2015

# LEMUR-2 Orbital Debris Assessment Report

NANOSATISFI MARKET MISSION PROFILE

PREPARED BY: NANOSATISFI INC

# Summarized List of Compliance Status to Orbital Debris Requirements

For convenience, below is a summarized list of the compliance status to orbital debris requirements. Detailed explanations for each of these compliance statements are available in ODAR Sections 1 through 8.

| | |
|---|---|
| 4.3-1, Mission-Related Debris Passing Through LEO: | COMPLIANT |
| 4.3-2, Mission-Related Debris Passing Near GEO | COMPLIANT |
| 4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: | COMPLIANT |
| 4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon: | N/A |
| 4.4-3, Limiting the long-term risk to other space systems from planned breakups: | COMPLIANT |
| 4.4-4, Limiting the short-term risk to other space systems from planned breakups: | COMPLIANT |
| 4.5-1, Probability of Collision with Large Objects: | COMPLIANT |
| 4.5-2, Probability of Damage from Small Objects: | COMPLIANT |
| 4.6-1, Disposal for space structures passing through LEO: | COMPLIANT |
| 4.6-2, Disposal for space structures passing through GEO: | N/A |
| 4.6-3, Disposal for space structures between LEO and GEO: | N/A |
| 4.6-4, Reliability of postmission disposal operations: | N/A |
| 4.8-1, Collision Hazards of Space Tethers | N/A |

# ODAR Section 1: Program Management and Mission Overview

<table>
<tr><td>Program / Project Manager</td><td>Peter Platzer</td></tr>
<tr><td>Mission Description</td><td>The purpose of the LEMUR-2 nanosatellite fleet is to provide high-revisit maritime domain monitoring data, as part of a market trial to test marked demand in this area. The mission consists of a set of 21 3U Cubesats satellites launched in four separate launch vehicles launches into various orbital planes, to increase average revisit time globally. The LEMUR-2 fleet is a continuation of the market trial currently underway with the single prototype LEMUR-1 satellite.</td></tr>
<tr><td>Foreign Government Involvement</td><td>None</td></tr>
<tr><td>Project Milestones:<br>Proposed Launch Date:<br>Proposed Launch Vehicles:<br>Proposed Launch Sites:<br>Launch Vehicle Operator:</td><td>The project milestones for the LEMUR-2 constellations align with the successive launch of vehicles into orbit. The table blow contains launch segment information for each launch of the constellation.
<table>
<tr><th>Vehicle</th><th>Proposed Launch Date (no earlier than)</th><th>Number of Satellites</th><th>Launch Vehicle Operator</th><th>Launch Site</th><th>Altitude</th><th>Inclination</th></tr>
<tr><td>PSLV</td><td>Q3 2015</td><td>4</td><td>Antrix / ISRO</td><td>Sriharikota, India</td><td>650 km</td><td>6 deg</td></tr>
<tr><td>Soyuz</td><td>Q4 2015</td><td>2</td><td>Roscosmos</td><td>Baikonur, Kazakhstan</td><td>600 km</td><td>98 deg</td></tr>
<tr><td>HII-A</td><td>January 2016</td><td>7</td><td>JAMSS / JAXA</td><td>Tanegashima, Japan</td><td>575 km</td><td>31 deg</td></tr>
<tr><td>Falcon-9</td><td>Q1 2016</td><td>8</td><td>Space-X</td><td>Vandenberg, CA, US</td><td>450 x 750 km</td><td>98 deg</td></tr>
</table></td></tr>
<tr><td>Mission Duration:</td><td>The operational lifetime of each satellite is estimated to be up to 2 years following deployment from the launch vehicle. The orbital lifetime for the constellation is nominally expected to be between 5-8 years, depending on the vehicle’s orbit, as described in Section 6.</td></tr>
<tr><td>Launch / Deployment Profile:</td><td>Launch<br>LEMUR-2 satellites will be injected directly into the target orbits outlined in the table above.<br><br>Checkout<br>For up to 1 month following deployment into orbit, LEMUR-2 satellites will remain in checkout phase. During this phase, ground operators will verify correct operation of the satellite and its payloads, and prepare it for the operational phase.</td></tr>
</table>

| | |
|---|---|
| | **Operations**<br>The operational phase of the satellite begins following the successful deployment of the satellite from the launch vehicle, and successful checkout. The operational phase continues until the end of the market study.<br><br>**Postmission Disposal**<br>Following the end of the operational phase, the satellites will remain on orbit in a non-transmitting mode while the orbit of the satellite passively decays until the satellite reenters the atmosphere and disintegrates. Other than the satellites launched as part of the PSLV vehicle, each of the satellites are nominally expected to reenter the atmosphere within 10 years following deployment from the launch vehicle, and the satellites launched as part of the PSLV vehicle are nominally expected to reenter the atmosphere within 18 years following deployment from the launch vehicle, as detailed in Table 2 of Section 6. |
| Selection of Orbit: | The selection of the chosen orbits was made due to available launch opportunities. |
| Potential Physical Interference with Other Orbiting Object: | As the satellites do not have any propulsion systems, their orbits will naturally decay following deployment from the launch vehicle.<br><br>As detailed in Section 5, the probability of physical interference between the satellites and other space objects is sufficiently unlikely that the satellite complies with Requirement 4.5. |

# ODAR Section 2: Spacecraft Description

**Physical Description:**

| Property | Value |
|---|---|
| **Total Mass at Launch** | 4.5kg |
| **Dry Mass at Launch** | 4.5kg |
| **Form Factor** | 3U CubeSat |
| **COG** | <3cm radius from geometric center |
| **Envelope (stowed)** | 100mm x 100mm x 340.5mm (excluding dynamic envelope) |
| **Envelope (deployed)** | 1m x 1m x 300mm |
| **Propulsion Systems** | None |
| **Fluid Systems** | None |
| **AOCS** | Stabilization/pointing with 3x orthogonal reaction wheels, desaturation + coarse pointing with magnetorquers, GPS navigation |
| **Range Safety / Pyrotechnic Devices** | None |
| **Electrical Generation** | Triple-junction GaAs solar panels |
| **Electrical Storage** | Rechargeable lithium-polymer battery pack |
| **Radioactive Materials** | None |

# ODAR Section 3: Assessment of Debris Released During Normal Operations

| **Objects larger than 1mm expected to be released during orbit:** | **None** |
|---|---|
| Rationale for release of each object: | N/A |
| Time of release of each object: | N/A |
| Release velocity of each object: | N/A |
| Expected orbital parameters of each object: | N/A |
| Calculated orbital lifetime of each object: | N/A |

| **Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2:** | |
|---|---|
| 4.3-1, Mission-Related Debris Passing Through LEO: | **COMPLIANT** |
| 4.3-2, Mission-Related Debris Passing Near GEO: | **COMPLIANT** |

A DAS 2.0.2 log demonstrating the compliance to the above requirements is available in Appendix A – “DAS 2.0.2 Log”.

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

**Potential causes for spacecraft breakup:**

There are only two plausible causes for breakup of the satellites:

- energy released from onboard batteries, and
- mechanical failure of the reaction wheels

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

The batteries aboard the satellites are two 42Wh Lithium-Polymer batteries, and represent the only credible failure mode during which stored energy is released. The main failure modes associated with Lithium Polymer batteries result from overcharging, overdischarging, internal shorts, and external shorts.

The battery pack onboard LEMUR-2 satellites complies with all controls / process requirements identified in JSC-20793 Section 5.4.3 to mitigate chance of any accidental venting / explosion caused by the above failure modes.

The only failure mode of the reaction wheel assemblies that could lead to creation of debris would be breakup of the wheels themselves due to mechanical failure while operating at a high angular rate. Risk mitigation strategies for breakups due to the reaction wheels include limiting the maximum rotational speed of the wheels, and containing them within a sealed compartment.

**Detailed Plan for any designed spacecraft breakup, including explosions and intentional collisions:**

There is no planned breakup the satellites on-orbit.

**List of components passivated at EOM:**

At the end of mission, the only components that will require passivation are the reaction wheels. At the end of the mission, the reaction wheels will be de-spun to passivate.

**Rationale for all items required to be passivated that cannot be due to design:**

N/A

| **Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:** | |
|---|---|
| 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 breakups:<br>There are no planned breakups of any of the satellites. | **COMPLIANT** |
| 4.4-4, Limiting the short-term risk to other space systems from planned breakups<br>There are no planned breakups of any of the satellites. | **COMPLIANT** |

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

**Probability for Collision with Objects >10cm:**

The probability of a collision of any of the satellites with an orbiting object larger than 10cm in diameter was sufficiently small that the simulation performed using DAS 2.0.2 software returned a probability value of 0.

| **Assessment of spacecraft compliance with Requirement 4.5-1 and 4.5-2:** | |
|---|---|
| 4.5-1, Probability of Collision with Large Objects: | **COMPLIANT** |
| 4.5-2, Probability of Damage from Small Objects: | **COMPLIANT** |

A DAS 2.0.2 log demonstrating the compliance to the above requirements is available in Appendix A – “DAS 2.0.2 Log”.

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

**Description of Disposal Option Selected:**

Following its deployment, the satellite's orbit will naturally decay until it reenters the atmosphere. Table 1~~Table 1~~ describes the mission scenarios for which lifetime analysis of LEMUR-2 was considered, and the effective area-to-mass ratio of the satellite in each scenario. The ratio was calculated using the external dimensions of the satellite and deployed arrays. Drag area from deployed antennas was neglected.

*Table 1 - Area-to-Mass Ratio of LEMUR-2 Satellites in Various Mission Scenarios*

| Scenario | Description | Effective Area-to-Mass (m2/kg) |
|---|---|---|
| Satellite Nonfunctional | ▪ Antennas do not deploy<br>▪ Solar arrays do not deploy<br>▪ Satellite tumbles randomly | 0.0074 |
| Solar panel failure | ▪ Antennas deploy<br>▪ Solar panels fail to deploy<br>▪ Satellite maintains +Z axis nadir<br>▪ Position around Z axis as planned for mission operations | 0.0130 |
| Operational, nominal | ▪ Antennas deploy<br>▪ Solar panels deploy<br>▪ Satellite maintains +Z axis nadir<br>▪ Position around Z axis as planned for mission operations | 0.0208 |
| ADCS Nonfunctional | ▪ Antennas deploy<br>▪ Solar arrays deploy<br>▪ Satellite tumbles randomly | 0.0169 |

Table 2~~Table 2~~ shows the simulated orbital dwell time for a LEMUR-2 satellite in each of the planned orbits of the constellation, in each of the identified mission scenarios. In all mission scenarios and orbits, the dwell time of the satellite was simulated using DAS 2.0.2 software to be less than 20 years.

*Table 2 – Orbit Dwell Time for LEMUR-2 Satellite in Each Planned Orbit and Mission Scenario*

| | | Orbital Lifetime (Years) | | | |
|---|---|---|---|---|---|
| Description | Effective Area-to-Mass (m2/kg) | Soyuz (2 satellites) | HII-A (7 satellites) | Falcon-9 (8 satellites) | PSLV (4 satellites) |
| | | 600km x 600km SSO | 575km x 575km, 31 deg | 750km x 450km, SSO | 650km x 650km, 6 deg |
| **Satellite Nonfunctional** | **0.0074** | **19.8** | **17.0** | **11.6** | **40.4** |
| Solar panels failure | 0.0130 | 11.1 | 8.8 | 8.0 | 23.2 |
| ADCS Nonfunctional | 0.0169 | 9.0 | 8.0 | 7.4 | 18.8 |
| **Operational, Nominal** | **0.0208** | **8.3** | **7.5** | **6.9** | **17.3** |

**Identification of Systems Required for Postmission Disposal:** None

**Plan for Spacecraft Maneuvers required for Postmission Disposal:** N/A

**Calculation of final Area-to-Mass Ratio if Atmospheric Reentry Not Selected:** N/A

| Assessment of Spacecraft Compliance with Requirements 4.6-1 through 4.6-4: | |
|---|---|
| 4.6-1, Disposal for space structures passing through LEO<br><br>All of the satellites will reenter the atmosphere within 25 years of mission completion and 30 years of launch. | **COMPLIANT**[1] |
| 4.6-2, Disposal for space structures passing through GEO: | **N/A** |
| 4.6-3, Disposal for space structures between LEO and GEO: | **N/A** |
| 4.6-4, Reliability of postmission disposal operations: | **COMPLIANT** |

[1] The only mission scenario in which the predicted orbital lifetime exceeds the limit of within 25 years of mission completion and within 30 years of launch is if both the deployable antennas and solar panels fail to deploy on the PSLV launch. As the satellites are nominally expected to perform, all will reenter within 17.3 years following launch.

# ODAR Section 7: Assessment of Spacecraft Reentry Hazards

**Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle:**

A system-level mass breakdown and primary materials list included in the generic satellite bus is available in the table below:

| Subsystem | Materials | Quantity | Mass (g) | Shape | Size (mm) |
|---|---|---|---|---|---|
| Solar Panels (long) | Glass, GaAs, FR4 PCB | 6 | 150 | Flat Plate | 100 x 300 |
| GPS Antenna (large) | Aluminum | 1 | 450 | Box | 300 x 80 x 8 |
| GPS Antenna (small) | Aluminum | 1 | 50 | Box | 50 x 50 x 17 |
| Subsystem PCBs | FR4 PCB | 12 | 80 | Flat Plate | 90 x 90 |
| Primary Structure | Aluminum | 1 | 560 | Box | 100 x 100 x 300 |
| Optical Camera | Aluminum, FR4 PCB, Glass | 1 | 350 | Cylinder | 30 x 100 |
| Reaction wheel assembly + enclosure | Aluminum, copper, FR4 PCB | 1 | 600 | Box | 100 x 100 x 56 |
| Battery pack | Li-Polymer | 2 | 470 | Box | 80 x 60 x 40 |

**Summary of objects expected to survive an uncontrolled reentry (using DAS 2.0.2 software):** None

**Calculation of probability of human casualty for expected reentry year and inclination:** 0%

| **Assessment of spacecraft compliance with Requirement 4.7-1:** | |
|---|---|
| 4.7-1, Casualty Risk from Reentry Debris: | **COMPLIANT** |

A DAS 2.0.2 log demonstrating the compliance to Requirement 4.7-1 is available in Appendix A – “DAS 2.0.2 Log”.

# ODAR Section 7A: Assessment of Spacecraft Hazardous Materials

**Summary of Hazardous Materials Contained on Spacecraft:** None

# ODAR Section 8: Assessment for Tether Missions

**Type of tether:** N/A

**Description of tether system:** N/A

**Determination of minimum size of object that will cause the tether to be severed:** N/A

**Tether mission plan, including duration and postmission disposal:** N/A

**Probability of tether colliding with large space objects:** N/A

**Probability of tether being severed during mission or after postmission disposal:** N/A

**Maximum orbital lifetime of a severed tether fragment:** N/A

| **Assessment of compliance with Requirement 4.8-1:** | |
|---|---|
| 4.8-1, Collision Hazards of Space Tethers: | **N/A** |

# Appendix A: DAS 2.0.2 Log

Below is the log of the DAS 2.0.2 simulation performed to demonstrate compliance to the above requirements.

```
01 29 2015; 18:35:20PM     DAS Application Started
01 29 2015; 18:35:21PM     Opened Project C:\Users\jspark\Desktop\Lemur-
2\ODAR\
01 29 2015; 18:35:47PM     Mission Editor Changes Applied
01 29 2015; 18:35:52PM     Project Data Saved To File
01 29 2015; 18:36:33PM     Science and Engineering - Orbit Lifetime/Dwell
Time

**INPUT**

     Start Year = 2015.500000 (yr)
     Perigee Altitude = 650.000000 (km)
     Apogee Altitude = 650.000000 (km)
     Inclination = 6.000000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Area-To-Mass Ratio = 0.013000 (m^2/kg)

**OUTPUT**

     Orbital Lifetime from Startyr = 23.392197 (yr)
     Time Spent in LEO during Lifetime  = 23.392197 (yr)
     Last year of Propagation = 2038 (yr)
     Returned Error Message: Object reentered
01 29 2015; 18:36:59PM     Science and Engineering - Apogee/Perigee History
for a Given Orbit

**INPUT**

     Perigee Altitude = 650.000000 (km)
     Apogee Altitude = 650.000000 (km)
     Inclination = 6.000000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Area-To-Mass Ratio = 0.013000 (m^2/kg)
     Start Year = 2015.500000 (yr)
     Integration Time = 30.000000 (yr)

**OUTPUT**

     Plot
01 29 2015; 18:38:21PM     Mission Editor Changes Applied
01 29 2015; 18:38:25PM     Project Data Saved To File
01 29 2015; 19:52:48PM     Science and Engineering - Orbit Lifetime/Dwell
Time

**INPUT**
```

Start Year = 2015.500000 (yr)
Perigee Altitude = 650.000000 (km)
Apogee Altitude = 650.000000 (km)
Inclination = 6.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.007400 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 40.388775 (yr)
Time Spent in LEO during Lifetime = 40.388775 (yr)
Last year of Propagation = 2055 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:53:06PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 650.000000 (km)
Apogee Altitude = 650.000000 (km)
Inclination = 6.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.016900 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 18.803559 (yr)
Time Spent in LEO during Lifetime = 18.803559 (yr)
Last year of Propagation = 2034 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:53:19PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 650.000000 (km)
Apogee Altitude = 650.000000 (km)
Inclination = 6.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.020800 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 17.264887 (yr)
Time Spent in LEO during Lifetime = 17.264887 (yr)
Last year of Propagation = 2032 (yr)

Returned Error Message: Object reentered
01 29 2015; 19:54:30PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 750.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.007400 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 11.570157 (yr)
Time Spent in LEO during Lifetime = 11.570157 (yr)
Last year of Propagation = 2027 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:54:40PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 750.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 8.043806 (yr)
Time Spent in LEO during Lifetime = 8.043806 (yr)
Last year of Propagation = 2023 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:54:50PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 750.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.016900 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 7.370294 (yr)
Time Spent in LEO during Lifetime = 7.370294 (yr)
Last year of Propagation = 2022 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:54:59PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 750.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.020800 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 6.921287 (yr)
Time Spent in LEO during Lifetime = 6.921287 (yr)
Last year of Propagation = 2022 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:55:17PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 575.000000 (km)
Apogee Altitude = 575.000000 (km)
Inclination = 31.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 8.750171 (yr)
Time Spent in LEO during Lifetime = 8.750171 (yr)
Last year of Propagation = 2024 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:55:28PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)

Inclination = 98.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 11.082820 (yr)
Time Spent in LEO during Lifetime = 11.082820 (yr)
Last year of Propagation = 2026 (yr)
Returned Error Message: Object reentered
01 29 2015; 19:57:02PM Processing Requirement 4.3-1: Return Status : Not Run

==========
No Project Data Available
==========

========== End of Requirement 4.3-1 ==========
01 29 2015; 19:57:05PM Processing Requirement 4.3-2: Return Status : Passed

==========
No Project Data Available
==========

========== End of Requirement 4.3-2 ==========
01 29 2015; 19:57:07PM Requirement 4.4-3: Compliant

========== End of Requirement 4.4-3 ==========
01 29 2015; 19:57:17PM Processing Requirement 4.5-1: Return Status : Passed

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

**INPUT**

Space Structure Name = Lemur2_PSLV
Space Structure Type = Payload
Perigee Altitude = 650.000000 (km)
Apogee Altitude = 650.000000 (km)
Inclination = 6.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 23.400000 (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 = 0.000002
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==========

**INPUT**

Space Structure Name = Lemur2_Soyuz
Space Structure Type = Payload
Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)
Inclination = 97.800000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 19.800000 (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 = 0.000002
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==========

**INPUT**

Space Structure Name = Lemur2_Falcon9
Space Structure Type = Payload
Perigee Altitude = 425.000000 (km)
Apogee Altitude = 750.000000 (km)
Inclination = 97.100000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 9.000000 (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 = 0.000001
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==========

**INPUT**

Space Structure Name = Lemur2_HIIB
Space Structure Type = Payload
Perigee Altitude = 575.000000 (km)
Apogee Altitude = 575.000000 (km)
Inclination = 31.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 17.000000 (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 = 0.000001
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==========

========== End of Requirement 4.5-1 ==========
01 29 2015; 19:57:20PM Requirement 4.5-2: Compliant
01 29 2015; 19:57:22PM Processing Requirement 4.6 Return Status : Passed

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

**INPUT**

Space Structure Name = Lemur2_PSLV
Space Structure Type = Payload

Perigee Altitude = 650.000000 (km)
Apogee Altitude = 650.000000 (km)
Inclination = 6.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 23.400000 (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**

Suggested Perigee Altitude = 650.000000 (km)
Suggested Apogee Altitude = 650.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

Released Year = 2038 (yr)
Requirement = 61
Compliance Status = Pass

==========

**INPUT**

Space Structure Name = Lemur2_Soyuz
Space Structure Type = Payload

Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)
Inclination = 97.800000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 19.800000 (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**

Suggested Perigee Altitude = 600.000000 (km)
Suggested Apogee Altitude = 600.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

Released Year = 2026 (yr)
Requirement = 61
Compliance Status = Pass

==========

**INPUT**

Space Structure Name = Lemur2_Falcon9
Space Structure Type = Payload

Perigee Altitude = 425.000000 (km)
Apogee Altitude = 750.000000 (km)
Inclination = 97.100000 (deg)

RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 9.000000 (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**

Suggested Perigee Altitude = 425.000000 (km)
Suggested Apogee Altitude = 750.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

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

==========

**INPUT**

Space Structure Name = Lemur2_HIIB
Space Structure Type = Payload

Perigee Altitude = 575.000000 (km)
Apogee Altitude = 575.000000 (km)
Inclination = 31.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 17.000000 (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**

      Suggested Perigee Altitude = 575.000000 (km)
      Suggested Apogee Altitude = 575.000000 (km)
      Returned Error Message = Reentry during mission (no PMD req.).

      Released Year = 2024 (yr)
      Requirement = 61
      Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
01 29 2015; 19:57:25PM     *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = Lemur2_PSLV
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Structure_tray
quantity = 2
parent = 1
materialID = 9
type = Box
Aero Mass = 0.200000
Thermal Mass = 0.200000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.005000

name = Structure_ribs
quantity = 10
parent = 1
materialID = 9
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.012000
Length = 0.083000
```

```
Height = 0.006000

name = Structure_mountingplates
quantity = 5
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.080000
Length = 0.100000

name = PCB
quantity = 15
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.080000
Thermal Mass = 0.080000
Diameter/Width = 0.080000
Length = 0.080000

name = Lenses
quantity = 2
parent = 1
materialID = 9
type = Cylinder
Aero Mass = 0.200000
Thermal Mass = 0.200000
Diameter/Width = 0.030000
Length = 0.120000

name = Reaction Wheels
quantity = 3
parent = 1
materialID = 67
type = Cylinder
Aero Mass = 0.120000
Thermal Mass = 0.120000
Diameter/Width = 0.030000
Length = 0.020000

name = solar_panels
quantity = 6
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.083000
Length = 0.324000
```

```
name = solar_cells
quantity = 61
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 0.015000
Thermal Mass = 0.015000
Diameter/Width = 0.040000
Length = 0.080000

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

name = Lemur2_PSLV
Demise Altitude = 77.996621
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structure_tray
Demise Altitude = 76.444527
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structure_ribs
Demise Altitude = 77.121871
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structure_mountingplates
Demise Altitude = 75.443886
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PCB
Demise Altitude = 76.127535
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lenses
Demise Altitude = 72.843566
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Reaction Wheels
Demise Altitude = 0.000000
Debris Casualty Area = 1.169982
```

```
Impact Kinetic Energy = 202.520203

************************************
name = solar_panels
Demise Altitude = 77.271605
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = solar_cells
Demise Altitude = 77.747871
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

***********INPUT****
 Item Number = 2

name = Lemur2_Soyuz
quantity = 1
parent = 0
materialID = 9
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Lemur2_Soyuz
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

*************OUTPUT****
Item Number = 2

name = Lemur2_Soyuz
Demise Altitude = 77.998722
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lemur2_Soyuz
Demise Altitude = 66.439011
```

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

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

**********INPUT****
 Item Number = 3

name = Lemur2_Falcon9
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Lemur2_Falcon9
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

**********OUTPUT****
Item Number = 3

name = Lemur2_Falcon9
Demise Altitude = 77.997660
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lemur2_Falcon9
Demise Altitude = 64.797706
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

**********INPUT****
 Item Number = 4

name = Lemur2_HIIB
quantity = 1
parent = 0
```

```
materialID = 9
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Lemur2_HIIB
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 4.500000
Thermal Mass = 4.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

**************OUTPUT****
Item Number = 4

name = Lemur2_HIIB
Demise Altitude = 77.995176
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lemur2_HIIB
Demise Altitude = 64.728616
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

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