ATTACHMENT D

Intuitive Machines-1 Orbital Debris Assessment Report (ODAR)

IM-1-ODAR-1.0

This report is presented as compliance with NASA-STD-8719.14B, APPENDIX A, 4/25/2019

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DAS Software Version Used In Analysis: v3.1.0

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Revision:	Date:	Affected Pages:	Changes:	Author(s):
1.0	11/2/2020	All –Initial	DAS Software Results Orbit Lifetime Analysis	D. Morse

VERSION APPROVAL and/or FINAL APPROVAL*:

IM-1 / Nova-C
Orbital Debris Assessment Report (ODAR)

Approved by

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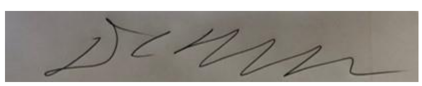
Prepared by



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* Approval signatures indicate acceptance of the ODAR-defined risk.

Contents

Self-assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14B:

A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14B.

Section	Status	Comments
4.3-1, Mission-Related Debris Passing Through LEO	COMPLIANT	
4.3-2, Mission-Related Debris Passing Near GEO	COMPLIANT	
4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon	COMPLIANT	
4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon	N/A	
4.4-3, Limiting the long-term risk to other space systems from planned breakups	COMPLIANT	
4.4-4, Limiting the short-term risk to other space systems from planned breakups	COMPLIANT	
4.5-1, Probability of Collision with Large Objects	COMPLIANT	
4.5-2, Probability of Damage from Small Objects	COMPLIANT	Based upon a 0.003 year mission duration (~1 day) follow by a Post Mission Disposal (PMD) or Trans-Lunar Injection (TLI) burn.
4.6-1, Disposal for space structures passing through LEO	COMPLIANT	
4.6-2, Disposal for space structures passing through GEO	N/A	
4.6-3, Disposal for space structures between LEO and GEO	N/A	
4.6-4, Reliability of post-mission disposal operations	COMPLIANT	
4.8-1, Collision Hazards of Space Tethers	N/A	

Assessment Report Format:

ODAR Technical Sections Format Requirements:

Intuitive Machines, LLC is a US company headquartered in Houston, TX. This ODAR follows the format in NASA-STD-8719.14B, Appendix A.1 and includes the content indicated as a minimum, in each of sections 2 through 8 below for the Nova-C Lunar mission. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

ODAR Section 1: Program Management and Mission Overview

Program/project manager: Troy LeBlanc, (Vice President for Control Center Business Unit, Intuitive Machines)

Senior Management: Steve Altemus (Chief Executive Officer, Intuitive Machines)

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination: The IM-1 mission will consist of a single Lunar lander, Nova-C, initially launched into Geostationary Transfer Orbit (GTO) with the following orbital parameters (inclination varies <1 degree depending on launch day):

- Apogee: 60,000 km
- Perigee: 185 km
- Inclination: 27 degrees

At this insertion orbit, Nova-C will spend approximately 19.2 hours being checked out before conducting a burn to place Nova-C into a TLI orbit with the following orbital parameters (inclination and apogee vary depending on launch day)::

- Apogee: 402,694km
- Perigee: 192 km
- Inclination: 27.4 degrees

If during checkout, unresolvable anomalies are detected which prevent mission completion, Intuitive Machines will work to deorbit Nova-C at a safe location.

Following TLI, the Nova-C spacecraft will be placed into a CIS-Lunar circular orbit with altitude of 100km by conducting a Lunar Orbit Insertion burn (inclination can vary with launch day).

- Apogee: 100 km
- Perigee: 100 km
- Inclination: -153 degrees

After ~12 lunar orbits, the Nova-C Lunar lander will conduct braking/descent burns in order to land on the lunar surface at approximately 25N 50W near Schroter's Valley and the crater Aristarchus.

Schedule of upcoming mission milestones:

- Delivery of Nova-C to Cape Canaveral for payload processing and integration: September 2021.
- Scheduled Launch Date: November 2021. Intuitive Machines' Nova-C Lunar lander will be launched upon a SpaceX Falcon 9

Mission Overview: IM-1 is a winner in the NASA Commercial Lunar Services Program (CLPS) to provide commercial lunar landing services for instruments and cargo. IM-1 is an autonomous lunar lander set to land near Schroeter's Valley and the crater Aristarchus in November 2021. IM-1 will carry multiple NASA and commercial payloads to the surface for scientific and engineering investigations. The primary surface mission will last approximately 14 days and end with the beginning of Lunar night. The surface mission will, if possible, continue during subsequent Lunar days, depending upon the survival of the Nova-C EPS though Lunar nights.

The IM-1 mission consists of a lunar lander that separates from a two stage Falcon 9 (F9) booster and is inserted into a unique Geostationary Transfer Orbit (GTO) with a perigee of 185km and apogee of 60,000km. Nova-C is a passive payload on the F9 until after separation. Nova-C will perform checkouts in this high GTO and then perform a TLI burn to head to the Moon. Nova-C will only remain in this GTO for ~19 hours and begin a 3-8 day Lunar transit culminating in a 24-36 hour Low Lunar Orbit (LLO) stay (all variable with launch day). This culminates in a descent and landing near Schroter's Valley on the Lunar Surface.

The IM-1 mission and Nova-C lander is designed to soft land on the lunar surface and disposal will be in situ on the Moon west of Schroter's Valley. Nova-C's helium pressurized methane and liquid oxygen propellant system will be vented upon touchdown just prior to a minimum of 14 days of surface operation after which the spacecraft will be operated till it is unresponsive. The spacecraft uses cold gas helium for reaction control in flight and this helium is drawn from the same reservoirs as the main propulsion system. This reaction control subsystem (RCS) will be passivated when the propulsion systems are vented on the surface. The spacecraft is powered by 3 battery boxes each featuring 72 P20 lithium ion batteries (216 cells total in the spacecraft) fed by SpectroLab solar cells and run to battery depletion in the Lunar night.

IM-1 is planning to feature one commercial deployed payload, EagleCAM, which will be a camera package released after landing to gently tumble onto the surface snapping pictures from several angles until it comes to rest. IM-1 is also planning 1-2 SPACEBIT Surface rovers. These surface rovers will be released once the Nova-C has touched down on the Lunar surface. This is NOT planned to be released during free flight. Additionally, there are deployable antennas, but they are not planned to deploy until IM-1 reaches the surface

Launch Vehicle and Launch Site: SpaceX Falcon 9 (F9) two stage Launch Vehicle. The launch site is Cape Canaveral, Florida. The Falcon-9 launch vehicle will transport only the Nova-C spacecraft into GTO.

Nova-C will be deployed into a GTO highly elliptical Earth orbit. Nova-C will be deployed from the F9 using a RUAG low shock, zero-debris separation system. Following deployment from the launch vehicle, the Nova-C will not deploy any subsystems until it has landed on the Lunar surface. The Nova-C spacecraft is expected to be deployed with the following orbital parameters:

Highest Apogee: 60,000 km

Highest Perigee: 185 km

Target Inclination: 27°

Mission Duration: The nominal lifetime of the spacecraft is approximately 21 days, with one day in Earth orbit, up to 7 days transit, 1 day in low lunar orbit, and landing and permanent rest on the lunar surface. The nominal active surface mission is baselined at 14 days of operations. The launch semester extends from October to December 2021 and launch day variance is controlled by adjusting the transit time and Low Lunar Orbit inclination at intercept of the Moon. For all launch windows the initial launch and 60,000 km Earth Orbit will be the same, and the Low Lunar Orbit, while differing in inclination, will be at the same altitude and all targeted for the exact same landing site. Actual long-term mission duration on the surface is heavily dependent upon the ability of the Nova-C lander to survive through Lunar night. IM will attempt to contact the spacecraft after lunar night, but it is not guaranteed to be functional thereafter.

ODAR Section 2: Spacecraft Description:

Physical description of the constellation: Basic physical dimensions of the Nova-C Lunar lander are 2.19 m x 2.385 m x 3.938 m high with a wet mass of approximately 1908 kg. The satellite is composed of the bus, three fixed, body-mounted solar panels, a liquid oxygen and liquid methane main propulsion system pressurized with Helium gas. The solar panels generate a maximum of 788 W of electric power which is stored in three 518 Wh COTS Li-Ion unpressurized 72-cell battery assemblies for a total electrical power storage capacity of 1554 Wh. The bus is 3-axis stabilized, employing redundant IMUs and star trackers for attitude knowledge and a dual-redundant cold gas reaction control system (RCS) using the pressurized Helium tank for attitude control.

The Nova-C satellite will be separated from the Falcon 9 launch vehicle using a RUAG separation system providing low shock, zero-debris actuation.

The Nova-C spacecraft is depicted in Figure 1 from various orientations.

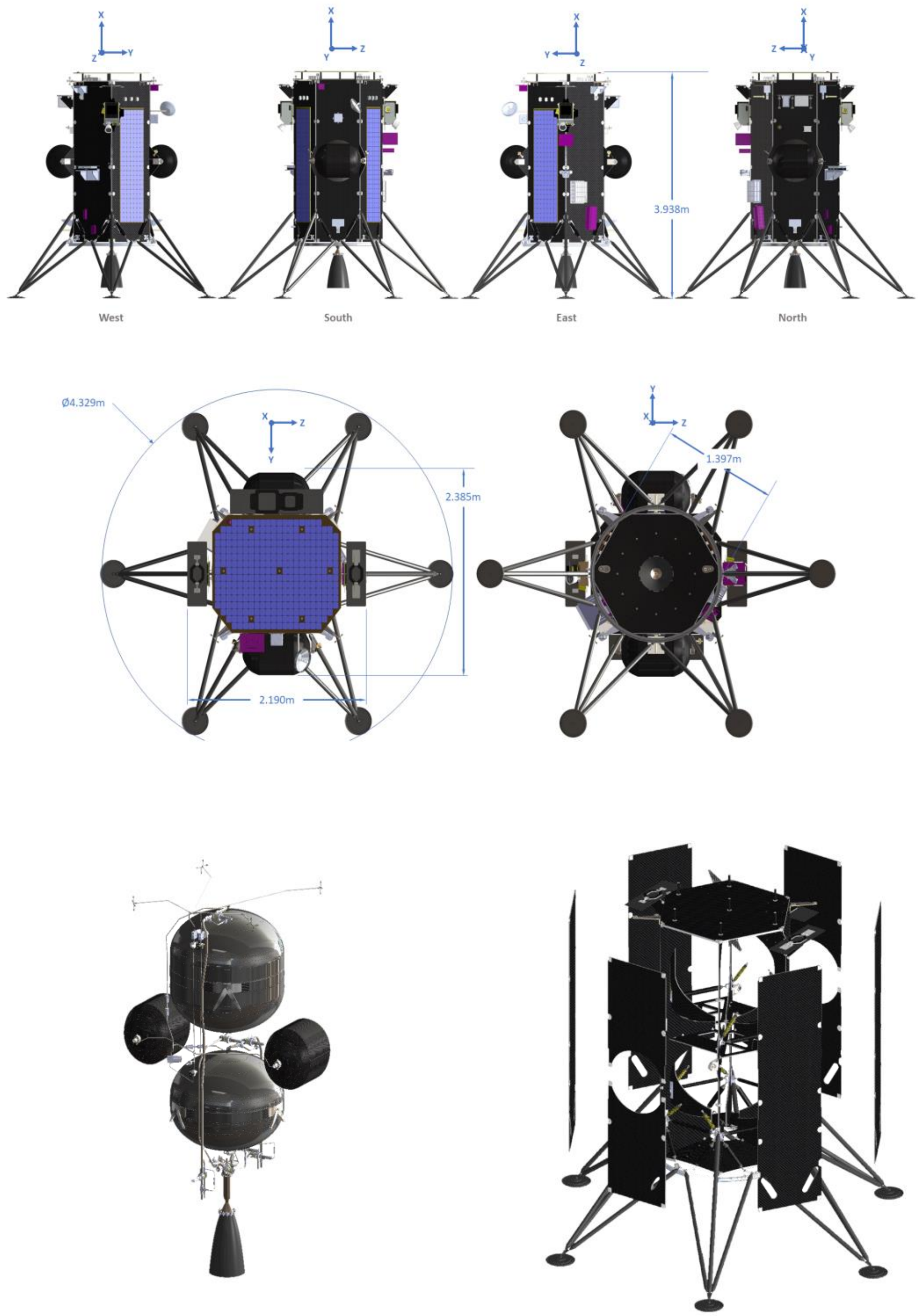

Figure 1 Nova-C Spacecraft Configuration

Total satellite mass at launch, including all propellants and fluids: 1908 kg.

Dry mass of satellites at launch: 624 kg. (excluding propellant and RCS/pressurizing gas)

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): Bi-propellant LOX and LCH4 with gaseous Helium as both pressurizer and cold gas RCS source.

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes:
845 kg of liquid methane gas (CH_4) at a maximum[1] pressure of 2.2 MPa
422 kg of liquid oxygen gas (O_2) at a maximum pressure of 2.2 MPa
17 kg of gaseous helium (He_2) at a maximum pressure of 41.3 MPa

Helium to be loaded at payload facility at the cape at flight pressure before moving to the launch pad at LC39A at Kennedy Space Center.

Cryogenic propellants to be loaded at the launch pad via umbilical at a loading pressure of 0.3 MPa. The pressure will be reduced prior to liftoff to ~0.03 MPa due to boiloff venting, and pressurized again in space prior to engine burns up to the Maximum Engine Operating Pressure (MEOP) of 2.2 MPa.

During acceptance testing (based on a tailored version of Space and Missile Systems Center Standard SMC-S-016), the propellant and Helium tanks and associated plumbing are proof tested to 1.25x MEOP. Also, qualification units for the propellant and Helium tanks are proof tested to 1.50x MEOP while the plumbing is qualification tested to 2.0x MEOP.

Fluids in Pressurized Batteries: None

The Nova-C satellite uses three 72-cell unpressurized standard COTS Lithium-Ion battery modules. Each module will be configured with nine (9) parallel strings of eight (8) Li-ion cells in series to provide a nominal bus voltage of 28 VDC (ranging from 27-33.6 VDC). The total capacity energy capacity per spacecraft is 1554 W-h. The battery cells have a mechanical overcharge disconnect and a vented leak-before-burst architecture, and thus do not pose an explosion risk even if overcharge conditions were to occur.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: The Nova-C spacecraft attitude will be 3-axis stabilized using a dual-redundant, cold-gas reaction control system (RCS).

[1] Boiloff venting will be conducted prior to liftoff, with the pressure expected to be reduced to 0.03 MPa.

- A *solar pointing mode* that is optimized for solar power generation from the satellite. The spacecraft's top deck solar panel will be oriented towards the sun.
- A *propulsion vector tracking mode*, which will allow the satellite +X axis (as shown in Figure 1) to be directed as necessary to support propellant burns, including descent and landing.
- A *communications HGA tracking mode,* that aligns the HGA boresight towards the Earth's surface to support long range communications

Description of any range safety or other pyrotechnic devices: None.

The Nova-C satellite will be released from the Falcon 9 launch vehicle using a RUAG low shock, zero-debris deployment system. No other mechanism will be deployed until the Nova-C Lunar lander is on the Lunar surface.

Description of the electrical generation and storage system:
The Nova C Lunar Lander power system will consist of:

- Photovoltaic Solar Panels (large top deck w/ 325 cells and two body panels w/ 168 cells each)
- Three Lithium Ion Batteries for energy storage
- 28 V unregulated system bus with a range between 27 V - 33.6 V
- Peak Power Point Tracking regulation system
- A Power Control and Distribution Unit will regulate power from the solar panels, charge the battery and distribute power to downstream loads.

Standard COTS Lithium-Ion battery cells are charged before payload integration and provide 1554 W-h of electrical energy during the eclipse portions of the satellite's mission. The SpectroLab solar cells generate a maximum on-orbit power of approximately 788 W (solar cell output degradation over mission life is not significant for such a short mission duration).

Identification of any other sources of stored energy not noted above: None

Identification of any radioactive materials on board: None

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations:

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material: None while the spacecraft is in orbit. The following paragraphs discuss planned releases on the Lunar surface. However, such releases do not result in any risk of orbital debris collisions with any other space systems.

IM-1 will feature 1-2 SPACEBIT surface rovers. These each feature enclosures that have two release mechanisms: a solenoid activated trap door on the enclosure, and an electromechanically released holding bolt on the rover itself.

IM-1 is also carrying EagleCAM which is a deployable camera unit that will tumble to the lunar surface just prior to landing to take photos of the lander at touchdown. It will utilize a commercially available nanoracks cubesat deployer and will not be fired until IM-1 is suborbital and nearly at the surface (~30 meters before touchdown)

Rationale/necessity for release of each object: Scientific data collection and lander performance data collection. (not applicable for the purpose/concerns of this ODAR)

Time of release of each object, relative to launch time: ~30 m above the Lunar surface and on the Lunar surface. 1-2 weeks after launch. (not applicable for the purpose/concerns of this ODAR)

Release velocity of each object with respect to spacecraft: < 1 m/s (not applicable for the purpose/concerns of this ODAR)

Expected orbital parameters (apogee, perigee, and inclination) of each object after release: N/A. Lunar surface.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): < 1 minute (not applicable for the purpose/concerns of this ODAR)

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v3.1.0)
4.3-1, Mission Related Debris Passing Through LEO: COMPLIANT
4.3-2, Mission Related Debris Passing Near GEO: COMPLIANT

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

Potential causes of spacecraft breakup during deployment and mission operations: There is no credible scenario that would result in spacecraft breakup during normal deployment and operations.

Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion:

Lithium Ion Batteries:

There are 3 conditions that could potentially put the battery module into a hazardous condition. These are:

- Overcharge
- high temperatures
- short circuiting.

Further detail about each of these failure mechanisms is described in the "Supporting Details and FMEA Rationale" following requirement 4.4-1.

Propulsion and RCS Systems:

The IM-1 Propulsion system can suffer the following failure modes:

- over-pressurization
- material failure
- valve failure
- ignition failure

Further detail about each of these failure mechanisms is described in the "Supporting Details and FMEA Rationale" following requirement 4.4-1.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions: There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:

- Three (3) Lithium Ion Batteries (72 Li cells per battery) – IM-1 will be operated into the lunar night and will discharge batteries in about 9 hours after lunar night begins. It is expected the batteries will freeze. Charging during the subsequent lunar day is possible, but degradation of the entire lander is expected. IM will attempt to contact the spacecraft on as many subsequent days as possible after the 14-day lunar night.
- Propulsion – IM-1 will vent residual fuel and oxidizer ~30 minutes after landing to passivate the main propulsion system. Prior to end of mission the remaining gaseous helium will be vented to passivate the RCS and Pressurization system.

Rationale for all items which are required to be passivated, but cannot be due to their design: While the primary mission ends at the conclusion of the first Lunar day on the Lunar surface, the official end of mission (EOM) will occur when the electrical power system (EPS) is not longer sufficient to support Lunar surface operations during a Lunar day. Since there is scientific value to collect and report as much data as possible and no credible risk of an explosion on the Lunar surface creating debris that would enter Lunar orbit, the value of collecting scientific data far outweighs any risks.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: *"For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449)."*

Compliance statement:

Required Probability: 0.001.

Expected probability: <0.001; COMPLIANT.

Supporting Rationale and FMEA details:

Battery explosion FMEA:

Each individual 18650 contains two devices to prevent catastrophic damage to the battery assembly. These are the current disconnect system and the cell vent system. These systems are physically incorporated into the design of each individual battery and functions throughout the lifetime.

Overcharging:

In the event of battery overcharge, cell qualification demonstrated the current disconnect system to activate and avoid an explosion. This overcharge protection was shown to activate in different charging rates at ambient temperatures and at both the cell and module level tests.

Short circuiting:

A short circuit can occur at the individual battery level or at the module level. Qualification showed that in both cases the current disconnect system and the cell vent system activated. This caused venting of the batteries but not a catastrophic explosion. In cell level shorting tests the effected cell vented as well. There was no thermal runaway or cell failure propagation within the battery module. The risk of short circuit is further mitigated with the use of double insulations techniques throughout the battery module.

High temperature:

The exact temperature at which catastrophic failure of the battery is in excess of 120 C. Data on the exact temperature at which the battery undergoes catastrophic damage is not available from the manufacturer. The battery operational temperature range of +5C to

+40C and the mission design, attitude timeline and thermal system are being designed to stay within these bounds.

It is also noted that mechanically crushing the battery such that the separator is damaged would lead to internal shorts and create temperature and pressures that cause venting of the batteries and possible explosion.

The battery cells are contained in three aluminum battery assembly boxes. These battery boxes are constructed of 1/8" thick 6061 aluminum sheet. In the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small battery cells is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the spacecraft due to the lack of penetration energy to the multiple enclosures surrounding the batteries.

Propulsion system explosion FMEA:

Over-pressurization:

For pressure related failures the tanks and plumbing manifolds are single fault tolerant to pressure levels above the Maximum Expected Operating Pressure (MEOP). A non-fragmenting burst disk is installed on each pressurized system (one each for LCH4 and LOX and helium, and one on each of two RCS branches) that will burst to relieve pressure when above MEOP but below the burst pressure for the associated system. A relief valve is installed downstream of each burst disk to limit the depressurization following a bust disk rupture to approximately the MEOP of that system. This relief valve will continue to limit the pressure rise in the system if required. For the RCS manifolds, the Nova-C flight software will monitor line pressure and will terminate helium flow to one or both branches due to unexpected pressure increases, providing some dual fault coverage. Additionally, the Nova-C flight software will also monitor the propellant tank pressures and will terminate helium flow to those tanks due to unexpected pressure increases. Since the propellant tanks can generate their own pressure the flight software intervention provides an additional layer of fault protection for the regulator fail open scenario but not all tank over-pressurization scenarios. While not guaranteed for rapid rise cases, human operators can intervene with manual valve operations for nominal system valves either through the RCS system for helium, or with vent and engine valves for the propulsion system if the off nominal case is slow enough to be seen in telemetry.

Material failure:

Tanks, plumbing, and engine components have potential for random burst or burn-through, but this is being mitigated by design and by extensive hotfire testing. During acceptance testing, the propellant and helium tanks will be proof tested to 1.25x expected pressures, with qualification hardware being tested to 1.5x MEOP. Additionally, the installed plumbing will be proofed 1.25x MEOP during vehicle build, with qualification hardware tested to 2.0x MEOP. The IM-1 engine design will be qualified for 4x life under environments beyond that expected in flight before the design is certified to fly. Pressure retaining components in the engine will be proofed to 1.25x during acceptance and 1.5x during qualification testing.

Valve failures:

Valve failures in some cases can threaten the ability to operate the engine or attitude control via RCS. If these valves fail for the main propulsion, the biggest risk is an inability to continue to maneuver the spacecraft in orbit or lunar flight with the worst case that IM-1 is stranded in the orbit the failure occurs in. As described for the overpressure case, short of the loss of maneuvering, there are still multiple ways to relieve pressure or offload gasses if needed. For RCS, there are redundant branches of RCS thruster quads and the spacecraft can be controlled in orbital flight for contingency operations with one branch available.

Ignition failures:

IM-1 features two igniter coils in the main engine that fire for every burn to initiate a maneuver. While both run every event, any one igniter is sufficient to start a burn.

Requirement 4.4-2: **Design for passivation after completion of mission operations while in orbit about Earth or the Moon:**

'Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post-mission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450)."

Compliance statement:

Nova-C IM-1 features a pressurized liquid methane and liquid oxygen main propulsion system. Each fluid tank features a drain valve for end of mission venting to release and boiloff residual propellant and pressurant. After lunar landing the propulsion system is no longer required and the valves are planned to be opened early in the surface operations timeline. In the event of a valve failure, the propellants can also vent via the main engine valves and nozzle assembly as a redundant plumbing path. There are no concerns of hazards to other spacecraft by this venting since it takes place on the surface of the Moon at zero velocity. The spacecraft will be static on the lunar surface so control is not an issue during the venting operation.

Nova-C IM-1 also uses pressurized helium for the reaction control system and pressurization of the propellant system. By landing, this system's pressure will have dropped by a factor of 20 since the helium is filling empty space in the propellant tanks and also significantly expended for RCS maneuvering. This system is no longer required on the lunar surface and can be vented through the RCS valves and plumbing by end of mission.

IM-1 will be operated into the lunar night and will discharge batteries in about 9 hours after lunar night begins. It is expected the batteries will freeze. Charging during the subsequent lunar day is possible, but degradation of the entire lander is expected. IM will attempt to contact the spacecraft on as many subsequent days as possible after the 14-day lunar night.

Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups: Compliance statement: This requirement is not applicable. There are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups: Compliance statement: This requirement is not applicable. There are no planned breakups.

ODAR Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v3.1.0, and calculation methods provided in NASA-STD-8719.14B, section 4.5.4):

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit:

"For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506)."

Large Object Impact and Debris Generation Probability: 0.000000025; COMPLIANT. Based upon the worst-case scenario where the Nova-C is launched into the GTO orbit and must passively deorbit into he atmosphere due to failures.

Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:

"For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and

meteoroids sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).”

Small Object Impact and Debris Generation Probability: Not applicable; following launch, the Nova-C spacecraft will only be in Earth orbit for ~19 hours[2] before either heading towards a Lunar orbit or making the decision to deorbit due to detected failures that would prevent safe completion of the mission. In the worst-case scenario, failures during launch would prevent either a TLI or PMD burn. In this case orbital disposal by atmospheric entry would occur within 3 months and does not require a specific spacecraft orientation and drag state to meet the disposal requirements. Therefore, no element or component of the spacecraft system is required to complete post-mission operations.

Out of an abundance of caution, an analysis was conducted based upon the assumption of a mission duration of 0.003 years (slightly more than the planned 19 hours) followed by a PMD burn. The surface of interest was the two propellant tanks but an ultra-conservative assumption of a 5 m^2 critical surface was analyzed and the aural density of the tank was based upon the thinnest tank wall thickness. Even with all of these conservative factors, the DAS software estimated a probability of collision of 0.00663 which is COMPLIANT.

Identification of all systems or components required to accomplish any post-mission disposal operation, including passivation and maneuvering: As described previously, the Nova-C will achieve atmospheric reentry within 3 months under worst-case failure conditions, therefore no subsystems are required for deorbit. However, a propulsion maneuver is planned within ~19 hours of launch to either transit the Nova-C to Lunar orbit or to deorbit Nova-C. The subsystems required to achieve this propulsion maneuver are:

- Attitude Control System (single fault tolerant)
- Reaction Control System (single fault tolerant for the regulator and valve-controlled thruster branches, not for the tanks and manifold)
- Main Propulsion System (dual redundant igniters)
- Flight Computer (single string but with watchdog timers to reset in case of SEE)
- Electrical Power Subsystem (single fault tolerant to battery failure)

ODAR Section 6: Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

6.1 Description of spacecraft disposal option selected: Under nominal operational conditions, the Nova-C Lunar lander will be abandoned on the Lunar surface. If the

[2] The DAS3.0 user guide states that requirement 4.5-2 is not applicable for launch vehicles because of the short mission life (less than 24 hours). Given the planned mission profile which would have the Nova-C either leave Earth orbit to head towards Lunar orbit or conduct a PMD maneuver within ~19 hours of launch would suggest this requirement is similarly not applicable.

mission cannot continue from the GTO insertion orbit, a PMD maneuver will be attempted. Under worst-case conditions, the Nova-C will deorbit naturally into the Earth's atmosphere within 3 months of launch.

6.2 Plan for any spacecraft maneuvers required to accomplish post-mission disposal: As described above, if the Nova-C is determined after launch to be incapable of safely completing it's mission, it can be commanded to employ up to 3000 m/s of delta-V to conduct a PMD burn to assure that atmospheric reentry occurs in a location that is safely away from human inhabitants.

6.3 Calculation of area-to-mass ratio after post-mission disposal, if the controlled reentry option is not selected:

Spacecraft Mass (Dry): 624 kg

Cross-sectional Area: 6.316 m^2

(Calculated by DAS 3.1.0). Area to mass ratio: 6.316/624 = 0.010122 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v3.1.0 and NASA-STD-8719.14B section): Requirement 4.6-1. Disposal for space structures passing through LEO:

"A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

a. Atmospheric reentry option: Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission."

Analysis: The Nova-C satellites' method of disposal is COMPLIANT using method "a." In the worst-case orbit altitude of 180 x 60000 km near-circular orbit, the passive deorbit time is 0.246 years after launch with orbit history as shown in Figure 2. It should be noted, that if accounting for the area to mass ratio based upon the wet-mass of the Nova-C satellite, the passive deorbit time only increases to 0.268 years. Every attempt would be make to conduct either a TLI or PMD burn. In the event that is not possible, propellant and Helium would be vented to accelerate deorbit and minimize risk of accidental explosion.

Under planned launch conditions, Nova-C will transit to Lunar orbit, land on the Lunar surface and never cause any form of orbital debris or human casualty risk.

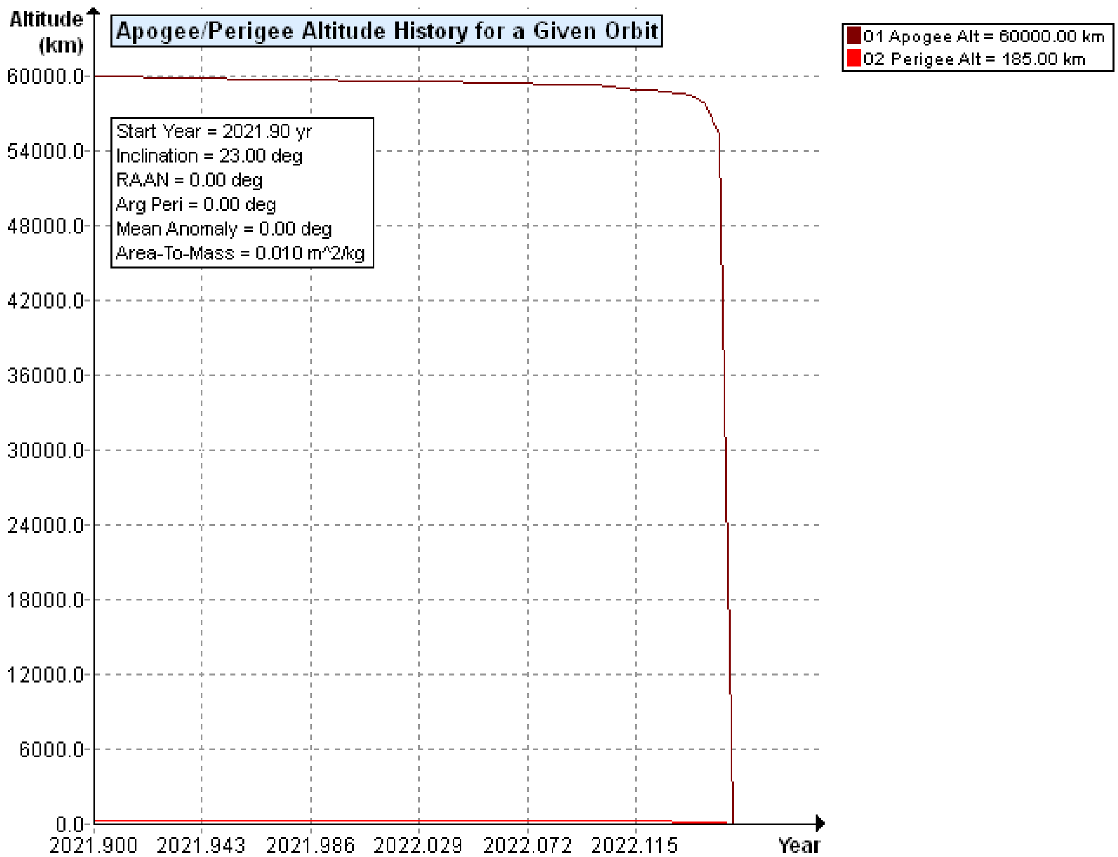

Figure 2 Nova-C Orbit History – at GTO Insertion Orbit of 185 km x 60000 km, 27-deg Inclination

Requirement 4.6-2. Disposal for space structures near GEO:
Analysis is not applicable.

Requirement 4.6-3. Disposal for space structures between LEO and GEO: Analysis is not applicable.

Requirement 4.6-4. Reliability of Post-mission Disposal Operations:
The probability that either a TLI or PMD burn can be conducted within the first 19 hours after launch has been estimated to be at least 90%.. The satellite will reenter passively without post mission disposal operations within the allowable timeframe.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards:

Assessment of spacecraft compliance with Requirement 4.7-1: Requirement 4.7-1. Limit the risk of human casualty:

"The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:
a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000).
b) For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 Joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.
c) For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000)."

Summary Analysis Results: DAS v3.1.0 reports that the Nova-C Lunar lander, when conducting an uncontrolled atmospheric reentry, poses a risk of human casualty of 1:1600, which translates to a probability of human casualty of 0.000625. The NASA requirement for limiting the risk of human casualty is 1:10,000, which translates to a probability of human casualty of 0.0001. However, for controlled reentry[3], the NASA requirement states that (from 4.7-1c above) "the product of the probability of failure of the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001". In order to meet this requirement, the Nova-C Lunar Lander must have a probability of failure of the reentry burn of not greater than 0.15, which translates to a deorbit reliability of at least 85%. Furthermore, since Nova-C poses no risk to human casualty once it has completed its Trans-Lunar Injection burn, the actual requirement is that the probability that Nova-C cannot conduct either a TLI burn or a PMD burn cannot exceed 0.15 (or 15%).

$P_{\text{Human Casualty (controlled)}} = P_{\text{Failed PFM or TLI burn}} * P_{\text{Human Casualty (uncontrolled)}}$

$P_{\text{Human Casualty (controlled)}} = 0.15 * 0.000625 = 0.00009375 < 0.0001$

Intuitive Machines has evaluated the probability of conducting either a TLI burn or a PMD burn to be significantly greater than 90% based on a basic evaluation of single point and redundant failure paths in the critical systems needed to do a pointed and controlled engine firing. This was done with very basic component reliability data from the space industry (electronics) and nuclear industry (valves). This is helped in a large part due to the short timescale Nova-C is at risk for these failures, however, even an order of magnitude change of these durations (days instead of hours) does not reduce reliability significantly and can allow for re-targeting and retries for critical burns outside of the

[3] The Nova-C has the ability to conduct a controlled re-entry in the case where a Trans-Lunar Injection burn cannot be accomplished with 3000 m/s of Delta-V.

mission timeline in Earth orbit. The remaining risk is infant/launch mortality and these are being mitigated through extensive testing. Nova-C will undergo environmental stress screening prior to launch, including random vibrations, shock and thermal vacuum cycling of components and subassemblies; and over 6800 seconds of hot fire engine testing (cumulatively ~7x the nominal mission duration requirements on the engine and supporting components), which should uncover most infant mortality situations. For components that are zero fault tolerant in the engine burn critical path, high quality components are being utilized with radiation tolerance (flight computer) and aerospace grade quality (cryogenic ball valves). Also, the Nova-C Lunar lander does not depend upon any deployment events in order to achieve either a TLI or PMD burn. Based upon the analysis above, that translates to Nova-C being COMPLIANT with requirement 4.7-1c. The following paragraphs highlight the key subsystems required to complete a TLI or PMD burn and describe fault tolerant features.

Command and Telemetry: IM-1 features two low rate S-band transponders for uplink and downlink, and two more high rate downlink transmitters. This makes command uplink single fault tolerant, and downlink capability three fault tolerant. Helical antennas are placed around the spacecraft for near-omni coverage. The flight computer does not have a backup but does feature watchdog timers to facilitate re-sets in the event of a Single Event Upset (SEU). In a stable orbit the team can recover the spacecraft from defaults after a reset event and then proceed with disposal operations. Any problems arising from programming errors will be mitigated by software testing on the ground.

Power: The Nova-C power controller is managed by an FPGA with redundant processing capabilities in the event of a SEU. Spacecraft batteries are single fault tolerant for most mission phases at nominal load. There are some launch windows that feature an eclipse in GTO that requires three batteries to survive nominally, but the spacecraft loads could be reduced if it was known the vehicle had to be passivated or de-orbited early at the expense of payloads and heater equipment. This would all be the judgement of operations teams. Furthermore, there are three solar panels of varying capacity around the vehicle. In a single Earth orbit the spacecraft is in sunlight a minimum of 14 hours out of 20 (varies by launch day), so the spacecraft should have plenty of power positive periods in which to manage failures and alternative end of mission actions.

Maneuvering Capability: The main engine is a singular unit so there are mechanical single points of failure that are being mitigated by ground testing (IM currently hot fires the engine prototypes about once a month and will continue to do so till the flight), but the engine does feature a redundant set of igniters to help ensure the propellants can be fired for TLI or disposal burn if required.

Attitude Determination and Control: IM-1 features two redundant and physically separated navigation pods each with its own IMU and star tracker making navigation measurements required to maintain attitude single fault tolerant. Cold helium reaction controls are split among two redundant branches each featuring two thrust quads for a total of four quads on the vehicle. Either branch is sufficient for control in Earth orbit should valves or regulators on one branch fail.

This represents an acceptable casualty risk, as calculated with DAS's modeling capability.

The DAS Output Summary Follows:

==============
Project Data
==============

INPUT

Space Structure Name = NOVA-C
Space Structure Type = Payload

Perigee Altitude = 185.000000 (km)
Apogee Altitude = 60000.000000 (km)
Inclination = 0.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.010000 (m^2/kg)
Start Year = 2021.900000 (yr)
Initial Mass = 1000.000000 (kg)
Final Mass = 615.000000 (kg)
Duration = 1.000000 (yr)
Station Kept = False
Abandoned = False
PMD Perigee Altitude = 10.000000 (km)
PMD Apogee Altitude = 60000.000000 (km)
PMD Inclination = 0.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Suggested Perigee Altitude = 185.000000 (km)
Suggested Apogee Altitude = 60000.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

Released Year = 2022 (yr)
Requirement = 61
Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
10 23 2020; 15:19:31PM *********Processing Requirement 4.7-1
Return Status : Passed

***********INPUT****
Item Number = 1

name = NOVA-C
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 615.000000
Thermal Mass = 615.000000
Diameter/Width = 2.385000
Length = 3.938000
Height = 2.190000

name = Thrust Chamber and Nozzle Assembly
quantity = 1
parent = 1
materialID = 47
type = Cylinder
Aero Mass = 13.200000
Thermal Mass = 13.200000
Diameter/Width = 0.410000
Length = 0.200000

name = Gimbal Actuators
quantity = 2
parent = 1
materialID = 16
type = Cylinder
Aero Mass = 1.355000
Thermal Mass = 1.355000
Diameter/Width = 0.190000
Length = 0.090000

name = LOX Tank
quantity = 1
parent = 1
materialID = 16
type = Sphere
Aero Mass = 51.560001
Thermal Mass = 51.560001
Diameter/Width = 1.080000

name = LCH4 Tank
quantity = 1
parent = 1
materialID = 16
type = Sphere
Aero Mass = 63.689999
Thermal Mass = 63.689999
Diameter/Width = 1.210000

name = GHe Tanks
quantity = 2
parent = 1
materialID = 37
type = Cylinder
Aero Mass = 39.090000
Thermal Mass = 39.090000
Diameter/Width = 0.850000
Length = 0.580000

name = Battery
quantity = 3
parent = 1
materialID = 8
type = Box
Aero Mass = 4.410000
Thermal Mass = 4.410000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.200000

name = Super-structure
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 66.440002
Thermal Mass = 66.440002
Diameter/Width = 1.400000
Length = 2.900000
Height = 1.400000

name = Closeout Bay A1 Panel
quantity = 1
parent = 1
materialID = 8

type = Flat Plate
Aero Mass = 14.361000
Thermal Mass = 3.951000
Diameter/Width = 0.710000
Length = 1.450000

name = Hemi Ant
quantity = 2
parent = 9
materialID = 8
type = Cylinder
Aero Mass = 0.080000
Thermal Mass = 0.080000
Diameter/Width = 1.450000
Length = 0.710000

name = MEC
quantity = 1
parent = 9
materialID = 8
type = Box
Aero Mass = 0.840000
Thermal Mass = 0.840000
Diameter/Width = 0.150000
Length = 0.230000
Height = 0.075000

name = MEC Power Prot.
quantity = 1
parent = 9
materialID = 8
type = Box
Aero Mass = 1.050000
Thermal Mass = 1.050000
Diameter/Width = 0.100000
Length = 0.130000
Height = 0.060000

name = HGA Dish & Filter
quantity = 1
parent = 9
materialID = 8
type = Flat Plate
Aero Mass = 1.140000
Thermal Mass = 1.140000
Diameter/Width = 0.130000

Length = 0.260000

name = LN1 Payload
quantity = 1
parent = 9
materialID = 8
type = Box
Aero Mass = 2.850000
Thermal Mass = 2.850000
Diameter/Width = 0.100000
Length = 0.200000
Height = 0.100000

name = ROLSES ANT BOX
quantity = 1
parent = 9
materialID = 8
type = Box
Aero Mass = 1.370000
Thermal Mass = 1.370000
Diameter/Width = 0.080000
Length = 0.200000
Height = 0.080000

name = RFMG
quantity = 1
parent = 9
materialID = 8
type = Box
Aero Mass = 3.000000
Thermal Mass = 3.000000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.200000

name = Closeout Bay A2 Panel
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 3.150000
Thermal Mass = 3.150000
Diameter/Width = 0.710000
Length = 1.450000

name = Closeout Bay B Panel

quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 15.648000
Thermal Mass = 7.323000
Diameter/Width = 0.710000
Length = 2.900000

name = Comm and Track Controller
quantity = 1
parent = 18
materialID = 8
type = Box
Aero Mass = 3.780000
Thermal Mass = 3.780000
Diameter/Width = 0.120000
Length = 0.210000
Height = 0.060000

name = Thermo Couple Box
quantity = 3
parent = 18
materialID = 8
type = Box
Aero Mass = 0.473333
Thermal Mass = 0.473333
Diameter/Width = 0.080000
Length = 0.160000
Height = 0.050000

name = RF Switch
quantity = 3
parent = 18
materialID = 8
type = Box
Aero Mass = 0.225000
Thermal Mass = 0.225000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = SCALPSS Camera
quantity = 1
parent = 18
materialID = 65

type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.070000
Length = 0.100000
Height = 0.050000

name = NDL Sensor Head
quantity = 1
parent = 18
materialID = 8
type = Box
Aero Mass = 2.350000
Thermal Mass = 2.350000
Diameter/Width = 0.240000
Length = 0.350000
Height = 0.170000

name = Main engine solenoid
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.000000
Thermal Mass = 1.000000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.200000

name = NavPod TRN/HRN (2x separate assemblies)
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 7.543000
Thermal Mass = 2.213000
Diameter/Width = 0.260000
Length = 0.350000
Height = 0.170000

name = IMU
quantity = 2
parent = 25
materialID = 8
type = Cylinder
Aero Mass = 0.620000

Thermal Mass = 0.620000
Diameter/Width = 0.080000
Length = 0.090000

name = Star Tracker
quantity = 2
parent = 25
materialID = 8
type = Box
Aero Mass = 1.340000
Thermal Mass = 1.340000
Diameter/Width = 0.100000
Length = 0.250000
Height = 0.100000

name = Laser
quantity = 2
parent = 25
materialID = 8
type = Box
Aero Mass = 1.670000
Thermal Mass = 1.670000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = LRF Receiver
quantity = 2
parent = 25
materialID = 8
type = Box
Aero Mass = 0.590000
Thermal Mass = 0.590000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = DC-DC Converter
quantity = 2
parent = 25
materialID = 8
type = Box
Aero Mass = 0.270000
Thermal Mass = 0.270000
Diameter/Width = 0.100000
Length = 0.100000

Height = 0.100000

name = Optical Camera
quantity = 2
parent = 25
materialID = 8
type = Cylinder
Aero Mass = 0.840000
Thermal Mass = 0.840000
Diameter/Width = 0.238000
Length = 0.107000

name = Closeout Bay C Panel
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 30.807001
Thermal Mass = 7.812000
Diameter/Width = 0.710000
Length = 2.900000

name = Payload Controller
quantity = 1
parent = 32
materialID = 8
type = Box
Aero Mass = 1.050000
Thermal Mass = 1.050000
Diameter/Width = 0.102000
Length = 0.127000
Height = 0.060000

name = Thales Radio
quantity = 2
parent = 32
materialID = 8
type = Box
Aero Mass = 0.925000
Thermal Mass = 0.925000
Diameter/Width = 0.150000
Length = 0.185000
Height = 0.105000

name = Igniter Control Box
quantity = 1

parent = 32
materialID = 8
type = Box
Aero Mass = 0.525000
Thermal Mass = 0.525000
Diameter/Width = 0.127000
Length = 0.207000
Height = 0.115000

name = ROLSES ANT BOX - 2
quantity = 1
parent = 32
materialID = 8
type = Box
Aero Mass = 1.370000
Thermal Mass = 1.370000
Diameter/Width = 0.080000
Length = 0.200000
Height = 0.080000

name = NDL Chassis
quantity = 1
parent = 32
materialID = 8
type = Box
Aero Mass = 13.100000
Thermal Mass = 13.100000
Diameter/Width = 0.240000
Length = 0.350000
Height = 0.170000

name = SCALPSS Camera - 2
quantity = 1
parent = 32
materialID = 65
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.070000
Length = 0.100000
Height = 0.050000

name = EagleCam
quantity = 1
parent = 32
materialID = 8

type = Box
Aero Mass = 5.000000
Thermal Mass = 5.000000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.200000

name = Closeout Bay D1 Panel
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 26.199999
Thermal Mass = 3.440000
Diameter/Width = 0.710000
Length = 1.450000

name = Flight Computer
quantity = 1
parent = 40
materialID = 8
type = Box
Aero Mass = 11.750000
Thermal Mass = 11.750000
Diameter/Width = 0.384000
Length = 0.386000
Height = 0.338000

name = PCDU
quantity = 1
parent = 40
materialID = 8
type = Box
Aero Mass = 8.400000
Thermal Mass = 8.400000
Diameter/Width = 0.222000
Length = 0.348000
Height = 0.170000

name = Battery Enabler Interconnect Box
quantity = 1
parent = 40
materialID = 8
type = Box
Aero Mass = 1.050000
Thermal Mass = 1.050000

Diameter/Width = 0.120000
Length = 0.120000
Height = 0.030000

name = Hemi Ant - 2
quantity = 2
parent = 40
materialID = 8
type = Cylinder
Aero Mass = 0.080000
Thermal Mass = 0.080000
Diameter/Width = 0.070000
Length = 0.070000

name = ROLSES ANT BOX - 3
quantity = 1
parent = 40
materialID = 8
type = Cylinder
Aero Mass = 1.400000
Thermal Mass = 1.400000
Diameter/Width = 0.080000
Length = 0.200000

name = Closeout Bay D2 Panel
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 3.414000
Thermal Mass = 3.414000
Diameter/Width = 0.710000
Length = 1.450000

name = Closeout Bay E Panel
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 18.799999
Thermal Mass = 7.355000
Diameter/Width = 0.710000
Length = 2.900000

name = RCS Controller
quantity = 1

parent = 47
materialID = 8
type = Box
Aero Mass = 0.840000
Thermal Mass = 0.840000
Diameter/Width = 0.160000
Length = 0.240000
Height = 0.060000

name = Igniter Control Box - 2
quantity = 1
parent = 47
materialID = 8
type = Box
Aero Mass = 0.525000
Thermal Mass = 0.525000
Diameter/Width = 0.127000
Length = 0.207000
Height = 0.115000

name = Thermo Couple Box - 2
quantity = 3
parent = 47
materialID = 8
type = Box
Aero Mass = 0.473333
Thermal Mass = 0.473333
Diameter/Width = 0.080000
Length = 0.160000
Height = 0.050000

name = Isolated Power suppply Quasonix
quantity = 2
parent = 47
materialID = 8
type = Box
Aero Mass = 0.420000
Thermal Mass = 0.420000
Diameter/Width = 0.080000
Length = 0.160000
Height = 0.080000

name = ROLSES Chassis
quantity = 1
parent = 47
materialID = 8

type = Box
Aero Mass = 5.200000
Thermal Mass = 5.200000
Diameter/Width = 0.150000
Length = 0.180000
Height = 0.150000

name = ROLSES ANT BOX - 4
quantity = 1
parent = 47
materialID = 8
type = Box
Aero Mass = 1.400000
Thermal Mass = 1.400000
Diameter/Width = 0.080000
Length = 0.200000
Height = 0.080000

name = SCALPSS Camera - 3
quantity = 1
parent = 47
materialID = 65
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.070000
Length = 0.100000
Height = 0.050000

name = SCALPSS DSU
quantity = 1
parent = 47
materialID = 8
type = Box
Aero Mass = 0.520000
Thermal Mass = 0.520000
Diameter/Width = 0.090000
Length = 0.130000
Height = 0.070000

name = SCALPSS USB Hub
quantity = 1
parent = 47
materialID = 8
type = Box
Aero Mass = 0.600000

Thermal Mass = 0.600000
Diameter/Width = 0.090000
Length = 0.130000
Height = 0.070000

name = Closeout Bay F Panel
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 9.691999
Thermal Mass = 7.547000
Diameter/Width = 0.710000
Length = 2.900000

name = RF Swtich - 2
quantity = 3
parent = 57
materialID = 8
type = Box
Aero Mass = 0.225000
Thermal Mass = 0.225000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = SCALPSS Camera - 4
quantity = 1
parent = 57
materialID = 65
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.070000
Length = 0.100000
Height = 0.050000

name = Main Engine Solenoid
quantity = 1
parent = 57
materialID = 8
type = Box
Aero Mass = 1.000000
Thermal Mass = 1.000000
Diameter/Width = 0.200000
Length = 0.200000

Height = 0.200000

name = Quasonix Radios
quantity = 2
parent = 57
materialID = 8
type = Box
Aero Mass = 0.185000
Thermal Mass = 0.185000
Diameter/Width = 0.050000
Length = 0.076200
Height = 0.030500

name = Landing Gear
quantity = 6
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 3.201833
Thermal Mass = 3.201833
Diameter/Width = 0.100000
Length = 0.500000

name = Motor Gimbal Controllers (MOGI)
quantity = 10
parent = 1
materialID = 8
type = Box
Aero Mass = 0.788000
Thermal Mass = 0.788000
Diameter/Width = 0.100000
Length = 0.120000
Height = 0.050000

name = VSDL to Ethernet converter
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.050000
Thermal Mass = 1.050000
Diameter/Width = 0.100000
Length = 0.140000
Height = 0.040000

name = RUAG Sep Ring

quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 11.843000
Thermal Mass = 11.843000
Diameter/Width = 0.200000
Length = 0.200000

name = VESTA
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 9.600000
Thermal Mass = 9.600000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.200000

name = SCOUT
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 5.000000
Thermal Mass = 5.000000
Diameter/Width = 0.200000
Length = 0.300000
Height = 0.200000

name = Moonlight
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.700000
Thermal Mass = 0.700000
Diameter/Width = 0.110000
Length = 0.200000
Height = 0.095000

name = ILO-X
quantity = 2
parent = 1
materialID = 8

type = Box
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = Gaseous helium plumbing valves and thrusters
quantity = 1
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 4.800000
Thermal Mass = 4.800000
Diameter/Width = 0.030000
Length = 2.000000

name = RCS System Plumbing
quantity = 1
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 7.200000
Thermal Mass = 7.200000
Diameter/Width = 0.050000
Length = 2.000000

name = Harnessing
quantity = 400
parent = 1
materialID = 20
type = Cylinder
Aero Mass = 0.101500
Thermal Mass = 0.101500
Diameter/Width = 0.005000
Length = 1.000000

name = Solar Cells
quantity = 661
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 0.024700
Thermal Mass = 0.024700
Diameter/Width = 0.050000
Length = 0.050000

name = MLI
quantity = 1
parent = 1
materialID = 44
type = Box
Aero Mass = 8.677000
Thermal Mass = 8.677000
Diameter/Width = 1.000000
Length = 1.000000
Height = 0.100000

name = Heaters
quantity = 50
parent = 1
materialID = 8
type = Box
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.040000
Length = 0.040000
Height = 0.040000

name = Thermocouples
quantity = 50
parent = 1
materialID = 8
type = Box
Aero Mass = 0.012000
Thermal Mass = 0.012000
Diameter/Width = 0.020000
Length = 0.020000
Height = 0.020000

name = Misc brackets and radiators
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 32.400002
Thermal Mass = 32.400002
Diameter/Width = 0.300000
Length = 0.300000
Height = 0.300000

**************OUTPUT****

Item Number = 1

name = NOVA-C
Demise Altitude = 77.997154
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Thrust Chamber and Nozzle Assembly
Demise Altitude = 0.000000
Debris Casualty Area = 0.785628
Impact Kinetic Energy = 16402.550781

****
name = Gimbal Actuators
Demise Altitude = 0.000000
Debris Casualty Area = 1.068041
Impact Kinetic Energy = 818.899292

****
name = LOX Tank
Demise Altitude = 0.000000
Debris Casualty Area = 2.424639
Impact Kinetic Energy = 53449.359375

****
name = LCH4 Tank
Demise Altitude = 0.000000
Debris Casualty Area = 2.796703
Impact Kinetic Energy = 64967.941406

****
name = GHe Tanks
Demise Altitude = 0.000000
Debris Casualty Area = 3.391135
Impact Kinetic Energy = 26188.033203

****
name = Battery
Demise Altitude = 59.025284
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Super-structure
Demise Altitude = 0.000000

Debris Casualty Area = 6.837932
Impact Kinetic Energy = 13321.166992

****
name = Closeout Bay A1 Panel
Demise Altitude = 74.496605
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Hemi Ant
Demise Altitude = 74.483139
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = MEC
Demise Altitude = 65.057648
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = MEC Power Prot.
Demise Altitude = 54.986332
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = HGA Dish & Filter
Demise Altitude = 0.000000
Debris Casualty Area = 0.614417
Impact Kinetic Energy = 629.572388

****
name = LN1 Payload
Demise Altitude = 48.625957
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ROLSES ANT BOX
Demise Altitude = 59.409523
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

name = RFMG
Demise Altitude = 0.000000
Debris Casualty Area = 0.640000
Impact Kinetic Energy = 1697.944214

****
name = Closeout Bay A2 Panel
Demise Altitude = 0.000000
Debris Casualty Area = 2.607072
Impact Kinetic Energy = 157.240219

****
name = Closeout Bay B Panel
Demise Altitude = 71.350967
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Comm and Track Controller
Demise Altitude = 0.000000
Debris Casualty Area = 0.543873
Impact Kinetic Energy = 8464.705078

****
name = Thermo Couple Box
Demise Altitude = 0.000000
Debris Casualty Area = 1.478330
Impact Kinetic Energy = 253.115448

****
name = RF Switch
Demise Altitude = 0.000000
Debris Casualty Area = 1.425994
Impact Kinetic Energy = 56.664276

****
name = SCALPSS Camera
Demise Altitude = 0.000000
Debris Casualty Area = 0.458952
Impact Kinetic Energy = 16.619440

****
name = NDL Sensor Head
Demise Altitude = 0.000000
Debris Casualty Area = 0.753184
Impact Kinetic Energy = 778.277283

****
name = Main engine solenoid
Demise Altitude = 72.941948
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = NavPod TRN/HRN (2x separate assemblies)
Demise Altitude = 72.352524
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = IMU
Demise Altitude = 62.564537
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Star Tracker
Demise Altitude = 64.227058
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Laser
Demise Altitude = 51.891781
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = LRF Receiver
Demise Altitude = 64.498604
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = DC-DC Converter
Demise Altitude = 68.638138
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Optical Camera
Demise Altitude = 68.539963

Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Closeout Bay C Panel
Demise Altitude = 73.436234
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Payload Controller
Demise Altitude = 48.226364
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Thales Radio
Demise Altitude = 60.088837
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Igniter Control Box
Demise Altitude = 67.728798
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ROLSES ANT BOX - 2
Demise Altitude = 56.538620
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = NDL Chassis
Demise Altitude = 0.000000
Debris Casualty Area = 0.753184
Impact Kinetic Energy = 24421.183594

****
name = SCALPSS Camera - 2
Demise Altitude = 0.000000
Debris Casualty Area = 0.458952
Impact Kinetic Energy = 16.618835

****

name = EagleCam
Demise Altitude = 0.000000
Debris Casualty Area = 0.640000
Impact Kinetic Energy = 4729.979004

****
name = Closeout Bay D1 Panel
Demise Altitude = 75.220421
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Flight Computer
Demise Altitude = 0.000000
Debris Casualty Area = 0.947295
Impact Kinetic Energy = 7675.562012

****
name = PCDU
Demise Altitude = 0.000000
Debris Casualty Area = 0.741608
Impact Kinetic Energy = 10934.754883

****
name = Battery Enabler Interconnect Box
Demise Altitude = 54.941036
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Hemi Ant - 2
Demise Altitude = 72.859985
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ROLSES ANT BOX - 3
Demise Altitude = 62.231274
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Closeout Bay D2 Panel
Demise Altitude = 0.000000
Debris Casualty Area = 2.607072
Impact Kinetic Energy = 184.709137

****
name = Closeout Bay E Panel
Demise Altitude = 72.626801
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = RCS Controller
Demise Altitude = 0.000000
Debris Casualty Area = 0.581377
Impact Kinetic Energy = 280.984833

****
name = Igniter Control Box - 2
Demise Altitude = 0.000000
Debris Casualty Area = 0.574962
Impact Kinetic Energy = 117.728073

****
name = Thermo Couple Box - 2
Demise Altitude = 0.000000
Debris Casualty Area = 1.478330
Impact Kinetic Energy = 253.161575

****
name = Isolated Power suppply Quasonix
Demise Altitude = 59.440609
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ROLSES Chassis
Demise Altitude = 0.000000
Debris Casualty Area = 0.584180
Impact Kinetic Energy = 8788.648438

****
name = ROLSES ANT BOX - 4
Demise Altitude = 0.000000
Debris Casualty Area = 0.527789
Impact Kinetic Energy = 1657.728394

****
name = SCALPSS Camera - 3
Demise Altitude = 0.000000

Debris Casualty Area = 0.458952
Impact Kinetic Energy = 16.620398

****
name = SCALPSS DSU
Demise Altitude = 0.000000
Debris Casualty Area = 0.492777
Impact Kinetic Energy = 260.884399

****
name = SCALPSS USB Hub
Demise Altitude = 0.000000
Debris Casualty Area = 0.492777
Impact Kinetic Energy = 347.550812

****
name = Closeout Bay F Panel
Demise Altitude = 0.000000
Debris Casualty Area = 4.140906
Impact Kinetic Energy = 744.460876

****
name = RF Swtich - 2
Demise Altitude = 0.000000
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = SCALPSS Camera - 4
Demise Altitude = 0.000000
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Main Engine Solenoid
Demise Altitude = 0.000000
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Quasonix Radios
Demise Altitude = 0.000000
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

name = Landing Gear
Demise Altitude = 66.492004
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Motor Gimbal Controllers (MOGI)
Demise Altitude = 66.814583
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = VSDL to Ethernet converter
Demise Altitude = 64.518105
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = RUAG Sep Ring
Demise Altitude = 45.909454
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = VESTA
Demise Altitude = 0.000000
Debris Casualty Area = 0.640000
Impact Kinetic Energy = 17516.064453

****
name = SCOUT
Demise Altitude = 63.197750
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Moonlight
Demise Altitude = 72.915298
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ILO-X
Demise Altitude = 71.536354
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Gaseous helium plumbing valves and thrusters
Demise Altitude = 59.657551
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = RCS System Plumbing
Demise Altitude = 53.908916
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Harnessing
Demise Altitude = 76.868065
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Solar Cells
Demise Altitude = 77.252022
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = MLI
Demise Altitude = 76.427643
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Heaters
Demise Altitude = 74.553841
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Thermocouples
Demise Altitude = 75.666969
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Misc brackets and radiators
Demise Altitude = 0.000000

Debris Casualty Area = 0.810000
Impact Kinetic Energy = 89033.921875

****

=============== End of Requirement 4.7-1 ===============

4.7-1b, and 4.7-1c:
These requirements are non-applicable requirements because the SW1FT mission does not use controlled reentry.

4.7-1, b): *"For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627)."*

Not applicable to YAM. The spacecraft does not use controlled reentry and no debris is expected to survive.

4.7-1 c): *"For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628)."*
Not applicable to SW1FT. It does not use controlled reentry and no debris is expected to survive.

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers used in the SW1FT mission.

END of ODAR for SW1FT

Appendix A: Acronyms

Arg peri	Argument of Perigee
CDR	Critical Design Review
cm	centimeter
COTS	Commercial Off-The-Shelf (items)
DAS	Debris Assessment Software
EOM	End Of Mission
FRR	Flight Readiness Review
GEO	Geosynchronous Earth Orbit
ITAR	International Traffic In Arms Regulations

kg	kilogram
km	kilometer
LEO	Low Earth Orbit
Li-Ion	Lithium Ion
m^2	Meters squared
ml	milliliter
mm	millimeter
N/A	Not Applicable.
NET	Not Earlier Than
ODAR	Orbital Debris Assessment Report
OSMA	Office of Safety and Mission Assurance
PDR	Preliminary Design Review
PL	Payload
ISIPOD	ISIS CubeSat Deployer
PSIa	Pounds Per Square Inch, absolute
RAAN	Right Ascension of the Ascending Node
SMA	Safety and Mission Assurance
Ti	Titanium
Yr	year