Starfish Space Otter Pup 2
RPOD Demonstration Mission
Orbital Debris Assessment Report (ODAR)

DAS Software v3.2.5

This report is presented as compliance with NASA-STD-8719.14C, APPENDIX A. December 15th, 2022

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Contents

Self Assessment per NASA-STD-8719.14

1 Program Management and Mission Overview

1.1 Schedule of upcoming mission milestones: 8
1.2 Mission Overview: 8
1.3 Launch Vehicles and Launch Sites: 8
1.4 Proposed Initial Launch Date: 8
1.5 Mission Duration: 9
1.6 Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination: 9

2 Spacecraft Description

2.1 Physical description of the spacecraft 9
2.2 Detailed illustration of the spacecraft 10
2.3 Total Satellite Mass 10
2.4 Dry Mass of the Satellite 11
2.5 Identification of All Fluids On-board 11
2.6 Description of Propulsion System 11
2.7 Description of Attitude Control System 11
2.8 Fluids in Pressurized Batteries 12
2.9 Description of Pyrotechnic Devices 12
2.10 Description of Electrical and Power System 12
2.11 Identification of Other Stored Energy 12
2.12 Identification of Any Radioactive Materials 12

3 Assessment of Debris Released During Normal Operations

3.1 Identification of Objects Expected to be Released at Any Time 12
3.2 Rationale for Release of Objects 12
3.3 Time of Release of Objects 13
3.4 Release Velocity 13
3.5 Expected Orbital Parameters After Object Release 13
3.6 Calculated Orbital Lifetime of Release Objects 13
3.7 Assessment of Compliance with Requirement 4.3-1 and 4.3-2 13
3.7.1 Requirements 4.3-1 13
3.7.2 Requirements 4.3-2 13

4 Assessment of Spacecraft Intentional Breakups and Potential for Explosions

4.1 Identification of all potential causes of spacecraft breakup during deployment and mission operation 13
4.2 Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion 13
4.3 Detailed plan for any designed spacecraft breakup, including explosions and inten-tional collisions 14

4.4 List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated 15
4.5 Rationale for all items which are required to be passivated, but cannot be due to their design 15
4.6 Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 15
4.6.1 Requirement 4.4-1 15
4.6.2 Requirement 4.4-2 18
4.6.3 Requirement 4.4-3 18
4.6.4 Requirement 4.4-4 19

5 Assessment of Potential for On-Orbit Collisions
5.1 Assessment of Compliance with Requirement 4.5-1 and 4.5-2 19
5.1.1 Requirement 4.5-1 19
5.1.2 Requirement 4.5-2 19
5.2 Identification of all systems or components required to accomplish any post- mission disposal operation, including passivation and maneuvering 19

6 Assessment of Post-Mission Disposal Plans and Procedure
6.1 Description of Spacecraft Disposal Option Selected 19
6.2 Plan for any spacecraft maneuvers required to accomplish post-mission disposal .19
6.3 Calculation of area-to-mass ratio after post-mission disposal, if the controlled reentry option is not selected 19
6.4 Assessment of Compliance with Requirement 4.6-1 Through 4.6-4 20
6.4.1 Requirement 4.6-1 20
6.4.2 Requirement 4.6-2 20
6.4.3 Requirement 4.6-3 21
6.4.4 Requirement 4.6-4 21

7 Assessment of Reentry Hazards
7.1 Assessment of Compliance with Requirement 4.7-1 21
7.1.1 Requirement 4.7-1 21

List of Tables

1 Assessment Report Format 7
2 Spacecraft ADCS Modes 11
3 RPOD Plan 14
4 RPOD Abort Triggers 14

List of Figures

1 Otter Pup 2 Spacecraft 10
2 Orbital History 20

Self-Assessment per NASA-STD-8719.14

A self-assessment in accordance with the format provided in Appendix A.2 of NASA-STD-8719.14 is shown below in Table 1.

Section	Status	Comment
4.3-1, Mission-Related Debris Passing Through LEO	Compliant	
4.3-2, Mission-Related Debris Passing Near GEO	N/A	
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	Compliant	
4.4-3, Limiting the long-term risk to other space systems from planned breakup	Compliant	
4.4-4, Limiting the short-term risk to other space systems from planned breakup	Compliant	
4.5-2, Probability of Damage from Small Objects	Compliant	
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 GEOs	N/A	
4.6-4, Reliability of post-mission disposal operations	Compliant	
4.7-1, Limit the risk of human casualty	Compliant	
4.8-1, Collision Hazards of Space Tether	N/A	

Table 1: Assessment Report Format

Assessment Report Format

Astro Digital US, Inc is a US company. This ODAR follows the format in NASA-STD-8719.14C, Appendix A.1 and includes the content indicated as a minimum, in each of sections 2 through 8 below. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

1 Program Management and Mission Overview

Astro Digital US Inc.
Systems Engineering: Philip Szerakowski
Mission Management: Jeff Mok
Executive Management: Chris Biddy

Starfish Space Inc.
Satellite Systems / Otter Pup Program Lead: Jesse Adams
Mission Management: Jonathan Kneller
Executive Management: Austin Link

Foreign government or space agency participation: N/A

Summary of NASA's responsibility under the governing agreement(s): N/A

1.1 Schedule of upcoming mission milestones:

- Shipment of spacecraft: Q3 CY2024
- First launch: Q4 CY2024

1.2 Mission Overview:

The Starfish Otter Pup 2 mission is a demonstration space tug developed to test Rendezvous, Proximity Operations, and Docking (RPOD) technologies in Low-Earth Orbit (LEO). It is a follow on of the first Otter Pup vehicle that successfully completed several key mission objectives in CY 2023 and the first half of 2024. Otter Pup 2 will approach, and dock to a client spacecraft: a D-Orbit Orbit Transfer Vehicle (OTV) called ION (potential docking scenarios are described in the following paragraph). The primary payloads are manufactured by Starfish Space and consist of the Nautilus Capture Mechanism, CETACEAN Relative Navigation software, and the CEPHALOPOD guidance and control software. Additional payloads, an electric propulsion thruster provided by Exotrail SA and a camera designed and built for relative navigation provided by Redwire, are integrated into a spacecraft bus based on the Astro Digital Micro+ design. This standardized satellite bus uses reaction wheels, magnetic torque coils, star trackers, magnetometers, sun sensors, and gyroscopes to enable precision 3-axis pointing without the use of propellant.

Starfish Space will collaborate with D-Orbit to dock with any or all three of the following D-Orbit ION OTVs:

- SCV-012 will deploy from Transporter-11 in June 2024, into an orbit at 590 km SSO, in the same orbital plane as Otter Pup 2, but several months earlier. After Otter Pup

2 is launched in October 2024, either or both spacecraft would conduct orbit changing maneuvers to rendezvous (Otter Pup would not raise its orbit to an altitude that would prevent it from naturally deorbiting in five years post mission completion). The rendezvous maneuvering could begin as soon as Otter Pup 2 is on orbit.

- SCV-014 and SCV-016 will be on the same launch vehicle as Otter Pup 2. They will deploy at 510 km, along with Otter Pup 2.
  - SCV-014 will become available for docking maneuvers one year post deployment (~Q3 2025).
  - SCV-016 will become available for docking maneuvers 30 days post deployment. Docking could then be conducted during an interval of 20 days before SCV-016 maneuvers to 1,200 km to complete its mission.

1.3 Launch Vehicles and Launch Sites:

SpaceX Falcon 9 rideshare mission, launch site Vandenberg Space Force Base

1.4 Proposed Initial Launch Date:

Q4 2024, SpaceX Transporter-12

1.5 Mission Duration:

The design lifetime of the spacecraft hardware is a minimum of 3 years. The time to complete the mission is expected to be 1 year while seeking authority to operate for 2 years.

1.6 Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

The Launch Vehicle (LV) will deploy the Otter Pup 2 spacecraft at the launch insertion altitude of 510 km. The spacecraft is expected to operate for approximately 1 year from an orbit with the following parameters:

- Average Orbital Altitude: 510 km ± 5 km (station-kept)
- Eccentricity: 0.0000 to 0.0033
- Inclination: 97.4°

After the spacecraft has demonstrated all relevant technologies and completed payload operations, it will be passivated and allowed to enter an uncontrolled re-entry trajectory.

2 Spacecraft Description

2.1 Physical description of the spacecraft

The Starfish Space Otter Pup 2 is based on the standard Corvus-Micro+ bus. The total wet mass is 40.08 kg (CBE) and total dry mass is 39.16 kg (CBE). The satellite has stowed dimensions of 77.834 x 38.939 x 45.704 cm and deployed dimensions of 76.719 x 38.222 x 107.718 cm**.** The satellite structure is comprised of six aluminum orthogrid plates, in which all components are mounted on the inner and outer faces. All structural panels are referenced against the body frame of the spacecraft as seen on Figure 1. A main structural panel in the -Z axis, two side plates on the +Y axis a base plate on the +x and a payload deck on the -X/+Z axis.

A total of three Main Solar Panels (MSPs) are used as the primary source of power generation. These MSPs are body mounted in the +/- Y axis and each have dimensions of 45 cm x 32 cm x 0.16 cm. Two of the MSPs are stowed for launch and deploy from the +/- Z faces after separation from the OTV. The deployment mechanism is a spring-loaded hinge with a burn wire that is activated upon separation. Three additional keep alive panels are mounted on the spacecraft, one on the -Y face and the other two on the +/- Z faces. They each have dimensions of 22.1 cm x 17.1 cm x 0.16 cm. A total of 3 Smart Panels (SP) are placed on the -Y and +/-Z axis. The Smart Sensor Panels have dimensions of 12.1 cm x 1.3 cm x 0.16 cm, and contain electronics embedded in them such as a coarse sun sensor and magnetometer.

The satellite avionics are enclosed inside the Data Power Module (DPM) which is comprised of a flight computer with integrated IMU, GPS module, TT&C transceiver, two battery packs, charging module, power distribution module and a high voltage power board. An additional battery pack containing two Direct Energy Pack (DEP) is also used to further supply power to the payload, regulate the high loads which the MSPs generate and provide temperature monitor and heaters. All the avionics components have previously flown in different Astro Digital missions. The satellite is equipped with a TT&C transceiver, Turva S-band/UHF. Two UHF antennas are placed on the top corners of the spacecraft -Z axis. Two S-band patch antennas are placed in the lower corners of the +/-Y axis. One XCOMM X-band transceiver is equipped to provide high payload data downlink. This transceiver is mounted in the interior of the satellite's -Y plate with the antenna mounted on the exterior of that same plate. The GPS is mounted inside the DPM and with its corresponding antenna mounted on the -Z axis.

The Attitude Determination and Control System (ADCS) consists of flight proven externally sourced hardware with one star tracker, a gyroscope, reaction wheels and torque rods. In addition to the external hardware a torque rod control module and a reaction wheel control module are used to regulate the high load required by these components. The star tracker is placed on –Z panel.

The primary payload components are fixed to the -X face and are comprised of three major subsystems. The Nautilus device, which is concealed in a protective shield for launch, LEOP, and non-RPOD operations is actuated using two EBAD Non-Explosive FC3 Frangibolts. These Frangibolts create no loose debris and are actuated in a set sequence to ensure proper deployment of the capture mechanism. To support capture, the -X face also includes a high-power light source and a stereo camera with two sensors that provide stereo vision (plus a non-stereo center lens for functional checks of Nautilus and docking validation).

The propulsion subsystem is based on the Exotrail nano XL hall effect thruster. The components are located on the internal +X face with the thruster headed pointed out of that direction on the exterior panel. The primary modules are the Thruster Control Unit (TCU) (120mm x 83mm x 95mm), the tank assembly, which is comprised of a 500mL pressure vessel and high pressure manifold (270mm x 110 mm x 135 mm), the Propellant Management System (PMS) (150mm x 90 mm x 60mm) and the Thruster Head Nano (THD), (95mm x 95mm x 90mm).

An 11.7-inch Planetary Systems Corporation Lightband on the +X panel of the satellite is used to deploy the spacecraft from the launch vehicle. (10.04 dia x 2.1 thickness)

2.2 Detailed illustration of the spacecraft

An illustration of the spacecraft is shown in Figure 1 below:

Figure 1: Starfish Space Otter Pup 2 Spacecraft

2.3 Total Satellite Wet Mass

The current best estimate for total satellite wet mass is **40.08 kg**

2.4 Dry Mass of the Satellite

CBE Minus 920 grams = **39.16 kg**

2.5 Identification of All Fluids On-board

The Exotrail nano XL uses 920 grams of pressurized Xenon as its propellant. At commissioning the gas exists in a supercritical state above 17C, below this temperature a gaseous and liquid state coexist. As the pressure decreases in the vessel due to operation, the gaseous regime becomes predominant. In expected low earth orbit pressures and temperatures any leaked liquid would rapidly boil into gaseous form.

2.6 Description of Propulsion System

The Exotrail nano XL is a Hall Effect Thruster (HET) developed by Exotrail SA. The system accelerates a Xenon plasma using magnetic and electric fields for high efficiency thrust. Xenon propellant is substantially safer than traditional bipropellants/monopropellants as it is non-toxic, inert, and found in relative abundance in the earth's atmosphere. Any leaked liquid xenon would boil into a gas and disperse uniformly into space. The system is designed with a passivation mode to relieve all pressure in the propellant tank down to 1 bar in preparation for re-entry.

2.7 Description of Attitude Control System

Scheduling after separation will consist of autonomous de-tumble followed by a safe mode sun tracking mode. Note that the spacecraft will be launched into a sun-synchronous orbit for which the amount of sunlight it will see throughout an orbit will vary depending on the LTDN. All the following attitude modes use a combination of the following sensors and actuators to perform maneuvers. A magnetometer, sun sensors, gyroscope, reaction wheels, torque rods and star trackers are used to orientate the spacecraft correctly.

ADCS Mode	Description
Nominal	The spacecraft will be tracking the sun vector on its +Y body axis to generate sufficient power to charge the batteries.
TT&C	During TT&C mode the spacecraft can perform a slew to track the ground station but may not be required based on the antenna placement and attitude of the spacecraft.
Downlink	The spacecraft will perform a slew to track the corresponding ground station when line of sight is available. The antenna is located on its -Y body axis.
Docked	Spacecraft is secured to the docking client via the Nautilus capture mechanism on +X body face.
RPOD	Spacecraft is free to move in any of its 6 DOF to safely rendezvous with the client satellite. Numerous abort flags and sequences ensure control throughout attempt(s)

Table 2: Spacecraft ADCS Modes

2.8 Fluids in Pressurized Batteries

None, Otter Pup 2 uses unpressurized COTS lithium-ion battery cells.

2.9 Description of Pyrotechnic Devices

N/A

2.10 Description of Electrical and Power System

Power is generated by the 3 Main Solar Panels (MSP), with one located on the +Y body face of the spacecraft with the other two deploying from the +/-Z faces to face the +Y. Each MSP is comprised of 14 cells in series with 3 strings for a total of 42 cells per panel. The MSPs peak power generation comes out to be 46 W per panel. Three keep alive panels face the -Y direction and one on the +Z serve as backup power generators in case of an uncontrolled tumble or clocking maneuvers. These keep alive panels are comprised of 12 cells in series with a power generation of 13 W per panel.

Starfish Space Otter Pup 2 will have two battery packs to accommodate the high load that the payload requires. The DPM battery pack contains a set of 8 Lithium-Ion battery cells in parallel with a capacity of 144 W-hrs. The DEP contains a set of 7 Lithium-Ion battery cells in series, with a capacity of 126 W-hrs. There are a total of two DEPs on Otter Pup 2 that will be connected in parallel to provide a total battery pack capacity of 252 W-hrs. The battery packs are all equipped with power regulation ICs which regulate the discharge state of the individual battery cells. All the power regulation required for operating the bus is done though the DPM. The DEP batteries function as the primary source of energy storage while the DPM batteries are used as backup. All battery packs are charged through the solar panels.

The satellite bus consumes 18W of power nominally with certain modes reducing or increasing the load. The payload is expected to consume between 15 to 66W depending on which components are being used., CBE plus margin. The charge/discharge cycle is managed by a power management system of 150W overseen by the Flight Computer and Electrical Power Subsystem.

2.11 Identification of Other Stored Energy

N/A

2.12 Identification of Any Radioactive Materials

N/A

3 Assessment of Debris Released During Normal Operations

3.1 Identification of Objects Expected to be Released at Any Time

N/A

3.2 Rationale for Release of Objects

N/A

3.3 Time of Release of Objects

N/A

3.4 Release Velocity

N/A

3.5 Expected Orbital Parameters After Object Release

N/A

3.6 Calculated Orbital Lifetime of Release Objects

N/A

3.7 Assessment of Compliance with Requirement 4.3-1 and 4.3-2

3.7.1 Requirements 4.3-1

"All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release. The total object-time product shall be no larger than 100 object-years per mission. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to collectively follow the same 100 object-years per mission deployment limit"

Compliance Statement Compliant

3.7.2 Requirements 4.3-2

N/A

4 Assessment of Spacecraft Intentional Breakups and Potential for Explosions

4.1 Identification of all potential causes of spacecraft breakup during deployment

and mission operation

There are three potential scenarios that could potentially lead to a breakup of the satellite.

1) Rendezvous failure resulting in uncontrolled collision (see 4.3 for further detail)
2) Lithium-ion battery cell failure (see 4.2 for further detail)
3) Xenon propellant tank pressurization failure (see 4.2 for further detail)

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

The in-orbit failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to such an explosion.

A failure of the Xenon propellant tank has the potential to result in an explosion. Increasing the temperature of the tank results in an increased internal pressure. These failure modes will be mitigated through extensive qualification testing, thermally isolating the propellant tank, two redundant pressure release valves, and fully passivating the system at End-Of-Life by releasing all stored propellant.

4.3 Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions

The Otter Pup 2 mission includes a docking event with the OTV, D-Orbit ION, that will be treated as an intentional collision for the purposes of this document. The planned speed of this controlled collision will be on the order of centimeters per second and will release no debris. The Nautilus mechanism includes two methods of attaching to the client satellite. The first, the "sunflower" end effector, utilizes electrostatic attraction to adhere to the surface. The backup secondary method, an electromagnet, relies on magnetic attraction to adhere. Once attached, the spacecraft will stay docked for a time (on the order of minutes), detach, and return to a safe distance from the client.

Phase	Description	Distance	Relative Velocity
Separation + spacecraft checkout	Spacecraft separates from Launch Vehicle via PSC Lightband. Detumble, 3-axis control achieved, and comms established.	< 10 km	< 3 m/s
Rendezvous	Spacecraft utilizes thruster to decrease relative speed and approach the client satellite	> 5 km	< 2 m/s
Proximity Ops	Spacecraft enters controlled safety ellipse around client. Orbit characterization occurs for final approach	5km – 50m	< 1 m/s
Docking	Spacecraft switches to local control. Minimizes ellipse size and speed, orients Nautilus device toward client, attaches.	< 50m	**< 5 cm/s**
Detach	Departure trajectory characterized, mechanism releases, fly away. Potential to repeat RPOD.	>100 m	< 1 m/s

Table 3. RPOD plan

An uncontrolled collision between the spacecraft and its docking client could cause the mission to fail. Significant measures are being enacted to ensure the probability of this is extremely unlikely. These measures include ground-based Monte Carlo simulation of viable approach trajectories, flight software defined go/no-go conditions for abort sequences, and human-in-the-loop monitoring of the rendezvous and proximity operations.

As distance and velocity are reduced per Table 3, software is constantly monitoring multiple points of telemetry. Each telemetry point has an acceptable range for the current phase of operation and if that range is exceeding or below the defined limit an abort sequence will be initiated by flight software. Upon initiating an abort, Otter Pup 2's trajectory is modified via the thruster such that the closest approach increases to at least three standard deviations away from the estimated client position certainty. The spacecraft would then enter a safety ellipse at the increased stand-off distance with the intention of resuming operations at the next opportunity, assuming all else is nominal. A list of autonomously monitored telemetry is listed in Table 4.

Condition	Reaction
Battery Power	If charge falls below threshold, abort. Recharge batteries
Propellant mass remaining	If amount falls below a certain threshold, abort.
Ground Command	If ground controller signals abort, abort.
Reaction Wheel Saturation	If reaction wheels are approaching their predefined saturation ceiling, abort.
Sensor Health (Camera, star tracker, gyro)	If state of health data indicates fault in any sensor, abort
Navigation Uncertainty	Ground uploads high resolution position and velocity data, if this data disagrees with software prediction by a significant margin, abort.
Actuator Uncertainty	If software understanding of actuators deviates from measured figures from flight computer, abort.
Future position threatens client	If software propagated position and velocity data are threatening to docking client, abort.

Table 4. RPOD Abort Triggers

During RPOD operations, TT&C data will be available at regular intervals, and a high-speed data downlink will be available for a large portion of the orbit. This will allow operators to monitor key telemetry and decide if the mission can continue as planned. Operators primary focus is preventing any unsafe contact with the client and will abort for any off-nominal scenario not captured by autonomous software monitoring.

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

After the satellite has reached its End of Lifetime (EOL) its 18 Lithium-Ion Battery Cells (4 DPM & 14 DEP) will be discharged completely. The solar array charging circuit will be disabled, which will fully discharge all cells within a few days.

Any remaining xenon propellant in the thruster tank will be expended via an EOL passivation mode which allows for excess xenon to be completely vented in a gaseous form.

4.5 Rationale for all items which are required to be passivated, but cannot be due to their design

N/A

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

4.6.1 Requirement 4.4-1

"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: 0.000

Supporting Rationale and FMEA Details

1) **Battery Explosion**
   - Effect: All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy of these small batteries 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.
   - Probability: Extremely Low. It is believed to be less than 0.01% given that multiple independent faults must occur for each failure to cause an explosion. Each battery cell is UL/UN certified with individual over-voltage and over-current protection. Identical batteries have been flown on all Astro Digital spacecraft.

Failure Mode 1: Internal short circuit

- Mitigation: Protoflight level sine burst, sine and random vibration in three axes of both spacecraft, thermal vacuum cycling of both spacecraft and extensive functional testing followed by maximum system rate-limited charge and discharge cycles were performed to prove that no internal short circuit sensitivity exists. Additional environmental and functional testing of the batteries at the power subsystem vendor facilities were also conducted on the batteries at the component level.
- Combined faults required for realized failure: Environmental testing AND functional charge/discharge tests must both be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate

- Mitigation: Battery cells were tested in lab for high load discharge rates in a variety of flight-like configurations to determine if the feasibility of an out-of-control thermal rise in the cell. Cells were also tested in a hot, thermal vacuum environment (5 cycles at 50° C, then to -20°C) in order to test the upper limit of the cell's capability. No failures were observed or identified via satellite telemetry or via external monitoring circuitry.
- Combined faults required for realized failure: Spacecraft thermal design must be incorrect AND external over-current detection and disconnect function must fail to enable this failure mode.

Failure Mode 3: Excessive discharge rate or short-circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

- Mitigation: This failure mode is negated by:
  - Qualification tested short circuit protection on each external circuit,
  - Design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure,
  - Observation of such other mechanical failures by protoflight level environmental tests (sine burst, random vibration, thermal cycling, and thermal-vacuum tests).
- Combined faults required for realized failure: An external load must fail/short-circuit AND external over-current detection and disconnect function must all occur to enable this failure mode.

Failure Mode 4: Inoperable vents

- Mitigation: Battery venting is not inhibited by the battery holder design or the spacecraft design. The battery is capable of venting gases to the external environment.
- Combined faults required for realized failure: The cell manufacturer OR the satellite integrator fails to install proper venting.

Failure Mode 5: Crushing

- Mitigation: Batteries are enclosed within spacecraft structure. Expected relative velocities of spacecraft and docking client are not conducive to structure disassembly. There are no moving parts in the proximity of the batteries.
- Combined faults required for realized failure: A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit AND the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.

- Mitigation: These modes are negated by:
  - Battery holder/case design made of non-conductive plastic, and
  - Operation in vacuum such that no moisture can affect insulators.
- Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators AND dislocation of battery packs AND failure of battery terminal insulators AND failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.

- Mitigation: Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures under a variety of modeled cases, including worst case orbital scenarios. Analysis shows these temperatures to be well below temperatures of concern for explosions.
- Combined faults required for realized failure: Thermal analysis AND thermal design AND mission simulations in thermal-vacuum chamber testing AND over-current monitoring and control must all fail for this failure mode to occur.

2) Pressurized Component Assembly Explosion

- Effect: The burst pressure of the tank and manifold components is somewhere above the qualified pressure. If the burst pressure were to be exceeded, the tank would rupture and potentially breach the aluminum walls of the spacecraft body, releasing debris.

- Probability: Extremely Low. The tank would need to be heated significantly beyond analysis values and pressure release valves would need to fail. The tank will be insulated from the rest of the spacecraft and there are no internal sources that could heat the tank to that temperature in any case. Any non-explosive failures would result in venting of gaseous xenon.

Failure Mode 1: Manufacturing error causes tank or manifold to burst below burst pressure

- Mitigation: The xenon tank and high-pressure manifold have a mean expected operating pressure (MEOP) of 225 bar at 60 degrees Celsius. The tank is qualified at twice this pressure (450 Bar) and the high-pressure manifold is qualified at 2.5 times the MEOP (563 Bar).
- Combined faults required for realized failure: Manufacturing defect AND testing equipment failure

Failure Mode 2: The tank temperature rises high enough that the burst pressure is achieved. Occurs at 137 deg Celsius at commissioning, higher as Xenon is expended.

- Mitigation: Thermal rise has been analyzed in combination with space environment temperatures showing that tank does not exceed normal allowable operating temperatures under a variety of modeled cases, including worst case orbital scenarios. The tank will be insulated from the rest of the spacecraft and there are no internal sources that could heat the tank to that temperature in any case. If temperature limits are exceeded on the device during operation, it will automatically shut down. Additionally, redundant thermistors are used, and faulty ones can be detected and ignored by software.
- Combined faults required for realized failure: Extreme heating environment AND thermal design failure OR combined thermistor failure

Failure Mode 3: Shut off valve fails closed due to damaged coil or stuck seat causing pressure buildup in low pressure area that could lead to burst.

- Mitigation: Relief valve is mounted downstream of the regulator to prevent pressure from exceeding expected maximum values.
- Combined faults required for realized faults: Shut off valve failure AND relief valve failure

Failure Mode 4: Crushing

- Mitigation: Tank is enclosed within spacecraft structure. Expected relative velocities of spacecraft and docking client are not conducive to structure disassembly. There are no moving parts in the proximity of the tank.
- Combined faults required for realized failure: A catastrophic failure must occur AND the failure must cause a collision sufficient to crush the tank AND the satellite must be in a naturally sustained orbit at the time the crushing occurs.

4.6.2 Requirement 4.4-2

"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 cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450)."

Compliance Statement
The spacecraft includes the ability to fully disconnect the Lithium Ion cells from the charging current of the solar arrays. Once the satellite reaches its End of Life (EOL), this feature will be used to completely passivate the batteries by removing all energy from them. In the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, the 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. The propulsion system will have the entirety of its propellant expended in a passivation mode which relieves any remaining pressure via release valves.

4.6.3 Requirement 4.4-3
N/A

4.6.4 Requirement 4.4-4
N/A

5.0 Assessment of Potential for On-Orbit Collisions

5.1 Assessment of Compliance with Requirement 4.5-1 and 4.5-2

5.1.1 Requirement 4.5-1
"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 does not exceed 0.001. For spacecraft and orbital stages passing through the protected region ±200 km and ±15 degrees of geostationary orbit, the probability of accidental collision with space objects larger than 10 cm in diameter shall not exceed 0.001 when integrated over 100 years from time of launch"

Compliance Statement
- Status: Compliant
- Probability: 2.7717E-06

5.1.2 Requirement 4.5-2
"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 post mission disposal maneuver requirements does not exceed 0.01"

Compliance Statement
- Status: Compliant

5.2 Identification of all systems or components required to accomplish any post-mission disposal operation, including passivation and maneuvering

The Flight Computer, Telemetry Transceiver, Propulsion subsystem and Electrical Power Subsystem are needed to complete passivation operations. The spacecraft will passively reenter within 3 years regardless of any orbit lowering maneuver.

6.0 Assessment of Post-Mission Disposal Plans and Procedure

6.1 Description of Spacecraft Disposal Option Selected

The satellite will de-orbit naturally by atmospheric re-entry.

6.2 Plan for any spacecraft maneuvers required to accomplish post- mission disposal

N/A

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

- Spacecraft Mass: 40.08 Kg (CBE+MGA)
- Cross-sectional Area: 0.7881 m^2 (Random Tumbling)
  - The cross-sectional area for the analysis was calculated for a random tumbling scenario where the spacecraft attitude is variable and has no particular direction.
- Area to mass ratio: 0.0197 m^2/kg

6.4 Assessment of Compliance with Requirement 4.6-1 Through 4.6-4

6.4.1 Requirement 4.6-1

"A spacecraft or orbital stage with a perigee altitude below 2,000 km shall be disposed of by one of the following three methods:"

- 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; or maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission
- Storageorbitoption: Maneuverthespacestructureintoanorbitwithperigeealtitudeabove 2000km and ensure its apogee altitude will be below 19,700 km, both for a minimum of 100 years
- Directretrieval: Retrievethespacestructureandremoveitfromorbitwithin10yearsafter completion of mission

Compliance Statement The orbit lifetime was assessed using the DAS Orbit Evolution Analysis tool. The estimate time of reentry, given the spacecraft parameters depicted in Section6.3, is to be three years after station keeping ceases. The estimated time falls under the required orbit dwell time. Figure 2 depicts the Apogee and Perigee of the orbit over time. Station keeping ceases two years from the launch date.

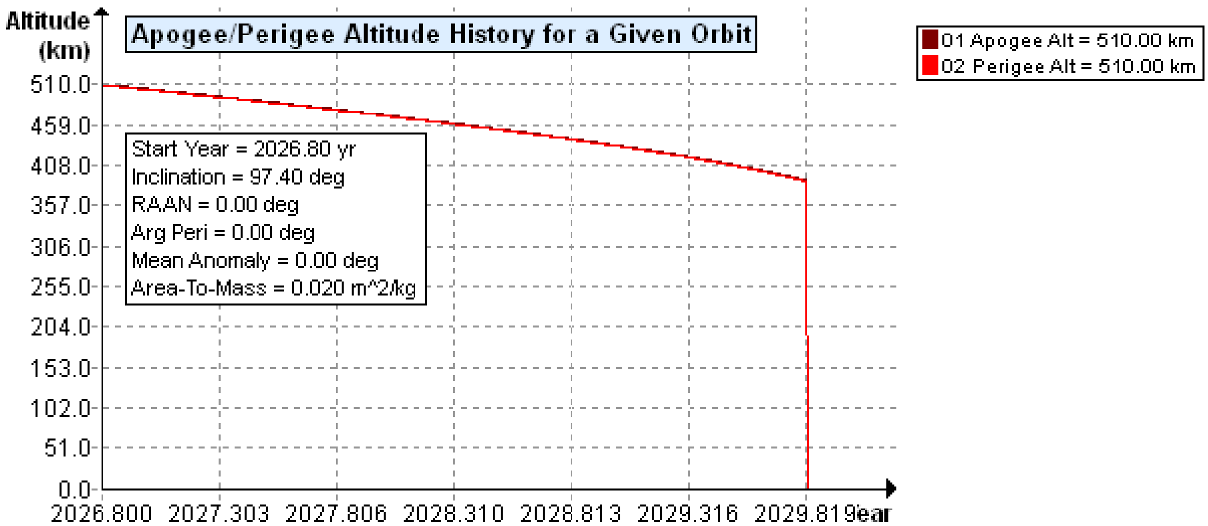

Figure 2: Orbital History

6.4.2 Requirement 4.6-2

N/A

6.4.3 Requirement 4.6-3

N/A

6.4.4 Requirement 4.6-4

The spacecraft will satisfy the requirement of deorbiting within 5 years after deployment as discussed in Section 6.4.1 Reliability of passive deorbit has been validated through different missions in which the accuracy of the orbit's dwell time has a small variation of a couple of months.

7.0 Assessment of Reentry Hazards

Astro Digital's bus is designed for demise in that all material selections are prioritized to have a low melting point and density, such as aluminum, where materials known to survive re-entry, such as tungsten or titanium, are avoided in large quantities. The Otter Pup 2 design is based on Astro Digital heritage designs as submitted and approved in prior ODAR filings. Except for a minor adjustment in the Frangibolt assembly of Nautilus, the Otter Pup 2 vehicle does not incorporate any new development materials.

7.1 Assessment of Compliance with Requirement 4.7-1

7.1.1 Requirement 4.7-1

"The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:"

- For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed

0.0001(1:10,000)

- 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
- For controlled reentries, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000)

Compliance Statement DAS calculates (all components listed in further detail in the full DAS results appended to this report) the risk of human casualty at zero. No such objects exist on Otter Pup 2

Appendix

=============== End of Requirement 4.3-1 ===============
Processing Requirement 4.3-2: Return Status : Passed

=============== End of Requirement 4.3-2 ===============
Processing Requirement 4.5-1: Return Status : Passed

==============
Run Data
==============

INPUT

Space Structure Name = Opup2
Space Structure Type = Payload
Perigee Altitude = 510.000 (km)
Apogee Altitude = 510.000 (km)
Inclination = 97.400 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0196 (m^2/kg)
Start Year = 2024.900 (yr)
Initial Mass = 40.080 (kg)
Final Mass = 39.160 (kg)
Duration = 2.000 (yr)
Station-Kept = True
Abandoned = True
Long-Term Reentry = True

OUTPUT

Collision Probability = 3.8216E-06
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

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

=============== End of Requirement 4.5-1 ===============
Project Data Saved To File
Requirement 4.5-2: Compliant

=============== End of Requirement 4.5-2 ===============

Processing Requirement 4.6 Return Status : Passed

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

INPUT

Space Structure Name = Opup2
Space Structure Type = Payload

Perigee Altitude = 510.000000 (km)
Apogee Altitude = 510.000000 (km)
Inclination = 97.400000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.019600 (m^2/kg)
Start Year = 2024.900000 (yr)
Initial Mass = 40.080000 (kg)
Final Mass = 39.160000 (kg)
Duration = 2.000000 (yr)
Station Kept = True
Abandoned = True
PMD Perigee Altitude = 510.000000 (km)
PMD Apogee Altitude = 510.000000 (km)
PMD Inclination = 97.400000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)
Long-Term Reentry = True

OUTPUT

Suggested Perigee Altitude = 100.000000 (km)
Suggested Apogee Altitude = 510.000000 (km)
Returned Error Message = Passes Long-term reentry orbit criteria

Released Year = 2026 (yr)
Requirement = 63
Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============

Processing Requirement 4.7-1
Return Status : Passed

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

name = Opup2
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 39.160000
Thermal Mass = 39.160000
Diameter/Width = 0.400000
Length = 0.760000
Height = 0.390000

name = Structural Panel +X
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.500000
Thermal Mass = 2.500000
Diameter/Width = 0.370000
Length = 0.370000
Height = 0.030000

name = Structural Panel -X
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.100000
Thermal Mass = 1.100000
Diameter/Width = 0.350000
Length = 0.350000
Height = 0.020000

name = Structural Panel +Y
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.500000
Thermal Mass = 1.500000

Diameter/Width = 0.350000
Length = 0.520000
Height = 0.010000

name = Structural Panel -Y
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.500000
Thermal Mass = 1.500000
Diameter/Width = 0.350000
Length = 0.490000
Height = 0.010000

name = Structural Panel +Z
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.540000
Thermal Mass = 1.540000
Diameter/Width = 0.350000
Length = 0.490000
Height = 0.010000

name = Structural Panel -Z
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.540000
Thermal Mass = 1.540000
Diameter/Width = 0.350000
Length = 0.490000
Height = 0.010000

name = Corner Rails
quantity = 4
parent = 1
materialID = 8
type = Box
Aero Mass = 0.210000
Thermal Mass = 0.210000
Diameter/Width = 0.032000
Length = 0.470000
Height = 0.032000

name = Star tracker bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.050000
Length = 0.070000
Height = 0.050000

name = Star tracker
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.110000
Thermal Mass = 0.110000
Diameter/Width = 0.090000
Length = 0.110000
Height = 0.090000

name = Reaction wheel bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.700000
Thermal Mass = 0.700000
Diameter/Width = 0.120000
Length = 0.134000
Height = 0.108000

name = DPM
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.860000
Thermal Mass = 2.860000
Diameter/Width = 0.152000
Length = 0.240000
Height = 0.090000

name = DEP
quantity = 2
parent = 1
materialID = 8

type = Box
Aero Mass = 1.220000
Thermal Mass = 1.220000
Diameter/Width = 0.190000
Length = 0.420000
Height = 0.120000

name = XCOMM
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.000000
Thermal Mass = 2.000000
Diameter/Width = 0.120000
Length = 0.120000
Height = 0.110000

name = HPA
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.210000
Thermal Mass = 0.210000
Diameter/Width = 0.050000
Length = 0.070000
Height = 0.030000

name = XPU
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.730000
Thermal Mass = 0.730000
Diameter/Width = 0.100000
Length = 0.120000
Height = 0.090000

name = Reaction wheel
quantity = 3
parent = 1
materialID = 8
type = Box
Aero Mass = 0.230000
Thermal Mass = 0.230000
Diameter/Width = 0.070000

Length = 0.080000
Height = 0.040000

name = Torque board
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.030000
Length = 0.090000
Height = 0.010000

name = Torque Rod
quantity = 3
parent = 1
materialID = 19
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.030000
Length = 0.050000
Height = 0.020000

name = Gyro
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.080000
Thermal Mass = 0.080000
Diameter/Width = 0.040000
Length = 0.050000
Height = 0.020000

name = Solar Panel Hinge
quantity = 6
parent = 1
materialID = 8
type = Box
Aero Mass = 0.040000
Thermal Mass = 0.040000
Diameter/Width = 0.070000
Length = 0.080000
Height = 0.010000

name = Keep alive panel

quantity = 3
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.370000
Thermal Mass = 0.370000
Diameter/Width = 0.170000
Length = 0.220000

name = Main solar panel (deployed)
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 1.310000
Thermal Mass = 1.310000
Diameter/Width = 0.320000
Length = 0.450000

name = Main solar panel (body mounted)
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.780000
Thermal Mass = 0.780000
Diameter/Width = 0.320000
Length = 0.450000

name = Smart panel
quantity = 3
parent = 1
materialID = 23
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.020000
Length = 0.150000
Height = 0.010000

name = X antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.240000
Thermal Mass = 0.240000
Diameter/Width = 0.080000

Length = 0.080000
Height = 0.020000

name = S-band RX antenna
quantity = 5
parent = 1
materialID = 8
type = Box
Aero Mass = 0.040000
Thermal Mass = 0.040000
Diameter/Width = 0.040000
Length = 0.060000
Height = 0.010000

name = GPS antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.030000
Length = 0.030000
Height = 0.020000

name = UHF antenna
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.030000
Length = 0.050000
Height = 0.010000

name = Hosted Avionics
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.000000
Thermal Mass = 1.000000
Diameter/Width = 0.100000
Length = 0.120000
Height = 0.090000

name = Nautilus Mechanism

quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.500000
Thermal Mass = 2.500000
Diameter/Width = 0.166000
Length = 0.320000
Height = 0.164000

name = Argus Camera
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.550000
Thermal Mass = 1.550000
Diameter/Width = 0.143000
Length = 0.257000
Height = 0.084000

name = Light Source Bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.040000
Length = 0.110000
Height = 0.030000

name = Light Source
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.060000
Length = 0.120000

name = Thruster Head
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.480000

Thermal Mass = 0.480000
Diameter/Width = 0.095000
Length = 0.095000
Height = 0.090000

name = Thruster Control Unit
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.640000
Thermal Mass = 0.640000
Diameter/Width = 0.105000
Length = 0.125000
Height = 0.047000

name = Tank Assembly
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.690000
Thermal Mass = 0.690000
Diameter/Width = 0.090000
Length = 0.270000

name = Propellant Management System
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.320000
Thermal Mass = 0.320000
Diameter/Width = 0.060000
Length = 0.150000
Height = 0.050000

name = Frangibolt
quantity = 2
parent = 1
materialID = 66
type = Cylinder
Aero Mass = 0.000800
Thermal Mass = 0.000800
Diameter/Width = 0.004800
Length = 0.009800

name = FrangiboltNut

quantity = 2
parent = 1
materialID = 66
type = Cylinder
Aero Mass = 0.000100
Thermal Mass = 0.000100
Diameter/Width = 0.003200
Length = 0.009500

name = FrangiboltBolt
quantity = 2
parent = 1
materialID = 66
type = Cylinder
Aero Mass = 0.000500
Thermal Mass = 0.000500
Diameter/Width = 0.004800
Length = 0.062000

name = FrangiboltWasher
quantity = 2
parent = 1
materialID = 66
type = Cylinder
Aero Mass = 0.000050
Thermal Mass = 0.000050
Diameter/Width = 0.001270
Length = 0.012700

name = Harness
quantity = 25
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.300000
Length = 0.200000

name = Fasteners
quantity = 40
parent = 1
materialID = 8
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.250000
Length = 0.250000

Height = 0.250000

**************OUTPUT****
Item Number = 1

name = Opup2
Demise Altitude = 77.993596
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structural Panel +X
Demise Altitude = 76.407392
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structural Panel -X
Demise Altitude = 77.211495
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structural Panel +Y
Demise Altitude = 77.246926
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structural Panel -Y
Demise Altitude = 77.197439
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structural Panel +Z
Demise Altitude = 77.176153
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structural Panel -Z
Demise Altitude = 77.176153
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Corner Rails

Demise Altitude = 77.703154
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Star tracker bracket
Demise Altitude = 77.738380
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Star tracker
Demise Altitude = 77.752598
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Reaction wheel bracket
Demise Altitude = 76.902862
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = DPM
Demise Altitude = 75.300621
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = DEP
Demise Altitude = 77.354817
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = XCOMM
Demise Altitude = 74.747343
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = HPA
Demise Altitude = 76.660409
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = XPU

Demise Altitude = 76.580787
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Reaction wheel
Demise Altitude = 76.952595
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Torque board
Demise Altitude = 77.696852
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Torque Rod
Demise Altitude = 75.698172
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Gyro
Demise Altitude = 77.096060
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Solar Panel Hinge
Demise Altitude = 77.725129
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Keep alive panel
Demise Altitude = 76.305739
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Main solar panel (deployed)
Demise Altitude = 75.732612
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Main solar panel (body mounted)

Demise Altitude = 76.645536
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Smart panel
Demise Altitude = 77.394567
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = X antenna
Demise Altitude = 76.698984
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = S-band RX antenna
Demise Altitude = 77.529238
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = GPS antenna
Demise Altitude = 77.388316
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = UHF antenna
Demise Altitude = 77.507992
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Hosted Avionics
Demise Altitude = 76.074138
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Nautilus Mechanism
Demise Altitude = 76.588832
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Argus Camera

Demise Altitude = 76.508159
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Light Source Bracket
Demise Altitude = 77.366295
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Light Source
Demise Altitude = 75.702876
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Thruster Head
Demise Altitude = 76.829964
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Thruster Control Unit
Demise Altitude = 76.411675
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Tank Assembly
Demise Altitude = 76.788084
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Propellant Management System
Demise Altitude = 77.188513
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Frangibolt
Demise Altitude = 76.994987
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = FrangiboltNut

Demise Altitude = 77.854129
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = FrangiboltBolt
Demise Altitude = 77.883193
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = FrangiboltWasher
Demise Altitude = 77.837981
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Harness
Demise Altitude = 77.949001
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Fasteners
Demise Altitude = 77.993596
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

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