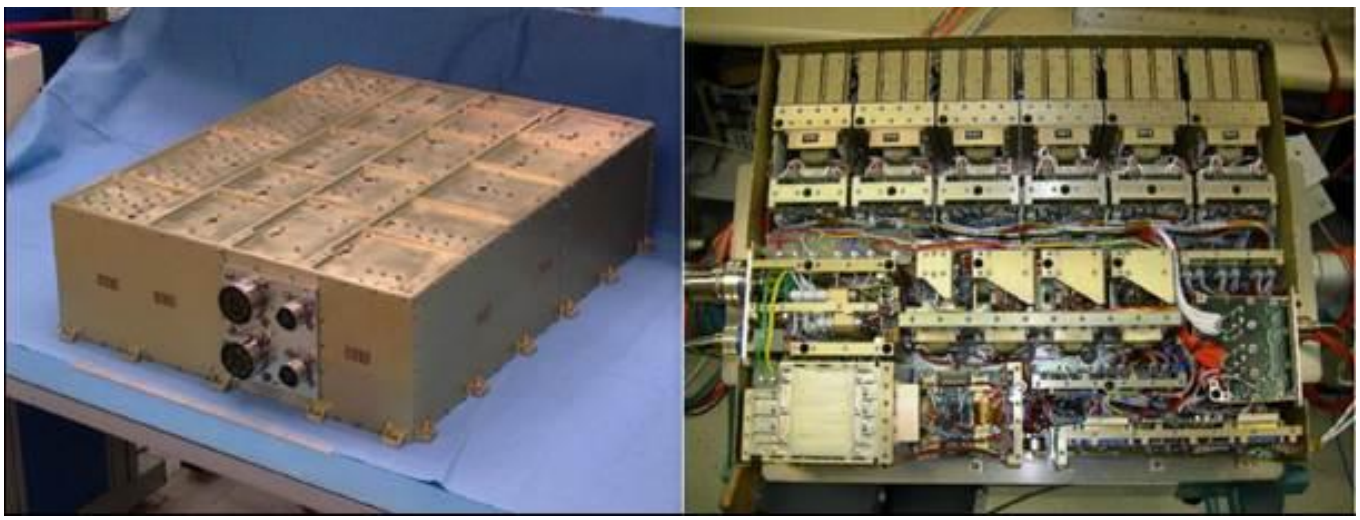

**Figure 2.2.1-1: NEXT EM PPU**

### 2.2.2 EM PPU Technical Issues

The NEXT technology project encountered a number of PPU technical issues during unit and system testing. Early issues involved a design error that was easily corrected and a second source part that did not have equivalent capability. The more demanding issue was multiple occurrences of multi-layer ceramic (MLC) capacitor failures. This issue was ultimately traced to the piezoelectric characteristic of the custom capacitor being excited in the PPU application. Reference 32 summarizes these issues and Reference 33 provides detailed information on the MLC capacitor failure resolution. Each issue was resolved with paths to flight production identified. The specific mitigations and lessons learned will be incorporated into the NEXT-C PPU development.

# 3.0 NEXT-C PROJECT FLIGHT COMPONENT DEVELOPMENT

The NEXT-C Project has two phases: a development phase and the flight hardware phase. The development phase provides risk reduction prior to building the NEXT-C flight hardware. The NEXT-C thruster and PPU will be readily available to future NASA users as a commercial product.

The NEXT-C contract was defined such that NASA considered modifications or alternatives to the existing design, particularly the PPU design, to facilitate broader use in non-NASA applications.

The following subsections provide a summary description of the NEXT-C flight hardware components.

## 3.1 GOVERNMENT-DEVELOPED COMPONENTS

The NEXT-C Project is a NPR 71200.5E project, with product development consistent with the Class B payload guidance in NPR 8705.4. The New Frontiers Announcement of Opportunity is currently planned to be released in January 2017, with final mission down-select in May 2019. The NEXT-C government developed components along with interface responsibilities of the mission spacecraft are shown in Figure 3.1-1. Implementation of DCIU functionality is user dependent. The NEXT-C Project will provide PPU/Feed System/Thruster control algorithms to the flow diagram level.

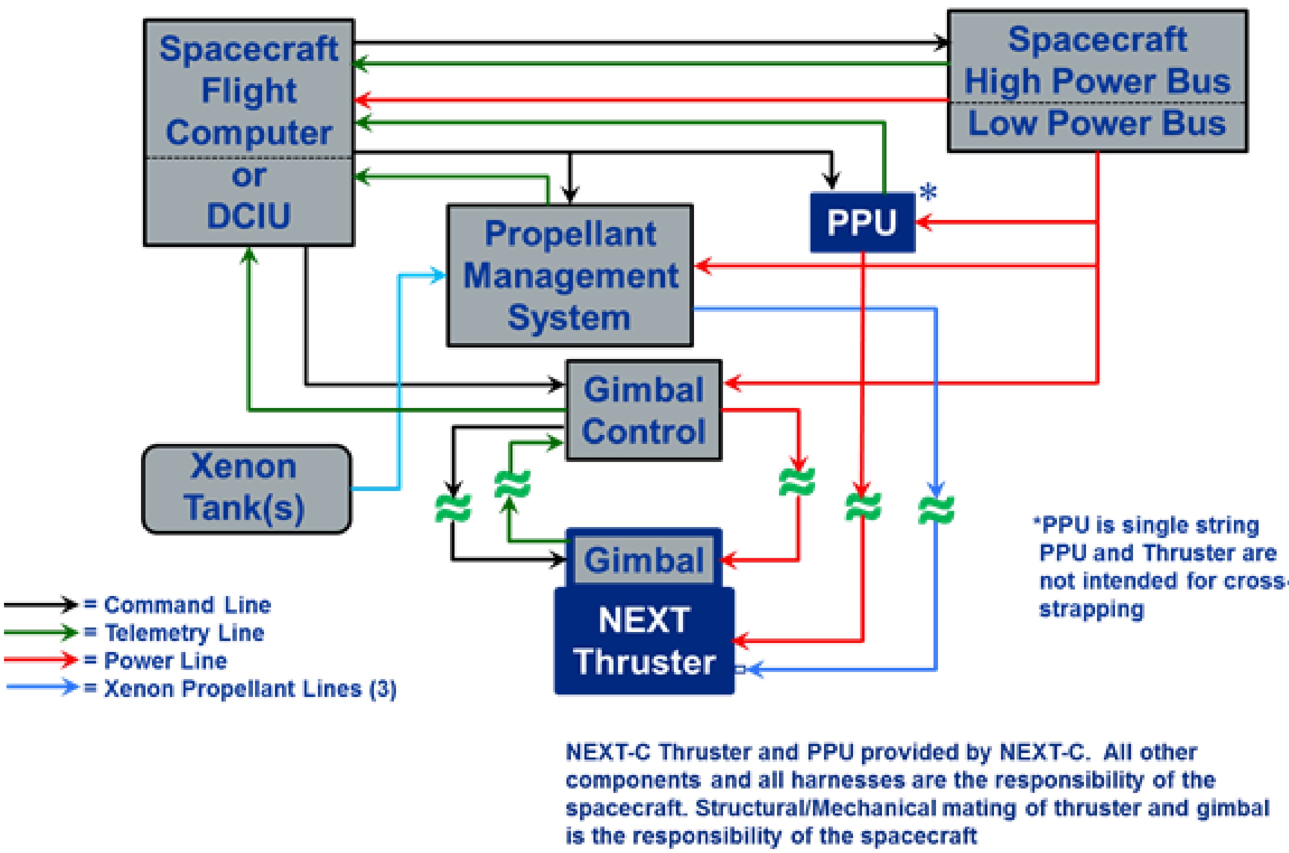


**Figure 3.1-1: NEXT-C/Spacecraft Functional Block Diagram**

## 3.2 NEXT-C FLIGHT THRUSTER

A summary of key design and performance requirements of the NEXT-C Thruster is shown in Figure 3.2-1.

| Performance Characteristics | |
|---|---|
| Thruster Power Range, kW | 0.5-6.9 |
| Max. Specific Impulse, sec | 4220 |
| Thrust, mN | 25-235 |
| Max. Thruster Efficiency | 70% |
| Beam Diameter, cm | 36 |
| Max. Beam Current, A | 3.52 |
| Max. Beam Voltage, V | 1800 |
| Mass (with harness), kg | <15.0 |

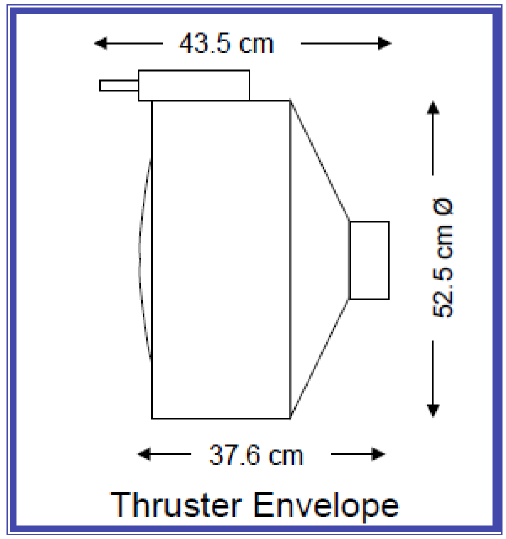


**Figure 3.2-1: Key Requirements of the NEXT-C Thruster**

Two NEXT-C thrusters will undergo a proto-flight test program as part of the NEXT-C project. The project will provide the flight thruster specification, acceptance data packages, analytical models, verification reports, interface control documentation, control algorithms to the flow diagram level, and operations documentation to the mission project. Development-level Government Support Equipment (GSE) and Technical Support Equipment (TSE) can be provided to support use of thrusters, but coordination with NASA and Aerojet Rocketdyne will be needed to accommodate those requests.

## 3.3 NEXT-C PPU

The NEXT-C Project will design, fabricate and test a prototype PPU during the development phase. A prototype unit is defined as:

- a form, fit, and function equivalent to a flight unit;
- use of non-flight parts acceptable for cost/schedule savings when equivalent flight parts are available;
- subjected to functional/performance testing across the full range of allowable conditions and qualification-level environmental testing.

Completion of prototype PPU verification at the unit level and in integrated PPU/thruster performance and EMI tests is planned for July of 2017.

Efficient conversion of array power to thruster power is important in achieving overall IPS performance. The PPU requirement for efficiency is shown in Figure 3.3-1. The NEXT-C PPU accepts unregulated primary power over a range of 80-160V.

| Parameter | Requirement |
|---|---|
| Input Power Range, W | 640-7360 |
| Peak Efficiency (HV Bus) | > 93.5% |
| High Power Input Voltage, V | 80-160 |
| Housekeeping Input Bus, V | 22-34 |
| Housekeeping Power, W | < 40 |
| Mass, kg | < 36.8 |

| Environmental Reqs. | |
|---|---|
| Operating Temp, C | -24 to +50 |
| Non-operating Temp, C | -40 to +71 |
| Vibration, Grms | 14.1Grms |

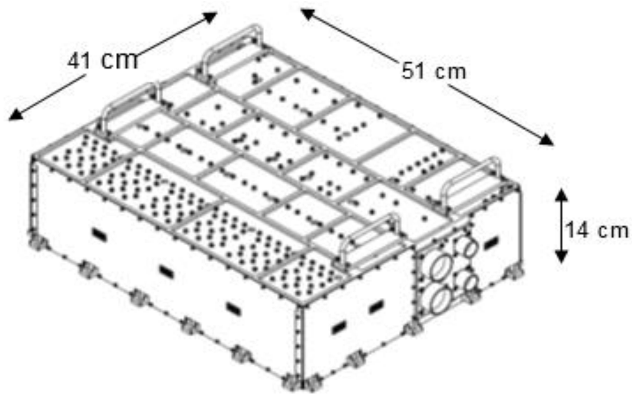


**Figure 3.3-1: Key Requirements of the NEXT-C Flight PPU**

The mission is responsible for flight harnesses between the PPU and thruster, and between the PPU and spacecraft interfaces. The project will provide the flight PPU specification, acceptance data packages, analytical models, verification reports, interface control documentation, control algorithms to the flow diagram level, and operations documentation to the mission project. PPU Ground Support Equipment (GSE) and/or Test Support Equipment (TSE) could be provided to the mission project to support spacecraft integration and test. Again, this would need to be coordinated with NASA GRC and Aerojet Rocketdyne. The mission project is responsible for any hardware simulators needed to support propulsion system or spacecraft-level integration and test.

## 3.4 NEXT-C SYSTEM INTEGRATION TESTS

The NEXT-C Project is planning to conduct the following system integration tests:

- Prototype PPU/PM thruster integrated performance and functional testing. This test will be performed after Prototype PPU verification testing at the unit level.
- Prototype PPU/PM thruster integrated EMI/EMC testing will follow above integration test.
- Flight PPU/Flight thruster integrated performance and functional testing will complete the acceptance test sequence.

## 3.5 NEXT-C PROJECT SCHEDULE

The NEXT-C Project Schedule is shown in Appendix-D of this document, and is current as of the publication date of this document. For the latest project schedule, please consult the point of contact shown in Section 5.0 of this document.

# 4.0 NEXT-C AND NEW FRONTIERS

## 4.1 NEW FRONTIERS AO OFFERINGS

While the NEXT-C project is developing the first two sets of NEXT-C flight thrusters and PPUs, the hardware will likely be utilized by other missions prior to New Frontiers. The New Frontiers 4 Draft Announcement of Opportunity offered a $10M incentive for the purchase of two NEXT-C thrusters, two NEXT-C PPUs and other supporting equipment (handling fixtures, GSE, etc.) The procurement of these thrusters can either be negotiated directly with Aerojet Rocketdyne, or the proposers may elect to work with NASA GRC to complete that negotiation on behalf of the proposer.

## 4.2 NEW FRONTIERS PROPOSAL SUPPORT

The NEXT-C Project will support mission teams during New Frontiers proposal development. All interactions will be coordinated through the NEXT-C Interface lead at NASA GRC. The interface lead will coordinate the GRC technical support required, and will coordinate interactions with the mission team to provide information and to coordinate interface definition and integration/operations planning.

The NEXT-C project is not currently funded for New Frontiers Phase A support. The NEXT-C project could support Phase A work, however that work should be scoped and included as part of the Phase A proposal and funded appropriately.

## 4.3 PHASE B – PHASE E SUPPORT

The NEXT-C project is not funded for any support of any New Frontiers missions should they be selected for Phase B and beyond. The support of the NEXT-C project should be negotiated with the GRC NEXT-C point of contact for New Frontiers and then incorporated into the mission proposer’s budget.

## 4.4 NEXT/NEXT-C ENGINEERING HARDWARE

There are significant hardware assets from the NEXT technology project as well as the NEXT-C project that could be made available to the proposers for their missions. Given that there is the potential for the use of that hardware by both New Frontiers proposers as well as other NEXT-C users, the use of the hardware should be negotiated with NASA GRC and Aerojet Rocketdyne in order to assure that it is available when needed. There is a wide variety of hardware available, so it is not listed here, but proposers can contact NASA GRC for further information.

## 4.5 NEXT-C DOCUMENTATION

The following information is available upon request to the contact identified below.

- NEXT-C/Spacecraft Interface Control Document (ICD) that contains pertinent information on PPU and thruster interfaces to the spacecraft.

- PPU Specification
- Other detailed analyses that have been completed by the project per the Aerojet Rocketdyne contract deliverables.

This information is ITAR-sensitive; release will be controlled through the following process:

1. Initiator notifies contact identified below of request.
2. NASA will provide an export control request form to initiator.
3. Initiator completes form and submits request.
4. Documentation is provided through appropriate controlled-release mechanism.

## 5.0 CONTACT INFORMATION

Please direct all inquiries and requests to the following individual:

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# 7.0 APPENDIXES

## A. NEXT TECHNOLOGY PROJECT COMPONENTS

### A.1 Introduction

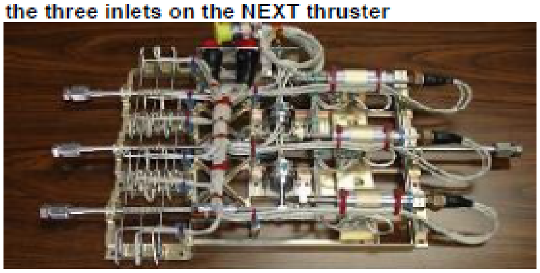
This appendix provides summaries of other ion-propulsion system components other than the Thruster and PPU that were developed under the NEXT technology project. These summaries are provided for information only. These components are not part of the GFE provisions of the NEXT-C project.

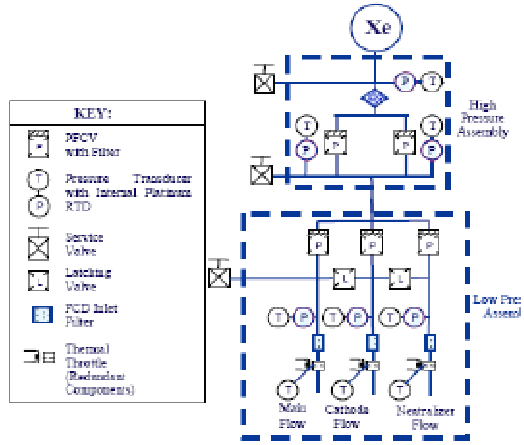
### A.2 Propellant Management Subsystem (PMS)

Aerojet designed and fabricated the NEXT EM high pressure and low pressure assemblies (HPA, LPA) and the primary flow control components of an overall xenon feed system. Both assemblies are shown in Figure A.2-1. The HPA, composed of parallel redundant proportional flow control valves (PFCV) and pressure transducers, steps the xenon pressure from tank pressure to a nominal regulated LPA inlet pressure of 35 psia, or provides unregulated pressure below 35 psia for end-of-mission operations. The LPA consists of three flow-control kernels to supply throttled xenon flow to the thruster main plenum, discharge cathode and neutralizer cathode. Initial validation of the propellant management system (PMS) technology was accomplished during breadboard system integration testing in the first NEXT project phase in 2003. EM assemblies were fabricated and tested in the project phase 2. Key PMS validation activities include performance acceptance and environmental testing, and testing in integrated single-string and multi-string thruster strings, all of which were successfully completed. The PMS assemblies were judged as TRL 6 in three of four independent TRL assessments.

High Pressure Assembly (HPA): Pressure stepdown from tank pressure to nominal operating pressure

Low Pressure Assembly: Xenon flow control to the three inlets on the NEXT thruster






Schematic

| Tested to Qualification-Level Environments | |
|---|---|
| Vibration | 14.1 $G_{rms}$<br>2 min/axis |
| Thermal/Vacuum | -12 to +70°C<br>3 full cycles<br>24 h of operations at -12 °C and +70°C |

| Performance Characteristics | |
|---|---|
| HPA Mass, kg | 1.9 |
| LPA Mass, kg | 3.1 |
| HPA Dimensions, cm | 33x18x7 |
| LPA Dimensions, cm | 44x28x7 |
| HPA Power Consumption, W | 1.6 |
| LPA Power Consumption, W | 8.1 |
| Flow Rate Accuracy | <3% |
| HPA Inlet Pressure, psia | <2700 |
| Tank unusable residual xenon | <1% |

LPA Operating Modes

Nominal:

- Pressure Control Loop
  - Fixed thermal throttle temperature
  - Variable PFCV orifice to control pressure and calibrated flow rate

Fault Mode

- Thermal Control Loop
  - Fixed PFCV orifice and internal pressure
  - Variable thermal throttle temperature to control flow rate
  - Allows control of multiple thruster flows with one or two PFCVs by opening cross-over latch valves.
  - LPA power consumption is higher in fault mode than in normal mode

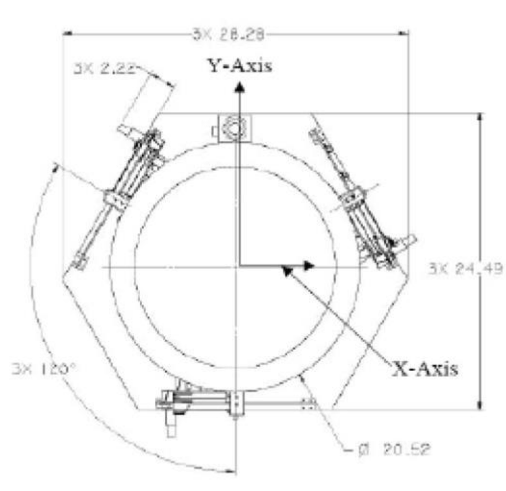
**Figure A.2-1: Propellant Management System**

## A.3 Gimbal Component Summary

ATK, under contract to the Jet Propulsion Laboratory (JPL), designed and fabricated the NEXT gimbal (Figure A.3-1). ATK delivered one complete gimbal assembly with sufficient parts for a second assembly. The gimbal provides maximum angular authority of ±19° and ±17° about the primary gimbal axes and a rough cone about the thruster centerline within those boundaries. The NEXT gimbal has a significantly smaller spacecraft interface footprint as compared to the Dawn/NSTAR gimbal. The gimbal is a flight-like design using JPL-approved materials with certifications, and stepper motors that have a space-rated option. The design of the gimbal was as a flight-packaged unit without substantive thermal analysis. Therefore, only functional testing and structural dynamic analyses and testing were performed on the gimbal. The gimbal successfully completed functionality tests with the PM thruster. The gimbal passed two qualification-level vibration tests and low-level shock tests with minor issues. The gimbal was judged as being across a range of TRL 4-6 in four independent TRL assessments.

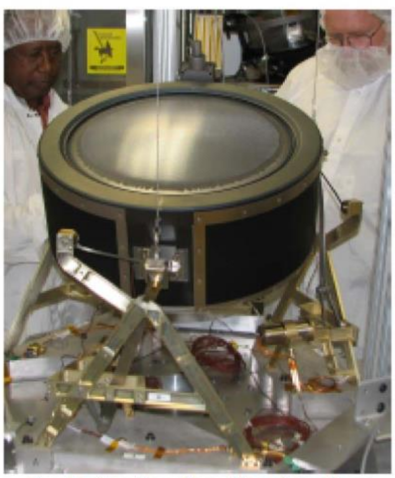
– Three strut attachment to spacecraft
– Thruster retention in launch position
– Thruster deployed to raised operation position after launch.

| Performance Characteristics | |
|---|---|
| Mass, kg | 6 |
| X-Axis Range of Motion, Degrees | ±19 |
| Y-Axis Range of Motion, Degrees | ±17 |
| Slew rate, degrees/sec | >0.6 |




Gimbal mounting envelope

| Tested to Qualification-Level Environments | |
|---|---|
| Vibration (in thruster/gimbal assembly) | 10 $G_{rms}$ 2 min/axis |



Post-vibration functional testing

**Figure A.3-1: Gimbal Assembly**

### A.4 Digital Control Interface Unit (DCIU) Summary

The NEXT project developed a simulator for the system Digital Control Interface Unit (DCIU), providing the capability to operate the key technology products in an integrated system. The primary functions of the DCIU are to interface to the spacecraft flight processor for high level commands and telemetry, and to control the PPU and PMS assemblies, effectively throttling the ion thruster(s). The simulator is personal computer-based test equipment with brassboard-level PM pressure loop control cards, and is capable of operating a three-thruster-string system.

### A.5 NEXT Technology Project System Integration Tests

Three test activities categorized as system-level tests were conducted during the NEXT technology project:

- multi-thruster array tests
- a single-string system integration test (SSIT)
- a multi-string system integration test (MSIT)

The objective of the multi-thruster array test was to assess thruster and plasma interactions with sensitivities to thruster spacing, gimbaled thrusters and neutralizer operating modes. The configuration included four GRC EM thrusters; three operating and one instrumented non-operating as well as an extensive suite of diagnostics to collect data for multi-thruster system modeling and analyses. The multi-thruster array test included single, dual, and triple thruster operations. Results indicate that expected thruster performance was achieved and thruster operations were understood without significant sensitivity to system configuration. Results from the multi-thruster array tests were documented in the following papers:

| | |
|---|---|
| AIAA 2006-5180 | NEXT Multi Thruster Array Test – Engineering Demonstration |
| AIAA 2006-5181 | Plasma Characteristics Measured in the Plume of a NEXT Multi-Thruster Array |
| AIAA 2006-5182 | Ion Beam Characterization of the NEXT Multi-Thruster Array Plume |
| AIAA 2006-5183 | Characterization of Plasma Flux Incident on a Multi-Thruster Array |
| AIAA 2006-5184 | Characterization of a NEXT Multi-Thruster Array with the Electrostatic Probes |

The scope of the Single-String System Integration Test (SSIT) was to verify that the integrated system of NEXT components meets the project requirements in a relevant environment. The primary objectives were to demonstrate:

- operation of the thruster over the throttle table with PPU and PMS,
- operation of system at off-nominal conditions,
- recycle and fault protection operation; and
- verification of a wide range of system-level requirements, including functional, performance, environmental and interface requirements

The test configuration included the PM thruster, EM PPU, the EM PMS as well as the DCIU simulator. The test started in May 2008 and continued through August when a PPU part failure interrupted the test sequence. Testing that did not require the PPU was then completed, resulting in completion of 70-80 percent of the test objectives.

A Multi-string System Integration Test (MSIT) was conducted following the SSIT, demonstrating successful operations of three thrusters (PM1R and two EM thrusters) with the PMS HPA and three LPAs controlled by the DCIU simulator.

## B. PM THRUSTER AND EM PPU PERFORMANCE

### B.1 NEXT PM Thruster Throttle Table 11

**Table B.1-1: NEXT PM Thruster Throttle Table 11 (Beginning of Life)**

| Throttle Level | Xenon Flow | Beam Current | Beam Voltage | Thrust | Isp | Thruster Efficiency | Thruster Input Power |
|---|---|---|---|---|---|---|---|
| | mg/s | A | V | mN | seconds | Efficiency | W |
| TL40 | 5.76 | 3.52 | 1,800 | 235 | 4,155 | 0.70 | 6,853 |
| TL39 | 5.76 | 3.52 | 1,567 | 219 | 3,886 | 0.69 | 6,046 |
| TL38 | 5.76 | 3.52 | 1,396 | 208 | 3,683 | 0.69 | 5,454 |
| TL37 | 5.76 | 3.52 | 1,179 | 192 | 3,408 | 0.68 | 4,703 |
| TL36 | 5.12 | 3.10 | 1,800 | 206 | 4,096 | 0.68 | 6,052 |
| TL35 | 5.12 | 3.10 | 1,567 | 193 | 3,838 | 0.68 | 5,341 |
| TL34 | 5.12 | 3.10 | 1,396 | 183 | 3,638 | 0.68 | 4,819 |
| TL33 | 5.12 | 3.10 | 1,179 | 169 | 3,360 | 0.67 | 4,158 |
| TL32 | 4.46 | 2.70 | 1,800 | 178 | 4,082 | 0.68 | 5,285 |
| TL31 | 4.46 | 2.70 | 1,567 | 167 | 3,823 | 0.67 | 4,666 |
| TL30 | 4.46 | 2.70 | 1,396 | 159 | 3,626 | 0.67 | 4,212 |
| TL29 | 4.46 | 2.70 | 1,179 | 146 | 3,348 | 0.66 | 3,636 |
| TL28 | 4.46 | 2.70 | 1,021 | 137 | 3,137 | 0.66 | 3,217 |
| TL27 | 3.92 | 2.35 | 1,800 | 155 | 4,032 | 0.66 | 4,614 |
| TL26 | 3.92 | 2.35 | 1,567 | 145 | 3,773 | 0.66 | 4,075 |
| TL25 | 3.92 | 2.35 | 1,396 | 137 | 3,571 | 0.65 | 3,680 |
| TL24 | 3.92 | 2.35 | 1,179 | 127 | 3,299 | 0.65 | 3,178 |
| TL23 | 3.92 | 2.35 | 1,021 | 119 | 3,090 | 0.64 | 2,814 |
| TL22 | 3.16 | 2.00 | 1,800 | 131 | 4,220 | 0.68 | 4,002 |
| TL21 | 3.16 | 2.00 | 1,567 | 123 | 3,951 | 0.67 | 3,541 |
| TL20 | 3.16 | 2.00 | 1,396 | 116 | 3,736 | 0.66 | 3,204 |
| TL19 | 3.16 | 2.00 | 1,179 | 107 | 3,450 | 0.65 | 2,778 |
| TL18 | 3.16 | 2.00 | 1,021 | 100 | 3,235 | 0.64 | 2,470 |
| TL17 | 2.60 | 1.60 | 1,800 | 104 | 4,087 | 0.64 | 3,244 |
| TL16 | 2.60 | 1.60 | 1,567 | 98 | 3,824 | 0.64 | 2,876 |
| TL15 | 2.60 | 1.60 | 1,396 | 92 | 3,613 | 0.63 | 2,606 |
| TL14 | 2.60 | 1.60 | 1,179 | 85 | 3,332 | 0.61 | 2,265 |
| TL13 | 2.60 | 1.60 | 1,021 | 80 | 3,117 | 0.60 | 2,019 |
| TL12 | 2.05 | 1.20 | 1,800 | 78 | 3,882 | 0.61 | 2,437 |
| TL11 | 2.05 | 1.20 | 1,567 | 73 | 3,633 | 0.60 | 2,160 |
| TL10 | 2.05 | 1.20 | 1,396 | 69 | 3,432 | 0.59 | 1,958 |
| TL09 | 2.05 | 1.20 | 1,179 | 63 | 3,163 | 0.58 | 1,702 |
| TL08 | 2.05 | 1.20 | 1,021 | 59 | 2,953 | 0.57 | 1,517 |
| TL07 | 2.05 | 1.20 | 936 | 57 | 2,839 | 0.56 | 1,419 |
| TL06 | 2.05 | 1.20 | 850 | 54 | 2,716 | 0.55 | 1,319 |
| TL05 | 2.05 | 1.20 | 679 | 49 | 2,449 | 0.53 | 1,120 |
| TL04 | 2.05 | 1.20 | 650 | 48 | 2,389 | 0.52 | 1,085 |
| TL03 | 2.05 | 1.20 | 400 | 37 | 1,850 | 0.43 | 788 |
| TL02 | 2.05 | 1.20 | 300 | 31 | 1,564 | 0.36 | 668 |
| TL01 | 1.85 | 1.00 | 275 | 25 | 1,395 | 0.32 | 545 |

## B.2 NEXT Expanded Throttle Levels

The Throttle levels below represent additional performance capability of the NEXT thruster, and are provided for reference information only.

**Table B.2-1: NEXT PM Thruster Extended Throttle Table 11 (Beginning of Life)**

| Throttle Level | Xenon Flow | Beam Current | Beam Voltage | Thrust | Isp | Thruster Efficiency | Thruster Input Power |
|---|---|---|---|---|---|---|---|
| | mg/s | A | V | mN | seconds | Efficiency | W |
| | | | | | | | |
| ETL3.52A | 5.71 | 3.52 | 1,021 | 177 | 3,169 | 0.66 | 4,155 |
| ETL3.52B | 5.66 | 3.52 | 936 | 170 | 3,060 | 0.66 | 3,861 |
| ETL3.52C | 5.66 | 3.52 | 850 | 162 | 2,926 | 0.65 | 3,563 |
| ETL3.52D | 5.66 | 3.52 | 700 | 146 | 2,638 | 0.62 | 3,038 |
| | | | | | | | |
| ETL3.1A | 5.07 | 3.10 | 1,021 | 156 | 3,147 | 0.66 | 3,676 |
| ETL3.1B | 5.02 | 3.10 | 936 | 150 | 3,042 | 0.65 | 3,416 |
| ETL3.1C | 5.02 | 3.10 | 850 | 143 | 2,898 | 0.64 | 3,154 |
| ETL3.1D | 5.02 | 3.10 | 700 | 129 | 2,624 | 0.62 | 2,694 |
| ETL3.1E | 5.02 | 3.10 | 679 | 127 | 2,581 | 0.61 | 2,629 |
| | | | | | | | |
| ETL2.7A | 4.41 | 2.70 | 936 | 130 | 3,018 | 0.65 | 2,991 |
| ETL2.7B | 4.41 | 2.70 | 850 | 124 | 2,875 | 0.63 | 2,763 |
| ETL2.7C | 4.41 | 2.70 | 700 | 113 | 2,606 | 0.61 | 2,364 |
| ETL2.7D | 4.41 | 2.70 | 679 | 111 | 2,565 | 0.60 | 2,306 |
| ETL2.7E | 4.41 | 2.70 | 650 | 108 | 2,506 | 0.60 | 2,228 |
| | | | | | | | |
| ETL2.35A | 3.88 | 2.35 | 936 | 114 | 2,993 | 0.64 | 2,617 |
| ETL2.35B | 3.88 | 2.35 | 850 | 108 | 2,851 | 0.63 | 2,418 |
| ETL2.35C | 3.88 | 2.35 | 700 | 98 | 2,585 | 0.60 | 2,071 |
| ETL2.35D | 3.88 | 2.35 | 679 | 97 | 2,544 | 0.60 | 2,023 |
| ETL2.35E | 3.88 | 2.35 | 650 | 95 | 2,487 | 0.59 | 1,955 |
| | | | | | | | |
| ETL2.0A | 3.21 | 2.00 | 936 | 96 | 3,053 | 0.63 | 2,304 |
| ETL2.0B | 3.21 | 2.00 | 850 | 92 | 2,909 | 0.61 | 2,136 |
| ETL2.0C | 3.21 | 2.00 | 700 | 83 | 2,639 | 0.58 | 1,844 |
| ETL2.0D | 3.21 | 2.00 | 679 | 82 | 2,598 | 0.58 | 1,803 |
| ETL2.0E | 3.21 | 2.00 | 650 | 80 | 2,541 | 0.57 | 1,747 |
| | | | | | | | |
| ETL1.6A | 2.63 | 1.60 | 936 | 77 | 2,982 | 0.60 | 1,886 |
| ETL1.6B | 2.63 | 1.60 | 850 | 73 | 2,839 | 0.58 | 1,752 |
| ETL1.6C | 2.63 | 1.60 | 700 | 66 | 2,574 | 0.55 | 1,518 |
| ETL1.6D | 2.63 | 1.60 | 679 | 65 | 2,534 | 0.55 | 1,485 |
| ETL1.6E | 2.63 | 1.60 | 650 | 64 | 2,479 | 0.54 | 1,440 |
| ETL1.6F | 2.63 | 1.60 | 400 | 50 | 1,921 | 0.45 | 1,043 |

## B.3 NEXT PM Thruster/EM PPU Curve Fits

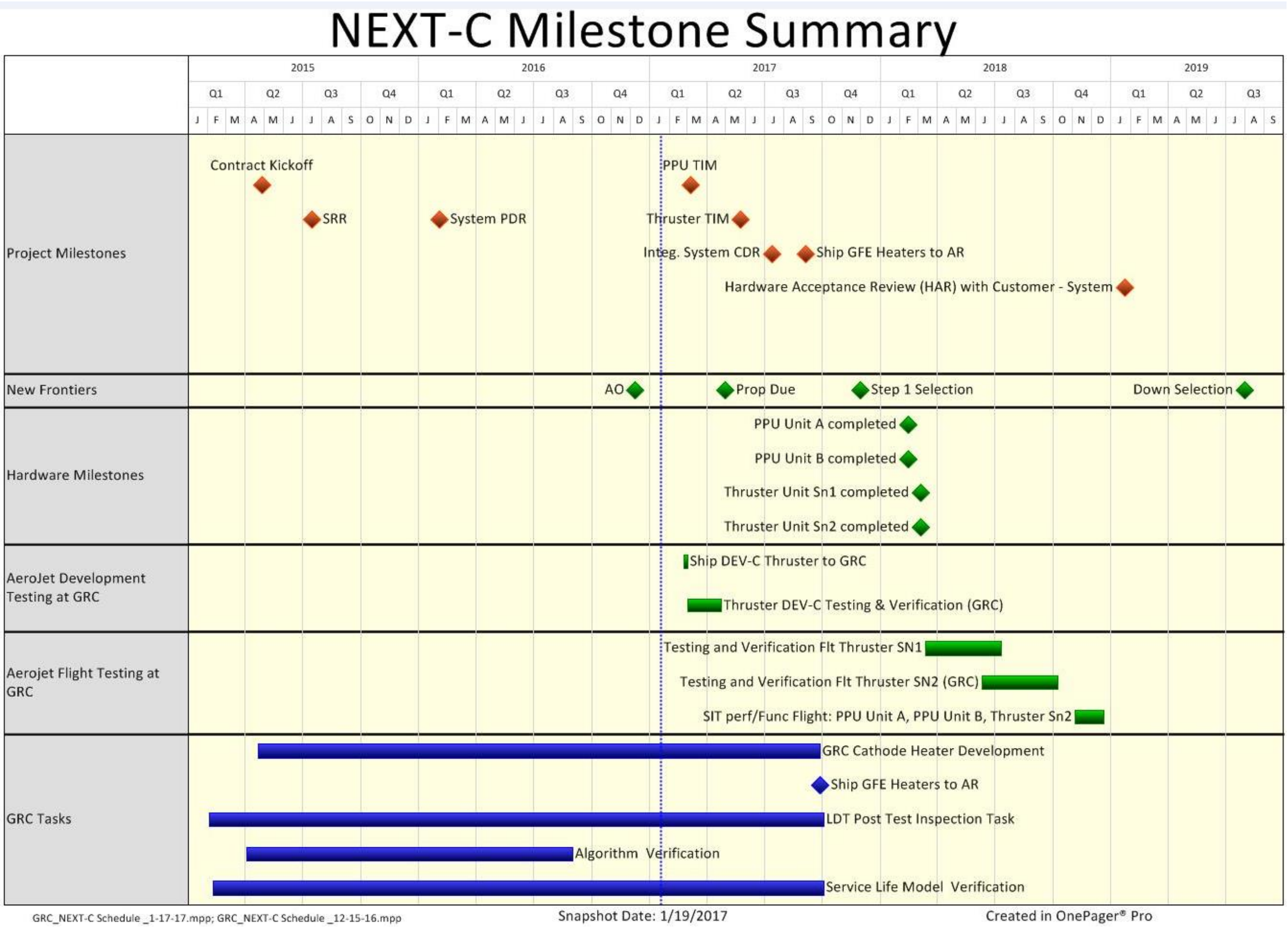
The following table provides curve fit coefficients for use in mission analysis. $P_0$ is power into the EM PPU in kilowatts. The three data sets represent the:

- High Specific Impulse boundary of the throttle table
- High Thrust boundary of the baseline throttle table (TL 1-40)
- High Thrust boundary of the throttle table including Expanded Throttle levels

**Table B.3-1: NEXT PM Thruster/EM PPU Curve Fits**

| | | | 1 | $P_0^1$ | $P_0^2$ | $P_0^3$ | $P_0^4$ |
|---|---|---|---|---|---|---|---|
| Baseline Throttle Table 11 (Throttle Levels 1-40) | High Thrust | Thrust Fit (N) | 1.19388817E-02 | 1.60989424E-02 | 1.14181412E-02 | -2.04053417E-03 | 1.01855017E-04 |
| | | Mdot Fit (kg/s) | 2.75956482E-06 | -1.71102132E-06 | 1.21670237E-06 | -2.07253445E-07 | 1.10213671E-08 |
| | | | | | | | |
| | High $I_{sp}$ | Thrust Fit (N) | 3.68945763E-03 | 4.05432510E-02 | -7.91621814E-03 | 1.72548416E-03 | -1.11563126E-04 |
| | | Mdot Fit (kg/s) | 2.22052155E-06 | -1.80919262E-07 | 2.77715756E-08 | 2.98873982E-08 | -2.91399146E-09 |
| Expanded Throttle Levels (ETLs) | High Thrust | Thrust Fit (N) | -8.04281458E-04 | 3.71873936E-02 | 5.17797704E-03 | -1.42659172E-03 | 8.51206723E-05 |
| | | Mdot Fit (kg/s) | 1.40535083E-06 | 5.34442545E-07 | 5.35910391E-07 | -1.38009326E-07 | 9.01951897E-09 |

## C. NEXT-C SCHEDULE



## D. ACRONYMS AND ABBREVIATIONS

| Acronyms | Definitions |
|---|---|
| AO | Announcement of Opportunity |
| AU | Astronomical Unit |
| AWG | American Wire Gage |
| BIT | Built in Test |
| BITE | Built in Test Equipment |
| CEI | Component End Item |
| dB | decibel |
| DCIU | Digital Control Interface Unit |
| EDU | Engineering Development Unit |
| EEE | Electrical, Electronic, and Electromechanical |
| EM | engineering model |
| EMC | Electro Magnetic Compatibility |
| ESD | Electro Static Discharge |
| ETL | Extended Throttle Level |
| F | Fahrenheit |
| FDIR | Fault Detection, Isolation, and Recovery |
| FU | Flight Unit |
| g | gravity |
| GFE | Government Furnished Equipment |
| GRC | Glenn Research Center |
| GSE | Ground Support Equipment |
| HPA | High Pressure Assembly |
| Hz | Hertz |
| ICD | Interface Control Document |
| IPS | Ion-propulsion system |
| ISPT | In-Space Propulsion Technology |
| ITAR | International Traffic in Arms Regulations |
| LDT | Long Duration Test |
| LPA | Low Pressure Assembly |
| MLC | multi-layer ceramic |
| MSIT | Multi-String System Integration Test |
| NASA | National Aeronautics and Space Agency |

| Acronyms | Definitions |
|---|---|
| NEDD | Natural Environments Design Document |
| NEXT | NASA’s Evolutionary Xenon Thruster |
| NEXT | NASA Evolutionary Xenon Thruster |
| NPR | NASA Procedural Requirements |
| NSTAR | NASA’s Solar Electric Propulsion Application Readiness |
| OFI | Operational Flight Instrumentation |
| PFCV | Proportional Flow Control Valve |
| PM | Prototype Model |
| PMS | Propellant Management System |
| PPU | Power Processing Unit |
| PWB | Printed Wiring Board |
| RMS | Root Mean Square |
| SBU | Sensitive But Unclassified |
| SEP | Solar Electric Propulsion |
| SMT | Surface Mounted Technology |
| SRU | Shop Replaceable Unit |
| SSIT | Single String Integration Test |
| TBD | To Be Determined |
| TBR | To Be Reviewed |
| TL | throttle levels |
| TSE | Test Support Equipment |
| TT11 | NEXT Throttle Table 11 |
| VDC | Volts Direct Current |