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July 26, 2016

EX PARTE LETTER VIA IBFS

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: Ex Parte Letter
File No. SAT-LOA-20151123-00078

Dear Ms. Dortch:

Spire Global, Inc. ("Spire") requests that the FCC deny the petition of ORBCOMM License Corp. ("ORBCOMM")[1] against Spire's application to launch and operate up to 175 technically identical satellites (the "Application"),[2] including eight LEMUR-2 satellites scheduled for launch on the Falcon-9 (Formosat-5) rocket during a launch window that opens on September 1, 2016.[3] Payload integration for this launch will occur August 15, 2016. Without timely disposition of the ORBCOMM Petition prior to August 15, Spire risks losing access to space and suffering harm to its business.

Summary of Coordination Efforts

Inter-party coordination with ORBCOMM has proven fruitless. Since ORBCOMM first raised concerns about orbital debris in February 2016, Spire sought to work with ORBCOMM to address its

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[1] *See* ORBCOMM License Corp. Petition to Dismiss, Deny, or Hold in Abeyance, File No. SAT-LOA-20151123-00078 (filed Feb. 22, 2016) ("Petition"); ORBCOMM License Corp. Reply to Opposition, File No. SAT-LOA-20151123-00078 (filed Mar. 18, 2016).

[2] *See* Application of Spire Global, Inc., File No. SAT-LOA-20151123-00078 (filed Nov. 23, 2015) ("Application"). The Commission previously granted in part the launch and operation of nine Spire LEMUR-2 satellites, pending the completion of coordination with NTIA. *See* Stamp Grant, File No. SAT-LOA-20151123-00078, Call Sign S2946 (granted in part and deferred in part Mar.18, 2016). The Commission also approved a further twenty Spire LEMUR-2 satellites, but was unable to approve those related to the Formosat-5 launch due to the Petition. *See* Stamp Grant, File No. SAT-LOA-20151123-00078, Call Sign S2946 (granted in part and deferred in part June16, 2016).

[3] *See* Letter from Jonathan L. Wiener and Henry Goldberg, attorneys for Spaceflight, Inc. to Marlene H. Dortch, Secretary, FCC, File No. SAT-STA-20150821-00060 (filed June 17, 2016).

concerns. Spire thought the parties had reached an agreement in principle after the International Bureau arranged a meeting among Spire, ORBCOMM, and Planet Labs Inc. ("Planet Labs"), which is another satellite operator manifested on the Formosat-5 launch, to discuss the coordination process. At that meeting, the parties agreed in principle that the Formosat-5 launch could proceed so long as Spire and Planet Labs agreed to provide GPS solutions to ORBCOMM in the case of a conjunction alert. Following the International Bureau meeting, ORBCOMM and Spire's legal counsel, Hogan Lovells, held a conference call during which ORBCOMM acknowledged that the eight LEMUR-2 satellites manifested on the Formosat-5 launch would not create an unacceptable risk of collision with ORBCOMM's OG2 satellite constellation ("OG2"). ORBCOMM's greater concern was Spire's future launch plans. ORBCOMM sought detailed orbital parameters for launches that might occur up to ten years in the future. In response, Spire indicated that it did not know and could not provide details on upcoming launches more than twelve to eighteen months from the present.[4] Spire and ORBCOMM were unable to reach an agreement in principle regarding an objective standard for assessing potential risk to the OG2 satellites from future launches of Spire satellites. In the interest of cooperation, however, Spire expressed its willingness to provide GPS-derived location estimates whenever relevant to minimize the occurrence of false positive conjunction alerts and maximize the effectiveness of any collision-avoidance maneuvers that might prove necessary.

For its part, ORBCOMM made no progress on its commitment to finalize standards for the exchange of GPS-derived location estimates with Spire (or Planet Labs).[5] Spire and ORBCOMM had a single meeting following ORBCOMM's commitment. At that meeting, the topic of conversation was not predominantly the proper time and format to provide GPS data to ORBCOMM. Instead, ORBCOMM raised new issues that ORBCOMM indicated Spire would have to address before ORBCOMM would finalize any agreement. ORBCOMM asked Spire to address: (1) the risk of in-plane collisions for the 90-odd payloads on the Spaceflight, Inc. ("Spaceflight") Sherpa mission over which Spire has no control; and (2) the risk that a second-stage ignition of a Falcon-9 rocket that Spire does not control could pose to OG2 satellites. On May 11, 2016, ORBCOMM filed a letter with the Commission opposing Spaceflight, Inc.'s Application for Special Temporary Authority outlining the same concerns and demands it had made to Spire.[6]

Over the subsequent month, Spire, Planet Labs and Spaceflight worked together to supply each other with information necessary to produce the in-plane collision analysis that ORBCOMM had said that it needed. Planet Labs personnel spent substantial time in performing the analysis ORBCOMM

[4] ORBCOMM is a direct competitor of Spire and making available its launch schedule could prejudice Spire's competitive position in the market.

[5] Spire is aware that ORBCOMM has provided no edits to the draft agreement between Planet Labs and ORBCOMM, despite having had that draft for more than two months. As discussed in the International Bureau meeting, the parties expected that ORBCOMM and Planet Labs would reach an agreement by the end of April, and that agreement would provide a model with respect to the exchange of GPS-derived location estimates between Spire and ORBCOMM.

[6] *See* Letter from Walter H. Sonnenfeldt, Regulatory Counsel, ORBCOMM License Corp., and Vice President, Regulatory Affairs, ORBCOMM Inc., to Marlene H. Dortch, Secretary, FCC, File No. SAT-STA-20150821-00060 at 4 (May 11, 2016) ("Spaceflight Letter"); *see also* Letter from Henry Goldberg and Jonathan L. Weiner, attorneys for Spaceflight, Inc., to Marlene H. Dortch, Secretary, FCC, File No. SAT-STA-20150821-00060 (filed May 13, 2016).

requested. On June 14, 2016, ORBCOMM rejected the analysis, but offered no analysis of its own regarding the risks involved. ORBCOMM also stated that the analysis must come from Spaceflight, which differed from ORBCOMM's original demand that Planet Labs or Spire needed to satisfy ORBCOMM about the absence of risk.

ORBCOMM's decision to forgo or withhold its own analysis despite detailed showings of third parties is consistent with ORBCOMM's approach since it filed its Petition in February of 2016. Specifically, at no time in the last five months of discussions has ORBCOMM provided an objective standard as to what constitutes an unacceptable risk or an undue burden. ORBCOMM has rejected other parties' objective analysis of the risk as flawed, but provided none of its own. Spire has concluded that additional discussions with ORBCOMM would serve no purpose other than to delay or deny Spire competitive access to orbital resources. Therefore, Spire respectfully requests the dismissal of ORBCOMM's Petition in full for the reasons set forth below.

Accepting Orbcomm's Position Would Set an Unwarranted and Dangerous New Precedent

ORBCOMM's core argument for the Commission to reject Spire's Application is its assertion that ORBCOMM must be *reasonably satisfied* that there is no unacceptable risk of intersection between ORBCOMM's OG2 satellites and any satellite launched into any orbital plane with a theoretical possibility of intersection.[7]

ORBCOMM has provided no precedent to support ORBCOMM's claim to be the arbiter of acceptable risk. The only language that ORBCOMM has identified for its position is the following 2004 statement by the Commission that:

> [I]n some instances the public interest would be served by a more detailed discussion of how an operator will avoid potential collisions. The first of these instances, as described in the Notice, is where a system will be launched into a low-Earth orbit that is identical, or very similar, to an orbit used by other systems. In such an instance we believe that the operator should submit, as part of its debris mitigation disclosure, an analysis of the potential risk of collision between the LEO systems and a description of what measures the operator plans to take to avoid in-orbit collisions.[8]

The language quoted by ORBCOMM applies to "identical" or "very similar" orbits. To consider a 450 km x 720 km, elliptical, 98 degree inclined, fast-decay orbit to be "identical" or "very similar" to a 715 km, circular, 47 degree, stable orbit would have the effect of defining virtually any orbits that have the theoretical possibility of intersection as "identical" or "very similar." To put the issue to rest, Spire engaged SpaceNav and NXTRAC, two well respected companies that perform space situational awareness, orbital determination and mission analyses, to determine the likely timeframe of the orbital decay of the 8 LEMUR-2s to be deployed from the Formosat-5 launch (the "NXTRAC Report").[9] This analysis was performed using Analytical Graphics Inc. Satellite Toolkit (STK), NASA Goddard Spaceflight Center's Generalized Mission Analysis Toolkit (GMAT) and OREKIT High

[7] *See* Petition at 6; Spaceflight Letter at 4-5.

[8] *Mitigation of Orbital Debris*, Second Report and Order, 19 FCC Rcd 11567 ¶ 50 (2004) (footnote omitted) ("*Mitigation of Orbital Debris*").

[9] *See* Letter from Dr. Darren D. Garber, NXTRAC, and Matt Duncan, SpaceNav to Jonathan Rosenblatt, Spire Global, Inc., RE: Spire Orbital Decay Analysis (May 10, 2016), attached as Exhibit A ("NXTRAC Report").

Fidelity Propagator. ORBCOMM will no doubt reject the assumptions in the NXTRAC Report, but the report at least demonstrates that these orbits are far from "identical" or "very similar."[10]

Moreover, the language noted by ORBCOMM does not in the least support its position that incumbent operators must be "reasonably satisfied" before an Application can proceed. ORBCOMM with its language and behavior has made clear that it wants a subjective standard to apply. That is, until ORBCOMM is satisfied, no launch can occur. The acceptance of ORBCOMM's position that incumbent operators have subjective veto rights over new entrants in low earth orbit until the incumbents are "*reasonably satisfied*" would set a new and dangerous precedent. As ORBCOMM has shown, any incumbent operator can easily disagree with a range of assumptions made in any analysis and thus remain "unsatisfied." In the situation of Formosat-5 alone, one incumbent operator has the potential to block the only US commercial launch opportunity available to secondary payloads in all of 2015 and 2016 (excluding ISS deployments that have unacceptably short lives for commercial constellations).

ORBCOMM directly competes with Spire, and denying Spire access to this launch opportunity would prevent Spire from securing a coverage profile that ORBCOMM currently lacks. Worse, the Commission's ruling would not apply to non-US operators, thus greatly handicapping US based companies.

Spire Meets the Objective Standards Required by the Commission for the Formosat-5 Mission

Even though not strictly applicable to its configuration, Spire has met (or will meet based on the attachments to this filing) the Mitigation of Orbital Debris requirements, including the requirement that certain applicants submit, "as part of its debris mitigation disclosure, an analysis of the potential risk of collision between the LEO systems and a description of what measures the operator plans to take to avoid in-orbit collisions."[11]

First, with respect to the Formosat-5 launch, Spire has filed an Orbital Debris Assessment Report ("ODAR") for ten satellites in a similar elliptical orbit (450 km x 750 km). This report shows that Spire's satellites satisfy the risk thresholds established by the National Aeronautics and Space Administration ("NASA").[12] Second, based on ORBCOMM's rejection of that report, Spire hereby submits an additional ODAR specifically prepared for the eight LEMUR-2 satellites in a 450 km x 720 km orbit at 98 degrees inclination (the "Supplemental ODAR"). As shown in the Supplemental ODAR, Spire's satellites are far below the applicable orbital debris and collision risk thresholds set forth by NASA.[13] Specifically, with respect to the chance of collision with an object of >10cm, NASA

[10] *See id.* at 4 showing how the different apogee latitudes cause large portions of time where the LEMUR-2s cannot even theoretically intersect the OG2 satellites. Using less sophisticated simulation tools and more conservative assumptions, Spire had previously estimated that the orbital altitude of a LEMUR-2 satellite would be less than 715 km in approximately 13 months. In any event, Spire has conservatively calculated, using the NASA DAS program, the risk of collision with objects of larger than 10 cm <u>for a 10-year period</u>, far longer than a LEMUR will be at or above the OG2 constellation in any circumstance.

[11] *Mitigation of Orbital Debris* ¶ 50.

[12] *See* ELS File No. 0705-EX-PL-2015, Exhibit B (filed Nov. 24, 2015).

[13] *See* Supplemental ODAR attached as Exhibit B, Appendix A: DAS 2.0.2 Log. Showing that Spire LEMUR-2s de-orbit in less than ten years (worst case) from deployment, that the probability of collision with an object of 10 cm or greater is $1x10^{-6}$ during the entire 10 year period, and that the LEMUR-2s will burn up upon re-entry posing no risk to persons or property on the ground.

DAS returns a risk of $1x10^{-6}$, which is 1,000x better than the 0.001 standard required by NASA. Third, Spire has commissioned the NXTRAC Report. The NXTRAC Report shows that the eight LEMUR-2s will decay below the ORBCOMM target orbit of 715 km within either approximately eight days (assuming nominal operations) or 39 days (assuming worse deployment characteristics).[14] Fourth, Spire worked with Planet Labs to create the in-plane conjunction analysis that ORBCOMM demanded which shows that: (1) the risk of in-plane collisions over a two-year period for all 91 objects (including the SHERPA) among themselves is 7.8×10^{-7}; and (2) the risk of collision over a two-year period between these objects and the OG2 satellites is 2.0×10^{-7}.[15] ORBCOMM will surely dismiss and disagree with all of the objective analysis provided to date. It will likely demand further analysis be done, but more than enough analysis has already been provided to satisfy an objective decision maker that ample precautions against in-plane collisions or orbital debris have occurred.

As a further safeguard, Spire has agreed and will continue to honor the agreement it made before the International Bureau that, upon notice of a conjunction alert received by ORBCOMM, Spire will provide ORBCOMM with a GPS solution so that ORBCOMM can verify what, if any, evasive maneuvers are necessary.

Having seen months of negotiation with ORBCOMM pass without agreement, further negotiations seem unlikely to serve any purpose. Spire respectfully requests that the Commission approve its Application without the “reasonably satisfied” condition ORBCOMM has requested.

Spire Will Meet the Objective Standards Set By ORBCOMM Itself for Future Missions that Theoretically Intersect with ORBCOMM’s 715 km Orbit

With respect to Spire’s future orbits that might theoretically intersect with ORBCOMM’s 715 km orbit, Spire is willing to address ORBCOMM’s concern by adopting an objective standard for orbital collision risk. Spire supports the Commission applying the same standard to Spire that all other satellite operators follow, namely the NASA standard that the risk of collision with objects over 10 cm be less than 0.001.[16] Spire will readily commit not to pursue any orbits where the risk of collision with objects larger than 10 cm (including, but not limited to, the OG2 satellites) is 0.001 or greater. Spire will submit an ODAR to the Commission for all launches and will meet all NASA DAS standards.

However, ORBCOMM will likely reject the standard that applies to all other operators as presenting an “unacceptable” risk or imposing an “undue burden.” Therefore, should the Commission not wish to adopt the NASA DAS standard with respect to orbits that theoretically intersect with ORBCOMM’s 715 km orbit, Spire offers an objective standard that ORBCOMM has already accepted as reasonable:

> To assess the likelihood of colliding with objects large enough to render an OG2 satellite a source of debris, ORBCOMM again turned to NASA’s Debris Assessment Software. The calculated annual collision probability with objects larger than 10 cm for the OG2 operational orbit is shown in Table 2 below…. As computed by DAS, the

[14] *See* NXTRAC Report at 3.

[15] Letter from Tony Lin, Counsel for Planet Labs Inc. to Marlene H. Dortch, Secretary, FCC, File No. SAT-MOD-20150802-0053, SAT-STA-20150821-00060, SAT-LOA-20151123-00078, Exhibit A at 5 (filed July 26, 2016).

[16] *See* Process for Limiting Orbital Debris, NASA-STD 8719.14A, Section 4.5.2.1.

> accumulated risk over the entire orbital life (five years of operational life and up to 25 years for disposal) for each OG2 spacecraft comes to 3.2×10^{-4}….Based on these findings, OG2 satellites do not constitute a significant risk of further contributing to the debris environment. The low probability of catastrophic collision over the life of the OG2 satellite mission satisfies the intent of the Commission's orbital debris mitigation Rules and policies….as demonstrated above, the risk of collision in the selected target altitude and inclination is *de minimis*.[17]

Specifically, Spire will accept a license condition not to launch satellites into any orbit that theoretically intersects with ORBCOMM's 715 km orbit when the risk of collision with objects of > 10 cm with respect to such satellite, as shown by NASA DAS, is greater than 3.2×10^{-4} during the period in which Spire's satellite theoretically intersects with ORBCOMM's 715 km orbit.

ORBCOMM's Other Arguments

ORBCOMM also presses two supporting arguments for its main argument on collision risk. The first is that its collision concerns are ostensibly exacerbated because "the current proposed design of the Spire satellites could make effective collision avoidance coordination difficult or impossible."[18] ORBCOMM asserts that because "Spire intends to launch up to 900 satellites to maintain a constellation of 175 operational spacecraft[,].... there could be more than 700 nonoperational Spire satellites in orbit with no available accurate location information."[19] ORBCOMM's secondary arguments are baseless and misleading.

With respect to future Spire launches, Spire has stated it will meet all NASA de-orbit requirements. That commitment means that Spire satellites must de-orbit within 25 years of the end of its operational life, regardless of whether the satellites are in circular or elliptical orbits. Spire has indicated that its highest circular orbit is 650 km and it has not applied for further orbits. That commitment means every circular orbital deployment will be located *below* the 715 km orbit that ORBCOMM is concerned with. ORBCOMM may protest that Spire could launch 900 satellites into an as-yet-unknown, highly unique, elliptical orbit that will take years to decay below the OG2 target orbit of 715 km, but then will somehow quickly decay through the rest of LEO so as to re-enter the atmosphere within 25 years. As Spire has stated in its application, this type of unusual orbital configuration is not Spire's intent. The launch market also does not support such a constellation rollout plan. Nor does such a unique orbit seem physically possible. Even so, there is still no precedent, rule or other requirement that Spire's satellites must de-orbit below ORBCOMM's target 715 km altitude during the satellites' functional life.

Again, ORBCOMM seeks to hold Spire to a higher standard than ORBCOMM wants for itself. ORBCOMM's post-mission disposal plan for the OG2 fleet is to use the remaining propellant to

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[17] Application of ORBCOMM License Corp. For Authority to Modify its Non-Voice, Non-Geostationary Satellite Service Space Segment License (S2103) to Revise the Next-Generation Satellite Deployment Plan, Third Amendment Narrative Exhibit, Attachment 1 Amended Orbital Debris Mitigation Showing, File No. SAT-AMD-20140116-00006, at 6-8 (granted Mar. 26, 2014) ("ORBCOMM Application").

[18] Petition at 4.

[19] *Id*.

move the OG2 satellites down to a perigee that is at 615 km.[20] From there, ORBCOMM's nonfunctional OG2s will pass through many layers of low-Earth orbit systems with many functional satellites. ORBCOMM will be unable to control or communicate with those satellites by its own admission.[21] We estimate that the OG2s will spend roughly 20-25 years after their useful life in a nonfunctional state somewhere between 615 km and re-entry and this is substantiated by ORBCOMM's own ODAR analysis.[22] They will carry highly combustible hydrazine fuel tanks with fuel remaining onboard.[23] Upon re-entry it is expected that portions of OG2s will survive re-entry such that one OG2 satellite has a 1 in 48,300 ($2x10^{-3}$) chance of causing a **human casualty**.[24] And yet, ORBCOMM has stated that this disposal plan "fully complies with the Commission's orbital debris mitigation Rules and policies."[25]

Spire's satellites will de-orbit in 17.3 years *from deployment* at the upper bound of the orbits that it requested in its Application (but far less at the orbit of concern for ORBCOMM),[26] do not carry highly combustible hydrazine fuel tanks, and will completely burn up upon re-entry posing no danger to life and property on the ground.[27] Spire's probability of colliding with any object > 10 cm, including the OG2 satellites is $1x10^{-6}$, orders of magnitude less than the likelihood of an OG2 killing someone on the ground following re-entry. ORBCOMM's representations that Spire presents an unacceptable risk and places an undue burden on ORBCOMM are truly remarkable in light of ORBCOMM's post mission disposal plan and the much greater risk profile of an OG2. If anything, ORBCOMM has imposed an undue burden on Spire and numerous other low-Earth orbit operators rather than the other way around.[28]

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[20] ORBCOMM Application at 9-12.

[21] *See* Application of ORBCOMM License Corp. For Authority to Modify its Non-Voice, Non-Geostationary Satellite Service Space Segment License (S2103) to Revise the Next-Generation Satellite Deployment Plan, File No. SAT-MOD-20111021-00207, Amendment, Supplement & Update FCC Form 312 Exhibit, Attachment 2 at 5 (filed Aug. 9, 2012) (stating that upon decommissioning OG2 satellites are expected to tumble randomly).

[22] *See id.* Attachment 3 at 8.

[23] *See* ORBCOMM Application, Attachment 1 at 10.

[24] *Id.* at 11-12.

[25] *Id*. at 12.

[26] *See* Application, Exhibit D ODAR at 10.

[27] *See id.* Appendix A: DAS 2.0.2 Log.

[28] One should bear in mind that ORBCOMM's satellites have a much greater surface area and mass than Spire's satellites and thus the risk of a giant debris cloud in orbits used by Spire, Planet Labs and others caused by ORBCOMM's OG2s is far higher than the risk posed to the 715 km orbit used by ORBCOMM by the Formosat-5 or any other cubesat deployment. With an aggregate mass of 2975 kg (175kg x 17) and an aggregate cross-sectional surface area of $41.31m^2$ ($2.43m^2$ x 17), the dead OG2s will have more collective mass than 660 LEMUR-2s (660 x 4.5 kg) and more collective cross-sectional surface area than 441 LEMUR-2s (441 x $.0936m^2$). *See* ORBCOMM, OG2 Mission 1 Press Kit 17 (May 2014), http://bit.ly/29xmlBX; Supplemental ODAR.

Summary

ORBCOMM's objections are without merit. The Commission's rules and precedents do not support ORBCOMM's position that the Commission should not grant applications to operate satellites in low earth orbit until the applicant demonstrates to the incumbent operator's "reasonable satisfaction that there is no unacceptable risk of collision" with the incumbent's existing satellite system.[29] The only precedent that ORBCOMM relies on is not applicable as the orbit at issue in the Formosat-5 mission is not "identical" or "very similar" to the ORBCOMM OG2 orbit, nor has Spire applied for a 715 km circular orbit in its Application. Even if the Commission wants to set new precedent that goes so far as requiring an elevated showing by any operator that wishes to use an orbit that theoretically intersects with an existing orbit and to arbitrate these issues in such cases, Spire has met that showing with respect to the Formosat-5 mission. With respect to future missions that might theoretically intersect with ORBCOMM's 715 km orbit, Spire has proposed the NASA DAS standard, and, if that standard is not acceptable, a standard that ORBCOMM itself has stated presents "de minimis" risks from an orbital debris and collision perspective.

To grant ORBCOMM's Petition or block the Formosat-5 launch on the basis of ORBCOMM's subjective and unsupported assertions and to raise the bar for other operators far above where it has been set for ORBCOMM will damage, and possibly kill, the emerging U.S. small satellite industry. The Formosat-5 is the only fully viable US commercial launch opportunity available to secondary payloads for 2015 and 2016. Spire meets all of the Commission's rules with respect to this issue and has gone to great lengths to accommodate ORBCOMM's subjective concerns without success. Further discussions place an undue burden on Spire and do not serve the public interest. Spire therefore respectfully asks that the Commission act now to deny ORBCOMM's Petition.

Sincerely,

Trey Hanbury
Counsel to Spire Global, Inc.
Hogan Lovells US LLP

cc: Jonathan Rosenblatt, Spire Global, Inc.

[29] See Petition at 6; Spaceflight Letter at 4-5.

Exhibit A

Spire Orbital Decay Analysis for 450 x 720 km SSO Orbit

Prepared for Spire Global, Inc. on 10 May 2016

Objective: Determine Spire Lemur-2 orbital decay rates from 450 x 720 km sun synchronous orbit with respect to the OrbComm constellation operational altitudes and inclination.

Background:

NXTRAC provides precision orbit determination, mission analysis and operational support services to multiple commercial and US Government customers. NXTRAC is currently supporting 9 operational programs from LEO to interplanetary missions and has ensured mission success on over 25 launches. NXTRAC personnel are senior consultants for NASA with respect to trajectory design, mission operations and anomaly resolution. NXTRAC's president, Dr. Darren Garber, is the technical co-chair for the US/Russia and US/China Space Situational Awareness Workshops regarding orbital debris tracking, assessment and mitigation.

SpaceNav is a Colorado-based applied mathematics & aerospace engineering company. We are headquartered in Denver, CO, with employees in Boulder, Denver, Colorado Springs, and Greenbelt, MD. SpaceNav delivers technical solutions in the areas of Space Situational Awareness, Systems Engineering, and Mission Operations. SpaceNav's expertise is in the areas of modeling & simulation, estimation, orbit determination, and optimization. SpaceNav builds mission critical software that is used for safety of flight analysis and operations.

Approach: Use high fidelity orbital simulations to understand the relative geometry and its evolution between between the elliptical Spire Lemur-2 orbit and the OrbComm constellation.

Summary of Results: Spire Lemur-2 orbits while initially crossing the OrbComm2 constellation will decay within 16 days to no longer intersect with the OrbComm2 constellation.

Initial Conditions per Sherpa Deployment post FormoSat-5 launch profile:

Spire Lemur-2 orbit parameters at deployment:

Epoch: 2016 June 15 17:00:00Z (10am LTAN sun synchronous orbit)

Semi-major axis:	6963 km
Perigee:	450 km
Apogee:	720 km
Eccentricity:	0.01938
Inclination:	97.6 deg
RAAN:	55.0 deg
Argument of Perigee:	180 deg
Mean Anomaly:	180 deg
Area to Mass ratio:	0.0208 m^2/kg

Note: 2 orbits were assessed differing only in Argument of Perigee to encompass all of the possible orbit scenarios:

Case 1: ArgP = 0: apogee on night side and perigee on day side

Case 2: ArgP = 180: perigee on day side and apogee on night side

OrbComm mission parameters:
Operational Altitude: 715km
Maximum Inclination: 47.0 deg

Multiple independent mission proven simulations were used in this analysis:
Analytical Graphics Inc Satellite Toolkit (STK)
NASA Goddard Spaceflight Center's Generalized Misson Analysis Toolkit (GMAT)

Each simulation utilized its high fidelity propagation capabilities and force models included:
Full 20x20 geopotential per EGM 2008
Solar and lunar perturbations per JPL DE421
Spherical radiation pressure
Atmospheric drag per NRL MSIS 2000

Orbital decay rates are dominated by variations in atmospheric conditions as determined by changes in solar flux (e.g. F10.7 cm) and the current geomagnetic conditions (e.g. ap index).

Predicting drag effects is challenging, so Monte Carlo trials were performed to address these challenging conditions and variations in vehicle attitude (e.g. stable, tumbling, etc.). The range of input environmental values are listed below and varies every 3 hours over the propagation interval to mirror the current reporting of these parameters:
Ap: base value 12 +/- 5 (1 sigma)
F107: base value 150 +/- 30 (1 sigma)

Results:

Case 1: Argument of Perigee = 0 (perigee on dayside)

In this case the Spire orbit experiences maximum drag effects, as the atmosphere swells on the dayside increasing the drag on the Spire vehicles at perigee resulting in apogee decreasing to below 715 km in 7.3 days +/- 1 day after 1000 Monte Carlo trials. A chart depicting this representative decay is shown in Figure 1 below:

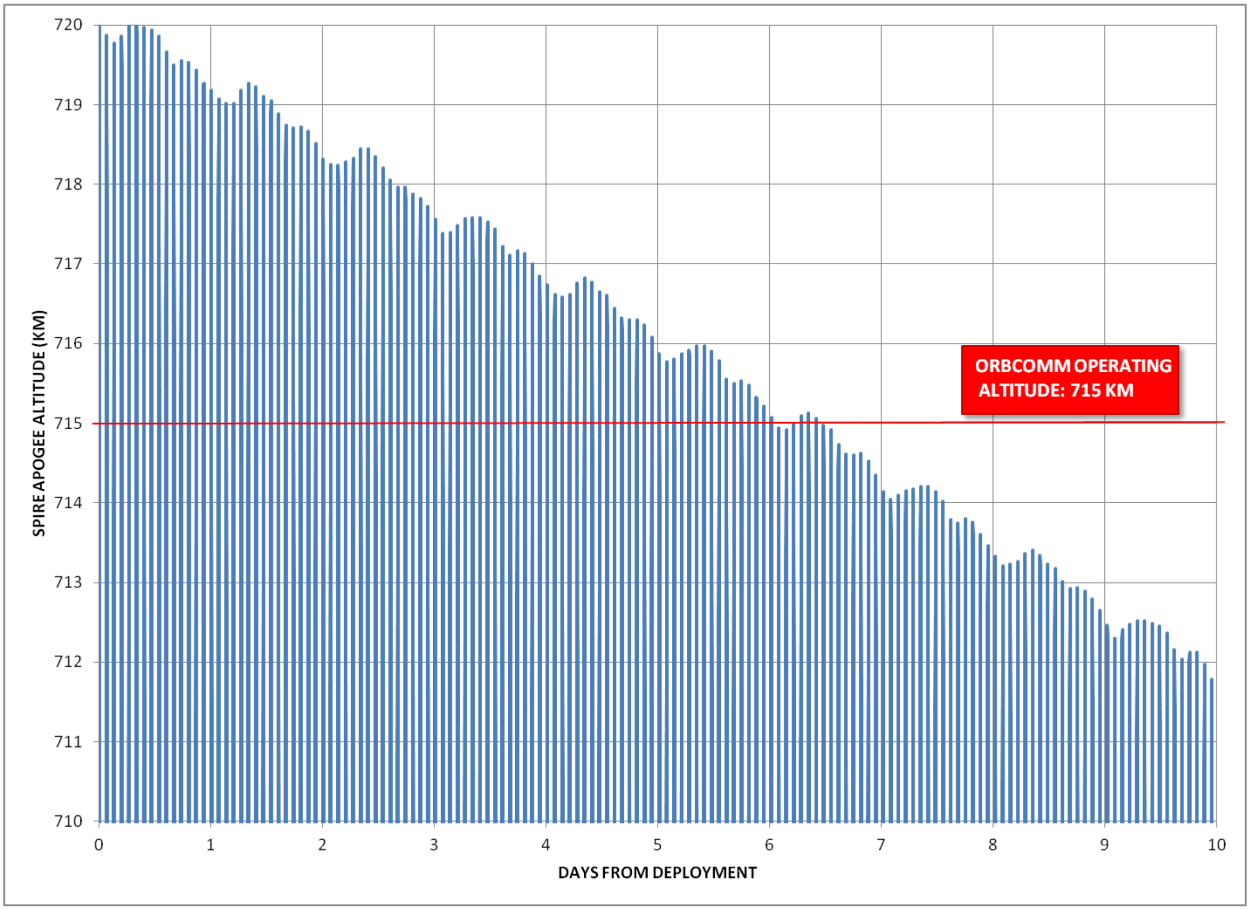

Figure 1: Case 1: Representative Apogee Altitude Decay Profile

Case 2: Argument of Perigee = 180 (apogee of dayside)

In this case the atmospheric decay rate on the Spire vehicle is reduced resulting in the time for apogee to be below the OrbComm constellation is on the order of a month +/- 1 week due to atmospheric conditions.

Despite this significant time, the Spire orbit is also being perturbed by geopotential and n-body effects due to solar and lunar gravity. These effects cause the orbit to rotate out of the equatorial plane with line of apsides (perigee to apogee) rotating at a rate of ~3.3 degrees per day. At this rate and after 16 days, the Spire apogee drifts to be above 47 deg latitude and therefore above OrbComm's maximum inclination. For the next 20 days Spire orbit's apogee increases to 81 degrees latitude and then begins decreasing back towards the OrbComm constellation. By the time the Spire apogee rotates back to 47 degrees latitude its altitude is less than the OrbComm operating altitude of 715 km. This decay and rotation profile is depicted in Figure 2 below.

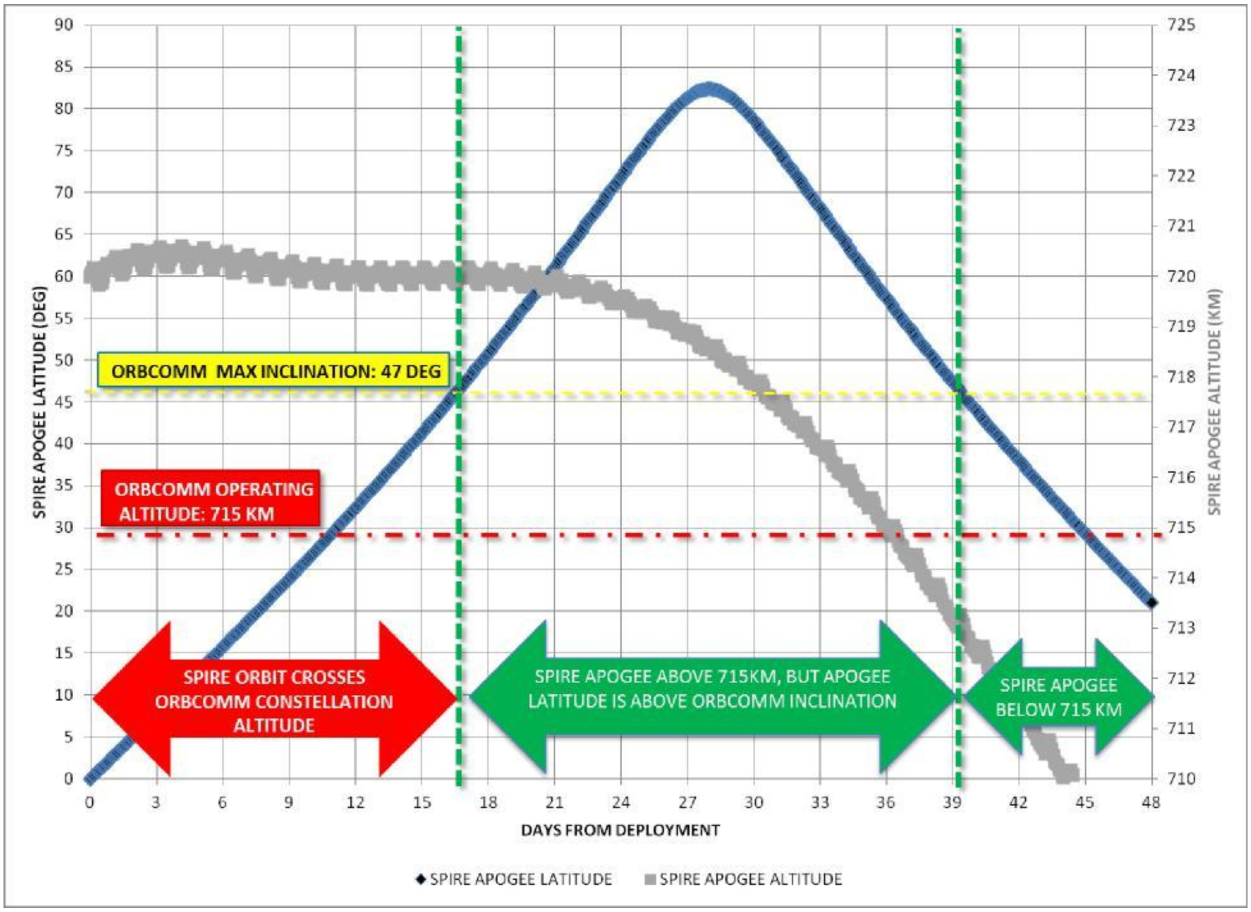

Figure 2: Case 2: Apogee Altitude and Latitude Profile

In Figure 2 the blue solid line shows the drift in the Spire orbit's latitude of apogee, while the gray line depicts the slow decrease in apogee altitude over the same period. The red and yellow lines depict the OrbComm altitude and inclination operating limits respectively. The two vertical green lines from left to right detail when the Spire apogee rotates above 47 degrees latitude and then when it returns to the same latitude. From the right green line, it is clearly shown that the apogee altitude is below 715 km and continues to decreases when the orbit rotates back to OrbComm's inclination.

Conclusion: Across the range of initial argument of perigees the 450 x 720 km orbit crosses the OrbComm constellation for a maximum of 16 days post deployment.

Dr. Darren D. Garber
NXTRAC President
darren.garber@nxtrac.com

Exhibit B

2016

Orbital Debris Assessment Report

450x720 km, 98 degrees

PREPARED BY SPIRE GLOBAL, INC.

Revision History

Revision	Description of Revisions	Release Date
1	Initial Release	7/18/2016
	A stand alone analysis of a high apogee elliptical orbit (450km x 720km, 98 degrees) which has been prepared for the purposes of analyzing the risk of collisions	

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:	N/A
4.3-2, Mission-Related Debris Passing Near GEO	N/A
4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:	COMPLIANT
4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon:	COMPLIANT
4.4-3, Limiting the long-term risk to other space systems from planned breakups:	N/A
4.4-4, Limiting the short-term risk to other space systems from planned breakups:	N/A
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
4.7-1, Casualty Risk From Reentry Debris	COMPLIANT
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 nanosatellite fleet is to provide high-revisit maritime domain monitoring data and GPS-Radio Occultation data. The particular mission addressed by this ODAR is a 450km x 720km, 98 degrees, secondary deployment from a Falcon-9 of 8 LEMUR-2 satellites, whose primary payload is the deployment of a Taiwanese satellite, Formosat-5 (the "Formosat-5 Mission"). The Formosat-5 is the only secondary payload launch opportunity on a US rocket available in 2015 and 2016.
Foreign Government Involvement	None
Project Milestones:	The anticipated launch date is October 15, 2016. The anticipated integration date is September 15, 2016.
Proposed Launch Date:	
Proposed Launch Vehicles:	Formasat-5 will utilize a Falcon-9 launch vehicle.
Proposed Launch Sites:	The Falcon-9 will launch from Cape Canaveral, Florida.
Launch Vehicle Operator:	The Falcon-9 is operated by SPACE EXPLORATION TECHNOLOGIES CORP., a US company.
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 Formosat-5 Mission is 5.8 years (at nominal operations). This meets the applicable NASA standards.
Launch / Deployment Profile:	**Launch** The Falcon 9 deploys Formosat-5, the primary payload, in a 720 km SSO circular orbit. A perigee-lowering burn brings the Falcon 9 to the target deployment altitude. The SHERPA (an integrated payload stack), separates from the Falcon-9 and sequentially deploys its secondary payloads, including the 8 LEMUR satellites. The 8 LEMUR satellites are deployed using ISIS QuadPacks on the SHERPA. **Checkout** For up to 1 month following deployment into orbit, LEMUR satellites will remain in checkout phase. During this phase, ground operators will verify correct operation of the satellites and their payloads, and prepare them for the operational phase. **Operations** The operational phase of the satellite begins following the successful deployment of the satellite from the launch vehicle, and successful checkout. **Postmission Disposal**

	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 5.8 years following deployment from the launch vehicle.
Selection of Orbit:	The selection of this orbit was based on it being the only LEO secondary payload launch opportunity on a US rocket available in 2015 and 2016 (other than ISS deployments).
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. 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:	**N/A**
4.3-2, Mission-Related Debris Passing Near GEO:	**N/A**

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, over-discharging, internal shorts, and external shorts.

The battery pack onboard LEMUR 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.

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: There are no planned breakups of any of the satellites.	**N/A**
4.4-4, Limiting the short-term risk to other space systems from planned breakups There are no planned breakups of any of the satellites.	**N/A**

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 $1x10^{-6}$ over the entire worst case conservatively calculated 10-year orbital life of a LEMUR.

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 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.

For purposes of Section 6, drag area from deployed antennas (2x 0.5m whip antennas, 3x 0.3m whip antennas) was omitted; 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 fail to deploy ▪ Satellite tumbles randomly	0.0074[1]
Solar panel failure	▪ Solar panels fail to deploy ▪ Satellite maintains +Z axis nadir ▪ Position around Z axis as planned for mission operations	0.0130
Operational, nominal	▪ Solar panels deploy ▪ Satellite maintains +Z axis nadir ▪ Position around Z axis as planned for mission operations	0.0208
ADCS Nonfunctional	▪ Solar arrays deploy ▪ Satellite tumbles randomly	0.0169

[1] This conservatively assumes the solar panels never deploy even though a nylon strip will degrade in the first five years forcing deployment.

Table 2 shows the simulated orbital dwell time for a LEMUR satellite in the orbit at issue, 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 10 years (worst case).

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

		Orbital Lifetime (Years)
Description	Effective Area-to-Mass (m2/kg)	Elliptical High Apogee
		450km x 720km, 98 deg
Satellite Nonfunctional	0.0074	9.39
Solar panels failure	0.0130	6.79
ADCS Nonfunctional	0.0169	6.20
Operational, Nominal	0.0208	5.81

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 All of the satellites will reenter the atmosphere within 25 years of mission completion and 30 years of launch.	**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**

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

NASA DAS was used to test the major spacecraft components for re-entry hazards. The major components tested included:

- Solar Panels and Cells
- GPS Antennas
- PCBs
- Primary Structure
- Cameras
- Reaction Wheel Assembly

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.

```
05 24 2016; 11:24:06AM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

      Start Year = 2016.700000 (yr)
      Perigee Altitude = 450.000000 (km)
      Apogee Altitude = 720.000000 (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 = 5.809719 (yr)
      Time Spent in LEO during Lifetime  = 5.809719 (yr)
      Last year of Propagation = 2022 (yr)
      Returned Error Message: Object reentered

05 24 2016; 11:24:11AM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

      Start Year = 2016.700000 (yr)
      Perigee Altitude = 450.000000 (km)
      Apogee Altitude = 720.000000 (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 = 6.198494 (yr)
      Time Spent in LEO during Lifetime  = 6.198494 (yr)
      Last year of Propagation = 2022 (yr)
      Returned Error Message: Object reentered

05 24 2016; 11:24:15AM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

      Start Year = 2016.700000 (yr)
      Perigee Altitude = 450.000000 (km)
      Apogee Altitude = 720.000000 (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 = 6.789870 (yr)
Time Spent in LEO during Lifetime = 6.789870 (yr)
Last year of Propagation = 2023 (yr)
Returned Error Message: Object reentered

05 24 2016; 11:24:21AM Science and Engineering - Orbit Lifetime/Dwell Time

INPUT

Start Year = 2016.700000 (yr)
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (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 = 9.390828 (yr)
Time Spent in LEO during Lifetime = 9.390828 (yr)
Last year of Propagation = 2026 (yr)
Returned Error Message: Object reentered

05 24 2016; 11:22:08AM Mission Editor Changes Applied

05 24 2016; 11:22:21AM Processing Requirement 4.5-1: Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (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 = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 ===============

05 24 2016; 11:22:24AM Requirement 4.5-2: Compliant
05 24 2016; 11:22:25AM Processing Requirement 4.6 Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload

Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (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 = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 = 450.000000 (km)
Suggested Apogee Altitude = 720.000000 (km)

Returned Error Message = Reentry during mission (no PMD req.).

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

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

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

05 24 2016; 11:22:55AM Processing Requirement 4.5-1: Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (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 = 0.016900 (m^2/kg)
Start Year = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 ===============

05 24 2016; 11:23:02AM Requirement 4.5-2: Compliant

05 24 2016; 11:23:03AM Processing Requirement 4.6   Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload

Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.016900 (m^2/kg)
Start Year = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 = 450.000000 (km)
Suggested Apogee Altitude = 720.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

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

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

=============== End of Requirement 4.6 ===============
05 24 2016; 11:23:11AM Mission Editor Changes Applied

05 24 2016; 11:23:24AM Processing Requirement 4.5-1:   Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (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 = 0.013000 (m^2/kg)
Start Year = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 ===============
05 24 2016; 11:23:26AM Requirement 4.5-2: Compliant

05 24 2016; 11:23:28AM Processing Requirement 4.6 Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload

Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2016.700000 (yr)

Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 = 450.000000 (km)
Suggested Apogee Altitude = 720.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

Released Year = 2023 (yr)
Requirement = 61
Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
05 24 2016; 11:23:36AM Mission Editor Changes Applied

05 24 2016; 11:23:52AM Processing Requirement 4.5-1: Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload
Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (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 = 0.007400 (m^2/kg)
Start Year = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 ===============

05 24 2016; 11:23:55AM Requirement 4.5-2: Compliant

05 24 2016; 11:23:56AM Processing Requirement 4.6 Return Status : Passed

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

INPUT

Space Structure Name = LEMUR-2
Space Structure Type = Payload

Perigee Altitude = 450.000000 (km)
Apogee Altitude = 720.000000 (km)
Inclination = 98.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.007400 (m^2/kg)
Start Year = 2016.700000 (yr)
Initial Mass = 4.500000 (kg)
Final Mass = 4.500000 (kg)
Duration = 10.000000 (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 = 450.000000 (km)
Suggested Apogee Altitude = 720.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

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

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

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


05 24 2016; 11:22:29AM *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = LEMUR-2
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 = 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

name = GPS Ant - Sm
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.050000
```

```
Length = 0.050000
Height = 0.017000

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

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 = 0.100000

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 - Mounting Plate
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 = GPS Ant - Lg
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 0.450000
Thermal Mass = 0.450000
Diameter/Width = 0.080000
Length = 0.300000
Height = 0.008000

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

name = LEMUR-2
Demise Altitude = 77.996238
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Panels
Demise Altitude = 77.057996
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Cells
Demise Altitude = 77.674183
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = GPS Ant - Sm
Demise Altitude = 75.053144
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PCBs
Demise Altitude = 75.610925
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
*************************************
name = Lenses
Demise Altitude = 71.581300
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Reaction Wheel Assy
Demise Altitude = 0.000000
Debris Casualty Area = 1.169982
Impact Kinetic Energy = 202.508621

*************************************
name = Structure - Tray
Demise Altitude = 77.071668
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structure - Ribs
Demise Altitude = 76.866230
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structure - Mounting Plate
Demise Altitude = 74.768293
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = GPS Ant - Lg
Demise Altitude = 72.724402
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

=============== End of Requirement 4.7-1 ===============
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CERTIFICATE OF SERVICE

I, Jeffrey Westling, hereby certify that on July 26, 2016, a true and correct copy of this *ex parte* letter was sent by United States mail, first class postage prepaid, to the following:

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Jeffrey Westling