LFPS-PLAN-211

EFFECTIVE DATE 3/31/2020

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Lunar Flashlight Propulsion System Fracture Control Plan

MARSHALL SPACE FLIGHT CENTER ADVANCED EXPLORATION SYSTEM

DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Cancelled)	Document Revision	Effective Date	Page	Section	Description
Baseline		2/4/2020			
Revision	A	3/31/2020			- Updates to include reference to approved ICD. - Revision to design loads and random vibration environments.

APPROVALS

Prepared By:

Hunter Williams Date
ER11/LFPS Propulsion Lead

Approved By:

Daniel Cavender Date
ST24/LFPS Project Manager

Concurrence By:

Donald McQueen Date
EE05/LFPS Chief Engineer

John Peugeot Date
ER11/Branch Chief

Contents

LIST OF FIGURES

LIST OF TABLES

1.0 SCOPE

This document is intended to replace a previously approved Fracture Control Plan (VACCO X16029-10-FCP1) for the Lunar Flashlight Propulsion System (LFPS). The current LFPS is a new design and therefore requires a new plan; however, the spacecraft interfaces have remained the same. This document describes the elements of the Marshall Space Flight Center (MSFC) Fracture Control Program and the responsibilities for managing these elements for the LFPS for the Lunar Flashlight CubeSat mission that will launch as a secondary payload on the Space Launch System (SLS). The purpose of this document is to establish a plan for the fracture control activities for MSFC's LFPS that will be used on the Lunar Flashlight CubeSat. This plan lists all the specific activities that will be performed to satisfy fracture control for this program. The provisions of this plan shall be met to demonstrate that the parts are in compliance with NASA's fracture control requirements for space flight hardware.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this document to the extent noted. Unless otherwise specified, the referenced documents are to be the latest issue date. In the event of a conflict between a referenced document and this document, NASA-STD-5019 will take precedence, over all documents as it is the governing fracture control document for the SLS Secondary Payloads.

2.1 NASA Documents

MSFC-STD-3029	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments
NASA-STD-5009	Non-destructive Evaluation Requirements for Fracture Control
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware
NASA-STD-6008	NASA Fastener Procurement, Receiving Inspection and Storage Practices for Spaceflight Hardware

NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft
AIAA-S-080	Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
MIL-HDBK-6870	Inspection Program Requirements Non-Destructive for Aircraft and Missile Materials and Parts
MIL-STD-130	Identification Marking of US Military Property

2.2 MSFC Documents

LFPS-RPT-316	Fracture Control Report for Lunar Flashlight Propulsion System
LFPS-RPT-303	Structural Analysis Report for Lunar Flashlight Propulsion System
ASTM-E1417	Standard Practice for Liquid Penetrant Examination
TBD	Electron Beam Weld Procedure

3.0 PROJECT DESCRIPTION

MSFC in conjunction with Georgia Tech Space Systems Design Laboratory (herein referred to as GT) will design the LFPS for NASA's Lunar Flashlight mission. The design will be supported by analysis, acceptance testing, and qualification testing, as necessary, to provide confidence that the hardware will meet the specified requirements.

3.1 Lunar Flashlight Propulsion System Hardware Description

The Lunar Flashlight Propulsion System is a self-contained, titanium alloy system that employs a combination of additively and traditionally manufactured parts. It has 4 canted green propellant thrusters that provide roll, pitch, yaw and ΔV. The system has a propellant storage tank that supplies propellant through a series of solenoid valves and an electrically-driven micro-pump to the four (4) thrusters.

The major external components of the Lunar Flashlight Propulsion System are identified in Figure 1.

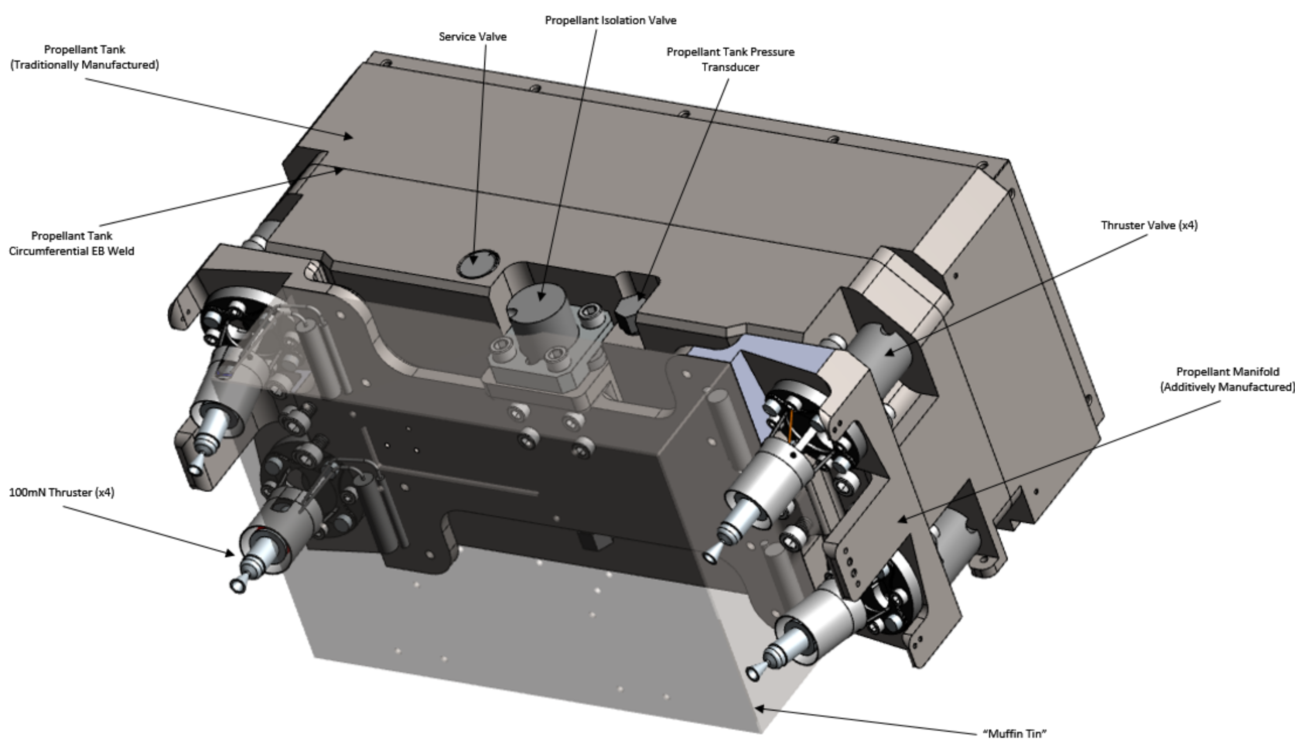

Figure 1 - Lunar Flashlight Propulsion System (pump and controller not shown)

Information concerning the classification of either fracture critical or non-fracture critical components and the methodology applied on those components is shown in Appendix A.

4.0 FRACTURE CONTROL PROGRAM

4.1 NASA MSFC FCB Responsibilities

NASA MSFC FCB shall be responsible for approving the FCP, FCR, any alternative approaches, and interpreting the requirements of NASA-STD-5019.

4.2 MSFC and GT Shared Responsibilities

- Fracture classification of parts.
- Identification and specification of required Nondestructive Evaluation (NDE) Inspections or any other special requirements on fracture-critical parts. GT will follow standard NDE procedures to perform required inspection as called out on the component drawings and post weld NDE inspection on corresponding assembly drawings.
- Implementation of traceability and documentation showing adherence of hardware to approved drawings, specifications, plans, and procedures.
- Preparation of fracture mechanics and structural analyses, to include:
    - Assessment of anomalies on fracture-critical parts
    - Decisions regarding questions or issues relating to fracture control.

4.3 Fracture Control Board Approval

The NASA MSFC Fracture Control Board (FCB) must approve this fracture control plan.

4.4 Traceability and Documentation

Traceability will be maintained for all fracture-critical parts throughout the program. Engineering drawings for fracture-critical parts will contain notes which:

- Identify the part as a "FRACTURE CRITICAL PART" on component drawings.
- Identify the weld as "FRACTURE CRITICAL WELD" where applicable.
- Specify the appropriate NDE technique to be used on the part. Relevant indications/discontinuities (crack size) exceeding the acceptance criteria shall be rejected and nonconformance initiated per NASA-STD-5009, Para 4.1.1.
- Specify that the part be marked with part number and serial number.

For parts that are too small to be marked on the part itself, the part will be bagged and tagged in accordance with MIL-STD-130.

All changes in design or process specifications, manufacturing discrepancies, repairs, and finished part modifications of all parts will be reviewed by NASA MSFC to ensure that fracture control requirements are still met.

5.0 FRACTURE CONTROL CLASSIFICATION OF COMPONENTS

Fracture control classification for all components will be determined in accordance with the requirements of NASA-STD-5019, based on failure modes, consequences of failure, applicable requirements, and experience.

5.1 Lunar Flashlight Propulsion System Component Classification Summary

5.1.1 Category 1: Components Exempt from Fracture Control

Per NASA-STD-5019 Section 4.1, exempt hardware typically includes non-structural items such as flexible insulation blankets, enclosed electrical circuit components/boards, electrical connectors (including locking devices), and wire bundles. Small mechanical parts, such as bearings and valve seats, that have been developed and qualified through strong test programs and rigorous process control to demonstrate their reliability, and whose failure does not directly lead to a catastrophic hazard may be exempt from fracture control with the approval of the RFCB.

5.1.1.1 Exempt - Non-Metallic

O-rings and seals are non-structural and exempt. They are also proof tested and checked for leakage during ATP. A listing of all o-rings and seals in the system, along with their respective fracture classifications, is provided in Appendix A.

5.1.1.2 Exempt - Electrical Components

Electrical circuit components, boards, connectors, wire bundles, and related components are non-structural and exempt per the above description. A listing of all electrical components in the system, along with their respective fracture classifications, is provided in Appendix A.

Table 1 - Summary of Exempt Electrical Components (full list in Appendix A)

PART NUMBER	QTY	PART DESCRIPTION
GLRG-LFPS-401	1	Main Board
GLRG-LFPS-402	1	Driver Connect Board
GLRG-LFPS-403	1	Sensor Connect Board
GLRG-LFPS-404	1	Harnessing
ThorLabs TH10K	5	Temperature Sensor
TBD	2	Propellant Tank Heater

5.1.1.3 Shims

Shims are stationary and not a primary load path during any system operating condition. Being contained, they do not contribute to any catastrophic failure scenario. Any potential shim fracture is of a fretting nature and would release only a non-hazardous small low energy mass.

5.1.1.4 External Locking Features

Lock-wire, helical inserts, and other external locking features represent secondary failure scenarios and are exempt per NASA-STD-5019 Section 4.1.1.6 and 4.1.2.3.

5.1.1.5 Non-Flight Hardware

Some packing covers, port plugs, and related hardware listed on the Bill of Material that are removed prior to mission operations are exempt from fracture control.

5.1.2 Category 2: Non-Fracture Critical Components

5.1.2.1 Non-Fracture Critical --- Contained

Per NASA-STD-5019 section 4.1.1.2, a failed part confined in a container or housing or otherwise positively restrained from free release and that does not result in a catastrophic hazard, can be classified non-fracture critical.

Contained hardware shall also be examined for potential damage effects of single-point mass releases inside the confinement itself. Release of masses (of any size) within a container that could credibly defeat an internal safety-critical function shall be precluded by appropriate technical measures, which can include compliance with requirements for low-risk part classification (see 4.1.1.12) or other techniques approved by the RFCB.

Release of a free mass from a fastener that is mechanically constrained (e.g., safety wired) can be assumed to be contained. All contained fasteners can be classified non-fracture critical if failure does not result in a catastrophic hazard due to loss of structural integrity of the fastener or loss of a safety-critical function.

Table 2 – Summary of Non-Fracture Critical Contained Parts (full list in Appendix A)

PART NUMBER	QTY	PART DESCRIPTION
GLRG-LFPS-902	1	Propellant Management Device Sponge
GLRG-LFPS-903	1	Propellant Management Device Vanes
GLRG-LFPS-702	1	Propellant Manifold
GLRG-LFPS-201	1	Muffin Tin Assembly
PP3490-B	4	Thruster Assembly
2212-M04X09-LF002	1	Micro-pump Assembly
IMER00761	4	Thruster Valve Assembly
TBD	1	Flow Control Device
GLRG-LFPS-803	1	Pump Recirculation Block

5.1.2.2 Low-Risk Parts

If parts have large structural margins and other considerations that make failure from a pre-existing flaw extremely unlikely, they can be classified as low-risk. For a part to be classified low-risk, it shall meet the requirements of NASA-STD-5019 section 4.1.1.12. Low-risk fasteners and shear pins shall meet only the requirements of section 4.1.1.6(b). If any fasteners are considered low-risk, low- risk fastener check sheets and evaluations will be provided in the fracture control report to demonstrate the low risk for the various fasteners. This low-risk fastener analysis calculation will be performed upon completion of the fastener analysis and will require NASA MSFC approval.

5.1.3 Category 3: Fracture Critical Components

Per NASA-STD-5019 section 4.1.2.1.4, lines, fittings, and other pressurized components (equipment that is part of a pressurized system) shall be considered fracture critical if they contain hazardous fluids or if loss of pressurization would result in a catastrophic hazard. All pressurized hardware within the LFPS meet the NASA-STD-5019 definition for pressurized components.

5.1.3.1 Fracture Critical --- Pressurized Components

Table 3 - Fracture Critical - Pressurized Components

PART NUMBER	QTY	PART DESCRIPTION
GLRG-LFPS-901	1	Tank Bottom Structure
GLRG-LFPS-801	1	Tank Top Structure
GLRG-LFPS-802	1	Weld Work Detail
IMER0762	1	MSFC Bulk Propellant Isolation Valve
IMER02733	1	Propellant Service Valve
TE XP5-X-150PA-/V05/L3M/Z02	1	Propellant Tank Pressure Transducer

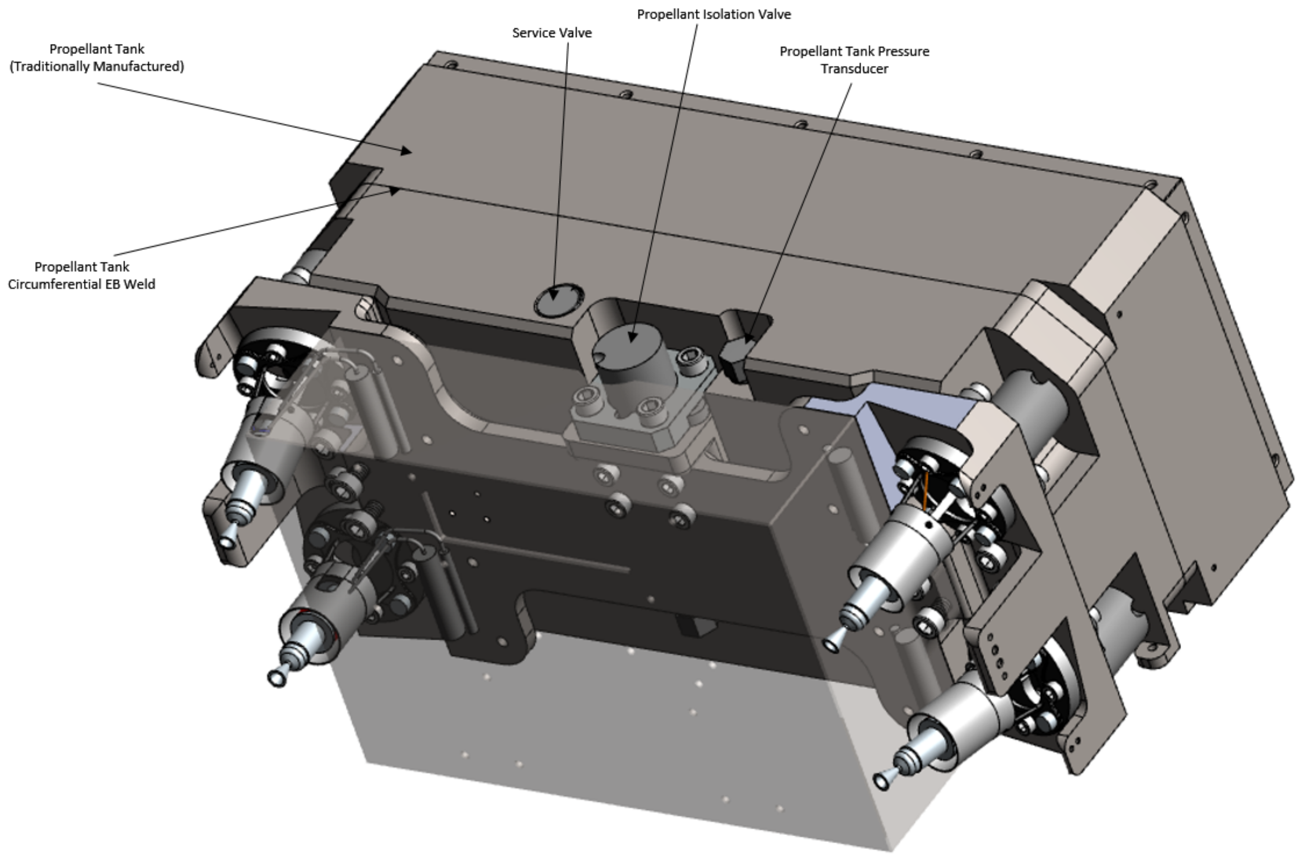

Figure 2 - Propulsion System Fracture Critical Components and Welds

Five (5) parts of the LFPS are loaded by pressure. Generally speaking, the following will be completed for these five parts (alternate approaches discussed in Section 8.0). The following components will be screened for flaws by surface NDE (penetrant inspection), and the raw material stock for the propellant tank will be screened for flaws by volumetric NDE prior to machining. Pre- and post-proof surface NDE of weld joints will also be performed. In addition, a Damage Tolerance Analysis will be prepared on the propellant tank and will be detailed in the Structural Analysis Report (LFPS-RPT-303) and Fracture Control Report (LFPS-RPT-316).

- Propellant Tank
- Propellant Tank Weldment
- Propellant Isolation Valve
- Propellant Service Valve
- Propellant Tank Pressure Transducer

All LFPS components will be proof tested (1.5 x MDP) during component level acceptance testing (ATP). After full system integration, system-level proof tests will be performed (1.1 x MDP of propellant tank) during the proto-flight test program (PTP) followed by leak test on all the components/weld that are loaded by pressure.

6.0 DESIGN, ANALYSIS, TEST, AND INSPECTIONS

6.1 Damage Tolerance Analysis and Tests

Safe-life verification, including DTA and/or tests, will be performed in accordance with NASA-STD- 5019. Any safe-life verification tests will be approved by the NASA MSFC FCB.

Where proof pressure testing is used on pressurized components, the proof test pressure shall be at least 1.5 x MDP.

Assemblies that may be candidates for proof testing to screen for flaws shall be mounted securely onto a test plate or fixture. For safety, a proof chamber or blast shield will be used during proof pressure testing. Leak tests shall be performed following proof pressure testing.

6.2 Non-Destructive Evaluations (NDE) and Inspections

All fracture critical parts will be subjected to proof testing and pre-/post-proof NDE to screen flaws. The selection of NDE methods and level of inspection will be based primarily on the safe-life acceptance requirements of the part. The NDE requirements as defined in NASA-STD-5009 will be followed, except that GT will perform NDE on fracture critical parts only. Additionally, GT will not etch sealing surfaces, other critical surfaces or highly polished surfaces, as etching will destroy those finishes. GT will not stop a surface cut operation to etch prior to cutting the final finished surface as this is not practical due to problems with setup and concentricity. Penetrant inspection will be performed per ASTM E1417, Type 1, Sensitivity Level 3. Use of initial crack sizes for geometries or NDE techniques not given in NASA-STD-5009 will require the approval of the NASA MSFC FCB.

6.3 Design

All parts will be designed to minimize the potential for cracks. Materials will be selected with the proper ductility and strength to withstand the specified loads and environments. Parts will have sufficient mass and material to withstand the subject loads. Edges and corners will be broken as needed to preclude stress risers and stress concentrations. A detailed stress analysis, thermal analysis, and damage tolerance analysis (if applicable) will be performed to confirm and ensure the adequacy of the design.

6.4 Materials

Materials for FC parts will be selected based on successful utilization in heritage hardware, where applicable, and to established selection criteria for new designs. NASGRO will be queried as applicable to confirm material properties as well as the crack-growth related properties. Grade “A” - Basis material will be used whenever possible. Structural properties shall be obtained from MMPDS (Metallic Materials Properties Development and Standardization, a MAPTIS replacement) when possible. A material usage agreement (MUA) will be generated and submitted to NASA MSFC that documents the criteria and rationale used for any material other than an A-Basis material.

6.5 Manufacturing

The processes used in the manufacturing of Lunar Flashlight Propulsion System will be those used for the similar or identical heritage hardware. These processes will be updated as needed to meet current requirements. Fracture critical components will be identified on the drawings and routers and will be subject to special handling, transportation and storage procedures, as applicable.

6.6 Quality Control

Quality Engineering will ensure that fracture critical components are properly identified on drawings and that these drawings contain the drawing notes and requirements applicable to fracture critical components. MSFC Quality Assurance will inspect all parts received at MSFC and will ensure that all documentation required for fracture critical components has been provided.

GT Quality Assurance will inspect all parts received at GT, in accordance with the LFPS Quality Memorandum of Agreement (MOA), and will ensure that all documentation required for fracture critical components is provided to MSFC.

7.0 DOCUMENTATION

7.1 Fracture Control Section

To certify fracture control compliance of a product, GT/MSFC will prepare the fracture control section as part of the Stress Analysis Report for review and approval by the NASA MSFC FCB. The Section will provide evidence that the system will meet the fracture control requirements defined in NASA- STD-5019. This fracture control report will include the following items:

- A description of the usage of the hardware.
- Sufficiently detailed drawings/sketches of the system will be furnished to show the general structure and function.
- A list showing the part name, part number, idealized dimensions used for analyses or tests, material, heat-treatment used, key location references, and the fracture control disposition (safe-life, test, acceptable durability, etc.) for all components. In addition, for fracture critical components, sketches, fracture mechanics properties, locations of maximum stress, loading spectra, and types of initial flaw will be provided. Ultimate margin of safety corresponding to the max stress at the flaw location should be provided for fracture critical parts. For non-fracture critical parts, a minimum ultimate margin of safety should be provided. Fracture critical parts that are limited life must be specifically noted. May use a list of accumulated loads, flaw screening results (NDE and proof testing) as applicable, damage tolerant testing results, and flaw acceptance rationale, as reference documents.
- Analyses and/or test data supporting the fracture control disposition will be furnished.
- The NDE and/or tests applied for fracture control purposes to each fracture critical part and to each low-risk part requiring specific inspection will be identified.

7.2 Supporting Data

Documents supporting the Fracture Control Report will be available for review by the NASA MSFC FCB. The documents required to support the acceptability of a fracture-critical part will include the following:

- Damage tolerance analysis or test data.
- Documentation of NDE, proof-tests, and leak tests.
- A description of the loading spectrum.
- Material crack growth properties used in the DTA.

8.0 ALTERNATE APPROACHES

In the event a particular requirement per NASA-STD-5019 cannot be met for a specific component, but an alternative or modified fracture control approach can be utilized to preclude a catastrophic hazard to the vehicle and its crew, the alternate approach shall be approved by the NASA MSFC FCB. The following alternate approaches are planned for the LFPS.

8.1 Service Valve

Due to its size and the risk of contamination, the service valve will forego dye penetrant inspection of its single circumferential weld. In order to alleviate concerns with bypassing this inspection, the following activities will be performed during qualification and acceptance:

- Valve design employs high factors of safety on system maximum expected operating pressure (>6X MEOP).
- Qualification unit will undergo burst testing to verify maximum design pressure.
- Pre- and post-weld coupons will be cross-sectioned to verify weld process.
- Leak test performed at component level.
- Proof test performed after installation into system.
- Leak test performed after system-level proof testing.
- Service valve cap, once installed, will keep weld in compression.

8.2 Isolation Valve

Due to the isolation valve geometry, radiographic inspection of the weld joint will not be performed. In lieu of this inspection, the following activities will be performed:

- Qualification unit will undergo burst testing to verify maximum design pressure.
- Pre- and post-weld coupons will be cross-sectioned to verify weld process.
- Pre-proof pressure testing dye penetrant inspection of weld joint.
- Proof test performed at 1.5X MDP.
- Post-proof dye penetrant inspection of weld.
- Component-level leak test.

8.3 Propellant Tank

Due to tank weld geometry, radiographic inspection of the propellant tank weld joint will not be performed. In lieu of this inspection, the following activities will be performed:

- A damage tolerance analysis will be performed to demonstrate that the weld is capable of withstanding significant damage. This analysis will show that failure doesn't occur using a starting flaw size that exceeds 90% of the thickness.
- Qualification unit will undergo burst testing to verify maximum design pressure.
- Pre- and post-weld coupons will be cross-sectioned to verify weld process. Coupons will also be inspected via radiography and surface dye penetrant.
- Post-weld dye penetrant inspection of tank and weld.
- Post-weld leak test.
- Proof test performed to 1.5X MDP.
- Post-proof dye penetrant inspection of tank and weld.
- Post-proof leak test.

9.0 FRACTURE CONTROL PROCESS

The fracture control process as detailed below will be followed:

1. **Damage Tolerance Analysis:** DTA will be performed on the propellant tank and tank weldment as defined in section 5.1.3.1.
2. **Raw Stock:** MSFC/GT will review the raw stock material certifications to check if volumetric Ultrasonic Test (UT) inspection was performed. Any relevant data will be noted in the fracture control report.
3. **EB Welding:** The weld vendor will develop the weld parameters specific the weld joint geometry and qualify the weld procedure. For the isolation valve, weld coupons will be made before and after each weld for metallographic verification of weld penetration. For the propellant tank, weld coupons will be made before and after each weld for radiographic and surface inspections, as well as metallographic verification of weld penetration.
4. **Pre-Proof Pressure Test Inspection of Welds:** Prior to proof test, a dye penetrant inspection will be performed on the isolation valve and propellant tank welds. No etching of the welds will be performed prior to inspection.
5. **Proof Pressure Test:** Proof pressure test (MDP x 1.5) will be performed on all fracture critical components and welds during hardware acceptance testing.
6. **Post-Proof Pressure Test Inspection of Welds:** Post-proof test, a dye penetrant inspection will be performed on the isolation valve and propellant tank welds. No etching of the weld will be performed prior to inspection.
7. **Burst Test:** A qualification unit for the service valve, isolation valve, and propellant tank will each be tested to burst pressure and then taken to failure to understand the failure mode of each component.

10.0 APPENDIX A

Table 4 - Fracture Control Classification for the Lunar Flashlight Propulsion System

Part Number	Name	Qty	Fracture Critical	Fracture Criticality Rationale	Damage Tolerance Analysis Required?	NDE Method
GLRG-LFPS-100	LFPS Top Assembly	1	Yes	Contains Fracture Critical Component(s)	No	N/A
GLRG-LFPS-200	LFPS Systems Assembly	1	Yes	Contains Fracture Critical Component(s)	No	N/A
GLRG-LFPS-300	LFPS System Components Assembly	1	Yes	Contains Fracture Critical Component(s)	No	N/A
GLRG-LFPS-400	LFPS Tank/Manifold Assembly	1	Yes	Contains Fracture Critical Component(s)	No	N/A
GLRG-LFPS-500	LFPS Tank Components Assembly	1	Yes	Contains Fracture Critical Component(s)	No	N/A
GLRG-LFPS-600	LFPS Tank Subassembly	1	Yes	Contains Fracture Critical Component(s)	No	N/A
GLRG-LFPS-900	Tank Bottom Subassembly	1	Yes	Contains Fracture Critical Component(s)	Yes	Dye Penetrant
GLRG-LFPS-901	Tank Bottom Structure	1	Yes	Pressurized Component	No	N/A
GLRG-LFPS-902	Propellant Management Device Sponge	1	No	Contained	No	N/A
GLRG-LFPS-903	Propellant Management Device Vanes	1	No	Contained	No	N/A
1203542-38-100-OF-B	Filter (10-micron)	1	No	Contained	No	N/A
	Fasteners	20	No	Contained	No	N/A
NAS1352N04-6	PMD Sponge Fasteners	4	No	Contained	No	N/A
NAS1352N02-3	PMD Vane Fasteners	6	No	Contained	No	N/A
2TLC-04C-0112	PMD Sponge Helicoils	4	No	Contained	No	N/A
2TLC-02C-0086	PMD Vane Helicoils	6	No	Contained	No	N/A
GLRG-LFPS-801	Tank Top Structure	1	Yes	Pressurized Component	No	N/A

GLRG-LFPS-802	Welding Work Detail	1	Yes	Pressurized Component	Yes	N/A
IMER00762	MSFC Bulk Propellant Isolation Valve	1	Yes	Pressurized Component	No	Dye Penetrant
GLRG-LFPS-701	Bulk Prop Iso Valve Bracket	1	No	Fail-safe/ Contained	No	N/A
IMER02733	Fill/Drain Valve	1	Yes	Pressurized Component	No	N/A
	Propellant Tank Heater	2	No	Exempt	No	N/A
	O-Rings	2	No	Exempt	No	N/A
OR01250396375	Iso Valve Inner O-Ring	1	No	Exempt	No	N/A
ARP-014-6375	Iso Valve Outer O-Ring	1	No	Exempt	No	N/A
	Fasteners	8	No	Contained	No	N/A
NAS1352N06H6	Iso Valve Fasteners	4	No	Fail-safe/ Contained	No	N/A
MS212-9F6-20	Helicoil	4	No	Contained	No	N/A
	Sensors	4	No	Exempt	No	N/A
TE XP5-X-150PA-/V05/L3M/Z02	Propellant Tank Pressure Sensor	1	Yes	Pressurized Component	No	N/A
ThorLabs TH10K	Propellant Tank Temperature Sensor	3	No	Exempt	No	N/A
GLRG-LFPS-700	LFPS Manifold Subassembly	1	No	Contained	No	N/A
GLRG-LFPS-702	Machined Manifold Structure	1	No	Contained	No	N/A
IMER00761	Thruster Valves	4	No	Contained	No	N/A
GLRG-LFPS-800	LFPS Recirculation Block Subassembly	1	No	Contained	No	N/A
GLRG-LFPS-803	Recirculation Block (RB)	1	No	Contained	No	N/A
JETAX0550550B	Fixed Orifice	1	No	Contained	No	N/A
	O-Rings	10	No	Exempt	No	N/A
OR01250396375	Thruster Valve Inner O-Ring	4	No	Contained	No	N/A
ARP-014-6375	Thruster Valve Outer O-Ring	4	No	Contained	No	N/A
AS-568A-K-011	Recirculation Block Inlet O-Ring	1	No	Contained	No	N/A
AS-568A-K-008	Recirculation Block Outlet O-Ring	1	No	Contained	No	N/A
	Fasteners	15	No	Contained	No	N/A
NAS1352N06H6	Thruster Valve Fasteners	8	No	Contained	No	N/A
NAS1352N04H6	Recirculation Block Fasteners	4	No	Contained	No	N/A
	Sensors	2	No	Exempt	No	N/A
TE XP5-X-150PA-/V05/L3M/Z02	Manifold Pressure Sensor	1	No	Contained	No	N/A
ThorLabs TH10K	Manifold Temperature Sensor	1	No	Exempt	No	N/A
	O-Rings	2	No	Exempt	No	N/A
OR01250396375	Pass-through Inner O-Ring	1	No	Exempt	No	N/A
ARP-014-6375	Pass-through Outer O-Ring	1	No	Exempt	No	N/A

	Fasteners	8	No	Contained	No	N/A
NAS1352N06H6	Pass-through Fasteners	4	No	Contained	No	N/A
NAS1352N08H6	Structural Fasteners	4	No	Contained	No	N/A
2212-M04X09-LF002	Pump	1	No	Contained	No	N/A
	Fasteners	6	No	Contained	No	N/A
NAS1352N04H6	Pump Fasteners	6	No	Contained	No	N/A
	Sensors	1	No	Contained	No	N/A
ThorLabs TH10K	Pump Temperature Sensor	1	No	Exempt	No	N/A
	Boards	3	No	Contained	No	N/A
GLRG-LFPS-401	Main Board	1	No	Contained	No	N/A
GLRG-LFPS-402	Sensor Connect Board	1	No	Contained	No	N/A
GLRG-LFPS-403	Driver Connect Board	1	No	Contained	No	N/A
GLRG-LFPS-404	Harnessing	1	No	Exempt	No	N/A
	Fasteners	30	No	Contained	No	N/A
93655A093	Connect Board Standoffs (6mm M3)	8	No	Contained	No	N/A
93655A222	Main Board Standoffs (22mm M3)	10	No	Contained	No	N/A
91828A211	M3 Nuts	2	No	Contained	No	N/A
91292A109	4mm M3 Screws	10	No	Contained	No	N/A
PP3490-B	Thrusters	4	No	Contained	No	N/A
GLRG-LFPS-201	Muffin Tin Structure	1	No	Contained	No	N/A
GLRG-LFPS-202	Thruster Covers	2	No	Non-flight	No	N/A
	Fasteners	20	No	Contained	No	N/A
NAS1352N04H4	Thruster Screws	16	No	Contained	No	N/A
NAS1352N08H10	Muffin Tin Screws	4	No	Contained	No	N/A

Note that all assemblies/sub-assemblies that contain fracture critical components are considered fracture critical. Since NDE is performed at component level, fracture critical assemblies/sub-assemblies show an NDE Method of “NA” or not applicable.