

May 15, 2020

BY ELECTRONIC FILING

Jose P. Albuquerque
Chief, Satellite Division
International Bureau
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

Re: *Space Exploration Holdings, LLC, IBFS File No. SAT-MOD-20200417-00037*

Dear Mr. Albuquerque:

On behalf of Space Exploration Holdings, LLC (“SpaceX”), we hereby respond to your letter dated May 6, 2020, in which you have requested additional information with respect to the above referenced application (“the Application”) to modify SpaceX’s existing authorization to deploy and operate a non-geostationary orbit (“NGSO”) satellite system.¹ SpaceX welcomes this opportunity to demonstrate the ways in which its proposed modification will improve the orbital environment. In SpaceX’s existing license, the Commission found that authorizing SpaceX to deploy and operate 4,425 satellites at orbital altitudes of 1,110-1,325 km would serve the public interest.² The Commission subsequently granted a modification authorizing SpaceX to relocate 1,584 satellites previously authorized to operate at an altitude of 1,150 km to an altitude of 550 km, finding that doing so would serve the public interest by, among other things, decreasing the potential for orbital debris.³

The current modification proposal would similarly decrease the potential for orbital debris by lowering the operational altitudes of the remaining satellites to the 540-570 km range. As the Commission has recognized, operating at these much lower altitudes has significant public interest benefits in that orbital debris (including failed satellites) tends to de-orbit in relatively short order, significantly decreasing the risk posed to ongoing operations in space.⁴ Accordingly, all of the orbital debris mitigation metrics for the system will be better under the proposed modification than they are as currently authorized. Indeed, as discussed in the Application, the denser atmospheric

¹ Letter from Jose P. Albuquerque to William M. Wiltshire, IBFS File No. SAT-MOD-20200417-00037 (May 6, 2020).

² See *Space Exploration Holdings, LLC*, 33 FCC Rcd. 3391, ¶ 11 (2018).

³ See *Space Exploration Holdings, LLC*, 34 FCC Rcd. 2526 (IB 2019).

⁴ See, e.g., *Mitigation of Orbital Debris in the New Space Age*, FCC 20-54, ¶ 43 (rel. Apr. 24, 2020) (“*Orbital Debris Mitigation Update Order*”) (“missions deploying above 650 km altitude may represent a greater risk from a long-term orbital debris perspective, since satellites that fail above that altitude will generally not re-enter Earth’s atmosphere within 25 years, and depending on the deployment altitude, may be in orbit for centuries or longer”).

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conditions at the 540-570 km altitude provide fully passive redundancy to SpaceX’s active disposal procedures such that, even assuming an extreme worst-case scenario – i.e., a spacecraft fails while in the operational orbit, has no attitude control, and solar activity is at a minimum – the longest decay time is still only approximately five years.⁵ Thus, the probability of successful disposal of each SpaceX satellite as defined by the Commission is deemed to be 100% – surpassing even the aspirational objective recently set by the Commission for large NGSO systems.⁶

Below we respond to each of the Bureau’s specific requests for information in turn.

- Using the NASA Debris Assessment Software or a higher fidelity model, please provide the in-orbit collision risk for a satellite at each of the various operational altitudes and inclinations specified in the modification application, assuming that the maneuver capability on the satellite is not available, and assuming alternative cases of a satellite for which attitude is maintained, and one that is tumbling. Please provide this analysis for both the current satellite design and the design that includes sun shade panels.***

SpaceX’s proposed modification will reduce the risk of collision by orders of magnitude from its current authorization. To confirm this conclusion, SpaceX used proprietary software it has developed to provide higher fidelity analysis using NASA’s Debris Assessment Software (“DAS”) database.⁷ For example, one satellite operating at the currently authorized altitude of 1,110 km would have a 0.0392 collision risk with attitude maintained. Table 1 demonstrates that SpaceX’s proposed modification will result in approximately 1,000 times improvement in collision risk.

Altitude (km)	Current Satellite Design		Satellite with Sun Shade Panels	
	Maintained	Tumbling	Maintained	Tumbling
540	0.000042	0.000031	0.000043	0.000033
560	0.000109	0.000091	0.000113	0.000094
570	0.000087	0.000068	0.000088	0.000071

Table 1. Collision Risk Assuming No Maneuver Capability

⁵ See Application, IBFS File No. SAT-MOD-20200417-00037, Attachment A at 19-20 (Apr. 17, 2020).

⁶ See *Orbital Debris Mitigation Update Order*, ¶ 96.

⁷ In particular, while DAS can provide decay times and collision probabilities at different altitudes, it does not actually propagate a decay trajectory through the different debris flux levels at different altitudes. SpaceX’s proprietary model uses the impact flux information that DAS uses to compute impact rate as a function of altitude.

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Indeed, the proposed modification would yield collision risk metrics that are approximately 10 to 30 times lower than the 0.001 benchmark recently adopted by the Commission.⁸

2. ***Please provide a discussion of the efforts that have been taken or will be taken to address collision risk with the respect to other satellite systems that have been licensed or plan to be operated at the same operational altitude ranges, including any coordination of operations that has occurred or that is planned.***

SpaceX has made clear that it intends to perform collision avoidance procedures, including conjunction assessment, execution of avoidance maneuvers, trajectory planning and conjunction assessment for any planned alteration of satellite trajectory, and notification to other potentially affected operators of any planned alteration of a satellite's trajectory. SpaceX will perform conjunction screening and avoidance maneuvers for all phases of operations, including any planned alteration of satellite trajectory, prior to passive disposal. All satellites will have sufficient propellant and capability to perform any avoidance maneuvers required for all phases of the satellites' mission.

SpaceX believes it is the industry leader in collision avoidance mitigation and will continue to take a number of steps to ensure that its constellation does not unduly affect other NGSO systems. For example, SpaceX has implemented autonomous conjunction avoidance technology on its spacecraft and expects to continue to upgrade that capability as it gains operational experience. Moreover, as stated above, SpaceX will perform nominal conjunction avoidance at all stages of flight. To aid with its other conjunction avoidance efforts, SpaceX has worked closely with the Combined Space Operations Center ("CSPOC") and will provide it or other relevant regulatory agencies with forecasts of vehicle positions, during both ballistic and propulsive phases of flight. Similarly, SpaceX provides all of its ephemeris data to other operators via spacetrack.org. SpaceX is also the first operator to optimize the usefulness of this data by supplementing it with co-variance data, which allows other operators to better predict the trajectories of SpaceX satellites.

SpaceX has also begun efforts to coordinate with other satellite systems that have been licensed or plan to be operated at the same operational altitudes as SpaceX proposes in its modification to further reduce the potential risk of collision. SpaceX has reached out to every operator licensed in the NGSO FSS processing rounds initiated in 2016 and 2017 to discuss physical coordination of systems. SpaceX is currently in active negotiations with those operators that were prepared to enter such discussions. However, at this point, not all operators have indicated that they are prepared for such discussions as their operational practices in general and collision avoidance strategies in particular are not yet fully formed. SpaceX is awaiting further information from those operators, and intends to engage them once it is available. Similarly,

⁸ See *id.* ¶¶ 33-34.

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SpaceX is awaiting information from those planning systems that have not been licensed on how they intend to operate, including information about their plans for orbit raising and de-orbiting.⁹

SpaceX is aware that the Commission has authorized a number of operators to deploy cubesats at altitudes from 400 km to 650 km with orbits that will naturally decay to lower altitudes due to lack of propulsion. These operators include: Astro Digital US Inc., Spire Global, Inc., and Swarm Technologies, Inc.¹⁰ There are also two applications under consideration for cubesat systems that will launch to an altitude of 600 km and naturally decay, filed by Hiber Inc. and Myriota Pty. Ltd.¹¹ Because these systems lack propulsion, they are capable of only very limited maneuvering. By contrast, SpaceX's propulsive capabilities enable it to avoid such non-propulsive systems unilaterally. Nonetheless, SpaceX intends to discuss arrangements under which such operators would assume at least some obligation for collision avoidance to the extent practicable.

In addition, to address non-U.S. licensed systems, SpaceX has reviewed the list of NGSO satellite networks with a perigee of 540-570 km for which a request for coordination has been published by the International Telecommunication Union ("ITU"). SpaceX identified more than 20 such filings currently on record filed by other administrations. However, while the ITU database identifies the administration that made each filing, it has no mechanism for identifying a specific operator on whose behalf it was submitted. Such identification typically takes place during international coordination. In such coordination discussions, SpaceX intends to engage other systems seeking to operate at the same nominal orbital ranges sought by SpaceX to carefully plan physical operations to ensure that their respective constellations can coexist safely.

3. *Please indicate whether any of the satellites launched to date have permanently lost maneuver capabilities at an altitude above the injection altitude, and, if so, please indicate at what altitude.*

SpaceX has launched 420 satellites since May 2019 to an operational altitude of 550 km. As summarized in Table 2 below, of the initial launch of the v0.9 spacecraft design, 6 lost maneuverability. SpaceX, employing its integrated and iterative approach, upgraded the satellite design (v1.0) for subsequent launches, which has shown dramatic improvement – only 1.7% of satellites out of 360 have since become non-maneuverable. Satellites that have become non-maneuverable at the highest operational orbits will passively de-orbit in under two years on average. SpaceX also uses a very low injection altitude of its satellites, which means satellites that lose maneuverability at deployment will demise in less than a month. SpaceX will continue to

⁹ See, e.g., Reply of Space Exploration Holdings, LLC, IBFS File No. SAT-MOD-20180319-00022, at 12-14 (Sep. 12, 2018) (discussing OneWeb's refusal to provide updated orbital debris mitigation information for application to nearly triple the size of its NGSO constellation).

¹⁰ See, e.g., Grant Stamp, IBFS File No. SAT-LOA-20170508-00071 (granted Aug. 1, 2018) (deployment altitude from 475-625 km); Letter from George John to Marlene H. Dortch, IBFS File No. SAT-LOA-20151123-00078 (June 26, 2019) (Annual Report for IBFS Call Sign S2946 showing deployments from 400-650 km); *Swarm Technologies, Inc.*, 34 FCC Rcd. 9469 (IB 2019) (deployment altitude from 400-550 km).

¹¹ See IBFS File Nos. SAT-PDR-2018910-00069 and SAT-PDR-20190328-00020.

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upgrade its satellites to drive reliability of the fleet throughout the license term as it de-orbits and replaces older satellites with upgraded models.

Count of satellites that lost maneuver capabilities above injection altitude	Altitude of satellite [km]	Notes
1	527	Initial launch of v0.9 spacecraft design
2	455	
3	529	
4	400	
5	552	
6	490	
7	549	Subsequent Launches of v1.0 spacecraft design (1.7%)
8	373	
9	550	
10	550	
11	401	
12	383	

Table 2. Summary of Satellites That Lost Maneuvering Capability

SpaceX has developed further design enhancements that it will immediately include on new satellites that will upgrade avionics and propulsion systems even further. The proposed modification will significantly improve any effect non-maneuverable Starlink satellites have on the space environment. The modification will reduce time in orbit for non-maneuverable satellites from centuries or millennia at its currently authorized altitudes to months and years after the modification, and reduce the time for active de-orbit from as much as a year at the currently authorized altitudes to as little as 60 days after the modification. Finally, even Starlink v1.0 satellites that have lost maneuverability entirely remain fully demisable, meaning that they cause no calculated risk to life on earth following reentry.

4. Please provide the estimated mission lifetime per satellite, and an estimate of the number of satellites that will be launched during the fifteen-year license term.

As stated in the Application, SpaceX satellites have been designed for a mission life of five years. As noted above, unlike systems flown by other operators that become less reliable over time, SpaceX specifically designed its system to improve service and reliability through the life of its constellation. Pursuant to Section 25.121(d)(2) of the Commission’s rules, the fifteen-year term

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of the license granted to SpaceX commenced on the date when its first space station reached its assigned orbit.¹² Accordingly, deployment of the more than 4,400 satellites remaining in its constellation can be expected to continue well into the license period. With this in mind, SpaceX estimates that, although it will not have any more than 4,408 active, on-station satellites at any given time, it will launch fewer than 10,000 satellites during its initial license term. This figure includes both initial satellite deployments and satellites launched to replace satellites that have reached the end of their intended operational lives.

* * *

Should you have any questions, please do not hesitate to contact me.

Sincerely,



William M. Wiltshire
Counsel to SpaceX

¹² See 47 C.F.R. § 25.121(d)(2).