Electric Propulsion Thruster Lifetime Qualification Standard Recommendation

Background:

The In-Space Propulsion Technology (ISPT) project initiated an effort in May of 2007 during the electric propulsion technology assessment group (TAG) meeting to investigate the challenges of thruster lifetime qualification for issues unique to planetary science missions. A need was identified for a method of quantifying the lifetime qualification rating of a thruster based on testing and analyses. The operational lifetime of a thruster is not only thruster specific, but also dependent on the mission throttle profile and configuration specific operations of the thruster. The throttle profile has potential to change throughout mission development and in some cases after launch.

A formal NASA standard is being proposed through the chief engineers' office as a parallel effort, but a NASA standard does not currently exist. In the interim, specifically for the use of primary electric propulsion on NASA's planetary science missions, the ISPT project recommends the following standard as an approach for thruster lifetime qualification. This recommendation is based on input from industry, academia, and NASA. It is recommended that concepts using primary electric propulsion include plans and resources to meet the following standard by the spacecraft preliminary design review (PDR).

Any questions or comments regarding this standard should be directed to the ISPT project:

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Supporting Information:

Dankanich, J. W., Brophy, J. R., and Polk, J. E., "Electric Propulsion Thruster Lifetime Qualification Requirements," 55th JANNAF Propulsion Meeting, Orlando, Florida, Decemver 8-12, 2008.

Brophy, J., Polk, J., Randolph, T., and Dankanich, J. W., "Lifetime Qualification Standards for Electric Thrusters for Deep-Space Missions," AIAA-2008-5184, 44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Hartford, CT, July 21-23, 2008.

1. SCOPE

1.1 Purpose

The purpose of this standard is to establish test and analysis guidelines to be used for electric propulsion thruster lifetime qualification. It is intended to provide a guideline that properly balances technical risk and development costs. The criteria in this standard are designed to provide a low risk for thruster wear-out failures.

1.2 Applicability

This standard establishes engineering practices for NASA programs and projects. It may be cited in contract, program, and other agency documents as a technical requirement or as a reference for guidance. Individual provisions of this standard may be tailored (i.e. modified or deleted) by contract or program specifications to meet specific program/project needs and constraints. Tailoring must be formally documented as part of program/project requirements and approved by the assigned Technical Authority.

The criteria in this standard are applicable to electric propulsion thrusters which are utilized for NASA class A and B missions. The standard presents acceptable minimum factors of safety for use in analytical assessment and test verification of lifetime adequacy of the flight hardware.

The requirements specifically excluded from this standard are tests and analyses for the mitigation of event consequence failures, which are assumed to be designed or tested out of existence for the intended mission application.

2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this standard as cited in the text of section 4. The applicable documents are accessible via the NASA Online Directives Information System at http://nodis3.gsfc.nasa.gov and the NASA Technical Standards System at http://standards.nasa.gov, or may be obtained directly from the Standards Developing Organizations of other document distributors.

2.2 Government Documents

NASA-STD-7009	Standard for Models and Simulation
NPR 7120.5	NASA Research and Technology Program and Project Management Requirements
NPR 8705.5	Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects

2.3 Non-Government Documents

None

3. ACRONYMS AND DEFINTIONS

3.1 Acronyms

NASA	National Aeronautics and Space Administration
NPR	NASA's Procedural Requirement

3.2 Definitions

Accumulated Damage: The summation of component degradation that leads to failure.

Critical Operating Points: Thruster throttle points identified and characterized as subject to life-limiting failure modes.

Development Model: A unit that is functionally equivalent to flight thrusters with as many of the same processes as can feasibly be incorporated during the thruster development phase.

Engineering Model: A high fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments.

Event Consequence Failure: A failure that is triggered by events or defects and are not attributed to wear.

Failure: The condition when the thruster is no longer able to meet the minimum required mission performance.

Significant Failure Mode: Wear-out failure modes that have a reasonable quantitative risk of occurring for the intended mission application.

Usage: Thruster operation including: nominal operation at mission specific operating conditions, heater and cathode cycles, and deep thermal cycles.

4. GENERAL REQUIREMENTS

A thruster shall have a service life of 1.5 times the worst-case planned mission usage.

The service life shall be validated through a combination of testing and analysis, demonstrating a non-failure probability due to wear-out of greater than 90%, including modeling uncertainties and assuming the thruster is operated for 50% more time at every

throttle level over the expected mission profile. Throttle points may be grouped provided the worst case operating point is used for the group.

Lifetime qualification can be completed by test alone, eliminating the analytical model requirement 5.4, provided a sufficient number of tests are performed to establish the location of the failure distribution.

5. DETALIED REQUIREMENTS

5.1 Failure Mode Identification and Understanding

The behavior on approach to failure shall be known for all of the significant failure modes over the applicable throttle range.

5.2 Minimum Test Experience

A test of a Development-Model fidelity thruster, or better, shall be executed in a relevant environment over the intended throttle range under nominal operating conditions and shall demonstrate an equivalent or greater accumulated damage, with emphasis on the progression of the first failure mode, than any individual thruster is anticipated to be subjected to for the proposed mission.

Thruster level testing shall demonstrate a total impulse greater than or equal to 100% of the worst-case planned thruster usage.

Cycle testing shall be completed at the thruster or component level with a minimum of 150% of the worst-case expected number of cycles demonstrated by test.

5.3 Engineering Model Hardware Tests

Extended-duration testing with an Engineering Model fidelity thruster or better must be performed to verify that the flight thruster life characteristics are consistent with expectations and to identify any significant failure modes that are sensitive to fabrication processes.

Vibration environmental testing shall occur prior to the Engineering Model hardware testing.

5.4 Analytical Model Requirements

A favorable external review, as defined in NASA-STD-7009, is required for each model of a significant failure mode. These models shall be used to perform a probabilistic risk assessment according to NASA's Procedural Requirement NPR 8705.5.