I. Spire Global, Inc. ("Spire") 6U Orbital Debris Risk Mitigation Plan

Spire believes that the introduction of 6U satellites to its constellation will create negligible additional orbital debris risks compared to existing systems approved by the Federal Communications Commission ("Commission"), and the satellites 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.

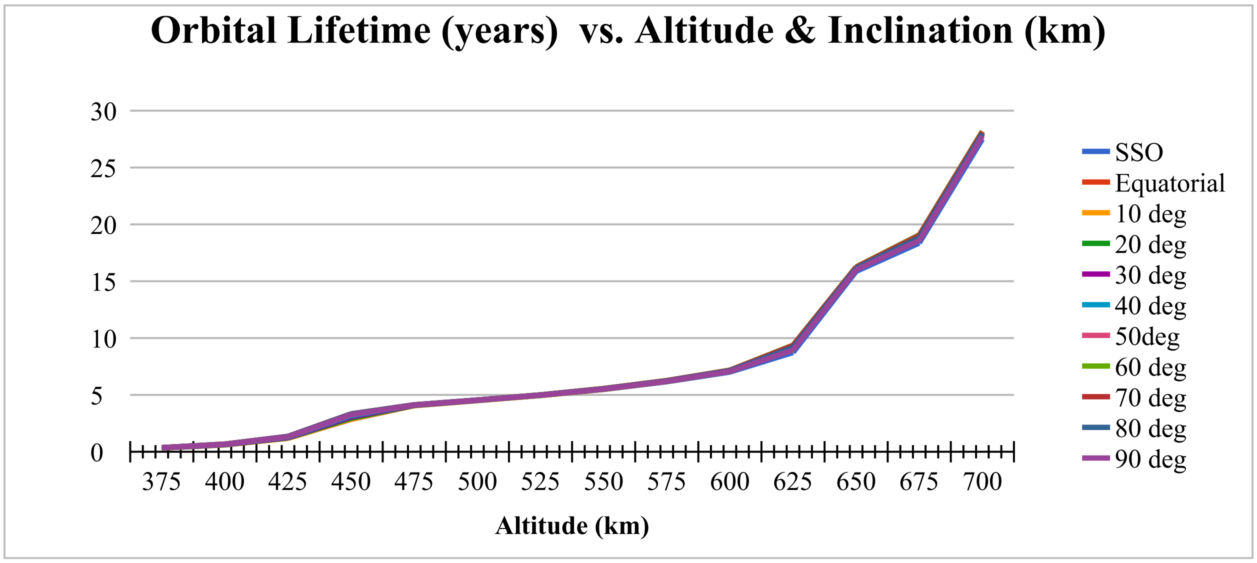
II. Orbital Dwell and Post Mission Disposal

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") v3.1.0, Spire has calculated the dwell times of the 6U satellites. At the highest orbit sought of 635 km, orbital lifetime would not exceed 22.6 years from launch in a conservative worst-case scenario; this is inclusive of the planned operational lifetime. This calculation is based on a conservative, worst-case scenario of a dead-on-arrival Spire satellite, launched in its maximum mass configuration[3], 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").[4] The actual expected lifetime for a nominal deployment is eighteen years at this worst-case altitude. This analysis is

[1] *See* 47 C.F.R § 25.114(d)(14); *see also* Orbital Debris Assessment Report: 175 Spire Satellites, Exhibit G ("Exhibit G").
[2] *See* 47 C.F.R. § 25.114(d)(14)(iii).
[3] Spire satellites have a total mass of 15.5 kg maximum.
[4] *See Process for Limiting Orbital Debris*, NASA-STD-8719.14A § 4.6.1 (Dec. 2011).

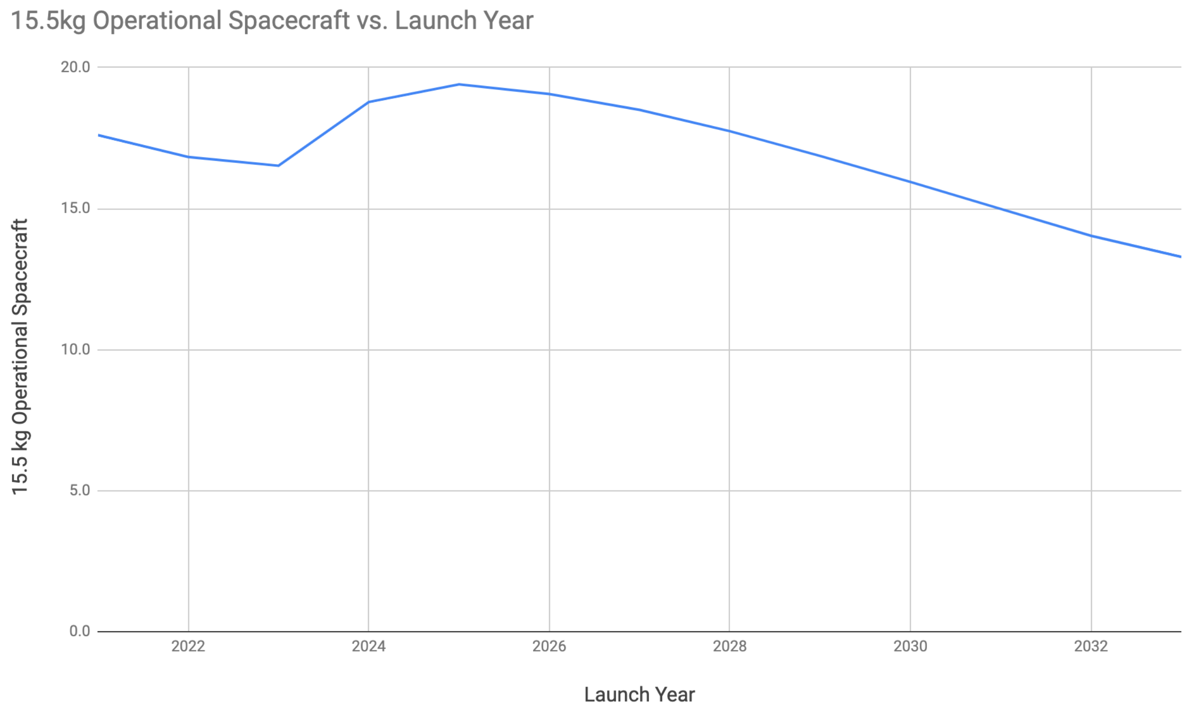
more conservative than the analysis conducted by most other operators, who do not limit orbit options based on the worst-case, dead-on-arrival basis.[5]

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 635 km. The results indicate that changes in inclination do not meaningfully affect orbital dwell times.



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 635 km. The results indicate that changes in solar cycle over the next decade have an overall positive impact on orbital dwell times (*i.e.*, lower the dwell times) and that at 635 km the 25-year requirement is met regardless of solar cycle assumptions.

[5] As of today, no Spire LEMUR-2 satellite has been dead on arrival.



The dwell times for all orbits below 635 km are predictably less than the 635 km orbit and thus also meet Requirement 4.6.1. Full details of the NASA DAS analysis with respect to orbital dwell times for all deployments sought by Spire are contained in the Orbital Debris Assessment Report ("ODAR").[6]

To ensure that Spire meets the NASA standard in all scenarios, Spire has included a triple fault-tolerant solar panel deployment mechanism, which will provide sufficient surface area and drag to comply with the NASA standard even if a satellite is dead on arrival. This deployment mechanism is the same as the one in the Phase I and Phase II satellites previously approved by the Commission and thus has extensive flight heritage. The satellite's solar panels are part of a built-in, post-deployment sequence programmed into onboard software prior to launch, which requires no direction from the ground. If the onboard sequence experiences a failure, solar array

[6] *See* Exhibit G.

deployment can be commanded from the ground. If a satellite is non-communicative, an entirely passive, redundant fail-safe is included on all Spire 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]

III. Re-entry Hazards

Spire has used NASA DAS to review the survivability of major components upon re-entry and found that zero objects are expected to survive re-entry, putting the risk to human life at 0.

IV. Planned Release of Debris

Spire's satellites will not undergo any planned release of debris. Spire also conducts extensive acceptance level environmental testing of all of its 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 but not limited to Falcon 9; Antares / Cygnus; Atlas-5; Vega; PSLV; Soyuz; H-II; and Electron, the satellite has been subjected to a battery of different testing standards, including those

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[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).

required by NASA for International Space Station ("ISS") deployments.

V. Limiting the Probability of Accidental Explosions

Spire 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. Additionally, solar panel shedding due to a runaway reaction wheel anomaly is analyzed.

The battery pack onboard the satellites complies with all controls and 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).

One failure mode caused by the reaction wheel assemblies that could create debris would be the breakup of the wheels themselves due to mechanical failure while operating at a high angular rate. A second failure mode caused by the reaction wheels could be a runaway torque event. In this scenario, high angular velocity could lead to the solar panels breaking up. The reaction wheels onboard the satellites are limited with respect to maximum rotational speed of the wheels and are contained within a sealed compartment, thus mitigating any risk of breakup of the wheels themselves into debris.

An analysis was performed to address the feasibility of a runaway torque event and the potential for solar panel shedding. Given the maximum stored momentum in the reaction wheels,

[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.

the bending stress and shear stress at the solar panel hinges was calculated, and a Factor of Safety of over 20,000 was found against solar panel shedding. The reaction wheels cannot provide sufficient torque to cause solar panel shedding, which is the most likely mechanical shedding through rotational motion.

Given the above analysis, the risk of a runaway torque event causing breakup of satellite hardware was deemed negligible.

VI. Collisions with Large Debris

The collision risk posed by the Spire 6U 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 amendment. The highest probability of collision occurs for the highest orbit of 635 km. The calculated probability is 2.10×10^{-5} over its entire orbital lifetime for a fully deployed satellite (*i.e.*, the maximum surface area).[10] 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] Details regarding aggregate collision risk for the entire constellation are also contained in the ODAR.

Additionally, Spire participates in a sharing agreement with the 18th Space Control Squadron to better register its satellites and 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 updated two-line element sets from the 18th Space Control Squadron, or "TLEs," which facilitate the identification and tracking of Spire's satellites. The 18th Space Control Squadron has a direct

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

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.

Spire has existing capabilities on the satellites that allow it to determine the precise location down to 15 centimeters. Such precise location capabilities set Spire apart as a commercial operator.[12] This hyper-precise location data will allow Spire satellites to have satellite orbital propagations predicted 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 crewed spacecraft, including the ISS. The operational altitude of the ISS is approximately 400 km. Although Spire typically deploys satellites at altitudes above the ISS, these satellites will naturally decay over time and pass through the ISS altitude. Spire will share all information and coordinate closely with NASA to assure protection of the ISS on an ongoing basis. Because Spire has participated in many ISS deployments, ISS program management has a detailed understanding of Spire's satellites.

Spire will work closely with its launch providers to ensure that the 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 satellites at once. Further, in advance of this filing, Spire has reached out to the other low-Earth orbit operators at or below 650 km that are identified in the Commission's Satellite Space Station Authorization List and has informed them of Spire's intention to coordinate to

[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.

further mitigate any collision risks.[13] In the event that Spire predicts a potential collision risk, the corresponding operator(s) will be notified and any relevant operational or ephemeris information will be shared. Additionally, Spire has established a relationship with LeoLabs whereby the companies share TLEs and object identification information. This provides an additional resource through which Spire can coordinate deployments and assess collision risks.

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 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.

VII. Collisions with Small Debris or Meteoroids

Per the DAS User's Guide Section 3.6, Requirement 4.5-2 applies only to subsystems vital to completing post mission disposal. The Spire spacecraft does not have any propulsion, nor does it require any commands or maneuvers to perform end-of-mission tasks. Therefore, requirement 4.5-2 is listed as N/A.

[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).