March 13, 2019

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-20181108-00083*

Dear Mr. Albuquerque:

On behalf of Space Exploration Holdings, LLC ("SpaceX"), we hereby respond to your letter dated February 26, 2019, in which you have requested additional information with respect to the above referenced application to modify SpaceX's existing authorization to deploy and operate a non-geostationary orbit ("NGSO") satellite system.[1]

1. ***Please provide an estimate of the collision risk, using NASA Debris Assessment Software or another recognized estimation tool, for a single satellite, assuming a propulsion or other system failure that renders the satellite incapable of collision avoidance immediately following orbital injection. Please provide that estimate assuming a satellite in both a stowed and a fully deployed configuration.***

Due to SpaceX's decision to minimize risk by using the low injection altitude of 350 km, in the unlikely event any satellites after the initial launch experience immediate failure upon deployment, they would decay to the point of demise very quickly – as little as two weeks to at most eight months depending on the solar cycle. Consistent with the prevailing NASA safety standard, which the Commission has regularly relied upon for orbital debris mitigation assessments,[2] the probability of accidental collision between a spacecraft passing through low-

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1 Letter from Jose P. Albuquerque to William M. Wiltshire and Paul Caritj, IBFS File No. SAT-MOD-20181108-00083 (Feb. 26, 2019).

2 *See* Requirement 4.5-1, NASA Technical Standard, Process for Limiting Orbital Debris, NASA-STD-8719.14A (with Change 1), at 32 (May 25, 2012), *available at* https://standards nasa.gov/standard/nasa/nasa-std-871914.

Earth orbit and space objects larger than 10 cm in diameter is calculated to be less than 0.001. Specifically, using NASA's Debris Assessment Software ("DAS"), the probability of collision between a space object larger than 10 cm in diameter and a SpaceX satellite if rendered totally incapacitated immediately following orbital injection is shown in Table 1 below:

	Solar Minimum	Solar Maximum
Stowed Configuration	0.000000303	0.000000114
Deployed Configuration	0.000000274	0.000000137

Table 1. Collision Risk of Incapacitated Satellite

Accordingly, SpaceX satellites satisfy the NASA safety standard by several orders of magnitude. Indeed, even assuming a highly unlikely and apocryphal case in which all 1,584 satellites proposed for deployment at 550 km were immediately incapable of maneuvering upon orbital injection, remained in a stowed configuration, and were de-orbiting during a period of solar minimum, the aggregate probability of collision would be 1,584 x 0.000000303 = 0.00048 – which is still less than half the 0.001 probability standard established by NASA. This extreme case is highly improbable given that SpaceX will deploy satellites in considerably smaller increments per launch, allowing SpaceX to halt deployments until it can address the root cause of such an extreme and unlikely widespread fault.

See also Mitigation of Orbital Debris in the New Space Age, FCC 18-159, ¶ 6 (2018) ("Both applicants and the Commission, however, have relied in a number of cases on standards and related assessment tools, such as the technical standards and related software tools developed by NASA for its space activities, to, respectively, prepare such orbital debris plans and assess their adequacy.").

As is clear from Table 1, one of the key assumptions in the DAS analysis is the stage of the solar cycle at the time of de-orbit.[3] During solar-max, the atmosphere swells up, making re-entry occur much more rapidly than during periods of solar-min. SpaceX expects a majority of its launches will happen at or near periods of solar-max. However, in the interest of showing a full range of outcomes, SpaceX has also provided a collision estimate assuming a local solar minimum such as that expected in the year 2029. As Table 1 demonstrates, the probability of collision satisfies the NASA standard under all of these scenarios.

2. Please indicate whether, as currently designed, the proposed satellites are capable of a controlled re-entry, i.e., re-entry specifically and reliably targeted at broad ocean areas, away from human populations.

SpaceX assumes that this question arises in connection with the system's imputed human casualty risk. As indicated in earlier filings, SpaceX has been working continuously towards the most direct method to minimize any such risk from its existing architecture to maximize the safety of the system by achieving 100% demisability of each of its spacecraft. After extensive research and investment, SpaceX has now developed a system architecture that will be completely demisable in versions subsequent to the initial deployment of satellites, which will be comprised of fewer than 75 satellites. As discussed below, after deploying that initial design of spacecraft, no components of subsequent iterations of the satellite will survive atmospheric re-entry, reducing casualty risk to zero.

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[3] By contrast, the vehicle configuration (*i.e.*, stowed vs. deployed) has relatively little effect on collision risk because the risks involved are offsetting. In other words, the smaller area of a stowed satellite reduces the likelihood of collision but also increases the time required for atmospheric demise. A fully deployed satellite presents a larger area for collision but experiences more drag and thus de-orbits more quickly.

All versions of the SpaceX spacecraft will leverage Hall-effect electric propulsion. These efficient propulsion systems are ideal for orbit raising, station-keeping maneuvers including the ability to avoid other satellites and debris, and initiating the de-orbit process by lowering the satellites' perigee from 550 km to approximately 300 km. In fact, the efficiency of these ion thrusters improves the overall safety of the system by enabling the vehicles to perform a vastly greater number of maneuvers for the same amount of fuel compared to alternative systems. These advanced systems achieve this level of efficiency by employing very low thrust, which on the other hand limits the ability to target re-entry precisely. Adding that type of functionality for the initial spacecraft design would involve a distinct trade-off. Specifically, the addition of secondary propulsion systems necessary for targeted re-entry would also require larger tanks and additional fuel that in turn bring a significantly higher risk of explosion, undercutting the relative safety benefits of targeted re-entry.

3. ***Please provide any updates concerning the additional, high fidelity studies of casualty risk during re-entry mentioned at Application, Technical Information Exhibit, p. 47.***

The higher fidelity study using NASA's Object Reentry Survival Analysis ("ORSAT") tool of the fewer than 75 first-generation SpaceX satellites that will not fully demise in the atmosphere has not been completed at this time.

4. In the event a high fidelity study has not been completed:

a. Please state SpaceX's current plans with respect to the number of satellites that will carry each of the alternative components discussed at pages 45-46 of the Technical Information Exhibit.

As discussed in its application, SpaceX plans to deploy two versions of its initial satellites with configurations that include a slightly different set of components. The first version, comprising fewer than 75 satellites, will include an iron thruster and steel reaction wheels on each satellite. As a result of its continuing efforts to attain full demisability, SpaceX now expects to replace the thruster and reaction wheel components in subsequent satellites to use components that will demise fully in the atmosphere. SpaceX no longer intends to deploy any satellites that include the silicon carbide component originally contemplated.

b. Please provide any additional information and analysis to support the choice of materials that will not demise upon re-entry.

At present, a small number of components incorporated in the initial satellite design version will be more resistant to demise in re-entry. Only a limited number of this version of satellites will be deployed. Thereafter, as discussed above, SpaceX's drive towards complete demisability has led to great strides across the spacecraft such that SpaceX now plans for a fully demisable spacecraft after the initial design version.

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

Sincerely,

William M. Wiltshire

William M. Wiltshire
Counsel to SpaceX