Spire Global, Inc. ("Spire") Orbital Debris Risk Mitigation Plan

Spire believes that an additional 100 LEMUR-2 Phase IB and Phase IC satellites create relatively little additional orbital debris risks compared to existing systems approved by the Federal Communications Commission ("Commission"), and the satellites certainly meet applicable orbital debris requirements as listed in Section 25.114(d)(14) of the Commission's rules.[1] Each section below addresses specific measures taken by Spire, as required under Section 25.114(d)(14), to limit the possibility that its space station operations will generate orbital debris.

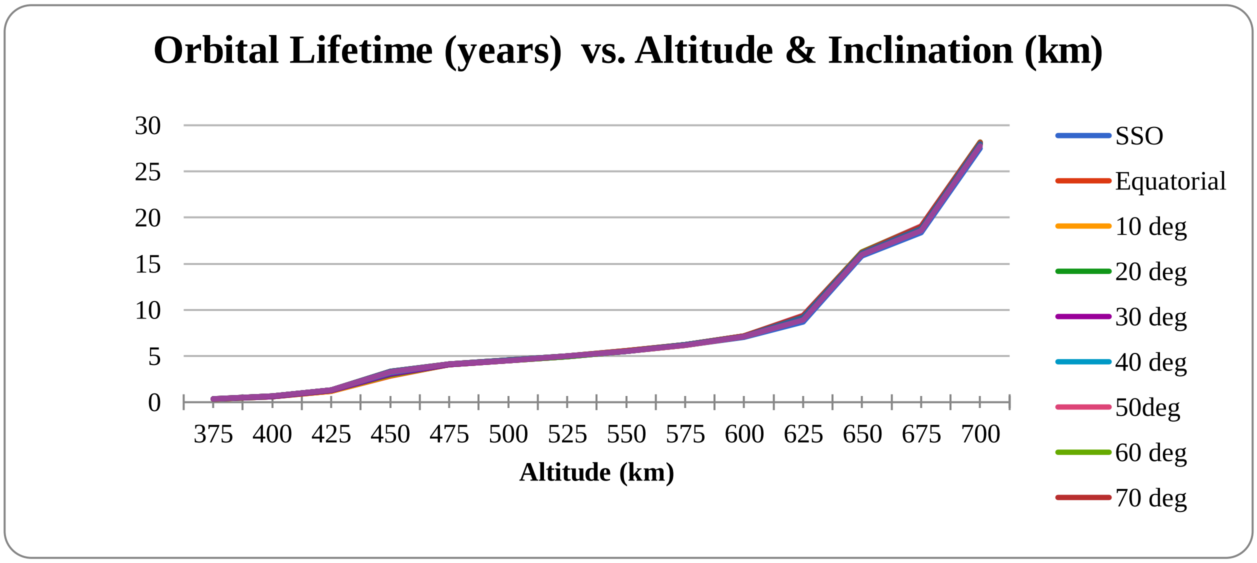
I. Orbital Dwell and Post Mission Disposal

The Commission's rules also call for indication of the anticipated evolution over time of the satellites' orbits.[2] Specifically, using the National Aeronautics and Space Administration ("NASA") Debris Assessment Software ("DAS"), Spire has calculated the dwell times of the Phase IB and Phase IC satellites. At the highest orbit sought of 600 km, orbital lifetime would not exceed 12.8 years from deployment in a conservative worst case scenario. This calculation is based on a conservative, worst-case scenario of a dead-on-arrival LEMUR-2 satellite and is still well within the standard of twenty-five years of mission completion and thirty years of launch set forth in Requirement 4.6.1 of NASA-STD-8719.14A ("Requirement 4.6.1").[3] The actual expected lifetime is seven years at this worst-case altitude. This analysis is more conservative

[1] *See* 47 C.F.R § 25.114(d)(14); *see also* Orbital Debris Assessment Report: 100 LEMUR-2 Phase IB and IC Satellites, Exhibit C ("Exhibit C").
[2] *See* 47 C.F.R. § 25.114(d)(14)(iii).
[3] *See Process for Limiting Orbital Debris*, NASA-STD-8719.14A § 4.6.1 (Dec. 2011).

than the analysis conducted by most other operators, who do not calculate orbital dwell time and do not limit themselves as to orbit based on a worst-case, dead-on-arrival basis.[4]

Spire has run an analysis measuring dwell times at inclinations from equatorial to sun synchronous to ensure that changes in inclination do not cause Spire to violate Requirement 4.6.1 at a maximum deployment apogee of 600 km. The results indicate that changes in inclination do not meaningfully affect orbital dwell times and that at any inclination at 600 km the 25-year requirement is met.[5]



Spire has also run an analysis measuring dwell times with different solar cycle assumptions to ensure that changes in launch schedule do not cause Spire to violate Requirement 4.6.1 at a maximum deployment apogee of 600 km. The results indicate that changes in solar cycle over the next two years have a positive impact on orbital dwell times (*i.e.*, lower them) and that at 600 km the 25-year requirement is met regardless of solar cycle assumptions.

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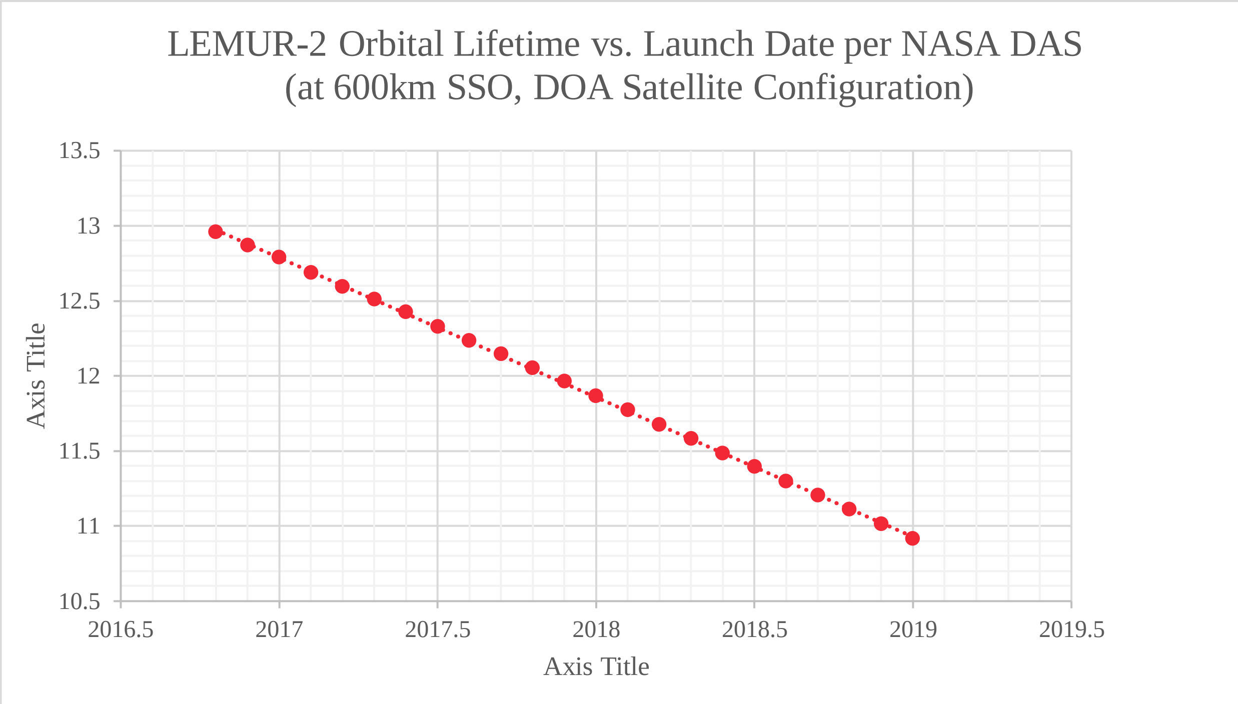
[4] As of today, no LEMUR-2 satellite has been dead on arrival.
[5] *See* NASA-STD-8719.14A § 4.6.1; *see also Mitigation of Orbital Debris*, Second Report and Order, 19 FCC Rcd 11567 ¶¶ 61, 83 (2004).



The dwell times for all orbits under 600 km are predictably less than the 600 km orbit and thus greatly exceed Requirement 4.6.1. Full details of the NASA DAS analysis with respect to orbital dwell times for all deployments sought by Spire with respect to the Phase IB and IC satellites are contained in the Orbital Debris Assessment Report ("ODAR").[6]

To ensure that Spire exceeds the NASA standard in all scenarios, Spire has included a double fault-tolerant solar panel deployment mechanism, which will provide sufficient surface area and drag to comply with the NASA standard even if a Phase IB or Phase IC satellite is dead on arrival. This deployment mechanism is the same as the one in the Phase I satellites previously approved by the Commission. The Phase IB and Phase IC satellite's solar panels are part of a built-in, post-deployment sequence programed into onboard software prior to launch, which requires no direction from the ground. If for some reason the onboard sequence fails, solar array

[6] *See* Exhibit C.

deployment can be commanded from the ground. If a Phase IB or Phase IC satellite is non-communicative, an entirely passive, redundant fail-safe is included on all Phase IB and Phase IC satellites in the form of a burn wire. The tensile strength of the burn wire has been tested and verified to degrade to a breaking point after 3600 hours or 150 days of UV radiation exposure.[7] Spire's worst-case scenario for dwell time conservatively models five years of non-deployed solar panels and no loss of altitude during those five years even though a dead on arrival satellite still has surface area that would cause at least some altitude loss.

Spire's post mission disposal plan is to allow its satellites to passively re-enter the atmosphere and completely burn up upon re-entry.[8]

Spire is also regulated by the National Oceanic and Atmospheric Administration's ("NOAA's") Commercial Remote Sensing Regulatory Affairs ("CRSRA") office which reviews and approves the company's post-mission disposal plan and its launches through an interagency review process, which, among other matters, considers orbital debris concerns of various U.S. government agencies.

II. Re-entry Hazards

Spire has used NASA DAS to review the survivability of major components upon re-entry and found that no objects are expected to survive re-entry, putting the risk to human life at 0.

III. Planned Release of Debris

Spire's Phase IB and Phase IC satellites will not undergo any planned release of debris.

[7] *See* Application of Spire Global, Inc., File No. SAT-LOA-20151123-00078, Test Summary: Tensile Properties Test with Accelerated UV Aging *A Demonstration of NOAA DeOrbit Guideline Compliance in an 'Edge Case' Scenario*, Exhibit E (filed Nov. 23, 2015).
[8] *See* 47 C.F.R. § 25.114(d)(14)(iv).

Spire also conducts extensive acceptance level environmental testing of all of its Phase IB and Phase IC satellites to provide further confidence in the structural integrity of the satellite in launch and space environments. In fact, because Spire launches with every major launch rocket that takes secondary payloads, including Falcon 9; Antares / Cygnus; Atlas-5; PSLV; Soyuz, H-II; and Dnepr (prior to its discontinuation), the Phase IB and Phase IC satellite has been subjected to a battery of different testing standards, including those required by NASA for International Space Station ("ISS") deployments.

IV. Limiting the Probability of Accidental Explosions

Phase IB and Phase IC satellites have no propulsion and accordingly do not carry highly volatile rocket propellant. The only energy sources (kinetic, chemical, or otherwise) onboard the spacecraft are a Lithium-Polymer battery system and reaction wheels.

The battery pack onboard the Phase IB and Phase IC satellites complies with all controls/process requirements identified in NASA Report JSC-20793 Section 5.4.3 to mitigate the chance of any accidental venting/explosion.[9] A battery cell protection circuit manages the charging cycle, performs battery balancing, and protects against over and undercharge conditions. The batteries will not be passivated at End-of-Mission due to the low risk and low impact of explosive rupturing. The maximum total chemical energy stored in each battery is ~144kJ (~288kJ total).

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

[9] *See Crewed Space Vehicle Battery Safety Requirements*, NASA Report JSC-20793 § 5.4.3 (Jan. 2014), https://standards.nasa.gov/file/657/download?token=DUcHF-J7.

limiting the maximum rotational speed of the wheels and containing them within a sealed compartment.

V. Collisions with Large Debris

The collision risk posed by the Phase IB and Phase IC satellites is extremely low due to their very small surface area and mass. Using NASA DAS, Spire has calculated the risk of collision for all deployments sought in this application. The highest probability of collision occurs for the highest orbit of 600 km. Even that probability is 2×10^{-6} over its entire orbital lifetime for a fully deployed Phase IB and Phase IC satellite (*i.e.*, the maximum surface area).[10] Most of the orbits sought by Spire register a risk in NASA DAS of 0. Full details of the NASA DAS analysis with respect to collision with large objects for each deployment sought in this application are contained in the ODAR attached to this application.[11]

As noted above, Spire is also regulated by NOAA's CRSRA office which, via an interagency process, reviews LEMUR-2 satellite launches for orbital debris hazards to national assets.

Spire also participates in a sharing agreement with the Joint Space Operations Center ("JSpOC") to better coordinate collision avoidance measures and receive conjunction threat reports. Spire's satellites carry onboard Global Positioning System receivers that provide for precise orbital position determination. Spire also receives from JSpOC updated two-line element sets, or "TLEs," which facilitate the identification and tracking of Spire's satellites. JSpOC has a direct line to Spire's satellite operations team that is accessible 24 hours per day/seven days per week to ensure that Spire can take immediate action to coordinate collision avoidance measures.

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[10] *See* Exhibit C.
[11] *See id.*

By early 2017, Spire will enable capabilities on the Phase IB and Phase IC satellites that allow it to determine the precise location of a LEMUR-2 down to 2 *centimeters*. To Spire's knowledge, such precise location capabilities are non-existent outside the context of very large government satellites and do not exist for *any* commercial operator.[12] This hyper-precise location data will allow Phase IB and Phase IC satellites to have orbits projected out with extreme precision, thus greatly lowering the number of false positive conjunction alerts and making collision avoidance measures far more well informed.

Special care is also given to minimizing the potential for collision with manned spacecraft, including the ISS. The operational altitude of the ISS is approximately 400 km. Spire will coordinate with NASA to assure protection of the ISS on an ongoing basis. Because Spire participates in many ISS deployments, ISS program management has a detailed understanding of the Phase IB and Phase IC satellites.

Spire will work closely with its launch providers to ensure that the Phase IB and Phase IC satellites are deployed in such a way as to minimize the potential for in plane collision. The risk is further mitigated with the typical small deployments undertaken by Spire; Spire is also not seeking to deploy more than 16 Phase IB or Phase IC satellites at once.

Further, in advance of this filing, Spire has reached out to the other low-Earth orbit operators at or below 600 km that are identified in the Commission's Satellite Space Station

[12] For reference, Spire's agreement with Orbcomm License Corp. specifies location accuracy of 20 meters as a threshold. TLEs received from JSpOC have accuracy measured in kilometers.

Authorization List and has informed them of Spire's intention to coordinate to further mitigate any collision risks.[13]

The Commission's rules call upon applicants to specify the accuracy, if any, with which the orbital parameters of their non-geostationary satellite orbit space stations will be maintained.[14] Because the Phase IB and Phase IC satellites will not carry maneuvering propellant, Spire will not maintain satellite inclination angles, apogees, perigees, and right ascension of the ascending node to any specified degrees of accuracy.

VI. Collisions with Small Debris or Meteoroids

Spire used NASA DAS to confirm that the Phase IB and Phase IC satellites meet the requirements of 4.5-2.[15]

[13] *See Approved Space Station List*, FCC, https://www.fcc.gov/approved-space-station-list (last updated June 3, 2016).
[14] *See* 47 C.F.R § 25.114(d)(14)(iii).
[15] *See Process for Limiting Orbital Debris*, NASA-STD-8719.14A § 4.5-2 (Dec. 2011).