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June 4, 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 June 3, 2020, 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] In SpaceX's existing authorization, 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] As SpaceX noted in its previous response, the current modification proposal would decrease the potential for orbital debris by lowering the operational altitudes of the remaining satellites to the 540-570 km range. All of the orbital debris mitigation metrics for the system will be better under the proposed modification than they are as currently authorized. SpaceX appreciates the Commission's attention to detail with respect to its orbital debris mitigation oversight, and looks forward to seeing requests for that same level of detail with respect to other pending NGSO applications.

Below we respond to each of the Bureau's specific requests for information in turn. With these additional responses, SpaceX requests that the Commission promptly put out for public comment its modification application.

1. Table 1 of the response specifies that the collision risks for a spacecraft with no propulsion capability at 560 km is larger than at the 570 km altitude. Please indicate whether these two rows were accidentally inverted.

These rows where not inverted. As shown in the following charts, NASA's Debris Assessment Software ("DAS") version 2.0.2 predicts a higher impact rate at the inclination planned for operations at 560 km such that, despite the longer decay times, operations at the 570 km altitude has less risk.

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1 Letter from Jose P. Albuquerque to William M. Wiltshire, IBFS File No. SAT-MOD-20200417-00037 (June 3, 2020).

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

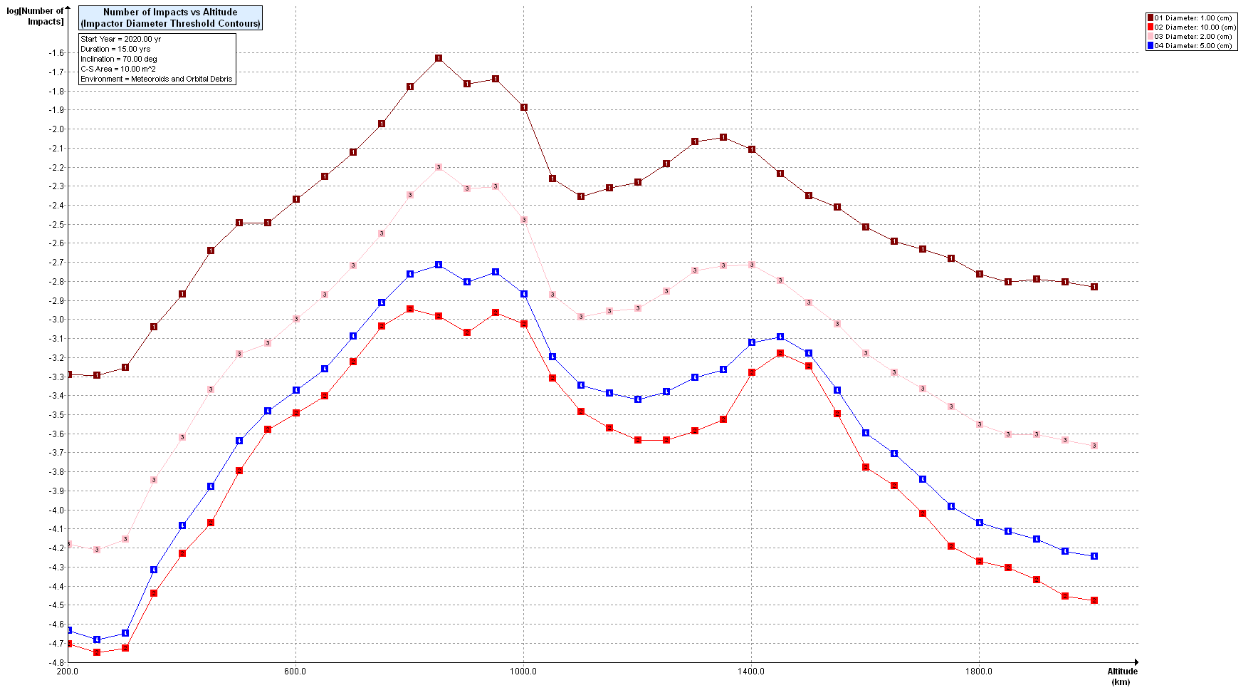

Chart 1: Number of Impacts vs. Altitude at 70 degree inclination.

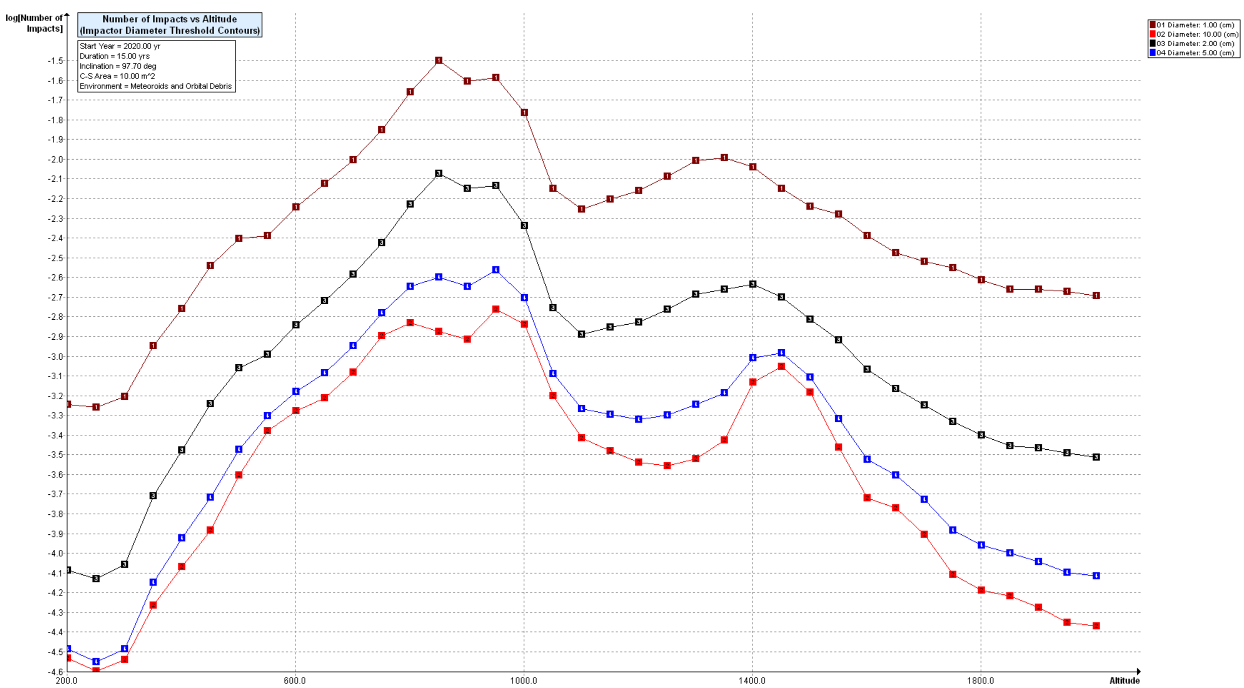

Chart 2: Number of Impacts vs. Altitude at 97.7 degree inclination

2. Concerning the data provided in Table 1, please indicate what method was used to calculate the cross-sectional area of the spacecraft, one of the two methods described in NASA-STD-8719.14b or some other method. If other methods were employed, please provide a description. What type of modeling was used in calculating the orbital lifetime of the spacecraft and what assumptions were included? Where were the debris flux numbers obtained? Were they extracted from the NASA ORDEM software or from some other source?

SpaceX calculated the cross-sectional area of its spacecraft using methodologies similar to but not entirely the same as those described in NASA-STD-8719.14b. For purposes of analyzing a satellite with attitude maintained, the cross-sectional area of the spacecraft is the summed area of the largest cross section of the solar panel and chassis. For purposes of analyzing a satellite that is tumbling, the cross-sectional area discussed above is multiplied by a factor of 0.5, which is the coefficient corresponding to the average area of a tumbling plate.

In modeling orbital lifetime of spacecraft, SpaceX's software is formulated to time step through the Gaussian planetary equations formulated for orbital elements. The orbital element formulation allows for accurate propagation through osculating Keplarian orbits in between time steps, which results in reduced numerical error. SpaceX assumes the third body gravitational perturbations due to the sun and moon and radiation pressure perturbations are not drivers of orbital decay at the low operational altitudes of its satellites and chose to focus modeling efforts on atmospheric effects and non-spherical earth gravitational effects. The atmospheric model used is the GOST atmospheric model. This model includes effective atmospheric densification due to solar activity (measured as 10.7 cm wavelength solar flux) and densification due to the Earth's geomagnetic activity. SpaceX accounts for the semi-annual effect on atmospheric density, effects of the atmospheric density distribution dependence on the declination and right ascension of the sun, and changing atmospheric density due to a deviation of the daily solar flux from the 81 day average solar flux. SpaceX includes effects of the atmosphere's rotation at these low Earth orbital altitudes as well as changes in atmospheric height due to the non-spherical shape of the Earth. The effects of Earth's oblateness are assumed to not drive orbital decay time so the spherical harmonic terms are truncated after the J2 term.

For the sake of this analysis, SpaceX assumes its satellites could lose function at any time, and thus uniformly disperses the time of loss of the satellite as a Monte Carlo variable. Due to the difficult task of predicting solar activity SpaceX leverages historical solar activity data for its Monte Carlo simulation. Furthermore, SpaceX chose to be conservative in its solar flux predictions by performing the Monte Carlo simulation over the most recent solar cycle, which was the weakest cycle of solar flux in recent history. Reported results are either the mean decay time of this Monte Carlo simulation or the worst case from the Monte Carlo depending on the context of the response.

SpaceX obtained the debris flux tables from DAS 2.0.2 using the "Debris Impacts vs. Orbit Altitude" tool in the "Science and Engineering" utilities at all operational inclinations.

3. Please provide additional information regarding the SpaceX software used to develop the collision risk figures: What is the frequency of collision calculations? How many times per year are the altitude and the debris flux levels at that altitude recalculated? Are the debris flux numbers obtained at average altitudes for each length of time or are they based at particular times during the calculated timeframe, such as the beginning, end or mid-point of the timeframe? Please also provide a basic template for the collision risk calculations for a single time unit and indicate the time unit. For example, using ORDEM fluxes, a potential template would be: Collisions_segN = (DebrisFlux_segN) * (Cross-sectional Area) * (Years spent in segN); CollisionSum = Collisions_seg1 + Collisions_seg2 + Collisions_seg3 + …; CollisionProbability = 1 – e^(-CollisionSum)

The SpaceX software recalculates atmospheric density and the debris flux levels every 6 hours of simulation as the longest duration and every 30 minutes of simulation as the shortest duration. Depending on the altitude, this results in up to over 17,000 collision calculations per year of simulation time.

The debris flux and drag numbers are calculated at the beginning of each time step. This is conservative in both cases because the beginning of the time step is at a higher altitude and the atmosphere is less dense at the higher altitudes and below 750 km DAS predicts a decrease in debris density with altitude.

Template:

Sum over all timesteps from satellite death to reentry[3] of {(duration of timestep in years)*(# of impacts per year predicted by DAS at altitude and inclination at time step start per 1m^2)*(cross sectional area)}

4. Please indicate whether the autonomous collision avoidance process is utilized during all phases of spacecraft operations, or whether some phases do not utilize it. If any phases of flight do not currently utilize this system, please indicate whether autonomous operations are under development for those phases, and the methods currently used to manage collision avoidance processes.

The autonomous collision avoidance system is currently active in all phases of flight except for the very early mission. In particular, the system is not active before the satellites start firing their thrusters to depart from the insertion orbit, and before the satellites raise their perigee above 350 km altitude, whichever comes later. The insertion orbits are chosen to be free of conjunctions with our existing satellites at 380 km altitude. The collision risk with other objects in this phase of flight is partially covered by the pre-launch conjunction screening conducted for each Falcon 9 launch, and is generally extremely low due to the low number of objects orbiting at the insertion altitude range.

[3] An object is considered reentered in SpaceX's software once its perigee falls below 130 km.

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

Sincerely,

William M. Wiltshire
Counsel to SpaceX