**Before the**
**Federal Communications Commission**
**Washington, DC 20554**

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| Spire Global, Inc. | ) | File No. SAT-LOA-20151123-00078 |
| | ) | Call Sign S2946 |
| Application for Authorization to Launch and | ) | |
| Operate a Non-Geostationary Satellite System | ) | |

## OPPOSITION TO PETITION TO DISMISS, DENY, OR HOLD IN ABEYANCE

Spire Global, Inc. ("Spire") opposes the Petition to Dismiss, Deny, or Hold in Abeyance ("Petition")[1] that ORBCOMM License Corp. ("ORBCOMM") has filed against Spire's Part 25 license application for a state-of-the-art low-earth orbit satellite system ("Application").[2] Spire's proposed system offers to the public sophisticated asset tracking and weather information using advanced satellite technology. The Application fully complies with the FCC's rules, including specifically its regulations governing orbital debris as well as the collision risk thresholds established by the National Aeronautics and Space Administration ("NASA"). ORBCOMM's arguments to the contrary are speculative and unsupported by FCC requirements. The FCC's rules do not require satellite applicants seeking to deploy in low-Earth orbits to identify or coordinate with every operational satellite theoretically impacted by the proposed deployment, as ORBCOMM suggests. Nor do the FCC's rules impose more stringent orbital debris requirements on those satellite operators that choose to operate propulsion-less systems.

ORBCOMM would prefer that Spire select orbits for its satellites that have no theoretical possibility of conjunction with OBRCOMM's constellation. But ORBCOMM has no such right

[1] ORBCOMM License Corp. Petition to Dismiss, Deny, or Hold in Abeyance, File No. SAT-LOA-20151123-00078 (filed Feb. 22, 2016).

[2] Application of Spire Global, Inc., File No. SAT-LOA-20151123-00078 (filed Nov. 23, 2015).

to exclude others from the fair use of limited and shared low-Earth orbit resources, especially where, as here, no reasonable likelihood of conjunction exists. ORBCOMM provides no credible basis to reject or otherwise delay action on the Application; therefore, Spire requests that the FCC deny the Petition and grant Spire's application for a next-generation satellite constellation.

**Background**

On November 23, 2015, Spire submitted an application to operate a total of up to 900 cubesats to be deployed over a 15-year term, as part of a low-Earth orbit, non-geostationary orbit satellite system (the "LEMUR System") to provide maritime monitoring, meteorological monitoring, and earth imaging services.[3] At any one time, there would be no more than 175 operational satellites.[4] Because of the number of satellites in the system and their intended launches as secondary payloads, Spire provided representative data to reflect the system and also requested waiver of any necessary FCC rules.[5]

As part of its filing, Spire provided a detailed orbital debris mitigation plan, including an Orbital Debris Assessment Report ("ODAR").[6] The ODAR demonstrated that the proposed system fully complied with applicable NASA guidelines.[7] Spire showed that the probability of a collision between any of the Spire satellites with an orbiting object larger than 10 cm in diameter

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[3] *See generally* Application, Exhibit A.

[4] *See id*. at 1-2.

[5] *See id*. at 25.

[6] *See id*. at 17-20; Application, Exhibit D.

[7] *See* ODAR § 5.

is "sufficiently small that the simulation performed using [NASA's] DAS 2.0.2 software returned a probability value of 0."[8]

Spire's Application also described the sharing agreement Spire has entered with the Joint Space Operations Center ("JSpOC") of the U.S. Strategic Command's Joint Functional Component Command for Space.[9] As part of its agreement with JSpOC, Spire obtains satellite location information from its reception of Global Positioning System ("GPS") signals onboard the satellites and communicates that information to JSpOC.[10] Spire also receives from JSpOC updated two-line element sets or TLEs, which allow for the identification and tracking of Spire's satellites.[11] JSpOC has a direct line of communications to Spire's satellite operations team, which is accessible twenty-four hours a day, seven days a week. This always-on line method of communication helps ensure that Spire can take immediate action to coordinate collision-avoidance measures.[12] In the unlikely event the JSpOC early-warning systems were to identify the potential for a conjunction between systems, Spire can use its two double-deployable solar array "wings" and its onboard magnetorquers and reaction wheels to perform collision-avoidance maneuvers.[13]

The FCC placed the Application on public notice on January 22, 2016.[14] On February 22, 2016, ORBCOMM filed the Petition asking the FCC to dismiss, deny, or hold in abeyance the

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[8] *Id*.

[9] *See* Application, Exhibit A at 18.

[10] *See id*.

[11] *See id.*

[12] *See id.*

[13] *See id*.

[14] *See* Public Notice, Report No. SAT-01130 (Jan. 22, 2016).

Application.[15] In the Petition, ORBCOMM argues that Spire has proposed to deploy the LEMUR System "in one or more orbital planes that would intersect with the authorized 47 degree-inclined 715 km target operational orbits of the entire fleet of ORBCOMM Generation 2 ('OG2') NGSO satellites."[16] Because the Application does not identify the specific orbital deployment plan for all the LEMUR satellites, ORBCOMM contends that Spire has not adequately assessed the potential risk of collision between the LEMUR System and the ORBCOMM's OG2 satellites.[17] ORBCOMM contends that it cannot adequately conduct its own collision risk analyses because Spire provided insufficient information.[18]

ORBCOMM also criticizes Spire for the lack of propulsion on its satellites and argues that Spire's satellite-design decision imposes an unfair obligation on ORBCOMM to assume all collision avoidance measures.[19] ORBCOMM proposes as a solution that Spire "select orbits that do not intersect with ORBCOMM's authorized orbits."[20]

**Discussion**

Spire has provided sufficient information regarding the deployment of its satellite system and demonstrated that its system meets the FCC's orbital debris requirements.[21] Although ORBCOMM asserts that the number of satellites and orbital information for the LEMUR System is vague, the FCC has allowed satellite applicants to identify ranges for both the number of

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[15] *See* Petition at 1. Prior to the filing of the Petition, Spire and ORBCOMM mutually agreed to participate in a conference call in an attempt to resolve OBRCOMM's concerns.

[16] *See id*. at 1-2.

[17] *See id*. at 3-4.

[18] *See id*. at 2-3.

[19] *See id*. at 4-5.

[20] *See id*. at 5.

[21] *See generally* Application.

satellites and their orbital deployments in the case where the proposed satellites would be launched as secondary payloads.[22] The flexibility accorded such applicants reflects the FCC's recognition that operators have different technological and business models and that the FCC should not dictate such choices, which could stifle innovation and market options.[23]

To be sure, the rules require a more detailed collision risk assessment where systems are operating in "identical" or "very similar" low-Earth orbits.[24] But, the Spire 450 km x 720 km, 98 degree inclination elliptical orbit and the ORBCOMM 715 km, 47 degree inclination circular orbit are neither identical, nor very similar.

Here, Spire submitted a detailed orbital debris mitigation plan[25] as well as an ODAR based on a worst-case scenario, *i.e.*, 175 satellites operating at the highest possible, proposed circular orbit of 650 km.[26] Because a hypothetical satellite in a 450 km x 720 km elliptical orbit has a shorter orbital lifetime (11.6 years, worst case) than a hypothetical satellite in a 650 km

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[22] *See, e.g.*, Stamp Grant, Planet Labs Inc., File No. SAT-LOA-20130626-00087 (granted Dec. 3, 2013); Stamp Grant, Skybox Imaging, Inc., File No. SAT-LOA-20120322-00058 (granted Sep. 20, 2012).

[23] *See, e.g.*, *Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in A Reasonable & Timely Fashion, & Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996*, Report, 14 FCC Rcd 2398 ¶ 5 (1999) ("Our role is not to pick winners and losers, or to select the best technology...."); *Creation of Low Power Radio Service*, Report and Order, 15 FCC Rcd 2205 (2000) (Statement of Chairman William Kennard) ("[I]t is not the business of the FCC to pick winners and losers. We should empower consumers to decide what he or she prefers, rather than ruling out some options on our own and depriving the listener of making that choice for him- or herself.").

[24] 47 C.F.R. § 25.114(d)(14)(iii); *see also Mitigation of Orbital Debris*, Second Report and Order, 19 FCC Rcd 11567 ¶ 50 (2004).

[25] *See* Application, Exhibit A at 17-20.

[26] *See* ODAR § 1. All of Spire's calculations were made using NASA's approved risk assessment software, DAS. That program determines orbital collision risk based on a well-established statistical model that estimates the weighted cross-sectional area flux for the orbital debris environment exposure, which is based on the mission's initial orbit, area-to-mass ratio, and launch date.

circular orbit (23.8 years, worst case), Spire did not identify the elliptical orbit in its ODAR. The ODAR analysis demonstrates that Spire's proposed constellation meets NASA's in-orbit collision risk threshold of 0.001.[27] In contrast, ORBCOMM provides nothing more than speculation that this analysis is inadequate.[28]

For completeness, Spire is attaching, as an appendix to this opposition, an ODAR that specifically considers the deployment of ten satellites in a 450 km x 750 km elliptical orbit. This ODAR was previously filed with the Commission as part of an experimental license filing.[29] As demonstrated in that document, even ten satellites at this higher elliptical orbit are compliant with NASA risk thresholds. Similarly, as demonstrated by another satellite applicant in a different application proceeding, operation of 120 satellites in the 450 km x 720 km elliptical orbit would be compliant with NASA risk thresholds.[30]

That there is no serious risk of collision is logical. The ORBCOMM and Spire satellites would be in different inclinations and have different apogee/perigee altitudes, meaning the resulting orbital paths can only come close to each other when the apsidal precision of a Spire satellite and the nodal precision of an ORBCOMM satellite coincide at a single point. The LEMUR satellites in this elliptical orbit also would experience rapid orbital decay. Spire

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[27] *See* ODAR, Appendix A: DAS 2.0.2 Log; *see also Process for Limiting Orbital Debris*, NASA-STD 8719.14A, Section 4.5.2.1.

[28] *See* Petition at 3-4.

[29] *See* Application, ELS File No. 0705-EX-PL-2015 (filed Nov. 24, 2015).

[30] Plant Labs Inc. Opposition to Petition to Dismiss, Deny or Hold In Abeyance, File No. SAT-MOD-20150802-00053, 7 (filed Feb. 3, 2016).

anticipates that the apogee of the satellites would be less than 715 km within 1 to 2 years, reducing collision risk.[31]

The FCC should also reject ORBCOMM's unsupported suggestions that Spire is not a responsible space actor. As the Application demonstrates, Spire has worked and continues to work closely with JSpOC to address satellite collision risk and avoidance.[32] Spire's use of GPS technology to locate its satellites greatly enhances tracking of its satellites and eliminates false positive conjunction alerts, reducing the need for any unnecessary satellite maneuvers.[33]

Spire is also capable of maneuvering its satellites to facilitate collision avoidance with twenty-four hours' notice.[34] Spire has a global earth station network and has satellite operational capabilities in many countries. Should a collision avoidance maneuver become necessary, Spire could take measures, such as pointing its satellites in different direction to affect the drag and relative position, within 30 minutes, which is approximately the time period for a Spire satellite to pass overhead one of the earth stations in Spire's global network.[35]

FCC rules do not impose stricter orbital debris requirements on satellites without propulsion systems. Nor do the FCC's rules preclude the licensing of satellites without propulsion systems. Indeed, in a prior rulemaking proceeding, the Commission specifically

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[31] Spire calculates, using the STK SatPro Satellite Lifetime Tool, that the orbital altitude will be less than 715 km in approximately 13 months, based on a nominal flying configuration with solar panels deployed and the satellite pointing nadir. *See* AGI Products Overview, Analytical Graphics, Inc., http://www.agi.com/products/stk/modules/default.aspx/id/stk-satpro (last visited March 7, 2016).

[32] *See* Application, Exhibit A at 18.

[33] *See id*. at 18.

[34] *See id*. at 18.

[35] Spire satellite operations personnel are on console twenty-fours a day, seven days a week.

rejected such proposals.[36] Moreover, ORBCOMM's fundamental premise that using propulsion systems on low-Earth orbit satellites necessarily produces a safer orbital environment is questionable. ORBCOMM has ignored the fact that the use of satellite propulsion systems increases the risk of explosion and the potential debris impact from any collisions.[37]

At bottom, ORBCOMM would prefer that Spire select orbits for its satellites that result in no theoretical possibility of conjunction with ORBCOMM's constellation.[38] But, ORBCOMM has no such right to exclude others from the fair use of limited and shared low-Earth orbit resources.[39] Moreover, such a policy would effectively give veto rights to incumbent operators in low-Earth orbit, allowing such operators to behave strategically and exclude new entrants from introducing competitive new services.

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[36] *Mitigation of Orbital Debris* at ¶ 86 (rejecting proposals to: (i) limit satellite systems without propulsion to orbital altitudes having lifetimes of less than five years; and (ii) require such systems to incorporate inflatable devices or other methods to decrease orbital lifetimes); *see also supra* note 23. Additionally, it would be inappropriate for the International Bureau to reconsider Commission conclusions in an application proceeding.

[37] *See, e.g*., Matthew Sparkes, "US military satellite explodes above Earth," The Telegraph (March 2, 2015), *available at* http://www.telegraph.co.uk/technology/news/11444155/US-military-satellite-explodes-above-Earth.html.

[38] *See* Petition at 5 ("From OBCOMM's perspective, the simplest solution would be for Spire to select orbits that do not intersect with ORBCOMM's authorized orbits."). A review of a similar petition filed against another satellite operator proposing to deploy in the same 450 km x 720 km elliptical orbit suggests that ORBCOMM's expressed concerns are a moving target. *See, e.g.*, Petition to Dismiss, Deny or Hold in Abeyance, SAT-MOD-20150802-00053, at 4 (Jan. 19, 2016) (criticizing applicant for failure to use on-board GPS); *compare* Petition at 4 (on-board GPS is ineffective when satellites are inoperative).

[39] Both FCC and international space policies encourage the shared and cooperative use of such resources. *See, e.g.*, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies art. I, Jan. 27, 1967, 18 U.S.T. 2410, T.I.A.S. No. 6347, 610 U.N.T.S. 205; Terms of Reference for the Inter-Agency Space Debris Coordination Committee (IADC), IADC-93-01 (rev. 11.3) (Apr. 2, 2015); *see also Mitigation of Orbital Debris*; *DIRECTV Enterprises, LLC*, Order and Authorization, 21 FCC Rcd 8028 ¶ 10 (IB 2006); *Morning Star Satellite Company, L.L.C.*, 16 FCC Rcd 11550 ¶ 13 (IB 2001); *Application of EchoStar North America Corporation*, 16 FCC Rcd 14262 ¶ 3 (IB 2001).

Spire also cannot simply withdraw its request to launch into the 450 km x 720 km elliptical orbit, as ORBCOMM proposes.[40] Unlike conventional satellites, Spire relies on the flexibility of dynamic launch schedules, which allows for more technical innovation, faster design refreshes, and materially lower launch costs. There are a limited number of launches available in the United States during any relevant timeframe,[41] and Spire's launch-risk mitigation strategy requires that it take advantage of suitable launch opportunities when they arise.[42]

Because Spire has provided all relevant orbital information and demonstrated that collision risk associated with its system meets FCC requirements and NASA risk thresholds, the FCC should deny the ORBCOMM Petition and grant Spire's Application.

Respectfully submitted,

*/s/ Jonathan Rosenblatt*
Jonathan Rosenblatt
General Counsel
Spire Global, Inc.
33 Norfolk Street
San Francisco, CA 94103

Dated: March 8, 2016

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[40] *See* Petition at 6.

[41] Indeed, the 450 km x 720 km elliptical orbit is the only U.S. launch available to commercial operators launching on a secondary basis in 2016, outside of deployments from the International Space Station.

[42] *See* Application, Exhibit A at 6.

**Technical Certification**

I, Jenny Barna, Launch Manager, hereby certify under penalty of perjury that:

- I am the technically qualified person responsible for preparation of the technical and other information contained in this Opposition.
- I am familiar with Part 25 of the FCC's rules and NASA's orbital debris standards; and
- The statements made herein are complete and accurate to the best of my knowledge.

*/s/ Jenny Barna*
Jenny Barna
Launch Manager
Spire Global, Inc.

Dated: March 8, 2016

# **Attachment 1**
# **Technical Appendix**

# LEMUR-2 Orbital Debris Assessment Report

NANOSATISFI MARKET MISSION PROFILE

PREPARED BY: SPIRE GLOBAL INC

REVISION 4

2015

# Revision History

| Revision | Description of Revisions | Release Date |
|---|---|---|
| **1** | (baseline version) | 02/10/2015 |
| **2** | Updated launch information based on new info from launch providers:<br>• PSLV expected launch date moved from Q3 2015 to Q4 2015<br>Added newly-booked launches:<br>• "TBD" launch updated to "Q4 2015 Atlas-V / Cyngnus" launch<br>• added Q1 2016 Soyuz launch<br>• updated quantity of satellites on Q1 2016 Falcon-9 launch to 10<br>New DAS log with updated launch information. | 04/22/2015 |
| **3** | Updated orbital decay information by including tensile strength decay of filaments | 05/23/2015 |
| **4** | Updated launch information in Section 1 and Section 6 to reflect a change in the manifest due to launch unavailability; updated results from DAS analysis accordingly:<br>• Remove Q4 2015 Atlas5 / Cygnus launch<br>• Add Q1 2016 Falcon9 / Dragon launch | 11/23/2015 |

# 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

| | |
|---|---|
| Program / Project Manager | Peter Platzer |
| Mission Description | 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 17 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. |
| Foreign Government Involvement | None |
| Project Milestones: | 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. |
| Proposed Launch Date: | |
| Proposed Launch Vehicles: | |
| Proposed Launch Sites: | |
| Launch Vehicle Operator: | |

| Vehicle | Proposed Launch Date (no earlier than) | Number of Satellites | Launch Vehicle Operator | Launch Site | Altitude | Inclination |
|---|---|---|---|---|---|---|
| PSLV | Q4 2015 | 4 | Antrix / ISRO | Sriharikota, India | 650 km | 6 deg |
| Falcon9 | Q1 2016 | 4 | SpaceX | Cape Canaveral, FL | ~400 km | 51.6 deg |
| Soyuz | Q4 2015 | 2 | Roscosmos | Baikonur, Kazakhstan | 600 km | 97.8 deg |
| HII-A | January 2016 | 7 | JAMSS / JAXA | Tanegashima, Japan | 575 km | 31 deg |
| Falcon9 | Q1 2016 | 8 | Space-X | Vandenberg, CA, US | 450 x 720 km | 97.1 deg |
| Soyuz | Q1 2016 | 4 | Roscosmos | Baikonur, Kazakhstan | 600 km | 98 deg |

| | |
|---|---|
| Mission Duration: | 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. |

| | |
|---|---|
| Launch / Deployment Profile: | **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.<br><br>**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. The satellite is nominally expected to reenter the atmosphere 10 years following deployment from the launch vehicle. |
| Selection of Orbit: | The selection of the chosen orbit was made due to available launch opportunities. |
| Potential Physical Interference with Other Orbiting Object: | As the satellite does not have any propulsion systems, its orbit 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** | Rechargable 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 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 (2x 0.5m whip antennas, 3x 0.3m whip antennas) was neglected; as such, the effective area-to-mass calculated below is a conservative case.

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

| Scenario | Description | Effective Area-to-Mass (m2/kg) |
|---|---|---|
| Satellite Nonfunctional | ▪ Solar arrays deploy only after 5 years<br>▪ Satellite tumbles randomly | 0.0000 (yrs 1-5)[1]<br>0.0169 (yrs 5+) |
| Solar panel failure | ▪ 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 | ▪ Solar panels deploy<br>▪ Satellite maintains +Z axis nadir<br>▪ Position around Z axis as planned for mission operations | 0.0208 |
| ADCS Nonfunctional | ▪ Solar arrays deploy<br>▪ Satellite tumbles randomly | 0.0169 |

[1] For the analysis, it was conservatively assumed that the satellite does not lose any altitude during the first 5 years (ie, an area of 0).

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) | Q4 2015 Soyuz (2 satellites) | Q1 2016 HII-A (7 satellites) | Q1 2016 Falcon-9 (10 satellites) | Q4 2015 PSLV (4 satellites) | Q1 2016 Falcon9 (4 satellites) | Q1 2016 Soyuz (4 satellites) |
| | | 600km x 600km SSO | 575km x 575km, 31 deg | 750km x 450km, SSO | 650km x 650km, 6 deg | 400km x 400km, ~52 deg | 600km x 600km SSO |
| **Satellite Nonfunctional** | **0.0074** | **19.8** | **17.0** | **11.6** | **23.8**[2] | **1.0** | **19.8** |
| Solar panels failure | 0.0130 | 11.1 | 8.8 | 8.0 | 23.2 | 0.5 | 11.1 |
| ADCS Nonfunctional | 0.0169 | 9.0 | 8.0 | 7.4 | 18.8 | 0.3 | 9.0 |
| **Operational, Nominal** | **0.0208** | **8.3** | **7.5** | **6.9** | **17.3** | **0.4** | **8.3** |

**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>All of the satellites will reenter the atmosphere within 25 years of mission | **COMPLIANT** |

[2] No decay in first 5 years, after that deployment of antenna and solar panel due to decay of nylon filament with an effective area/mass of 0.0169 m2/kg

| | |
|---|---|
| completion and 30 years of launch. | |
| 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** |

# 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.

```
04 22 2015; 22:49:55PM     DAS Application Started
04 22 2015; 22:49:57PM     Opened Project C:\Program Files (x86)\NASA\DAS 2.0\project\
04 22 2015; 22:50:57PM     Opened Project C:\Users\nanosatisfi\Downloads\ODAR-2015-04-22\ODAR\
04 22 2015; 22:51:47PM     Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

     Start Year = 2015.500000 (yr)
     Perigee Altitude = 500.000000 (km)
     Apogee Altitude = 500.000000 (km)
     Inclination = 51.600000 (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 = 7.178645 (yr)
     Time Spent in LEO during Lifetime  = 7.178645 (yr)
     Last year of Propagation = 2022 (yr)
     Returned Error Message: Object reentered
04 22 2015; 22:52:41PM     Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

     Start Year = 2015.500000 (yr)
     Perigee Altitude = 500.000000 (km)
     Apogee Altitude = 500.000000 (km)
     Inclination = 51.600000 (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 = 6.121834 (yr)
     Time Spent in LEO during Lifetime  = 6.121834 (yr)
     Last year of Propagation = 2021 (yr)
     Returned Error Message: Object reentered
```

04 22 2015; 22:52:51PM     Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 500.000000 (km)
Apogee Altitude = 500.000000 (km)
Inclination = 51.600000 (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 = 5.700205 (yr)
Time Spent in LEO during Lifetime  = 5.700205 (yr)
Last year of Propagation = 2021 (yr)
Returned Error Message: Object reentered

04 22 2015; 22:53:02PM     Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

Start Year = 2015.500000 (yr)
Perigee Altitude = 500.000000 (km)
Apogee Altitude = 500.000000 (km)
Inclination = 51.600000 (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 = 5.212868 (yr)
Time Spent in LEO during Lifetime  = 5.212868 (yr)
Last year of Propagation = 2020 (yr)
Returned Error Message: Object reentered

04 22 2015; 22:53:24PM     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)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.020800 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 8.268309 (yr)
Time Spent in LEO during Lifetime = 8.268309 (yr)
Last year of Propagation = 2023 (yr)
Returned Error Message: Object reentered

04 22 2015; 22:53:38PM 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)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.016900 (m^2/kg)

**OUTPUT**

Orbital Lifetime from Startyr = 8.974675 (yr)
Time Spent in LEO during Lifetime = 8.974675 (yr)
Last year of Propagation = 2024 (yr)
Returned Error Message: Object reentered

04 22 2015; 22:53:46PM 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)
RAAN = 0.000000 (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

04 22 2015; 22:53:57PM 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)
    RAAN = 0.000000 (deg)
    Argument of Perigee = 0.000000 (deg)
    Area-To-Mass Ratio = 0.007400 (m^2/kg)

**OUTPUT**

    Orbital Lifetime from Startyr = 19.805613 (yr)
    Time Spent in LEO during Lifetime  = 19.805613 (yr)
    Last year of Propagation = 2035 (yr)
    Returned Error Message: Object reentered
04 22 2015; 22:55:47PM     Mission Editor Changes Applied
04 22 2015; 22:56:24PM     Mission Editor Changes Applied
04 22 2015; 22:56:28PM     Project Data Saved To File
04 22 2015; 22:56:48PM     Processing Requirement 4.3-1:    Return Status : Not Run

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

=============== End of Requirement 4.3-1 ===============
04 22 2015; 22:56:51PM     Processing Requirement 4.3-2: Return Status : Passed

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

=============== End of Requirement 4.3-2 ===============
04 22 2015; 22:56:53PM     Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
04 22 2015; 22:57:01PM     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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 17.300000 (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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 8.300000 (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 = 0.020800 (m^2/kg)
      Start Year = 2015.500000 (yr)
      Initial Mass = 4.500000 (kg)
      Final Mass = 4.500000 (kg)
      Duration = 6.900000 (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 = 0.020800 (m^2/kg)
      Start Year = 2015.500000 (yr)
      Initial Mass = 4.500000 (kg)
```

Final Mass = 4.500000 (kg)
Duration = 7.500000 (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_AtlasV
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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 5.200000 (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

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

**INPUT**

Space Structure Name = Lemur2_Soyuz2
Space Structure Type = Payload
Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 8.300000 (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

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

=============== End of Requirement 4.5-1 ===============
04 22 2015; 22:57:09PM     Requirement 4.5-2:  Compliant
04 22 2015; 22:57:12PM     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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 17.300000 (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 = 2032 (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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 8.300000 (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 = 2023 (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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 6.900000 (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 = 2021 (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 = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 7.500000 (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 = 2022 (yr)
Requirement = 61
Compliance Status = Pass

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

**INPUT**

Space Structure Name = Lemur2_AtlasV
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 = 0.020800 (m^2/kg)

Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 5.200000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 248.048791 (km)
PMD Apogee Altitude = 256.789865 (km)
PMD Inclination = 51.571325 (deg)
PMD RAAN = 7.848664 (deg)
PMD Argument of Perigee = 74.605471 (deg)
PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

Suggested Perigee Altitude = 248.048791 (km)
Suggested Apogee Altitude = 256.789865 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2020 (yr)
Requirement = 61
Compliance Status = Pass

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

**INPUT**

Space Structure Name = Lemur2_Soyuz2
Space Structure Type = Payload

Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.020800 (m^2/kg)
Start Year = 2015.500000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 8.300000 (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 = 2023 (yr)
      Requirement = 61
      Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
04 22 2015; 22:58:19PM      *********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

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

***********INPUT****
 Item Number = 5

name = Lemur2_AtlasV
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_AtlasV
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 = 5

name = Lemur2_AtlasV
Demise Altitude = 77.993738
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Lemur2_AtlasV
Demise Altitude = 65.304866
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

***********INPUT****
 Item Number = 6

name = Lemur2_Soyuz2
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_Soyuz2
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 = 6

name = Lemur2_Soyuz2
Demise Altitude = 77.997137
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Lemur2_Soyuz2
Demise Altitude = 66.448152
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

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

Below is update for ODAR Revision 4 to add 400km ISS mission to analysis:
-------------------------------------------------------------------------
11 23 2015; 18:34:55PM DAS Application Started
11 23 2015; 18:34:56PM Opened Project C:\Users\jspark\Desktop\Lemur-2\ODAR\
11 23 2015; 18:35:04PM Processing Requirement 4.3-1:  Return Status :  Not Run
=====================
No Project Data Available
=====================
=============== End of Requirement 4.3-1 ===============
11 23 2015; 18:36:25PM Mission Editor Changes Applied
11 23 2015; 18:36:47PM Processing Requirement 4.3-1:  Return Status :  Not Run
=====================
No Project Data Available
=====================
=============== End of Requirement 4.3-1 ===============
11 23 2015; 18:36:51PM Processing Requirement 4.3-2: Return Status : Passed
=====================
No Project Data Available
=====================
=============== End of Requirement 4.3-2 ===============
11 23 2015; 18:36:53PM Requirement 4.4-3:  Compliant
=============== End of Requirement 4.4-3 ===============
11 23 2015; 18:36:57PM Processing Requirement 4.5-1:  Return Status :  Passed
==============
Run Data
==============
**INPUT**
        Space Structure Name = Lemur2_400km51deg
        Space Structure Type = Payload
        Perigee Altitude = 400.000000 (km)
        Apogee Altitude = 400.000000 (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 = 0.013000 (m^2/kg)
        Start Year = 2015.500000 (yr)
        Initial Mass = 4.500000 (kg)
        Final Mass = 4.500000 (kg)
        Duration = 1.000000 (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 ===============
11 23 2015; 18:37:04PM Requirement 4.5-2:  Compliant
11 23 2015; 18:37:06PM Processing Requirement 4.6     Return Status :  Passed
==============
Project Data
==============
**INPUT**
        Space Structure Name = Lemur2_400km51deg
        Space Structure Type = Payload
        Perigee Altitude = 400.000000 (km)
        Apogee Altitude = 400.000000 (km)
        Inclination = 51.600000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Area-To-Mass Ratio = 0.013000 (m^2/kg)
        Start Year = 2015.500000 (yr)
        Initial Mass = 4.500000 (kg)
        Final Mass = 4.500000 (kg)
        Duration = 1.000000 (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 = 400.000000 (km)
        Suggested Apogee Altitude = 400.000000 (km)
        Returned Error Message = Reentry during mission (no PMD req.).
        Released Year = 2016 (yr)
        Requirement = 61
        Compliance Status = Pass
==============
=============== End of Requirement 4.6 ===============
```

## CERTIFICATE OF SERVICE

I, Roma Nandwani, hereby certify that on March 8, 2016, a true and correct copy of the above Opposition to Petition to Dismiss, Deny, or Hold in Abeyance was sent by United States mail, first class postage prepaid, to the following:

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Vice President, Regulatory Affairs
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