Asgardia-1 Orbital Debris Assessment Report (ODAR)

In accordance with NPR 8715.6A, this report is presented as compliance with the required reporting format per NASA-STD-8719.14, APPENDIX A.

Note: This analysis only covers Asgardia-1.

No analysis is implied for the launch vehicle or other systems.

Report Version: 1.0

Document Data is Not Restricted.
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DAS Software Version Used In Analysis: v2.1.1

This document is a part of the Asgardia-1 Satellite Project Documentation, which is controlled by the Asgardia-1 Project Configuration Manager.

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Record of Revisions				
REV	**DATE**	**AFFECTED PAGES**	**DESCRIPTION OF CHANGE**	**AUTHOR (S)**
1.0	June 14, 2017	All	Original Release	Mike Miller, Jeff Dailey

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Self Assessment of ODAR Requirements (per Appendix A.2 Of NASA-STD-8719.14):

The orbital debris self-assessment matrix following, summarizes the result of this report. The template for this table is provided in Appendix A.2 of NASA-STD-8719.14. This is provided for the convenience of those to whom it may concern

Orbital Debris Self-Assessment Report Evaluation: Asgardia-1 Mission

Requirement #	Launch Vehicle (Not Applicable (see note 1))				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No intentional release of debris in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No intentional release of debris in LEO. See note 1.
4.3-2	☐	☐	☒	☐	☒	☐	☐	N/A - LEO. See note 1.
4.4-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.4-2	☐	☐	☒	☐	☒	☐	☐	Asgardia-1 only has batteries that will be passivated at mission end.
4.4-3	☐	☐	☒	☐	☒	☐	☐	Compliant. No planned breakups. See note 1.
4.4-4	☐	☐	☒	☐	☒	☐	☐	Compliant. No planned breakups. See note 1.
4.5-1	☐	☐	☒	☐	☒	☐	☐	Compliant. See note 1.
4.5-2	☐	☐	☒	☐	☒	☐	☐	Compliant. See note 1.
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-2	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-3	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-4	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-5	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.7-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.8-1					☒	☐	☐	NA. No tethers used.

Notes:

1. The launch vehicle is the responsibility of others.

Assessment Report Format

ODAR Technical Sections Format Requirements:

This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the required content in each section, 2 through 8, below for the Asgardia-1. Sections 9 through 14 of the standard apply to the launch vehicle ODAR and are not covered here since the launch vehicle is the responsibility of a separate project.

ODAR Section 1: Program Management and Mission Overview

Asgardia-1 Project Manager: Marcia Blount

Senior Management: Mike Lewis, Chief Technology Officer

Foreign government or space agency participation: None.

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

Schedule of mission design and development milestones from mission selection through proposed launch date, including spacecraft PDR and CDR (or equivalent) dates:

Mission Preliminary Design Review: March 30, 2017

Mission Critical Design Review: April 24, 2017

MRR: August 15, 2017

PSRR: August 15, 2017

Launch: September 12, 2017; Deploy December 15, 2017

Mission Description:

The Asgardia-1 satellite will be launched as a payload aboard the Orbital-ATK OA-8 rocket, a NASA CRS (Commercial Resupply Mission) inside a NanoRacks CubeSat Deployer (NRCSD), on September 12, from Wallops Island, VA. About 90 days after this launch, the OA-8 will un berth from the ISS, boost to a higher orbit, and deploy the satellite. The satellite will be inserted into a near-circular orbit at 500 km at an inclination of 51.6 degrees from the equator. Transmission will begin 30 minutes after deployment and will remain active through the life of the mission. Atmospheric friction will slow the satellite and reduce the altitude of the orbit until de-orbiting occurs, approximately 4.6 years after launch.

The primary experiment functions include long term data storage and radiation exposure, in LEO. These experiments will be completed within 2 years of launch. Data from the experiments are recovered via duplex link to the GlobalStar constellation. The satellite will operate in its circular orbit until natural orbit decay results in reentry. There are no propellants.

Launch vehicle and launch site:

Orbital-ATK OA-8 rocket, from Wallops Island, VA

Proposed launch date and Mission Duration:

Launch Date: September 12, 2017. About 90 days after this launch, the OA-8 will un berth from the ISS, boost to a higher orbit, and deploy the satellite.

Mission Duration: (24 months active mission, orbital life estimated at 4.6 years by DAS analysis.)

From the time of deployment, the spacecraft is expected to remain in LEO for about 4.6 years, prior to reentry after natural decay of the orbit. However, the planned mission operations are to last only 24 months after launch. Upon the decision to stop active operations, commands will be sent to the spacecraft to disconnect the solar panels from the batteries, and allow the batteries to discharge. This leaves the spacecraft inactive and de-energized. It will re-enter through natural decay of its orbit.

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

1. Asgardia-1 launches from the Nanoracks deployer on the Cygnus resupply vessel.

2. Asgardia-1 is deployed to, operates in, and decays naturally from, the orbit defined as follows:

Orbital Lifetime: 4.6 Years (Per DAS 2.1.1)
Perigee: 499 km
Apogee: 500 km
Inclination: 51.65 degrees
RAAN: 112.5347 degrees
Argument of perigee: 216.6336 degrees
Eccentricity: 0
Period: 95 minutes
Mass: 2.21 kg

Reasons for Selection of the Operational Orbit:

The orbit was selected because of accessibility via the Cygnus resupply vessel boost from the ISS. It allows timely passive disposal of the spacecraft by natural decay of orbit.

Identification of interaction or potential physical interference with other operational spacecraft:

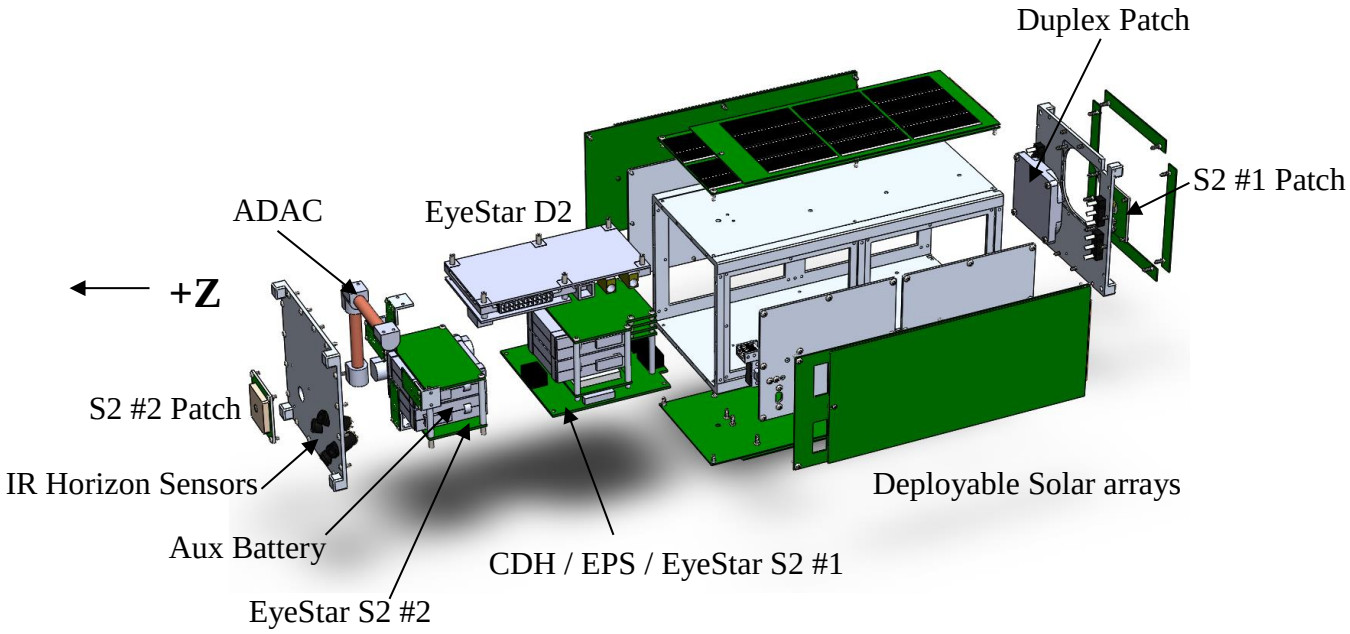
Asgardia-1 has no propulsion and therefore does not actively change orbits. There is no parking or transfer orbit.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:

Asgardia-1 is a 2U Cubesat with stowed outer dimensions of 10 cm x 10 cm x 20 cm. The satellite structure is 6061 aluminum alloy.

Figure 1 Asgardia-1 Overview



Asgardia-1 has one radio transceiver, 2 radio transmitters, a battery pack, attitude determination and control system and flight computer system, and two deployable solar arrays. There is no propulsion system.

Total satellite mass at launch, including all propellants and fluids: 2.21 kg.

Dry mass of satellite at launch, excluding solid rocket motor propellants: 2.21 kg

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): None.

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: None

Fluids in Pressurized Batteries: None. The COTS Tenergy 925050 Li-Polymer cells contain no fluid, just a rubbery lithium polymer material.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector:

Attitude control uses a passive neodymium permanent magnet located at the CG of the spacecraft, which provides general orientation throughout the orbit. This is the only critical component of the attitude control system. A secondary system consists of (3) torque coils oriented along the three axes of the spacecraft located at the +Z end. Four (4) horizon sensors on the +Z axis provide supplemental orientation feedback to the system, allowing for command and control of the torque coils.

Normal attitude is with the Z axis perpendicular to the Earth magnetic field lines.

Description of any range safety or other pyrotechnic devices: No pyrotechnic devices are used.

Description of the electrical generation and storage system: The electric generation and storage system is a direct energy transfer system using a solar array producing approximately 3.47 W of orbit average power to charge the 65 W-hr battery system. The solar arrays utilize Alta Devices Gen4 photovoltaic cells. The batteries are 8 total COTS Tenergy 925050 Li-Polymer cells.

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: There are no intentional releases.

Rationale/necessity for release of each object: N/A.

Time of release of each object, relative to launch time: N/A.

Release velocity of each object with respect to spacecraft: N/A.

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

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.1.1)

***Requirement 4.3-1*, Mission Related Debris Passing Through LEO:** COMPLIANT

***Requirement 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 planned intentional breakup and there is no credible scenario that would result in spacecraft breakup during normal deployment and operations.

Failure of a battery cell or protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The analysis below shows that no such explosion can cause breakup or any release of material from the spacecraft.

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:

Only the battery pack contains stored energy. The battery is comprised of 8 Tenergy Lithium Polymer 3.7V 2200mAh (925050) cells. The total potential for stored energy is about 65 Watt-hours.

Passivation is implemented by use of a commanded "Disposal Mode", which is initiated in the on board software. When in disposal mode the system disconnects the solar panels from the batteries, and discharges the batteries.

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

Not applicable.

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:

Malfunction of lithium ion or lithium polymer batteries and/or associated control circuitry has been identified as a potential cause for spacecraft breakup during deployment and mission operations. However the following demonstrates that in this design, breach of the spacecraft is not a credible outcome of any such malfunction.

Natural degradation of the solar cell and battery properties will occur over the mission period, 2 years. These conditions pose a possible increased chance of undesired battery energy release. The battery capacity for storage will degrade over time, possibly leading to changes in the acceptable charge rate for the cells. Individual cells may also change properties at different rates due to time degradation and temperature changes. The control circuit may also malfunction as a result of exposure to the space environment over long periods of time. The cell pressure relief vents could be blocked by small contaminants. Any of these individual or combined effects may theoretically cause an electro-chemical reaction that result in rapid energy release in the form of combustion. However, the batteries still meet Req. 56450 by virtue of the fact that they cannot "cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft".

The batteries are consumer-oriented devices. All battery cells have been recognized as Underwriters Laboratories (UL) tested and approved. Furthermore, safety devices incorporated in the design include pressure release, over current charge protection and over current discharge protection.

These batteries have passed the UL standard testing procedures that characterize their explosive potential. Of particular concern to NASA Req. 56450 is UL Standard 1642, which specifically deals with the testing of lithium batteries. Section 20 Projectile Test of UL 1642 (ref. (e)) subjects the test battery to heat by flame while within an aluminum and steel wire mesh octagonal box, "[where the test battery] shall remain on the screen until it explodes or the cell or battery has ignited and burned out" (UL 1642 20.5). To pass the test, "no part of an exploding cell or battery shall penetrate the wire screen such that some or all of the cell or battery protrudes through the screen" (UL 1642 20.1).

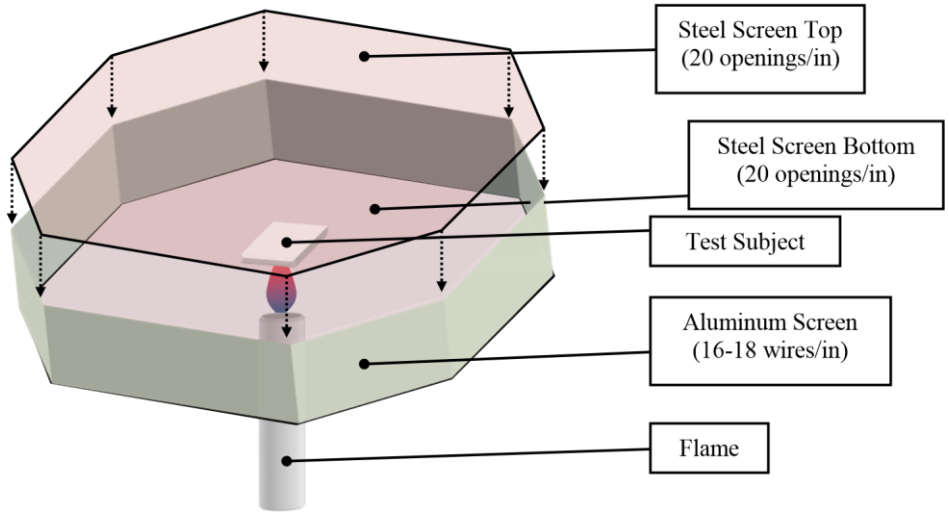


Figure 2: Underwriters Laboratory Explosion Test Apparatus

The spacecraft batteries will experience conditions on orbit that are generally much less severe that those seen during the UL test. While the source of failure would not be external heat on orbit, it is unlikely but possible that the continual charging over the lifetime of the mission may expose the batteries to overcharging, which could cause similar heat to be generated internally. Through the UL testing, it has been shown that even in this unlikely case, these batteries do not cause an explosion that would cause a fragmentation of the spacecraft.

A NASA Glenn Research Center guideline entitled Guidelines on Lithium-ion Battery Use in Space Applications (ref. (d)) explains that the hazards of Li-Ion cells in an overcharge situation result in the breakdown of the electrolyte found in Li-ion cells causing an increase in internal pressure, formation of flammable organic solvents, and the release of oxygen from the metal oxide structure. From a structural point of view a battery in an overcharge situation can expect breakage of cases, seals, mounting provisions, and internal components. The end result could be "unconstrained movement of the battery" (ref. (a), pg 13). This document clearly indicates that only battery deformation and the escape of combustible gasses will be seen in an overcharging situation, providing further support to the conclusion that CubeSat fragmentation due to explosion is not a credible scenario for this application. It is important to note that the NASA guide to Li-ion batteries makes no mention of these batteries causing explosions of any magnitude whatsoever.

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

Compliance statement:
Compliant. Passivation is implemented by use of a commanded "Disposal Mode", which is initiated in the on board software. When in disposal mode the system disconnects the solar panels from the batteries, and discharges the batteries.

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 v2.1.1, and calculation methods provided in NASA-STD-8719.14, 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).

- **DAS 2.1.1 Calculation:**
  Large Object Impact and Debris Generation Probability:
  DAS gives the probability as 0.00000, and the status as COMPLIANT.

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 post mission disposal requirements is less than 0.01 (Requirement 56507).

- **DAS 2.1.1 Calculation:**
  Probability of Damage from Small Debris:
  Probability of Penetration = 0.000471; COMPLIANT

- **Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering:**

  As there is no propellant, no maneuvering is possible.

  Systems required for accomplishing post-mission passivation: Passivation via ground command requires radio and spacecraft processor, along with adequate power to operate these systems.

ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal: None

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

Spacecraft Mass: 2.21 kg

Cross-sectional Area: 0.07 m^2 for the deployed configuration.

Area to mass ratio: 0.07/2.21 = 0.032 m^2/ kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-4 (per DAS v 2.1.1 and NASA-STD-8719.14 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 satellite reentry is COMPLIANT using method "a. Atmospheric reentry, 'natural forces' option." Asgardia-1 will be left in a near circular orbit at the end of the 2 year mission: at that time it will have apogee 487 km and perigee 473 km, reentering about 4.6 years after launch with orbit history as shown in Figure 3.

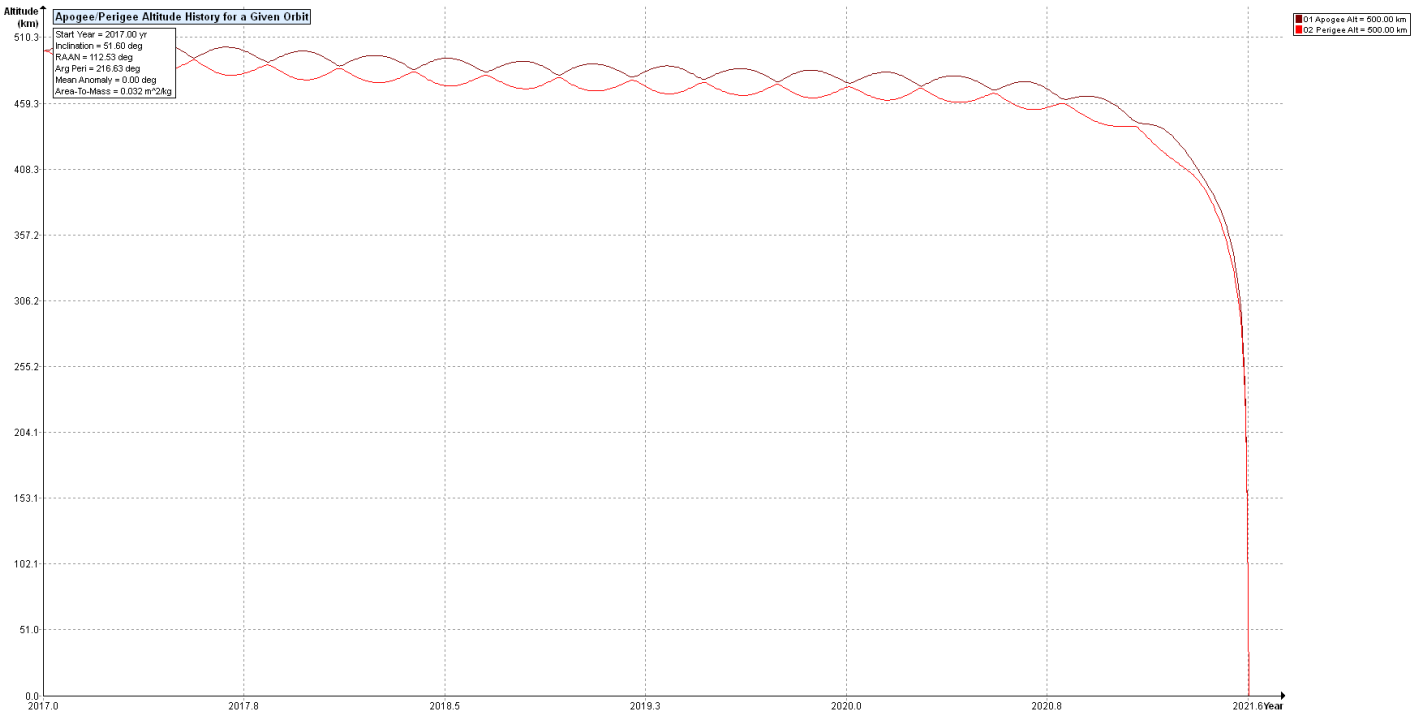


Figure 3, Asgardia-1 Projected Orbit History

Requirement 4.6-2. Disposal for space structures near GEO.

Analysis: Not applicable. Asgardia-1 orbit is LEO.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.

Analysis: Not applicable. Asgardia-1 orbit is LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: For purposes of performing a margined analysis, we will assume that the operational mission becomes extended up to three years post-deployment, and the Asgardia-1 battery passivation will occur at the end of the three year period when commanded by the ground. This is doubly conservative, in that it is planned to execute the end of mission operation after 2 years, and also, at about 4.6 years after launch, the spacecraft is expected to deorbit regardless of any end of mission action.

Reliability of this function exceeds 99%, based on combined reliability of COTS electronics to functionally survive after 3 years of space exposure.

Radiation design factor (RDF) is estimated to be very large (greater than 5) using SPENVIS and SHIELDOSE-2 trapped particle, *Bremsstralung*, and Solar Protons, plus estimated GCR. The SPENVIS data is the result of a worst case aluminum sphere shielding assumption around a silicon target. The RDF estimate is based on a generally accepted rule of thumb that COTS electronics can

typically withstand 5 kRAD exposures ("Spacecraft Systems Engineering", 3ed; c. John Wiley and Sons, Ltd.; P. Fortescue, J. Stark, and G. Swinerd editors.).

To exceed 5 kRAD dose, multiple large Solar Particle Events (SPE's) resulting in >4 kRAD additional dose would have to occur within the 3 year period. This represents more than four (4) times the predicted solar proton dose for the shielding model analyzed and is therefore a negligible possibility.

Therfore, the reliability of the electronics needed to passivate the batteries is best derived from the generic reliability of COTS electronics after burn-in testing and environmental stress screening tests, rather than from the much lower random probability of a disabling GCR hit. In this regard, any one of 3 independent critical electronics boards would need to fail to prevent the passivation function from occurring. This type of circuit board has been assessed to have generic life failure probability of ~1E-8/hr each. So, for a three year duration, the total failure probability due to component life failure is estimated as:

Pf = (3*1E-8/hr)*(8760 hr/yr)*(3 yr)*100 = 0.08%

The reliability of this function is therefore 99.92 percent. That is, there is roughly one (1) chance of functional failure of the battery passivation "disposal" design in 1,200 design-identical 3 year missions based on generic design reliability expectations.

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) (Requirement 56626).

Summary Analysis Results: DAS v2.1.1 reports that Asgardia-1 is COMPLIANT with demise altitudes above 73 km for all components. **Total human casualty probability is reported by the DAS software as 1:100000000, which is interpreted as zero probability (no probability could be calculated given that no impacts are expected).** As seen in the analysis outputs provided in Appendix A below, the impact kinetic energy is 0.0 Joules and Debris Casualty Area is 0.0 m^2.

Requirements 4.7-1b, and 4.7-1c below are non-applicable requirements because the spacecraft does not use controlled reentry.

4.7-1, b) **NOT APPLICABLE.** 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).

4.7-1 c) **NOT APPLICABLE.** 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).

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers in the Asgardia-1 mission.

References

A. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP08-75. NASA Glenn Research Center Cleveland, Ohio

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END of ODAR for Asgardia-1.

Appendix A: Analysis per DAS v2.1.1

```
06 14 2017; 06:32:11AM Activity Log Started
06 14 2017; 06:32:11AM Opened Project C:\Users\Mike\Documents\All
SatLicensing\Nanoracks\Asgardia\DAS\
06 14 2017; 06:32:20AM Activity Log Started
06 14 2017; 06:32:20AM Opened Project C:\Users\Mike\Documents\All
SatLicensing\Nanoracks\Asgardia\DAS\
06 14 2017; 06:35:43AM Processing Requirement 4.6   Return Status :  Passed

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

**INPUT**

      Space Structure Name = ASGARDIA-1
      Space Structure Type = Payload

      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.032000 (m^2/kg)
      Start Year = 2017.000000 (yr)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Duration = 2.000000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 472.699660 (km)
      PMD Apogee Altitude = 486.936250 (km)
      PMD Inclination = 51.596611 (deg)
      PMD RAAN = 106.529504 (deg)
      PMD Argument of Perigee = 55.068886 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 472.699660 (km)
      Suggested Apogee Altitude = 486.936250 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2021 (yr)
      Requirement = 61
      Compliance Status = Pass

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

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

06 14 2017; 06:37:25AM Science and Engineering - Apogee/Perigee History for a Given Orbit

INPUT

Perigee Altitude = 500.000000 (km)
Apogee Altitude = 500.000000 (km)
Inclination = 51.600000 (deg)
RAAN = 112.534700 (deg)
Argument of Perigee = 216.633600 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.032000 (m^2/kg)
Start Year = 2017.000000 (yr)
Integration Time = 25.000000 (yr)

OUTPUT

Plot
06 14 2017; 06:47:21AM Processing Requirement 4.5-1: Return Status : Passed

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

INPUT

Space Structure Name = ASGARDIA-1
Space Structure Type = Payload
Perigee Altitude = 500.000000 (km)
Apogee Altitude = 500.000000 (km)
Inclination = 51.600000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.032000 (m^2/kg)
Start Year = 2017.000000 (yr)
Initial Mass = 2.210000 (kg)
Final Mass = 2.210000 (kg)
Duration = 2.000000 (yr)
Station-Kept = False
Abandoned = True
PMD Perigee Altitude = -1.000000 (km)
PMD Apogee Altitude = -1.000000 (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

Collision Probability = 0.000000
Returned Error Message: Normal Processing

```
      Date Range Error Message: Normal Date Range
      Status = Pass

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

=============== End of Requirement 4.5-1 ===============
06 14 2017; 06:52:40AM Requirement 4.5-2:  Compliant

================================================
Spacecraft = ASGARDIA-1
Critical Surface = Duplex Antenna
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 2.800000 (g/cm^2)
      CS Surface Area = 0.002500 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No

**OUTPUT**

      Probabilty of Penetration = 0.000139 (0.000139)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = ASGARDIA-1
Critical Surface = Duplex Radio
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
```

```
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 0.800000 (g/cm^2)
      CS Surface Area = 0.007100 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 0.800000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000156 (0.000156)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = ASGARDIA-1
Critical Surface = EPS - COMM
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 0.800000 (g/cm^2)
      CS Surface Area = 0.007100 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 0.800000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000156 (0.000156)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
```

```
Spacecraft = ASGARDIA-1
Critical Surface = Battery 1
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 3.000000 (g/cm^2)
      CS Surface Area = 0.002800 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 0.800000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000005 (0.000005)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = ASGARDIA-1
Critical Surface = Battery 2
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 3.000000 (g/cm^2)
```

```
      CS Surface Area = 0.002800 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 0.800000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000005 (0.000005)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = ASGARDIA-1
Critical Surface = Battery 3
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 3.000000 (g/cm^2)
      CS Surface Area = 0.002800 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 0.800000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000005 (0.000005)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

================================================
Spacecraft = ASGARDIA-1
Critical Surface = Battery 4
================================================

**INPUT**

      Apogee Altitude = 500.000000 (km)
      Perigee Altitude = 500.000000 (km)
```

```
      Orbital Inclination = 51.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.032000 (m^2/kg)
      Initial Mass = 2.210000 (kg)
      Final Mass = 2.210000 (kg)
      Station Kept = No
      Start Year = 2017.000000 (yr)
      Duration = 2.000000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 3.000000 (g/cm^2)
      CS Surface Area = 0.002800 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 0.800000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

      Probabilty of Penetration = 0.000005 (0.000005)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range


06 14 2017; 07:01:14AM *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = ASGARDIA-1
quantity = 1
parent = 0
materialID = 7
type = Box
Aero Mass = 2.210000
Thermal Mass = 2.210000
Diameter/Width = 0.101000
Length = 0.227000
Height = 0.100000

name = NSL 2U CubeSat Chassis
quantity = 1
parent = 1
materialID = 7
type = Box
Aero Mass = 0.812000
Thermal Mass = 0.812000
Diameter/Width = 0.101000
Length = 0.227000
Height = 0.100000
```

```
name = NSL 2U x2 Deploy Solar Array
quantity = 4
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.104000
Thermal Mass = 0.104000
Diameter/Width = 0.083000
Length = 0.213000

name = NSL Duplex Antenna
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.069000
Thermal Mass = 0.069000
Diameter/Width = 0.050000
Length = 0.050000
Height = 0.011000

name = NSL Simplex Antenna
quantity = 2
parent = 1
materialID = 23
type = Box
Aero Mass = 0.015000
Thermal Mass = 0.015000
Diameter/Width = 0.035000
Length = 0.035000
Height = 0.007000

name = NSL RBF Switch Assembly
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.005000
Thermal Mass = 0.005000
Diameter/Width = 0.020000
Length = 0.020000
Height = 0.005000

name = Rail Switches
quantity = 4
parent = 1
materialID = 26
type = Box
Aero Mass = 0.002000
Thermal Mass = 0.002000
Diameter/Width = 0.010000
Length = 0.020000
```

```
Height = 0.007000

name = NSL IR Horizon Sensor
quantity = 4
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.002000
Thermal Mass = 0.002000
Diameter/Width = 0.009000
Length = 0.017000

name = NSL EPS / Simplex 1
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.087000
Length = 0.090000
Height = 0.014000

name = NSL Dual Lipo Battery Pack UL 925050 Tenergy
quantity = 4
parent = 1
materialID = 7
type = Box
Aero Mass = 0.083000
Thermal Mass = 0.083000
Diameter/Width = 0.050000
Length = 0.055000
Height = 0.017000

name = Cabling
quantity = 1
parent = 1
materialID = 52
type = Cylinder
Aero Mass = 0.075000
Thermal Mass = 0.075000
Diameter/Width = 0.000320
Length = 95.000000

name = Fasteners
quantity = 60
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.001083
Thermal Mass = 0.001083
Diameter/Width = 0.005000
```

```
Length = 0.008000

name = NSL D2F Duplex Module
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.060000
Length = 0.118000
Height = 0.028000

name = NSL S2F Simplex 2
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.056000
Thermal Mass = 0.056000
Diameter/Width = 0.045000
Length = 0.082000
Height = 0.014000

name = NSL ADACS Coil
quantity = 3
parent = 1
materialID = 19
type = Cylinder
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.008000
Length = 0.070000

name = NSL ADACS Module
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.042000
Length = 0.070000
Height = 0.005000

name = NSL Peak Power Tracker
quantity = 2
parent = 1
materialID = 23
type = Box
Aero Mass = 0.009000
Thermal Mass = 0.009000
```

```
Diameter/Width = 0.020000
Length = 0.050000
Height = 0.005000

name = NSL Entergetic Partical Detector
quantity = 2
parent = 1
materialID = 23
type = Box
Aero Mass = 0.005000
Thermal Mass = 0.005000
Diameter/Width = 0.016000
Length = 0.028000
Height = 0.007000

name = NSL Deploy Module
quantity = 4
parent = 1
materialID = 23
type = Box
Aero Mass = 0.003000
Thermal Mass = 0.003000
Diameter/Width = 0.015000
Length = 0.032000
Height = 0.005000

name = SSD 500GB Micro SD XC
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.001000
Thermal Mass = 0.001000
Diameter/Width = 0.011000
Length = 0.016000
Height = 0.003500

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

name = ASGARDIA-1
Demise Altitude = 77.995804
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL 2U CubeSat Chassis
Demise Altitude = 73.384232
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
```

```
name = NSL 2U x2 Deploy Solar Array
Demise Altitude = 76.862755
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL Duplex Antenna
Demise Altitude = 73.428543
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL Simplex Antenna
Demise Altitude = 76.773720
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL RBF Switch Assembly
Demise Altitude = 76.509270
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Rail Switches
Demise Altitude = 77.833946
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL IR Horizon Sensor
Demise Altitude = 77.157883
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL EPS / Simplex 1
Demise Altitude = 75.580154
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL Dual Lipo Battery Pack UL 925050 Tenergy
Demise Altitude = 73.803070
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Cabling
Demise Altitude = 77.949760
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = Fasteners
Demise Altitude = 75.720581
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL D2F Duplex Module
Demise Altitude = 77.132805
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL S2F Simplex 2
Demise Altitude = 76.461945
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL ADACS Coil
Demise Altitude = 75.131126
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL ADACS Module
Demise Altitude = 77.586624
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL Peak Power Tracker
Demise Altitude = 77.202553
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL Entergetic Partical Detector
Demise Altitude = 77.232597
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = NSL Deploy Module
Demise Altitude = 77.530052
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = SSD 500GB Micro SD XC
Demise Altitude = 77.607521
```

```
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************

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