National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

April 4, 2019

Reply to Attn of: Human Exploration and Operations Mission Directorate

Ms. Marlene Dortch, Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

Subject: IB Docket No. 18-313, Mitigation of Orbital Debris in the New Space Age

Dear Ms. Dortch:

The National Aeronautics and Space Administration (NASA) submits this letter in response to the Federal Communications Commission's (FCC) Public Notice of February 19, 2019, (IB Docket No. 18-313) titled "Mitigation of Orbital Debris in the New Space Age." NASA has considerable assets in low-Earth orbit (LEO) including astronauts living and working on orbit, the International Space Station (ISS), and more than twenty high-value scientific spacecraft. NASA is providing comments during the public comment period for the purpose of providing a better understanding of NASA's interests with respect to its personnel and assets on-orbit, as well as the Agency's expertise in orbital debris mitigation and collision avoidance for the mutual benefit of all involved in space operations.

Specifically, NASA offers the following observations and recommendations:

1. In general, NASA uses the term "orbital debris mitigation" more narrowly than is covered by this proposed rulemaking. The NASA use of the term "orbital debris mitigation" describes the effort to preserve the orbital environment by minimizing the creation of new orbital debris. This rulemaking covers this narrow meaning of orbital debris mitigation, as well as broader space traffic management related operational topics, such as collision avoidance and orbit selection.

2. With this in mind, NASA notes that an applicant's choice of orbit should be informed by space traffic management "best practices" and, consequently, should be evaluated and chosen *much earlier* than during the typical licensing effort. This would include a knowledge of the orbital environment being considered for operations or through which frequent transits would be required (e.g., other operating spacecraft including inhabited or inhabitable spacecraft, debris population).

3. Concerning "Control of Debris Released During Normal Operations," NASA notes that the entity seeking a license should be required to disclose any spacecraft deployed from the entity's spacecraft that does not require an application for a license from the Commission for radio communications (e.g., a passive retroreflector).

4. Concerning "*Quantifying Collision Risk*" associated with collisions with large objects, NASA endorses the broad application of the Agency requirement limiting collisions to 0.001 over a satellite's orbital lifetime. Historically, the evaluation of this requirement has occurred at design time, with a flux-based modeling approach used to determine the satellite's lifetime exposure to collisions with large objects, with the satellite's posture to performing on-orbit collision avoidance either not considered or presumed to reduce to zero the risk of collision during the satellite's active mitigation period. Based on the present state of the conjunction assessment community, we agree with this historical approach.

   To quantify the risk addressed by conjunction assessment and potential mitigation of the risk with collision avoidance is an important operational question. It is also a key element in space traffic management. Specific challenges are noted below:

   - During the operational portion of the satellite's lifetime, even when active collision avoidance is being performed and mitigation actions are being pursued, the collision risk with large objects is not and should not be presumed to be zero. Instead, it is the amalgamated risk presented by all of the unmitigated conjunctions and the residual risk levels remaining after the conjunction mitigations have taken place. This amalgamated risk value is a function of the size of the satellite, the level at which the owner/operator chooses to mitigate conjunctions, and the period of time during which active collision avoidance is being performed. Depending on the choice of mitigation thresholds and procedures, it can itself easily be on the order of the overall 0.001 requirement.

   - Collision avoidance intentions and thresholds should be considered at satellite design time. If active collision avoidance reduces risk against collision with large objects, the parameters to be used for the active collision avoidance period (e.g., risk thresholds at which mitigation actions will be taken) should be established and the risk reduction considered when allocating the overall collision risk budget.

   While it is straightforward to make statements such as the above, their implementation is actually a difficult technical problem. The calculation of on-orbit collision avoidance residual risk can be approached in different ways and requires a number of assumptions, each of which should sustain formal examination and testing before implementation in order to ensure their reasonableness. The combination of on-orbit collision avoidance residual risk (derived from individual conjunction data) and satellite passive exposure risk to collision with large objects (obtained from flux-based modeling analysis) derive from different domains; and they can be combined into a single omnibus risk value again only by making certain assumptions, which should be tested and verified. The Agency is just beginning to work these problems; and while there are promising leads, a fully-vetted solution ready for implementation at the Agency is unlikely to be available for some time. When a more comprehensive approach is available that explicitly considers the on-orbit collision avoidance portion, then the regulation should be updated to include this more comprehensive understanding and apportionment of risk. If an on-orbit collision avoidance rule of thumb is desired, there is an emerging industry consensus, although it is not grounded in any specific analysis, to mitigate conjunctions against large objects when the probability of collision at the mitigation action commitment time exceeds $1x10^{-4}$.

NASA does not recommend applying this requirement in an aggregate manner for constellations but instead simply ensure that each launched satellite, whether in a constellation or not, conforms to the 0.001 lifetime collision risk against large objects requirement.

Lastly, the framing of the above requirement in terms of collisions with large objects is a serviceable simplification for whether a collision, should it occur, is expected to be catastrophic (will generate a large amount of debris) or non-catastrophic (will generate relatively few debris pieces). In general, collisions between objects 10 cm or larger will produce catastrophic collisions, so the use of 10 cm as a large-object threshold is appropriate.

5. Concerning "*Quantifying Collision Risk*" associated with collisions with small debris, NASA notes that the Agency requirement to limit the probability of damage to less than 0.01 as caused by collisions with small debris and meteoroids sufficient to prevent post-mission disposal, has been very achievable and cost-effective with shielding, use of redundant systems, or other design or operational options. NASA does not recommend applying this requirement in an aggregate manner for constellations, but instead simply ensure that each launched satellite, whether in a constellation or not, conforms to a requirement to limit the probability of damage to critical components to less than 0.01 as a result of collision with small micrometeoroids and orbital debris.

6. Concerning "*Quantifying Collision Risk*" associated with identifying and coordinating with operational satellites to which the proposed satellites could pose a collision risk, NASA recommends that such coordination and other measures the operator plans to use to avoid collision to be done over the orbital lifetime of the proposed space station.

7. Concerning "*Orbit Selection*" associated with potential disruption to the ISS, NASA offers that spacecraft residing in circular orbits above the ISS, and decaying passively through the ISS altitude range, pose a small likelihood of requiring an ISS debris

avoidance maneuver over the timeframe that the object is decaying through the ISS altitude. Elliptical orbits, although advantageous to accelerating the post-mission disposal process, can significantly extend the timeframe that the object is crossing the ISS altitude. This method of post mission disposal coupled with a constellation could impose a significant disruption to ISS operations. However, such disruption would be lessened if spacecraft in the process of disposal through atmospheric reentry remain active and able to maneuver until apogee is below the ISS altitude. In addition, NASA suggests that it might be prudent to establish an order of priority that would have the "transiting" spacecraft (with maneuvering capability) take an action to avoid a "stationary" spacecraft (which may or may not have maneuvering capability), as opposed to the other way around.

8. Concerning "*Orbit Selection*" associated with limiting orbital lifetime commensurate with operational lifetime, NASA analysis shows that as long as short duration spacecraft adhere to the 25-year rule, their negative contribution to the orbital environment is not significant.

9. Concerning "*Orbit Selection*" associated with areas of space more populated with debris, NASA notes that although the intent may be appropriate, depending on how early an operator begins the licensing process, it may be too late for operators to redesignate their orbital destination. As noted in the second comment above, this assessment would be better performed and approved early in an operator's design/development phase.

10. Concerning "*Orbit Selection*" associated with requiring propulsion capabilities, NASA recommends the need for propulsion be driven by the spacecraft's ability to meet the 0.001 lifetime collision risk rule and the 25-year rule.

11. Concerning "*Orbit Selection*" associated with a maximum limit for variances in orbit, while NASA endorses the concept of establishing an orbit variance as a method to determine a spacecraft's acceptable proximity to other active spacecraft, the Agency acknowledges the difficulty of establishing a durable value for this variance. The value is likely to be orbit-regime-dependent and evolve with improved technologies. An information disclosure requirement for the spacecraft's expected orbital variance over its mission lifetime may be the best option to inform future applications for a similar orbit. This option would also allow consideration of the method of "spiraling out" used by some low-thrust spacecraft to adjust orbits.

12. Concerning "*Tracking and Data Sharing*" associated with trackability of launched payloads, NASA recommends that the term "satellite trackability" be interpreted as meaning that an object is trackable if, through the regular operation of SSA assets, it can be tracked and maintained so as to be reacquirable at will and the object's orbital data is sufficient for conjunction assessments. This will typically mean that the object possesses trackability traits (e.g., sufficient size and radar/optical cross section) to

allow it to be acquired routinely by *multiple* SSA assets in their *regular* modes of operation. In LEO, the 10 x 10 x 10 cm cube, of any surface properties, should meet this standard. This "satellite trackability" would enable orbital data that can better serve as a basis for collision avoidance operations. Although disclosures about whether tracking is through active or passive measures might seem prudent, NASA cautions against relying on active tracking assistance that would no longer occur once the spacecraft is unpowered. Lastly, at the present time, on-board tracking improvement methods, such as beacons or corner cubes, are not sufficiently supported by SSA assets to enable significant and reliable tracking improvements (although this could change as the commercial SSA industrial base broadens).

13. Concerning "*Tracking and Data Sharing*" associated with data sharing, NASA endorses the sharing of information with the 18th Space Control Squadron (18 SPCS). NASA currently shares launch and on-orbit spacecraft ephemerides, including covariance data, major orbit relocations, and any spacecraft anomalies that could affect their flight dynamics. NASA recommends that commercial operators do the same.

14. Concerning "*Tracking and Data Sharing*" associated with conjunction warnings, NASA recommends that applicants submit their plan outlining the collision avoidance practices they intend to follow operationally in order to minimize collision risk. That would typically include the industry-recognized best practices of submitting ephemerides to the 18 SPCS for screening, examining and processing all resultant conjunction warnings arising from each conjunction screening, mitigating high-interest events at a level consistent with the mission's risk mitigation strategy, and explicit CA screening by the 18 SPCS of ephemerides that include any risk mitigation maneuvers prior to maneuver execution. Additionally, if the secondary object in a potentially serious conjunction is an active satellite, a contact protocol between both satellite owners/operators should be initiated so that potential mitigation actions can be coordinated and any planned maneuvers fully shared.

15. Concerning "*Maneuverability*" disclosures, NASA supports applicant disclosure of maneuver methods and capabilities, as well as any other mechanisms to mitigate conjunction likelihood (e.g., cross-sectional area modulation) as part of a submitted plan to minimize collision risk. Informed by a NASA constellation of eight spacecraft located at 520 km that utilize differential drag for collision avoidance, the Agency offers that this approach does not provide the full range of collision avoidance functions that best protect safety of flight. Because the approach changes orbit trajectories much more slowly, it is necessary to act significantly earlier in the development of a typical collision avoidance event, using more coarse information; this results in having to perform more mitigations than would be necessary otherwise. Late-notice conjunction events, which are less common, but hardly unusual and will increase in frequency as solar maximum is approached, cannot be addressed satisfactorily with this methodology; and one must expect that they often cannot be

addressed at all. In addition, long periods of satellite attitude modulation are often required to achieve the desired change in orbit trajectory (a day or longer); this typically affects the satellite mission adversely (which can thus result in a reluctance to pursue a mitigation). The overall efficacy of this technique will depend on the orbit altitude, the phase of the solar cycle, the degree to which the satellite's ballistic coefficient can be modulated, and the predicted frequency of high-risk conjunctions that require mitigation. Lastly, NASA offers that electric propulsion, as presently employed, often suffers from some of these same limitations: it is slow-acting, and in general to mitigate conjunctions it is simply turned off (rather than sustain a change in thrust pattern) to alter the current trajectory.

16. Concerning "*Multi-Satellite Deployments*," NASA notes that the uncertainty (or error) involving a small-satellite deployer, especially a free-flying deployment device, is currently unknown. In the meantime, NASA suggests that any active spacecraft within a radial distance of 10km during such a deployment be alerted to the plan.

17. Concerning "*Design Reliability*" under the category of "Safe Flight Profiles," and "*Probability of Success of Disposal Method*" under the category of "Post-Mission Disposal," NASA notes that the Agency focuses on the reliability of post-mission disposal (PMD) as that is the more significant spacecraft function when addressing orbital debris mitigation. There are three different metrics mentioned in these paragraphs: 0.90, 0.99 and 0.999. NASA currently requires 0.90 PMD reliability for individual spacecraft not part of a large constellation. NASA's recently completed study for large constellations found that PMD reliability should be no less than 0.99 to keep the debris population increase in low-Earth orbit close to an acceptable level for 200 years. (The study assumed constellations totaling approximately 8000 spacecraft at operational altitudes above 1000km maintained over multiple years.) In recent interagency discussions, it was agreed to address smaller constellations (100 or more spacecraft), for which a recommended PMD reliability should be at *a level greater than* 0.90. For larger constellations (1000 or more spacecraft), the goal should be 0.99 or better. A PMD reliability metric of 0.999 is not supported by any available technical study. In fact, NASA's study found that a reliability of 0.999 provides only minor benefit. In our opinion, a design reliability of 0.999 per spacecraft cannot be justified from a technical or cost perspective. As in previous topics, NASA recommends applying reliability rules on a per-satellite basis versus on the aggregate. Normalizing the reliability metric on the constellation versus per-spacecraft would give a skewed perspective of risk.

18. Concerning "*Other Requirements for Satellites with Planned Operations in LEO*," NASA recommends that the PMD reliability metric be imposed rather than requiring an initial deployment altitude below 650km followed by satellite maneuvers to a higher operational altitude. The latter practice would add complexity to the deployment of the spacecraft and not significantly reduce risk. NASA also notes that

the spacecraft would be required to transit through a highly populated altitude range (approximately 600 to 1000km). Given a launch collision avoidance analysis is employed, a launch vehicle can perform this very precisely. Similarly, any failsafe or automatically initiated disposal actions should carefully examine the associated risks including unintended consequences.

19. Concerning "*Means of LEO Spacecraft Disposal*," NASA notes the language of the Space Policy Directive-3, which states: "The United States should pursue active debris removal as a necessary long-term approach to ensure the safety of flight operations in key orbital regimes. This effort should not detract from continuing to advance international protocols for debris mitigation associated with current programs."

20. Concerning "*Disposal of NGSO Satellites In Orbits Above LEO*," NASA notes that the use of unstable orbits in which the perigee lowers due to natural forces until re-entry occurs has not been accepted by the international community. NASA does not believe these practices are sufficiently developed, and the collision risk and operational impacts to spacecraft below, including inhabited systems, needs to be factored into this choice over graveyard orbits.

21. Concerning "*Post Mission Lifetime*," NASA notes that the 25-year disposal guideline was established as a balance of limiting growth in the debris environment with limiting propellant costs and the complications imposed by performing a maneuver to a limited lifetime orbit. NASA first proposed the requirement in the 1990's and since then, it has been adopted by the space agencies of other nations and by the Inter-Agency Space Debris Coordination Committee (IADC) after a thorough technical assessment. Further, NASA analyzed the guideline for large constellations over a 200-year period and found that it remained a sufficient benchmark for limiting the growth in the debris environment. The effects of solar activity on orbital lifetime is a second-order effect and accounting for these variations is not justified. If the effect on the orbital lifetime yielded 25.5 years rather than 25 years, the effect on the overall orbital debris environment is very small and does not justify additional design cost.

22. Concerning "*Casualty Risk Assessment*," NASA recommends the use of 1 in 10,000 as the limit on the probability of human casualty for an uncontrolled satellite reentry. NASA also recommends this requirement be applied on a per-spacecraft basis (versus on the aggregate, for the reasons mentioned previously) and consistently across all applicants.

23. Concerning "*Amateur and Experimental Operations*," NASA notes that it imposes, without any automatic exclusions, the same orbital debris mitigation requirements, as captured in the NASA-STD-8719.14 "Process for Limiting Orbital Debris," on all of the Agency's spacecraft projects regardless of size, scope or budget. NASA also would agree that small spacecraft can present the same public interest concerns as larger spacecraft, and would contend that the reverse is also true.

24. Concerning duplication of effort, NASA notes that there may be situations where another U.S. Government department/agency has effective oversight over a non-Federal operation in space, and that in such instances, duplication of effort regarding orbital debris mitigation may occur. NASA would recommend consultation between the respective Federal entities in these instances to eliminate any ambiguity and potential duplication.

25. Concerning the use of performance-based regulations versus prescriptive regulations, NASA offers that its orbital debris mitigation requirements, as captured in the NASA-STD-8719.14 “Process for Limiting Orbital Debris,” are, for the most part, performance-based requirements that have held up well over time with relatively few waivers or exceptions approved.

Should you have any questions, do not hesitate to contact me at 202-358-3784 or anne.sweet-1@nasa.gov.

Sincerely,

Anne E. Sweet

NASA Representative to the Commercial Space Transportation Interagency Group
Human Exploration and Operations Mission Directorate, Launch Services Office