Response to FCC 18-159

December 18, 2018

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Executive Summary: I am pleased to see such a comprehensive and fact-based document submitted for public review and comment regarding space debris and related space safety regulatory topics. You have highlighted many very important topics and reflect sound suggestions for further consideration. However, I believe that there are several areas where there needs to be more emphasis placed now to assure reliable space operations now and for future generations. I will provide a chronological dialogue in response to FCC 18-159 after this Executive Summary. However, key points that I want to highlight upfront so as to assure that they will not be lost in the comments to follow are:

- The 25-year rule should be examined closely for modification based on the advanced spacecraft technology and expanded debris population in comparison to when the rule was originally crafted. I believe that it is irresponsible to continue to consider the 25-year as a responsible guideline for debris mitigation. It should be at least much shorter and preferably risk-based (i.e., modulated depending on the size and mission lifetime of the space system). I like the threshold proposed by OneWeb: remove the object within twice the operational lifetime not to exceed five years.

- Consideration should be given to managing the non-operational massive derelicts in LEO that pose the greatest debris-generating potential now and in the future. There is much more debris-generating potential in the ~800 abandoned massive derelict objects, comprising nearly 2 million kilograms of mass, than in the thousands of satellites being proposed to be deployed in large constellations. Debris remediation operations such as active debris removal (ADR) and just-in-time collision avoidance (JCA) should be pursued in earnest to address the debris-generating risk from existing massive derelict objects.

- While the discussion on determining a threshold for acceptable safety of flight, I think that the document seemed to underestimate the difficulty in actually calculating the probability of collision in a repeatable and mutually-verifiable approach.

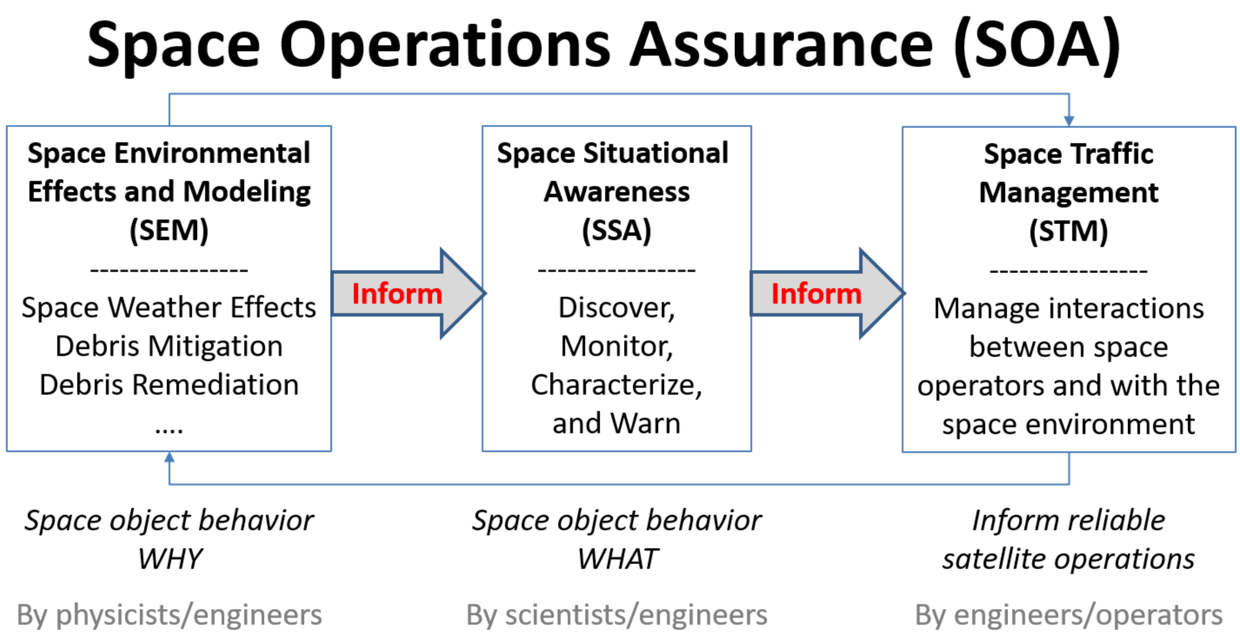
- Responsible behavior in space must include an ability to avoid collisions, therefore, it should be mandatory for any satellite that is launched above any manned space station to have propulsive and command & control capabilities.

- It is proposed that PMD devices should be selected based on more than just de-orbit time and system reliability. Consideration should be given to the overall risk the device poses over the lifetime of its use due to its greater projected area and/or its dynamic orbital state (i.e., changing constantly as it is slowly deorbiting).

- It is proposed that the policy of the GSO graveyard orbit be re-examined due to the potential that there is already small debris from the graveyard orbit filtering down in the proximity of operational GSO satellites.

- A major addition to future satellite design would be to add an omni-directional beacon that would help in tracking/cataloguing and avoiding collisions.

At the highest level, this document had some very insightful suggestions and the implementation of these recommendations will be beneficial to the space community. However, I would suggest that the entire dialogue and regulatory process would benefit from a clear objective and related subobjectives. I submit the figure below as a framework for consideration as I believe that the Administration's goal is indeed global space operations assurance (SOA). As part of this SOA objective, there are three major dimensions that often get merged together and called either space traffic management or space situational awareness; in reality these are two components of SOA.



I would also like to emphasize that many of the proposed actions may not enhance space safety if not implemented globally.

Dialogue in Response to FCC 18-159:

In Section III A, I applaud the closer scrutiny of operational debris especially as it pertains to the deployment of many satellites at once since it is often difficult to assign those payload interfaces to one single satellite operator.

In Section III B, the discussion about persistent fluid releases is a good addition to other operational debris considerations in the past.

In Section III C.1, the quantifying of collision risk is definitely required, however, I believe that it is much more difficult than presented in this section. The issues related to positional and velocity covariances for objects derived from radar/telescope measurements versus GPS/telemetry-based sources vary significantly. There are a wide variety of possible ways to aggregate and use that information to calculate a probability of collision. The threshold to be selected as a concern is just the first step in this process; one must also agree on the algorithms to be applied and standard response modes (e.g., a satellite heading toward an operational orbital location has the primary responsibility to maneuver vice a satellite in a well-maintained operational orbit.).

In Section III C.2, the orbit selection commentary is needed especially when it comes to constellation deployments. The orbit selection is intimately related to the potentially risk-based debris mitigation guidelines and quantifying collision risk. Indeed, the overlapping of constellations will create special safety issues. It is relevant to mention that there are actually clusters of massive derelicts in LEO that present a unique and significant debris-generating potential; these clusters are centered at 775 km, 850 km, 975 km, and 1500 km.[1] The clusters at 775 km and 850 km are very near the peak of maximum number of total catalogued objects. The spacing of constellations should be no more than 100 km but this policy is really irrelevant if international cooperation is not started soon. For example, China is projecting to deploy a 320-satellite constellation right where the OneWeb constellation is set to be deployed.

In Section III C.3, data sharing is important but it should be noted that avoidance of collision with trackable objects only eliminates about 3% of the mission-terminating risk from orbital debris as there are 500,000 – 700,000 lethal but nontrackable (LNT) debris in LEO. With that said, the model employed by the Space Data Association (SDA) is a great approach to be encouraged in the future. It is critical that not only space systems communicate with others in which they may have potential conjunctions but it is likely that space operators should be moving toward an automated system to streamline the data flow.

In Section III C.4, maneuverability should be required for any space system that is deployed above manned space stations. The technology for small, efficient propulsion systems have

[1] McKnight, D., et al, Preliminary Analysis of Two Years of the Massive Collision Monitoring Activity," 68th International Astronautical Congress, Adelaide, Australia, September 2017; McKnight, D., et al, "Assessing Potential for Cross-Contaminating Breakup Events from LEO to GEO," 68th International Astronautical Congress, Bremen, Germany, October 2018.

progressed so much of late that this does not create an unreasonable constraint on space systems and is really just responsible behavior; would we allow aircraft to fly that could not avoid other aircraft?

In Section III C.5, multi-satellite deployments should be monitored closely from an operational debris perspective (as mentioned earlier) but also for safety purposes immediately after deployment. The deploying system operator also needs to verify that the satellites indeed have been licensed properly and have followed debris mitigation guidelines and other required constraints.

In Section III C.6, design reliability is probably one of the most difficult aspects of spacecraft design to actually verify. While reliability for execution of collision avoidance maneuvers and end-of-life disposal activities should be 0.99, it is also important that the space systems also show an ability to react to and operate through anomalies. Both high system reliability and operational resiliency to anomalies and failures are needed.

In Section III D, the topic of post-mission disposal (PMD) was handled well. The issue of reliability of the PMD device is indeed very important; I suggest that it should be encouraged to have a failsafe PMD device that activates automatically and has a separate power source. The discussion of shorter time threshold for de-orbiting of missions with shorter operational lifetimes makes great sense, as discussed previously. However, one issue not addressed was the overall risk posed to others from the use of a PMD device; there is a chance for unintended negative consequences. For example, if a satellite is retired at 1,000 km altitude and a drag-augmentation device is deployed to deorbit it within five years, the size of the device will have to be so large that it might actually pose a greater collision hazard being deorbited then if left on-orbit.

I would suggest that you carefully examine the efficacy of the four primary PMD strategies (propulsion, drag-augmentation, solar sail, and electrodynamic tether) and restrict the use of all but the propulsion devices to altitudes below 700 km. An ongoing study by the International Academy of Astronautics and the United Nations is compiling a design handbook for satellites less than 100 kg for examining the best PMD option. This would be suggested reading for the FCC; I am leading the study group so can get you a copy upon its completion in early 2019.

I do not think that there needs to be any adjustment to the casualty risk assessment process or threshold.

Section III D.4, discusses GSO license extensions. The rapid improvements of robotic servicing may make this discussion moot, as a satellite will be able to be “revived” fairly easily. The FCC should follow the satellite servicing industry carefully.

Section III E, discusses proximity operations and includes the utility of satellite servicing. The main issue related to proximity operations that seems to be forgotten is that the nearness of two objects is only one component of whether such an event is hazardous. The other

parameters are relative velocity, command & control capabilities, mission, and communications between the two objects. I agree that you need to ask more about these types of activities.

Section III F, orbit raising and maintaining ephemeris data are closely related. It is prudent to pursue more information on these issues, however, I believe that it is imperative to reinvestigate the efficacy of a GEO graveyard orbit. There have been indications that debris is being liberated due to satellite deterioration and minor collisions in the graveyard orbit. Due to the higher area-to-mass ratios of these liberated debris they have been pushed down into the GEO belt. They are often referred to collectively as high area-to-mass ratio (HAMR) objects. Not all HAMR objects come from the graveyard orbit but current hypotheses support that many are likely being spawned in this manmade collection of old payloads and rocket bodies.

I agree that uplinks/downlinks should be encrypted but not just for GSO satellites, also for LEO satellites.

Section III G, I believe that the USG should do all in its power to empower satellite system operators to be more aggressive with both PMD usage and active debris removal (ADR), which has not even been addressed in this document. One of the major drawbacks to ADR operations is the liability that an operator or ADR solution provider would have to accept. The current system dis-incentivizes people to try to clean up abandoned space hardware (i.e., there is no liability if derelict is left abandoned but once someone tries to move it they can be held liable for potential collision risks); this should be reversed to help accelerate the potential for operational debris remediation systems.

Section III H, the desire to expect amateur and experimental satellites to follow the same rules as all other satellites makes perfect sense. However, there might be a good compromise in reducing the oversight of items launched 50 km below or from any manned space stations on orbit or 400 km, whichever is lowest. The discussion related to non-US-licensed satellites is very relevant; there must be consistency globally. Therefore, I would suggest that the FCC catalyze a USG push to try to adjudicate international licenses of constellations. Even if every country does a good job of policing their own licensed systems individually, in aggregate the situation in space may become very unsafe very quickly.

Section III I, this section on regulatory impact analysis is very forward-thinking. However, this is very tricky ground to tread if there is not international consensus on these approaches. Of the six approaches to manage space risks (fewer launches; changes in satellite design; changes in operations and disposal procedures; use of economic incentives; active collision avoidance; and active debris cleanup) I think that they should be prioritized as follows (most important first):

- Active Debris Cleanup: There is much more risk to current and future satellite operations from the 4.5 million kilograms of abandoned rocket bodies and nonoperational payloads than from the 1,700 operational spacecraft or the possibly thousands of new satellites that might be deployed in the next decade. The mass in only 18 SL-16 rocket bodies abandoned at around 850 km has more mass than the entire

proposed OneWeb constellation! There is also another debris remediation approach that should be examined more closely: just-in-time collision avoidance (JCA).[2] A JCA mission would nudge one of two massive derelicts (via a talc cloud or laser impulse) to prevent an imminent collision. JCA requires more precise characterization of conjuncting objects' orbits but may be 20x less expensive than an ADR mission.

- Active Collision Avoidance: It is essential that we improve the quality of the data used for collision avoidance (more specifically, positional uncertainties must be reduced even if by use of active beacons on spacecraft) and the data sharing required to implement these maneuvers, possibly even performing collision avoidance via an automated system.

- Changes in Operations and Disposal Procedures: As already discussed, more reliable and altitude-specific PMD devices are critical to manage future debris growth. In addition, changing spacecraft operations to sensibly arrange large constellations is also prudent.

- Changes to spacecraft design to be more resilient to all potential failure mechanisms and to integrate in debris-minimizing designs is wise. A major addition to future satellite design would be to add an omni-directional beacon that would help assist being tracked/catalogued and could provide information to assist in avoiding collisions.

- Limiting the number of launches makes little sense. However, having more responsible launches does make sense. By more responsible, I mean fewer pieces of operational debris; more clearly identifying the identity of each satellite released in multiple satellite deployments; and being more responsible about monitoring safety of objects deployed to include assuring adherence to required debris mitigation guidelines and licensing responsibilities.

[2] Bonnal, C. and McKnight, D., "Options for Generating JCA Clouds," 4th International Workshop on Space Debris Modelling and Remediation, Paris, France, June 2016.

In summary, the figure below provides four major areas that must be addressed to assure viable space operations and ensure reliable space traffic management. It should be empathized that these all need to be addressed NOW. The proposal to focus on debris mitigation and collision avoidance now and then later consider characterizing the lethal nontrackable population and performing active debris removal (ADR) efforts in earnest will have deleterious effects on space operations in the near-term. More pointedly, at the latest JAXA Space Debris Workshop, Allesandro Rossi of the University of Florence, reported that "improving collision avoidance for operational satellites from 80% to 100% only decreased eventual debris growth by 4%." His research clearly shows that removal of massive derelicts is much more important than either collision avoidance or mitigation compliance. His criticality index highlighted the severity of the potential events occurring between massive derelicts at 975 km.