Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, D.C., 20554

In the matter of	)	
Mitigation of Orbital Debris in the New	)	IB Docket 18-313
Space Age	)	

COMMENTS OF

ASTROSCALE U.S. INC.

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I. Summary and Introduction

Astroscale U.S. Inc. (Astroscale) is pleased to provide comments in response to the Commission's *Further Notice of Proposed Rulemaking for Orbital Debris Mitigation in a New Space Age* ("Further Notice").[1] Astroscale is the first private company with a vision to secure the safe and sustainable development of space for the benefit of future generations, and is dedicated to on-orbit servicing across all orbits. We thank the Commission for its attention towards the issue of orbital debris, one that will directly affect the success and sustainable development of the space industry.

The space environment is experiencing a surging growth in activity, and operations in Earth orbit are taking place in a more congested domain than ever before. Innovative mission design, technologies, and variations of spacecraft operators are serving the public interest in novel ways. However, with this growth also comes increased risk from orbital congestion and debris, degrading the safety of the operational environment and its long-term sustainability. The Commission holds a considerable role in shaping the state of the space domain for generations of operators to come.

How the United States addresses the challenge of orbital sustainability in this decade will shape the parameters for the safety of space operations through the next century and beyond. As the government agency tasked with the review of U.S. commercial satellite operator debris mitigation plans, as well as for those seeking U.S. market access, the Commission's mandate to serve the public interest holds a palpable weight in ensuring that satellites providing critical services across a variety of economic sectors on Earth are not subject to undue risk.

For the United States to adhere to the mandate of Space Policy Directive-3 and promote unfettered access and freedom to operate in space,[2] this proceeding marks a critical opportunity. The Commission should implement balanced, proactive, and performance-based regulation for orbital debris mitigation. Incorporating formal regulatory requirements

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[1] *Mitigation of Orbital Debris in the New Space Age*, Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd. 4156 (2020), https://docs.fcc.gov/public/attachments/FCC-20-54A1.pdf.

[2] *Space Policy Directive-3*, *National Space Traffic Management Policy*, Presidential Memoranda (June 18, 2018), https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/.

informed by industry-led standards of best practice and transparency will not only serve the public interest, but will strengthen the industry itself, ensuring that today's innovation never costs us tomorrow's safe operations. The recent update to the Orbital Debris Mitigation Standard Practices (ODMSP),[3] led by the National Aeronautics and Space Administration (NASA), introduced several baseline metrics for mitigation of orbital debris, from which effective commercial regulation can be developed. And, we wholeheartedly agree with the 2019 ODMSP preamble that, "[w]hen practical, operators should consider the benefits of going beyond the standard practices and take additional steps to limit the generation of orbital debris." In line with this sentiment, assessment of Federal Communication Commission (FCC) license requests may require the Commission to regulate beyond the ODMSP guidelines and establish the balanced components of environmental safety and regulatory certainty to ensure that commercial satellite systems are used in the public interest.

To achieve this balanced approach, Astroscale recommends that the Commission:

1. Apply a calculation of the Probability of Collision (Pc) in the aggregate (including all planned satellites of an entire system over the license period). The Commission must seek accuracy in measuring the complete risk of the entire system when reviewing applications and granting licenses. This requires a measurement of Pc in the aggregate, which not only assesses the risk of a single satellite, but the total number of satellites considered in a license application. Measuring total risk of a system, with Pc in the aggregate as a key element of that measurement, is the simplest, most effective performance-based method for mitigating the creation of new orbital debris.
2. Materially limit the collision risk, Pc, posed by a licensed system to other operators. We suggest an aggregate Pc limit per system of 1/1000. A by-product of this limit will naturally be the capping of the number of failed satellites in orbit for a system at any given time. In order for a cap to be enforceable, measurable and near-real time reporting of a system's satellite collision avoidance status will be needed, and accordingly its aggregate Pc. Additionally, assuring a risk cap per system requires timely and effective action if and when a licensee exceeds the threshold aggregate

[3] *U.S. Government Orbital Debris Mitigation Standard Practices*, National Aeronautics and Space Administration Johnson Space Center (Nov. 2019), https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf.

Pc[4]. Other tools and practices such as post-mission disposal (PMD) reliability rates do not independently constitute full mitigation of the risk of debris creation for all types of operators. For example, today, any operator under a natural deorbit threshold of 25 years (at around 600-650 km or below) can tout 100% PMD reliability, even if each satellite in their constellation fails.

3. For spacecraft operating below 600 km, refrain from imposing a specific maneuverability requirement that otherwise consistently maintains an aggregate Pc below 1/1,000 for a system and are not at risk of creating long-term debris. For most systems above 400km, maintaining a 1/1,000 Pc may indeed require maneuverability, but the Commission should allow operators the flexibility to demonstrate a 1/1,000 Pc using the technology of their choice. For spacecraft operating above 600 km, where any collision would result in the creation of long-lived debris, Astroscale recommends that the Commission require a collision avoidance capability, using the technologies of their choice.
4. Encourage a reduction of the post-mission time to disposal limit from 25 years to as soon as possible, but no more than 5 years, particularly for large constellations. We also recommend the Commission consider the ability to approve, on a case-by-case basis and with strict scrutiny of aggregate Pc, exceptions for short-term activities that provide innovation such as single-satellite demonstration missions.
5. Support indemnification of the U.S. Government from U.S. commercial space activities licensed by the Commission, on the condition that a financial cap is assured. Total indemnification of the U.S. Government for all FCC licensed activities in space is not conducive to growth in the satellite industry. At the same time, neither is an orbital environment ridden with debris. A capped liability system, modelled after the Commercial Space Launch Act of 1988 (51 U.S.C. § 50915)[5] and as seen in other regulatory environments such as the United Kingdom, represent a good compromise that accounts for operators' agency and still promotes continued expansion and advancement in the industry.
6. Refrain from imposing a performance bond as described in the Further Notice on U.S. satellite operators, and establish a working group to fully assess appropriate and

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[4] For a full proposal of this concept, see the Appendix, attached.
[5] 51 U.S.C. § 50915, https://uscode.house.gov/view.xhtml?path=/prelim@title51/subtitle5/chapter509&edition=prelim.

effective financial incentives with all stakeholders. This working group should create and engage in a whole-of-government dialogue to investigate financial incentives that have been proven effective in other high-risk industries which operate and decommission systems in extreme environments, such as the nuclear industry. These incentives may include, but are not limited to fees, performance bonds, fines, and tax incentives, among others. We also urge the Commission, in conjunction with the working group, to investigate how financial incentives for safe and effective commercial operator post-mission disposal can be supplemented and accomplished with on-orbit servicing measures (such as station-keeping, life extension services, active debris removal and end-of-life services, and the like), as these measures are currently playing a positive role in the mitigation and remediation of orbital debris.

II. Background

A. Operators are currently developing and implementing industry best practices to mitigate debris

Today, satellite operators are more aware of the risks orbital debris poses to their operations than ever. Since the last rule adopted in 2004,[6] improvements to the accuracy of space situational awareness technologies have drawn back the curtain on the true state of the operating environment for spacecraft of all mission types and classes, making the urgency and benefit of orbital debris mitigation rules ever more apparent. In response, many individual operators and industry groups have repeatedly demonstrated both the willingness and ability to move ahead of current regulations.[7] The Commission should consider this proceeding as a chance to codify these practices into formal rules, which will help to neutralize the dangers brought on by increased congestion in orbital operations before they occur.

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[6] *Mitigation of Orbital Debris in the New Space Age*, Report and Order and Further Notice of Proposed Rulemaking, (Adopted 9 June 2004), https://docs.fcc.gov/public/attachments/FCC-04-130A1.pdf.

[7] For example, the industry group the Space Safety Coalition, comprised of 40+ members, maintains a post-mission disposal recommendation of as soon as practical for their operators, with completion of the deorbit phase within 5 years of end-of-mission for propulsive spacecraft, in their Best Practices document. *See Best Practices for the Sustainability of Space Operations*, Space Safety Coalition 12 (Aug. 2019), https://spacesafety.org/wp-content/uploads/2019/08/Endorsement-of-Best-Practices-for-Sustainability_v10-002.pdf.

B. U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) are a baseline that the Commission can build upon for applicant debris mitigation plans

The 2019 update to the ODMSP, intended for United States government spacecraft adherence, represents minimum standard practices and we encourage the Commission to build upon them in this proceeding. The 2019 ODMSP itself states that it should be viewed as a "reference to promote efficient and effective space safety practices for other domestic and international operators," but that "…when practical, operators should consider the benefits of going beyond the standard practices and take additional steps to limit the generation of orbital debris."[8] Astroscale urges the Commission to assess these government operator practices within the lens of its regulatory obligations, both to authorize and continuously supervise private space activities and to serve the public interest. Due to the critical importance of satellites, delivering services, security, and science to society, and the necessity to keep Earth-orbits sustainable, it is essential that the Commission assess the ODMSP in a thorough manner, understanding the specifics of modeling and measuring the total risk of licensing and maintaining oversight of FCC-licensed operations orbiting Earth.

Considering that the United States Government is not currently planning for the volume nor range of activities to the extent proposed by actors in the private sector, it is our view that a wholesale adoption of the ODMSP standards for commercial industry licensees is insufficient. We believe it is within the Commission's purview to assess the updated ODMSP in detail and augment them with additional requirements as necessary when licensing private operators.

C. The Commission should enact performance-based rules, not those that are proscriptive

As recently as a decade ago, the type and number of commercial operations in space were markedly different from today. It is no longer sustainable to operate satellites with rules designed for a different era and a starkly different operating environment. We urge the Commission to focus its efforts on the development of rules governing the behavior of licensed operators under its jurisdiction wherever possible, and not constrain the choices of

[8] *See supra* note 4 at 1.

technologies used to meet those standards of performance. This allows the industry the flexibility to align its technological and decisional means of meeting behavioral standards along the continually diversifying types of operators that are engaging in space activities.

A focus on behavioral standards also ensures that rules are future-proofed for any novel solutions that may be developed in the future to order to remediate debris and otherwise mitigate risks posed by orbital debris, including active and passive debris removal solutions. Performance-based requirements limit the risk to the U.S. government, and serve the public interest. What follows in section II are Astroscale's views regarding how to implement such requirements effectively and accurately.

D. The Commission should prioritize the mitigation of lethal non-trackable debris (LNT) creation, as it poses a significant danger to space safety

The most abundant class of debris is known as *lethal non-trackable* debris (LNT), due to the difficulty of tracking small objects (typically and currently less than 10 cm in diameter) with current space domain awareness technologies. Comprising 96% of objects in orbit greater than 1 cm in diameter,[9] the inability to track and avoid LNT debris today makes it a primary risk to operational satellites. While an operator may be able to avoid collisions with larger and more energetic tracked objects (typically and currently 10 cm in diameter and larger), currently it is not yet possible to consistently plan for and engage in collision avoidance maneuvers for objects in space that are not reliably tracked, so the risk posed by objects typically smaller than 10 cm, at this time, cannot be mitigated.

However, it is anticipated that recent and upcoming advances in space situational awareness technologies, including the Department of Defense's Space Fence[10] and commercial services such as those provided by LeoLabs[11] will enable larger LNT debris to be consistently trackable, illuminating risks operators already face, but previously could not directly assess

[9] *See* Safety and Security: *Space Debris by the Numbers*, European Space Agency (Feb. 2020), http://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers.
[10] *See* Gregory P. Fonder et al., *AN/FSY-3 Space Fence System-Sensor Site One/Operations Center Integration Status and Sensor Site Two Planned Capability*, Advanced Maui Optical and Space Surveillance Techs. Conf. (AMOS) (2017), https://amostech.com/TechnicalPapers/2017/SSA/Hughes.pdf.
[11] *See* Michael Nicolls et al., *Conjunction Assessment for Commercial Satellite Constellations Using Commercial Radar Data Sources*, Advanced Maui Optical and Space Surveillance Techs. Conf. (AMOS) (2017), https://amostech.com/TechnicalPapers/2017/Astrodynamics/Nicolls.pdf.

and avoid. These and other factors mean that when performing a technical assessment of risk of collision in space between Commission-licensed low-Earth orbit (LEO) satellite systems and other space objects, the catalog of reliably traced space objects in LEO will likely radically increase, from the current circa 30,000 to potentially up to several hundreds of thousands, when objects down to 1-2 cm size are considered. With this in mind, the Commission should create rules that are future-proofed and take into account this pending increase in the population of smaller 1-10 cm space debris that will be increasingly detected, catalogued and tracked.

LNT debris were created from various sources over several decades, such as in-orbit collisions, breakups, and intentionally shed debris from larger human-made objects. The risk LNT debris poses to operations can be particularly catastrophic for operations in LEO, where human operations are put at risk. Several recent examples of International Space Station maneuvers to avoid debris highlight the seriousness of the issue and a glimpse of what is to come with pending private spaceflight experiences.[12]

Another less frequently considered factor regarding LNT debris is that they may linger in orbit for longer periods of time than their intact predecessors, posing an extended threat. This is due to the low area-to-mass ratio of small pieces of debris, which can make them less susceptible to solar flux and atmospheric drag than large objects with a more significant area-to-mass ratio. Additionally, when LNT debris are formed from a collision, the exchange of energy is likely to place debris into higher orbits, where the "self-cleaning" attribute of LEO is not present.

The most effective way for the Commission to limit the creation of LNT debris is to regulate the risk of breakups, release of debris, and collisions involving intact spacecraft: stopping larger objects from degrading into debris fragments. With this primary motive of preventing the creation of LNT debris in mind, Astroscale submits the following responses to the questions posed in the Further Notice.

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[12] Mary Beth Griggs, *The ISS Just Avoid a 'piece of nuknown space debris*, The Verge (Sept. 23, 2020, 11:38 AM), https://www.theverge.com/2020/9/23/21451587/iss-space-junk-debris-avoidance-maneuver.

III. Responses to Items Within the Further Notice

A. Total Probability of Collisions with Large Objects

For any industry operating in extreme or risk-laden environments, a sustainable regulatory approach takes the state of the environment itself into account by shaping the standards of acceptable risk posed by operators, to create healthy environmental conditions for safe ongoing use. The application of a critical lens of space sustainability when enacting license conditions goes beyond the abatement of near-term or immediate risks a system poses. For the Commission to effectively regulate in the public interest, it must employ assessments of collision risk that produce a comprehensive appreciation of all contributing factors faced by license applicants, in their entirety. Only then will it attain a complete and accurate understanding.

The Commission should apply quantification of the risk of collision for an entire system, over the entire length of the license. This means an aggregate risk calculation of all satellites in a system must be obtained at the time of application and regularly updated. Limiting risk analysis to a single spacecraft, abstracted to the rest of the system, does not accurately portray a holistic scope of the actual risk posed, and can lead to erroneous conclusions. The following explains why assessing risk in the aggregate is needed.

1. *Satellite system licenses that do not measure probability of collision (Pc) in the aggregate are incomplete and do not accurately portray real risk*

Probability of collision (Pc) is a critical metric that should be used when deciding if an application has an adequate orbital debris mitigation plan to minimize the generation of space debris in its lifetime and disposal phases, in service of the public interest. When complemented by other requirements, such as reduction in time to disposal, reliability of disposal, and maneuverability, Pc metrics can lead to a meaningful understanding of the total risk of the applicant's filing request.

Pc must be measured in the aggregate of a complete system to achieve the most realistic understanding of the impact of the entire system. For a large constellation, the Commission should consider the big picture of how aggregate Pc of a system will affect current and future orbital users, both with operational congestion and debris that may persist in orbit after its lifetime.

To demonstrate this, first consider collisions to be statistically independent events.[13] Basic statistics defines that the probability of N independent events, each with probability of success equal to P, all resulting in *success* is equal to P^N. To put this another way, if the probability of *failure* is Pc, then the probability of *success* must be 1-Pc, and thus, the probability of N events all resulting in successes would be (1-Pc)^N.

Astroscale has performed an analysis using basic principles of binomial distributions, and presents the results in Figure A. We consider three sets of data and resulting Pc with large objects: 1,000 satellites, 10,000 satellites, and 100,000 satellites.

1,000 satellites: Were the Commission to consider solely Pc per individual satellite, limiting that Pc to 1/1000, the probability of having no collisions (i.e. all successes) over a 15-year license period would be equal to (1 - 0.001)^1000, or 37%.

10,000 satellites: A more likely scenario given operational plans for multiple constellations is 10,000 satellites in orbit that the Commission licenses or otherwise provides market access.

As shown by the blue lines in Figure A, 10,000 satellites launched during a15-year license period with an example active disposal reliability of 90% (where 90% are assumed to have Pc = 0, which itself is a problematic assumption), the remaining 10% of satellites (N = 1000) will pose a substantial environmental risk. In this scenario, again applying Pc per individual satellite and capping this risk at 1/1000, there would be a *1 in 10 probability of having three or more collisions, and a 1 in 1000 probability of more than six collisions over the license period*.

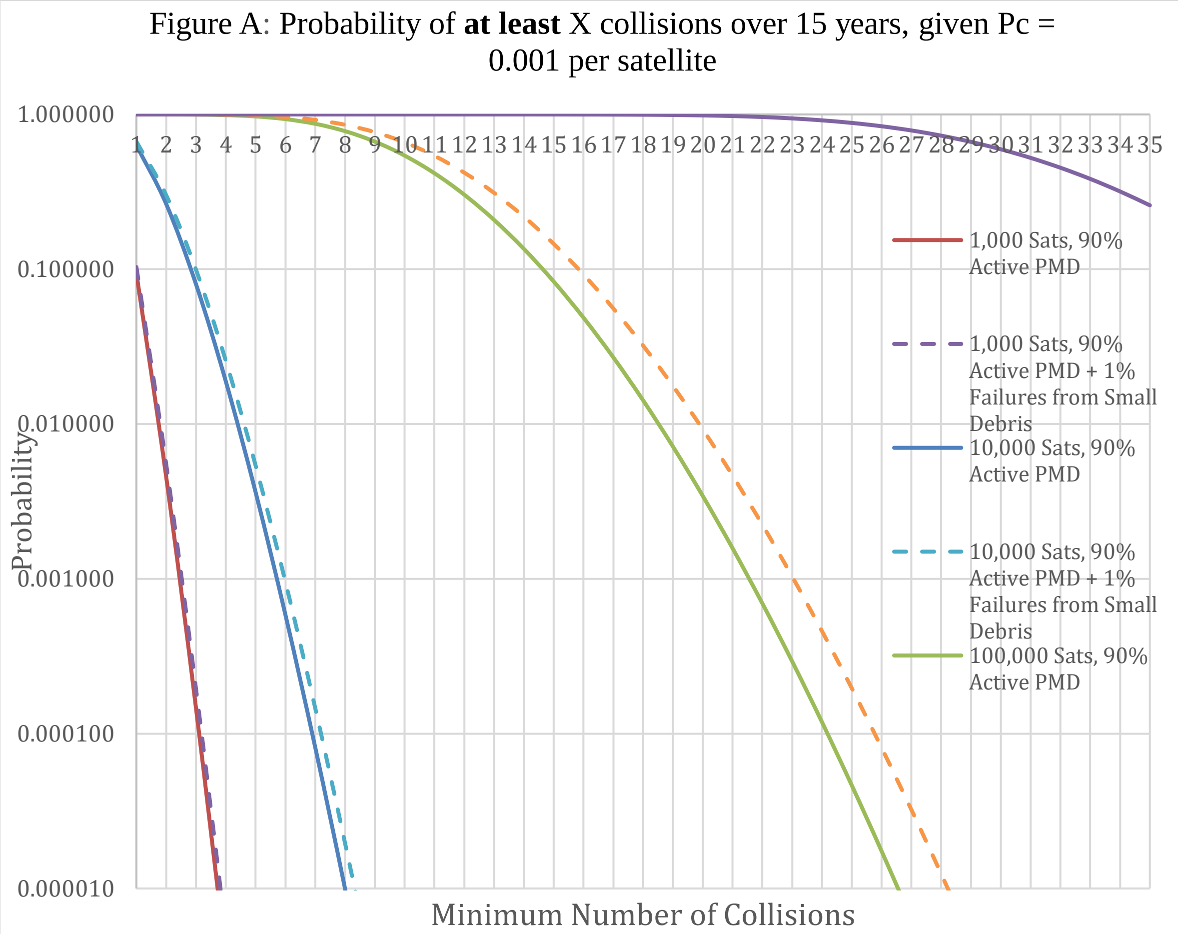
100,000 satellites: While it may be difficult to imagine 100,000 satellites being launched in LEO, the Commission's recent processing round and foreign constellation announcements have signalled the interest for an extremely large number of satellites in LEO.[14] The resulting risk of this level of satellite congestion, as expected, is much worse than the other two

[13] This is optimistic, as one collision will almost certainly increase the risk of subsequent collisions due to the creation of additional debris, but for the purposes of this demonstration, we can temporarily accept this simplification.

[14] As examples, See SAT-MPL-20200526-00062 (47,884 satellites), SAT-LOA-20200526-00055 (30,000 satellites), SAT-MPL-20200526-00053 (1,671 satellites), SAT-MPL-20200526-00056 (1,588 satellites), and *China Pushes Ahead with Giant Broadband Satellite Constellation* (12,994 satellites) https://spacewatch.global/2020/10/china-pushes-ahead-with-giant-broadband-satellite-constellation/

scenarios. Here, for simplicity, we assume one third (33,333) satellites are launched every five years up until a 15-year timeframe. Keeping an active disposal reliability of 90%, the number of passively deorbiting satellites in this scenario would equal 10,000 (N=10,000). Figure A (green and yellow lines) show the effect of such a scenario. There would be a nearly *1 in 10 probability of having one collision per year, on average.*

It should be noted that in lower altitudes where atmospheric drag can be used for compliance with current disposal regulations (i.e. 25 year disposal timeframe), there are effectively no requirements to ensure maneuverability during disposal, which means a 90% or more active PMD rate may itself be optimistic. As an example, by decreasing active disposal reliability to only 70% and relying solely on atmospheric drag to deorbit the other 30% (while still, under current standards, achieving a 100% PMD rate within 25 years), the probability of collisions follows the dark purple line along the top of the chart. The certainty of frequent collisions is an outcome that the public cannot accept and so, both aggregate probability of collision and active disposal reliability, as it pertains to collision avoidance capability, must be adequately considered and regulated.



2. *The Commission already requires risk analysis in the aggregate, such as that of radio frequency interference*

The commission asks whether assessing the total probability of collision on a system-wide basis is consistent with the public interest. This is not only in the public interest but represents the minimum that should be done given the significant increase in both the number of NGSO systems being deployed and number of satellites proposed in each system.

The FCC already has a relevant and useful precedent for computing aggregate risk, which is the Commission's methodology used to quantify the impact of multi-satellite NGSO systems on GSO systems, from a communications spectrum perspective. For the reader's convenience, this methodology is restated below, to underscore how the Commission limits the aggregate probability of GSO service outages caused by multiple, multi-satellite NGSO systems. Astroscale asserts that a similar methodology could also be applied to collision risk.

In order to protect geostationary satellite orbit (GSO) Broadcasting Satellite Services (BSS) and Fixed Satellite Service (FSS) services from non-geostationary (NGSO) constellations operating in the same radio frequencies, the Commission requires that NGSO operators comply with Article 22 of the International Telecommunications Union (ITU) Radio Regulations.[15] These rules effectively limit the probability of GSO service outages caused by interference from NGSO systems by requiring their strict compliance with equivalent power flux density (EPFD) limits. By demonstrating compliance with these EPFD limits, a complete NGSO system guarantees that it will not cause an unacceptable probability of outage to GSO service.

The computation of EPFD from each NGSO system is not simply performed on a per satellite basis, as this would severely underestimate the risk impact. The ITU, and accordingly the Commission, acknowledge that quantifying total risk necessitates the aggregation of all relevant contributions to EPFD, which must include every satellite from all NGSO systems. In the case of the EPFD limits in Article 22, which effectively limit the total risk to GSO services, their derivation is predicated on the understanding that there will be as many as 3.5 NGSO systems operating simultaneously and contributing to the overall risk collectively in the aggregate. To account for this, each NGSO system is allowed to contribute as much as 1/3.5 of the total acceptable risk, which ensures that the GSO services are still protected when multiple NGSO systems are operating.

In the case of collision risk, a similar approach must be adopted by the Commission if it is to be appropriately quantified and limited. We urge the Commission to incorporate two facts when quantifying risk:

a. NGSO systems comprise multiple satellites, and each contributes risk, and
b. Many NGSO systems can and do operate in LEO with each contributing to risk.

If the Commission deems that the risk of a collision creating thousands of pieces of LNT debris over the next 15 years should be limited to some value X, and there are Y total NGSO systems, then it is mathematically necessary to apportion a risk allowance of X/Y to each NGSO system such that the total aggregate risk from all systems, approximately equal to

[15] *See Article 22: Space Services*, Int'l Telecomm. Union Radio Reguls., https://life.itu.int/radioclub/rr/art22.pdf

X/Y*Y, is limited to X. For example, if each system is allowed a risk of 0.001 and there are ten systems, then the total aggregate risk is closer to 0.01. (It should also be noted that even this calculation is optimistic, because it assumes that the risk of each system is independent and does not influence the risk of the others.)

A side-by-side demonstration of how the Commission's RF interference regulations provide a meaningful precedent for collision risk regulations is presented in the table below.

		RF Interference	**Orbital Debris**
1	*Negative impact to be limited*	GSO Service Outage	Collision
2	*Acceptable risk to the environment due to all NGSO Systems*	10% increase in outage probability	0.01 probability of collision (for example)
3	*Anticipated number of NGSO Systems*	3.5	10 (for example)[16]
4	*Risk apportionment per NGSO System*	~3% increase in outage probability	0.001 probability of collision
5	*Per-satellite input value*	PFD Mask	Pc (from NASA Debris Assessment Software [DAS] or equivalent)
6	*Required NGSO System inputs*	Orbits and Operational Parameters	Number of Satellites (N), Predicted and actual Failure Rate (Pf)
7	*NGSO System calculation methodology*	ITU-R S.1503-3	Total Risk = 1 - (1 - Pc)^(N*Pf)
8	*Additional Notes*	PFD masks are difficult to measure and validate empirically, S.1503-3 is very complex, and the process is not transparent	DAS is relatively straightforward, N and Pf can be easily validated with empirical observations and disclosures, and DAS is available widely to all operator types.

[16] 3.5 systems may be an appropriate estimate for the number of systems that are co-frequency, but as collision risk arises from all operators, regardless of frequency use, 10 is a more appropriate value.

3. *Current models do not consider the future state of the operational environment in which applicants are being licensed to operate, making even an aggregate calculation utilizing current models an understated calculation*

While models such as DAS are periodically updated to reflect the latest understanding of the current orbital debris environment, it is still challenging to utilize them to calculate future risks when attempting to include approved constellations anticipated to launch in the near future. DAS has not yet been extended to consider how the space environment could change based on forecasted models; rather, it is currently limited to conducting calculations based only on models of the current catalogue of debris and operational spacecraft.

Despite missing parameters such as growth of satellite population, usage of the most up-to-date version of DAS still represents the most readily accessible method for licensed operators to conduct Pc calculations currently. However, Astroscale supports operators who alter or choose to utilize different software from DAS, so long as software modifications that differ from DAS are transparent and deemed appropriate by the Commission. There should be no proprietary reason for concealing calculations used to assess the collision risk of a system that will affect other operators.

4. *To ensure certainty and consistency, an aggregate Pc metric should be an operational requirement rather than simply a disclosure metric*

Satellite designs can change over time, and unexpected failures of satellites or critical sub-systems occur at all altitudes, resulting in an ever-shifting debris environment. An ideal Pc requirement would be a behavioral standard that adapts to the continuing evolution of the debris environment. However, satellite operators argue that updates to orbital debris mitigation were not definitive enough, with too many opportunities for the Commission to decide at disclosure, on a case-by-case basis that permitted waivers.[17] While a disclosure requirement can be interpreted as a de facto operational requirement, in this case, Astroscale

[17] *See Notice of Ex Parte Presentation: FCC Draft Order and FNPRM on Orbital Debris Mitigation*, Satellite Industry Ass'n, at 1 (Apr. 15, 2020), https://ecfsapi.fcc.gov/file/1041588217831/SIA_Orbital_Debris_Ex_Parte_Sullivan_041520.pdf.

urges the Commission to make a Pc metric an operational requirement, to increase the clarity of the rule.

5. *An aggregate Pc metric should apply to market access applicants in addition to U.S. applicants*

Astroscale believes that the power of the U.S. market and alignment of like-minded nations ensures that implementation of an aggregate Pc metric would not risk operators moving their businesses outside the United States. We also recommend that the Commission apply these rules equally to non-U.S. operations requesting U.S. market access, if a) the Commission determines that the licensee's original regulators do not have effective oversight of debris mitigation, or b) if the foreign regulator assesses debris mitigation plans in a significantly different way than the Commission. We assert that regulatory regions considered to be "regulatory competitors" with the United States are more aligned than not, and that an application for a large constellation in those regions would fall under similar scrutiny. The U.S. government has demonstrated a robust orbital debris oversight regulatory regime, and while certainty in other regulatory regions may not be guaranteed, we believe the United States should continue to demonstrate leadership in this area.

In the future, as the sensitivity and reliability of government and commercial space situational awareness systems improve, they will grow to reliably and consistently track the large population of objects that are less than 10 cm in diameter. We recommend that once smaller debris is reliably detectable and trackable, the Commission should plan to set a requirement on all licensed satellite systems, including LEO satellite systems, to assess the risk this debris poses in their aggregate Pc calculations. Additionally, the Commission should require that such a high-fidelity Pc analysis be submitted to the Commission on a regular basis, or when a material change to any system element which affects a variable of a risk calculation is made, in keeping with the suggested satellite failure cap proposal outlined within this comment.[18]

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[18] For a detailed explanation of the satellite failure cap proposal, refer to the attached Appendix.

B. Maneuverability Above a Certain Altitude in LEO

Astroscale emphasizes that aggregate Pc should dominate risk assessment for license requests and views maneuverability as just one element to mitigate the risk of a system over its operational lifetime and deorbit phases. Therefore, should the Commission agree with Astroscale's proposal to cap aggregate Pc of a system to 1/1000, an additional maneuverability requirement would be superfluous regulation. The one exception would be for spacecraft that operate above 600 km, where any collision would result in the creation of long-lived debris. Astroscale recommends that the Commission require such spacecraft maintain a collision avoidance capability, using the technologies of their choice.

Many systems operating below 600km, that are required to maintain a 1/1,000 aggregate Pc, may necessitate the capability to maneuver regardless, like large constellations or spacecraft with large area/mass ratios. Small constellations, single demonstration missions, or objects that are trackable and identifiable but otherwise less likely to collide with other large objects due to their size should aim to follow industry practice of designing for maneuverability for collision avoidance. However, Astroscale urges the Commission to allow all operators the flexibility to demonstrate adherence to a 1/1,000 Pc using the technologies, design choices, and collision avoidance methods of their choice.

Above all, it is crucial that the Commission remain technology-neutral in how a system achieves maneuverability, both for collision avoidance purposes and end-of-life disposal. These technologies should be mandated only insofar as they are necessary for an operator to maintain an acceptable aggregate Pc threshold, with the Commission welcoming operators' use of external services to provide this capability, such as end-of-life debris removal services and other on-orbit servicing opportunities.

Further, while the Commission continues to assume a zero risk of collision for satellites that maneuver,[19] history has shown us otherwise. One of the most severe debris-generating events on record, the Iridium-Cosmos collision of 2009, generated nearly 2,000 pieces of large debris (that were trackable) and many thousands smaller yet non-trackable pieces. This

[19] *See* Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd. 4156 at 35 "The collision risk may be assumed zero for a space station during any period in which the space station will be maneuvered effectively to avoid colliding with large objects."

collision involved the maneuverable satellite, Iridium 33.[20] That a spacecraft simply has the capacity to maneuver does not in itself suggest a zero, or even necessarily a negligible probability of collision.

Determining whether to maneuver for collision avoidance can depend on a number of factors, including overall collision probability, date to time of closest approach, probable miss distance, and type of mission, among others. While NASA and ESA typically choose Pc of 1/10,000 as a threshold for maneuver,[21] there is no guarantee that a licensed operator with a maneuverable satellite will take action to avoid collision at that same level. An operator that decides not to move at or below a Pc of 1/10,000 has indeed introduced a probability of collision that is non-zero for that conjunction. Although the Commission requires certification that an applicant "[t]ake all possible steps" to assess collision risk as well as mitigate the collision risk if necessary,[22] there are no specific risk thresholds that require operators to conduct avoidance maneuvers, and no limits imparted on the acceptable residual risk that remains after such maneuvers. The operational reality is that operators of satellites with maneuvering capabilities can and do regularly accept calculable collision risks to varying and undisclosed degrees.

Therefore, operator behavior, communication among operators, and transparency about the risk tolerances they utilize in their decision-making process towards the execution of a collision avoidance maneuver are, among others, all key factors at play in collision risk. Maneuverability in a satellite itself alone does not eliminate risk of collision. Alone, it is neither a *necessary* (in the case of spacecraft which utilize alternative approaches such as securing space tug services) nor a *sufficient* condition for total elimination of collision risk; rather, it is an important consideration that may be effective for assessing and mitigating collision risk.

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[20] *2009 Iridium-Cosmos Collision Fact Sheet*, Secure World Found. (2010), https://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf.

[21] *See* M.D. Hejdduk, *CARA Risk Assessment Thresholds*, NASA, 23-26 (May 2016), https://strives-uploads-prod.s3.us-gov-west-1.amazonaws.com/20160006111/20160006111.pdf?AWSAccessKeyId=AKIASEVSKC45ZTTM42XZ&Expires=1602175399&Signature=iaM4fEgkRd2oesYNQvmZVljU4s8%3D;
See ESA Spacecraft Dodges Large Constellation, European Space Agency (Mar 9, 2019) https://www.esa.int/Safety_Security/ESA_spacecraft_dodges_large_constellation.

[22] *See* Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd. 4156 at 101.

C. Post-Mission Orbital Lifetime

Like maneuverability, adherence to post-mission disposal reliability is one of many factors contributing to the overall impact of a system on the operational space domain. We urge operators to dispose of their satellites as quickly as possible immediately after the end of their mission, with a limit of no more than 5 years as a feasible passive disposal timeframe, except as explicitly allowed by the Commission for short-term activities that contribute to innovation, such as single-satellite technology demonstrations. Further, third-party end-of-life and active removal services can play a crucial role in enabling operator adherence to PMD reliability and maintaining an aggregate Pc metric. End-of-life services would be particularly effective for large constellations (within which a collision of a failed or otherwise slowly deorbiting satellite would result in a step-function increase in aggregate collision risk for the overall system), and the Commission should support such uses of on-orbit services as a positive development for overall sustainability of space.

We submit the following positions regarding post-mission orbital lifetime:

1. *25 years as a disposal timeframe no longer serves the public interest*

Astroscale asserts that, for the protected LEO orbit in particular, the current 25-year rule is outdated, and in most cases is too long a timeframe to remain in orbit without active collision avoidance to effectively mitigate collision risk. Recent NASA analysis suggests that 25-year disposal timeframe is seemingly adequate for long-term debris generation in low Earth orbit,[23] but this analysis discounts the growth of the industry and does not consider the disruption to satellite operations due to an increase in collision avoidance maneuvers. There is inevitably going to be a measurable increase in conjunctions between various space objects, and with the implementation of new and updated SSA capabilities those will become increasingly visible to operators. As that transpires, it will concurrently become increasingly feasible and essential to assess the scope and extent of collision risks involving space objects space debris down to 1-2 cm size in LEO orbits.

[23] *See* comments of J.C. Liou in *Orbital Debris mitigation guidelines still useful, if complied with*, SpaceNews (Jan.15 2020), *https://spacenews.com/orbital-debris-mitigation-guidelines-still-useful-if-complied-with/*.

Further, the 25-year rule has resulted in commercial operators formulating their mission designs and plans solely around this limitation rather than with a holistic approach to space safety. This adherence solely to the maximum (but not the spirit) of the requirement has led to increasing spacecraft congestion around and below the 600-650 km altitude range and ultimately contributed to increased conjunctions and risk in LEO operations.

A new industry norm of behavior is forming among LEO commercial satellite operators around a timeline of 5 years to fully deorbit spacecraft after their missions, such as that put forth by the Space Safety Coalition (of which Astroscale is a member).[24] Further, large constellation operators have also proposed less than 5-year disposal timeframes in their orbital debris mitigation plans.[25] Beyond industry, NASA's ODMSP recognizes direct retrieval as an emerging method for disposal and suggests, when direct retrieval is used, that operators do so within a 5-year timeframe after end of mission.[26]

Ultimately, we encourage and expect operators committed to space safety to dispose of their satellites immediately after end of mission as a standard practice with the Commission considering the aggregate risk of a system through the entirety of its potential passive deorbit timeframe.

2. *The number of failed satellites for a system in orbit should be capped to reduce risk regardless of post-mission disposal reliability*[27]

While post-mission disposal reliability of 90% (or more for large constellations) has been a useful target metric to mitigate the creation of additional debris in upper LEO ranges (above

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[24] *See supra* note 8 at 12.

[25] For example, see the Starlink modification request, which commits to a deorbit time frame of less than five years "even under worst-case assumptions." Space Exploration Holdings, LLC, Application Narrative, IBFS File No. SAT-MOD-20200417-00037, at 7 (Apr. 17, 2020), https://licensing.fcc.gov/myibfs/download.do?attachment_key=2274315.

[26] *See supra* note 4 at 6.

[27] It is important to define what we consider to be a "failed satellite" for purpose of this proposal. A satellite whose payload may fail yet can still conduct collision avoidance would not be considered "failed" in this scenario. A satellite whose attitude control eliminates its ability to conduct a collision avoidance maneuver would, in effect, be deemed "failed." Therefore, we offer satellites that lose their original capability to conduct collision avoidance maneuvers (that is, launched with propulsion or other methods to conduct a maneuver along with the ability to be commanded to maneuver, and then loses one or more elements essential to collision avoidance) is deemed a failed satellite.

600-650 km), it loses its effectiveness for operations below the approximate range of 600-650 km. Due to the atmospheric drag in orbits below 600-650 km, satellites that fail at that altitude will likely passively deorbit within the current international norm of 25 years. This means, in effect, even if each LEO constellation satellite at or below 600-650 km provided service in its operational orbit until it lost all maneuverability or otherwise unexpectedly failed, by the Commission's current definition, a 100% PMD reliability rate would still be achieved. In reality, the failure of dozens of satellites at this altitude, despite obtaining 100% PMD, would create an increased risk for operators as the failed satellites slowly descend through congested orbits.

In the absence of regulatory measures to mitigate this risk, Astroscale proposes the following concept to cap the number of failed satellites in a system by maximizing a system's aggregate Pc to 1/1000. This proposal includes a feedback loop to the Commission, increasing its capacity to effectively monitor operator behavior, enforce existing debris mitigation rules, and establish rules based on an informed understanding of the contemporary state of the industry. The full concept can be found in the attached Appendix.

3. *Satellite Failure Cap Concept*

   a. The Commission should recognize that satellite design iterations will change from application to launch

Currently, the Commission requests information of a system's initial design and operational parameters that may change considerably between application, launch and operations. The Commission's assessment on the entire operational lifetime of a system is based on a snapshot in time pre-launch. This process does not work well for operators that use iterative design approaches for their businesses and can result in a scenario where parameters within a debris mitigation plan stated at time of application often have little bearing whatsoever to those in effect at actual launch.

Numerous factors can change within the period of application to grant, in the period from grant to launch, and during a system's lifetime.[28] These factors can materially change the risk

[28] These factors include, but are not limited to, the number of satellites, shell configuration, plane inclination, launch deployment orbit, operational orbit, disposal orbit, trajectory design, CAM strategy and risk thresholds reached before CAM are conducted, design cross sectional area vs. cross-sectional area at time of failure, design mass vs. mass at time of failure, satellite design reliability,

profile of a system through design changes from the time of an initial license application, but they can also be changed by anomalies on-orbit.[29] Furthermore, NASA's Orbital Debris and Engineering Model (ORDEM) and Debris Assessment Software (DAS) models and propagates the current orbital environment without consideration for future deployments.

b. The Commission should limit the aggregate probability of collision of a system in orbit to 1/1000

A regulatory regime which allows an unlimited number of failed satellites to drift uncontrolled through low Earth orbit for up to 25 years poses a major risk to space safety, and would negatively impact the sustainability of not only low-Earth orbit but also geostationary transfer (GTO) and highly-elliptical (HEO) orbits with perigees below 600-650 km. To effectively manage and limit this risk, it is Astroscale's position is that the Commission should condition any grant of licenses upon the requirement that an operator continuously maintain an aggregate system Pc below an acceptable limit of 1/1000 as discussed in section A of this comment, but take into account real-time changes in the number, condition, and location of failed satellites an operator maintains in orbit.

For clarity, Astroscale does not intend to suggest that a single failed satellite denotes irresponsible behavior from an operator. However, the current situation does not actively monitor on-orbit failures, resulting in a regulatory "wild west," and an abundance of uncertainty around the orbital environment's future condition. This is a detriment to innovators, investors, insurers, regulators, and operators themselves.

c. The Commission should establish regular updates and review of certain parameters of the licensed and operational system

Given the sheer numbers of satellites being inserted into orbit, even a 1-2% failure rate comes with measurable increase in risk for all operators. Astroscale suggests the establishment of a system for check-ins between licensees and the Commission, where the risk of collision of the system, to include failed satellites, is calculated and presented at regular intervals, with design, orbital, or environmental changes assessed and noted. We

debris environment at application vs. during operations and at time of failure, solar activity during operations and at time of failure, propagation models, and presence and behavior of nearby operators.

[29] For example, if solar arrays do not initially deploy properly, the approved design area is changed, affecting things like collision risk and deorbit time, because the area-to-mass ratio changes.

suggest a regular interval could be monthly or semi-annually, depending on the cadence of launch.

The Commission could use these regular update requirements to standardize its review of changes to constellation architectures, affording regular opportunities to query operators as to the state of their constellations, the number and risk profiles of failed satellites, request evidence of effects of their operations on the environment near their constellations and inquire as to plans to mitigate any risk increases. In essence, these sessions serve as a proposed enforcement function that has otherwise been absent. Licensees in this scenario would conduct DAS aggregate Pc reviews for their system as a routine part of constellation operations and provide the following example information to the Commission at regular intervals:

i. Collision avoidance capability status and orbital elements of all satellites in the system
ii. Estimated mass of the failed satellites
iii. Estimated cross-sectional area of failed satellites
iv. Pc of each failed satellite and aggregate Pc of entire system

d. The Commission should establish enforcement mechanisms for licensees whose systems exceed an aggregate Pc of 1/1000

As explained above, the periodic reviews are meant to increase transparency and serve as an enforcement function themselves, allowing the Commission to determine if further action needs to be taken. By simply establishing a reporting requirement, this may be enough to incentivize operators to quickly remove failed satellites in a safe manner. We suggest a progressive enforcement process for systems that breach an aggregate Pc of 1/1000. Some actions could include:

i. More frequent updates to the Commission
ii. Place a condition on the license limiting operations of additional satellites until a per-operator aggregate Pc of 1/1000 or below is re-established
iii. Requirement for a clear risk abatement plan
iv. Establish a fine or other financial incentive

It may not be a distinct or binary choice to action one of these enforcement mechanisms, but a further review state at the Commission's discretion should be mandatory if the aggregate Pc threshold is breached.

For a detailed description of how the proposed failed satellite cap and ongoing real-time review process could be implemented, please see the Appendix, attached. Regardless of whether a near real-time failed satellite check-in scheme is adopted, for all deorbit mitigation techniques, they should be considered in tandem with overall aggregate collision risk.

D. Indemnification

Astroscale recommends the United States government be indemnified from U.S.-licensed private space operations if, and only if, there is a cap on such an indemnity. Astroscale urges the Commission to define the specifics of a capped indemnification model in consultation with Congress and the wider United States interagency.

There is a cost to utilize the space environment in terms of risk. Likewise, there is a value to a clean, safe, and sustainable orbital environment. Accordingly, it is in the public interest for the government to discourage behavior that lessens that value and decreases space safety and space sustainability, either by creating debris or by failing to remove potentially hazardous debris. Today, there are costs that U.S.-licensed satellite operators have previously not had to pay; however, that dynamic is changing. As congestion and debris-generating activities increase in frequency, satellite operators are met with more risk in operations. This risk has compounding negative effects, due to both decreased operational service capability as well as capital and operational expenditures associated with the performance of increased collision avoidance maneuvers.

The U.S. Government under relevant UN treaties and in its role as a launching State ultimately bears the responsibility of supervising private U.S. actors in space.[30] An

[30] *See* Treaty on Principles Governing the Activities of States in the Exploration and use of Outer Space, including the Moon and Other Celestial Bodies, U.N., Office of Outer Space Affairs (Dec. 19, 1966), https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html. Article VI: "States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty."

See also Convention on International Liability for Damage Caused by Space Objects, otherwise known as the *Liability Convention*, U. N., Office of Outer Space Affairs (last visited Oct. 7, 2020), https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html. The Liability Convention provides that a launching State shall be absolutely liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft, and liable for damage indemnification requirement on FCC-licenced satellite operators could promote a positive outcome for space sustainability and serve to further promote responsible commercial behavior and stewardship in the space environment. However, a total or unlimited indemnification condition would impose a chilling effect on satellite operators.

A more practical option is a capped indemnification system, where FCC-licensed operators are responsible for covering the costs of any third party liability claim brought against the U.S. Government up to a set limit, after which any remaining third party liability claim amount above that cap would fall to the U.S. Government. This model is consistent with United States' responsibility for both liability and continuing supervision of commercial activities. Satellite operators would need to procure third party liability insurance from the commercial insurance market to cover exposure up to the specific liability cap. For non-standard missions that pose significant additional risk of collision, a higher cap could be determined on a case-by-case basis, as appropriate.

1. *There is precedence for capped indemnification within the U.S. aerospace industry*

As the Commission has noted, there is already precedence for a capped liability system within the Federal Aviation Administration (FAA). FAA licenses to launch or re-enter fall under the Commercial Space Launch Act (51 USC 50915) of 1988, at Chapter 509.[31] This provision requires licensees to enter into a combination of reciprocal waivers with its customers, the government, and its contractors, as well as secure financial responsibility requirements in the form of third-party liability insurance. Chapter 509 also provides a legal mechanism for Congressional discussion and voting, in the event of a claim, on whether to appropriate funds for damages exceeding the limits of the operator's insurance. When a licensed launch or re-entry results in damages exceeding a commercial operator's insurance, Chapter 509 requires the FAA and the Secretary of Transportation to recommend a compensation plan for the President to submit to Congress, which cannot exceed US $1.5 billion (adjusted for inflation). From there, the Senate has 60 days to consider the plan.

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due to its faults in space. The Convention also provides for procedures for the settlement of claims for damages and relevant provision.

[31] *See supra* note 6.

In tandem, these mechanisms and requirements comprise a de facto "capped" indemnification system, falling short of total indemnification of the U.S. government from liability claims, and therefore remaining in keeping with its treaty obligations. Astroscale urges the Commission to engage in further consultation with Congress, industry, and the interagency with the objective of applying a similar model to commercial satellite operators licensed by the Commission.

2. *There is precedence for capped indemnification among other spacefaring nations*

Other nations which license commercial space operations have also implemented conditions-based, capped indemnification schemes.[32] For example, in the UK, satellite systems which are owned or operated by a UK company are presently licensed under the UK's Outer Space Act.[33] The UK Space Agency acts on behalf of the UK Government to assess proposed commercial space systems' risk and license those systems that demonstrate acceptable risk profiles. The UKSA also mandates that space operators for licensed space systems take out a minimum level of third party liability (TPL) insurance cover from the commercial market, to indemnify the UK Government against liability claims which may be brought against the UK, given its obligation under the Outer Space Treaty to supervise UK commercial activities.

For standard LEO or GEO space systems and mission types, the minimum level of TPL insurance coverage required under this scheme is EUR 60 million per "occurrence" or per spacecraft.[34] Provided that the operator continues to meet the UKSA's overall licensing requirements for the operation of the satellite system, the UK caps the liability on the operator at that level, and the UK assumes the liability for any claims exceeding EUR 60

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[32] Per the Satellite Finance Network Small Satellite Insurance Workshop, which took place on July 10, 2020, various other European countries (such as France, the Netherlands, Austria, Luxembourg) have regulatory provisions in their space system licensing regimes which enables the setting of a minimum TPL insurance cover to be put in place by the licensed operator, with the government being usually prepared to accept the excess liability above a given limit under specific conditions (depending on the risk profile of the particular satellite system).

[33] The recently enacted Space Industry Act will also apply to relevant UK-licensed operators.

[34] *See* Fact Sheet: The UK Space Agency's New Requirements for In-orbit Third-Party Liability Insurance, UK Space Agency (Oct. 1, 2018) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/744408/TPL_Insurance_Fact_Sheetsw2.pdf.

million. For NGSO satellite systems which involve several spacecraft, the UKSA determines on a case-by-case basis an appropriate level of minimum TPL insurance which must be secured by the operator, in proportion to its evaluation of non-standard risk. Since the commercial insurance market usually only offers TPL insurance policies for 1-year terms, UK operators renew or update the TPL insurance policy for each year of in-orbit operations. To maintain its supervision, the UKSA conducts annual reviews with operators on the status and health of its licensed space objects.

The UKSA also requires that the licensed operator must immediately inform the UKSA of any material changes to the operating characteristics of the licensed satellite system, such as any changes which increase the risk of its operations in space. The UKSA reserves the right to maintain or update the license conditions for that space system at any time in accordance with these changes and, if necessary, to rescind the space license. However, in such a case, the UKSA will not typically agree to terminate the operator's license obligations (including that of indemnification of the UK Government against third party claims) until the operator has properly effected an end-of-life disposal plan for the licensed space objects which meets the requirements of the UKSA.

Astroscale recommends a similar system be implemented in the United States; that, up to a cap, the U.S. government be indemnified from liability for commercial space companies licensed by the Commission that diligently meet their technical and operational requirements throughout the lifecycle of their licensed systems, and keep the Commission aware of material changes as they occur. Such an approach would incentivize responsible practices of U.S. licensed satellite operators, both in the design of space systems and in their on-orbit operation, without implementing an undue burden that could disincentivize participation in the industry.

Astroscale proposes that a capped liability system is a reasonable compromise that balances the pace of industry innovation and growth in delivery of valuable services, while still accounting for the cost of the inherent risk of operating in the space environment. This system would serve as further incentive for operators to design missions and operate technologies in responsible ways that reduce the risk of orbital debris creation and increase safety.

E. Performance Bonds for Successful Disposal

Astroscale recommends the Commission not apply a performance bond as proposed in the Further Notice at this time, but strongly encourages the establishment of a working group or commission that would study and recommend a suite of effective financial incentives for debris mitigation through disposal. Such a working group must include both U.S. government and non-government stakeholders, who would have a specific timeline to study and recommend these incentives as an outcome.

Though we strongly advocate for the application of financial incentives for commercial satellite operators to expeditiously dispose of their spacecraft at end-of-life, the proposal as outlined in the Further Notice requires further careful assessment and review. The formulas for calculating performance bond amounts in the Further Notice would place undue financial harm on the industry, particularly for on-orbit services such as those Astroscale offers, which would be penalized for extending the lives of satellites in GSO. The Commission should be encouraging the use of satellite services to safely dispose, upgrade, refuel or extend the operational lifetime of satellites, as these activities support the mitigation and remediation of orbital debris. Indeed, life extension, especially when provided by persistent on-orbit assets, eliminates launches that are currently required to replace still-functional spacecraft that merely need replenishment of fuel or augmentation.

Furthermore, the proposed NGSO performance bond calculation could lead to unintended consequences whereby satellite operators seek to minimize the bond value, at the expense of space safety. The bond calculation proposed by the Commission considers the deployment altitude of satellites and does not acknowledge either: a) failures can occur at higher operational altitudes or b) the risk that satellites pose to the wider orbital environment is not captured by altitude alone. While the proposed rule on performance bonds as written is not ready for implementation, Astroscale provides the following information for the Commission to consider as they further develop financial incentives in conjunction with all stakeholders.

1. *Other industries operating in risk-laden, extreme environments utilize financial incentives*

As mentioned with regards to indemnification, just as there are monetary costs associated with a debris-filled, risk-laden space environment, there also exists a monetary value associated with a lower-risk, clean space environment. If debris creation is not mitigated to the widest extent possible, operators will pay financially, as high collision risk forces expenditures to avoid increased conjunctions. Operators will face design and manufacturing cost increases to protect their assets against debris in order to maintain a high quality of service. Therefore, implementation of financial incentives to reduce those future costs represents the most logical course of action, for both operators and for regulators.

Space operations have some similarities to other high-risk industries in terms of the responsibility to abate, predict, and prepare for risky operations. Other industries that face significant risks and operate in similarly extreme environments, such as the nuclear industry, the oil and gas mining industry, and the offshore wind industry utilize financial incentives to maintain the safety of their operating environments.[35] For these industries, financial incentives can take many forms, such as prepayment plans, fines and penalties, performance bonds utilized towards decommissioning operational equipment at end-of-life, levies, and taxes, among others. Additionally, many industries that operate under risk-laden conditions in extreme environments benefit from varying levels of government subsidies, tax incentives, and other financial incentives for decommissioning at end-of-life. This is true for both more robust industries such as nuclear power as well as newer industries like offshore wind power.[36]

Though the performance bond proposal issued in the Further Notice is not recommended for adoption, rather than categorically denying the applicability of a financial incentive such as a performance bond for the U.S. space industry, we believe the existing and future risks associated with commercial operations in Earth orbit are significant enough that these financial incentives merit immediate further study and with the intention of successful application to space activities.

As in many other sectors, once satellites reach their end-of-life, they are no longer providing revenue to the operator, which means funds are not necessarily available for decommissioning at the time it is required. This presents a challenge for the financing of debris mitigation measures if funds are not accounted for during the operational and revenue generating phase of an asset's life. In other sectors, solutions including the use of

[35] Brettle, Harriet et. al, Applying Lessons Learned from Decommissioning in non-Space Sectors to Active Debris Removal, 70th International Astronautical Congress (2019).
[36] *Ibid.*

performance bonds and insurance, often in combination, ensure that funds are available at the end of operations to return the environment to its natural state.

For example, in the nuclear industry end-of-life practices must be considered and financially accounted for from the beginning of operations.[37] In the United States, nuclear operations licensees must provide financial assurance for decommissioning costs before they begin any operations that could result in contamination requiring later clean-up.[38] There are typically three ways that this is achieved:

a. *Prepayment:* funds are deposited in a separate and dedicated account before operational service begins. Such funds cannot be withdrawn for any purpose other than for decommissioning.

b. *External sinking fund:* Funds are set aside during the operational lifetime of the asset through an additional levy fee that is passed onto consumers. Such funds are placed in a trust fund outside the operator's control.

c. *Surety fund, letter of credit, or insurance*: third-party liability insurance guarantees decommissioning costs will be covered, even if the operator defaults.

As currently written, the performance bond concept posed by the Commission does not explicitly advocate for the use of the bond for satellite servicing or end-of-life services, in fact denoting that application as outside the scope of this proceeding.[39] Astroscale reasserts that the exclusion of such an application is antithetical to the purpose of a performance bond, as has been successfully applied in other industries to the benefit of their operational environments and overall industry safety. We welcome the Commission's consideration of innovative solutions to space debris mitigation, and encourage the Commission to engage with wider U.S. stakeholders across government and industry in an expeditious interagency investigation into the application of financial incentives for space sustainability, including debris removal for NGSO spacecraft or life extension for GEO spacecraft.

[37] " Decommissioning Nuclear Facilities, World Nuclear Association (updated Aug. 2020), https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx.
[38] Financial Assurance for Decommissioning, U.S. Nuclear Regulatory Commission (updated July 25, 2019), https://www.nrc.gov/waste/decommissioning/finan-assur.html.
[39] *See supra* note 2, at 91.

IV. Conclusion

Space systems are essential to modern society, and Astroscale applauds both the space industry's efforts to launch and operate spacecraft in a responsible and safe manner and the Commission's attention to the urgent matter of orbital debris mitigation. The United States maintains an oversight and continuing supervision requirement when licensing satellite operations and is ultimately responsible for actions and activities of its private space activities. The licensing process helps to ensure U.S. satellite operators and applicable market access applicants demonstrate clear and complete understandings of risk and adhere to realistic debris mitigation requirements. When there is a significant change that affects other operators (and space safety in general), the Commission should solicit the necessary information needed to assess the comprehensive risk profile of a system. The Commission should then make this information available, so that other operators are able to better predict the impact to their own operations. Assessing whether a system is likely or not to create an unsafe and unsustainable orbit is in the public interest; it requires factual and transparent information, such as described above.

The Commission holds an influential role within the U.S. government for integrating balanced debris mitigation guidelines into regulation. At the same time, when considering proposals for entirely new paradigms for operators, such as the imposition of a performance bond, we encourage the Commission to engage widely and often with interagency groups across the U.S. government.

Furthermore, Astroscale maintains the concern we presented in our previous NPRM comment,[40] a comprehensive analysis and enforcement of debris mitigation in a new space age requires sufficient in-house expertise specific to orbital debris matters. To mitigate this issue, we recommend the Commission collaborate with experts in the debris mitigation plan review process while ensuring not to add on to the complexity or time required towards a license. We reiterate our previous recommendation that the Commission should also consider establishing an advisory committee made up of academic, non-governmental, and industry experts in order to access expertise and advice regarding orbital debris mitigation. Such a committee would be analogous to other government Federal Advisory Committees, such as

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[40] *See* Comments of the Global NewSpace Operators (GNO), IB Docket No. 18-313, at 21 (filed Apr. 5, 2019)

the FAA's Commercial Space Transportation Advisory Committee (COMSTAC). We are also concerned that there is inadequate monitoring and enforcement of debris mitigation rules. We urge the Commission to consider frequent "health check-ups" for licensees, such as implementing our proposed satellite failure cap plan, and to outline explicitly how it intends to monitor licensee activities in space for adherence to the rules and specify methods of enforcement.

Astroscale also recommends that the Commission's orbital debris mitigation rules should apply to market access applicants in most cases, provided the Commission establishes there is not effective oversight and authorization of the applicant's orbital debris mitigation practices, or debris mitigation oversight diverges substantially from those of the Commission.

As summary of our positions, we recommend the Commission:

1. Apply a calculation of the probability of collision in the aggregate (including all planned satellites of an entire system over its license period).
2. Materially limit the collision risk, Pc, posed by a licensed system to other operators by capping the system's number of failed satellites in orbit at any given time, and ensure a process for recurring review of system performance. We suggest a maximum Pc of 1/1000 for a system.
3. Refrain from imposing a specific maneuverability requirement to systems that operate below 600 km that otherwise consistently maintain an aggregate Pc below 1/1,000 and would not otherwise create long-term debris.
4. Reduce the post-mission time to disposal limit from 25 years to as soon as possible, but no more than 5 years, while allowing for the consideration of some exceptions to this standard on a case-by-case basis (with strict scrutiny of aggregate Pc) for short-term activities that provide innovation, such as single-satellite demonstration missions.
5. Support indemnification of the U.S. Government from liability for U.S. commercial space activities licensed by the Commission, provided a cap is assured.

6. Refrain from imposing a performance bond as described in the Further Notice on U.S. satellite operators and establish a working group to fully assess appropriate and effective financial incentives with all stakeholders.

In conclusion, a mix of industry best practices, updated standards and regulations, and economic incentives are needed in order minimize the risk posed by new and growing activities in space, and to mitigate the creation of orbital debris. This is not the sole responsibility of the FCC; whole-of-government, international, and industry efforts are underway that must also be taken accounted for. We strongly believe the above proposals will contribute to the long-term sustainable use of space in the public interest. We thank the FCC for establishing this FNPRM and the opportunity to provide comments towards this critical issue.

Respectfully submitted,

___*/s/ Charity Weeden*___

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Appendix

Failed Satellite Cap Concept

Currently, a commercial satellite operator's prediction of risk is established at the point of application for a license, which can be between two to six years in advance of launch. Given the increasing occurrence of iterative design for larger constellations, this one-time snapshot is insufficient to maintain effective oversight of systems. Astroscale therefore recommends the Commission restructure its supervision of private activity by implementing a new system to monitor changes in risk, with regularly scheduled near-real time updates. Currently, if the parameters within an operator's debris mitigation plan are listed in the application period and violated later once on orbit, the Commission is unlikely to enforce additional conditions during operations. The unknown actual risks of a system as well as the crowding just below 600-650 km, requires some semblance of an upper limit of actual failed satellites[41] in orbit to cap the actual risk of a system.

For clarity, Astroscale does not believe or intend to suggest that a single failed satellite denotes irresponsible behavior from an operator. However, the current state of affairs has resulted in a regulatory "wild west," and an abundance of uncertainty around what the orbital environment will actually be like in the future. This is a detriment to operators, to investors, insurers, regulators, and operators themselves. Satellite failure rates, even with modern, tested designs and manufacturing capabilities can vary greatly.[42] Given the sheer numbers of satellites being inserted into orbit, even a 1-2% failure rate comes with measurable increase in risk for all operators. So, what is the failure line, in absolute terms, that will be

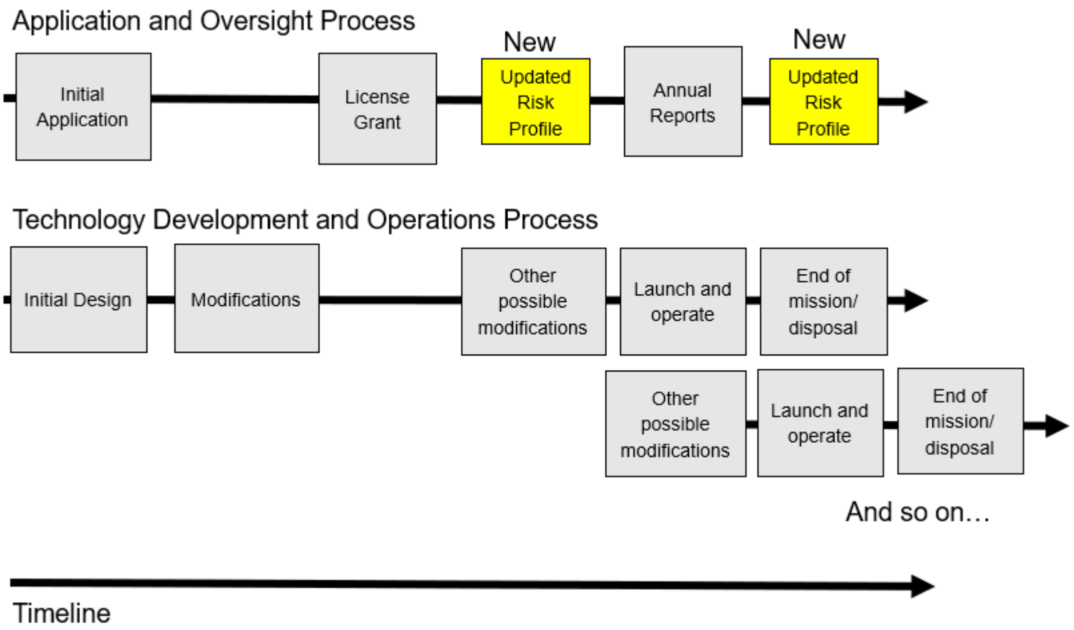
[41] It is important to define what we consider to be a "failed satellite" for purpose of this proposal. A satellite whose payload may fail yet can still conduct collision avoidance would not be considered "failed" in this scenario. A satellite whose attitude control eliminates its ability to conduct a collision avoidance maneuver would, in effect, be deemed "failed." Therefore, we offer satellites that lose their original capability to conduct collision avoidance maneuvers (that is, launched with propulsion or other methods to conduct a maneuver along with the ability to be commanded to maneuver, and then loses one or more elements essential to collision avoidance) is deemed a failed satellite.

[42] The original Iridium constellation had an in-orbit failure rate of 30% and a NASA study from 2019 revealed that 41% of all small satellites (defined as 1-200 kg) launched from 2000 to 2016 failed in-orbit. Many of these failures were nanosat sized (1-10 kg).
https://spacenews.com/starlink-failures-highlight-space-sustainability-concerns/
https://ntrs.nasa.gov/citations/20190002705

manageable for the congested orbits? What follows is our concept to answer this question and address this risk.

A near real-time risk review system should be implemented to curb higher than expected risk resulting from failed satellites.

Astroscale suggests the establishment of a system for more numerous updates between licensees and the FCC (with the revisit time open for discussion among the Commission and operators, we suggest somewhere between monthly to semi-annually, depending on the launch rate of a system), where the risk of failed satellites in a system is calculated and presented to the FCC at regular intervals, with design, orbital, or environmental changes noted. This overall process for application/oversight and an operator's technology development/operations lifetime is illustrated below in Figure A:



The new item we are proposing is a frequent risk profile assessment. The Commission could use these risk assessment "check-ins" to standardize its review of changes to constellation architectures, affording regular opportunities to: query operators as to the state of their constellations, the number and risk profiles of failed satellites; request evidence of effects of their operations on the environment near their constellations, and; inquire as to plans to mitigate any risk increases. In essence, these sessions serve as a proposed enforcement function that is needed with increased congestion and debris in orbits.

The risk review itself under this proposal would be conducted in three stages, as outlined in Figure B: operator risk review, Commission risk assessment, and Enforcement.

1. *Operator Risk Review:* The licensee in this scenario would conduct DAS Pc reviews for their system as a routine part of constellation operations, and provide the following information to the Commission at regular intervals:

    i. Collision avoidance capability status and orbital elements of all satellites in the system
    ii. Estimated mass of the failed satellites
    iii. Estimated geometry (number and distribution of pieces, cross-sectional area) of failed satellites
    iv. Pc of each failed satellite and aggregate Pc of entire system

This information would be provided, one by one for all failed satellites in a constellation. For example, if a satellite lost propulsion at 350 km, the operator would take that unique altitude, the unique area and unique mass, input it into DAS to compute unique risk of that satellite, and report its individual risk, its effect on the environment, and any subsequent aggregate increase in constellation risk overall. Though it may be imperfect, we are proposing the utilization of DAS for this proposal because it is commonly used already, and its results can be repeated and validated by third parties.

2. *Commission Risk Assessment*: After being briefed, the FCC will review the presented DAS Pc data and compare it to its aggregate thresholds. If the risk is below FCC's thresholds for an individual system, no further action would be needed at that time. However, if the risk is above threshold for an individual system, the FCC would initiate some further form of review status upon the operational license:

    a. PLAN/ITERATE: An initial state of inquiry wherein the operator must publicly submit of a clear risk abatement plan for the failed satellites. This could take the form of 60, 90, 150-day plans, at the discretion of the Commission. Proof of design improvements or planned use of on-orbit servicing support would be material information to support the operator's case they are actively resolving any issues.

b. HOLD: If, after those periods, the risks have still not been abated back below thresholds, a “hold” period could take effect, and one of the lighter enforcement stages would begin. Operators would submit a revised risk abatement plan. Proof of design improvements or planned use of on-orbit servicing support would be material information to support the operator’s case they are actively resolving any issues.

c. INCENTIVES: If, after the hold period, the failure states continue to remain above acceptable thresholds for an individual system, heavier enforcement stages could be activated.

3. *Enforcement:* As explained above, the review states are meant to increase transparency, allowing the Commission to determine if regulatory action needs to be taken. By simply establishing a reporting requirement, this may be enough to incentivize operators to remove quickly failed satellites in a safe manner. We suggest that it may not be a distinct or binary choice to place a hold or action, but a further review state at the Commission’s discretion should be mandatory if the Pc threshold is broken.

Below are options for possible levels of enforcement for the Commission to consider:

a. No direct penalty action – the fact that operators report to the Commission and (publicly) could be incentive enough

b. A hold state placed on launching replacements until Pc falls under threshold (this would not fall to the FCC directly, but could be integrated with the wider USG interagency)

c. Temporary suspension or revocation of license. A situation should **not** be created where an operator will go bankrupt or significantly harmed financially and leave operating or failed satellites in orbit without passing along the responsibility of this requirement. The Commission should incentivize proactive safe behavior.

d. Imposition of a fine. This is not an ideal solution for two key reasons; first, because many large companies could afford to pay them without changing their behavior; and second, because it could create more barriers for smaller operators who cannot pay but act in good faith. Additionally, failures on orbit are often unpredictable despite the best efforts of operators, so temporary holds and public filing of risk abatement action plans may be sufficient in and of themselves. Should fines be used, those funds should go towards the active removal of failed satellites.

The aggregate collision risk thresholds for a space system should be 1 in 1,000 over their license period.

While the specific risk threshold rate for a system can be debated, it must be calculated in the aggregate. For example, if 4,000 satellites are approved a license period of 15 years, the risk and impact of all 4,000 satellites over that 15-year timeframe must be calculated in the risk assessment. DAS software should still be used to calculate this risk; however, this must be recognized as a minimum estimate, not actual.

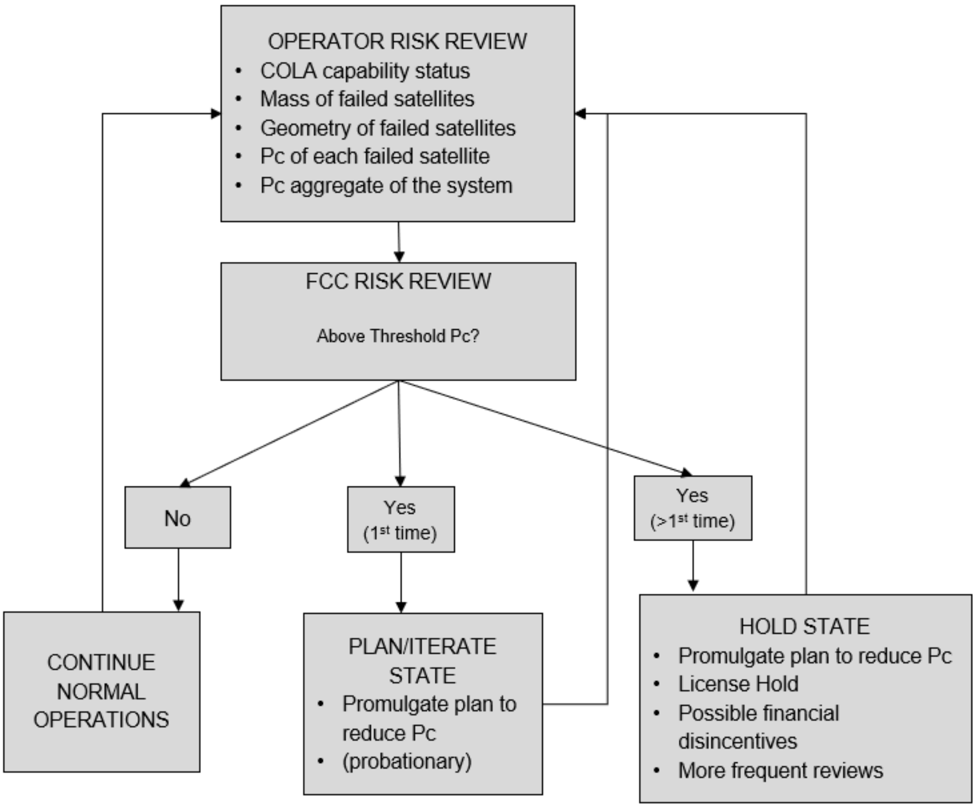


Figure B. Decision Tree for risk review

We propose a risk threshold (that is, pre-grant of license, and at the times of periodic risk assessment) of Pc = 1/1000 for the entire system. If more satellites fail than anticipated, the

Pc for the system may increase to a level above 1/1000 as a result. It is at that point the operator must take action to reduce the Pc of its system.

We also submit that perhaps there is room for additional consideration for a different Pc threshold other than Pc = 1/1000. Should operators have other suggestions, these would need to come with proper analysis showing the impact to the environment of such a threshold. A 1/1000 threshold would allow a small margin for unexpected failures leading to operator loss of some number of satellites in their fleet without punitive measures, but not to the extent that it will cause the overall constellation to impose a significant risk on the space environment. When coming to a determination of an appropriate aggregate Pc threshold, the Commission also take into consideration that the total risk to the environment includes (among other factors) both the Pc allowed for each licensed system and the number of licensed systems in operation.

To illustrate how such a concept might be applied, we present the following example scenario, illustrated in Figure D.

Year	1	2	3	4	5	6		
Sat IDs	**Pc**							
ID390	0.0009	0.0005	0.0001	0	0	0		**Maneuverable**
ID662	0	0	0.0009	0.0005	0.0001	0		**Failed**
ID011	0	0	0	0.0009	0.0005	0.0001		**Reentered**
ID098	0	0	0	0.0009	0.0005	0.0001		
ID423	0	0	0	0	0	0.0009		
Agg Pc	0.00090	0.00050	0.00100	0.00230	0.00110	0.00110		
Action	na	na	na	**Inquiry**	**Hold**	**Inquiry**		

Inquiry:	If Aggregate Pc will not be below 0.001 in one year, then operator must either take action to ensure this, or it cannot launch any more satellites.
Example:	In year 4, the aggregate Pc is over the threshold. The Commission would then ask the operator how it will reduce this within 1 year. Operator can either show that passive decay can achieve this, or employ other means to actively reduce aggregate Pc. If in one year the aggregate Pc is still over the limit, the operator is banned from launching more satellites until aggregate Pc is below 0.001.

Figure C: Example license review states for a LEO constellation of 5 spacecraft, over a 6-year period.

Year one: An operator launches a constellation of 5 satellites in low Earth orbit. In its first year of operation, one of its satellites fails, and during the operator risk assessment, the system has an aggregate Pc of 0.0009, which it reports to the FCC in its semi-regular review. Because the overall constellation's aggregate Pc risk falls under the FCC's threshold of 1 e-3, no further action is taken.

Year two: The same failed satellite is still in orbit, but because it has lowered in altitude since the previous check-in, its Pc risk is slightly lower, falling from 0.0009 to 0.0005. Still no action is taken, because the constellation's aggregate Pc falls below the FCC's threshold.

Year three: A second satellite in the constellation fails, with a Pc of 0.0009, and the first failed satellite's risk falls again with its natural decay in altitude, this time to 0.0001. The constellation's aggregate Pc still remains below the threshold, so no action is taken.

Year four: The first failed satellite has re-entered, and the second failed satellite's Pc falls to 0.0005. However, two more satellites have failed, each with Pc of 0.0009. Because the aggregate constellation risk has now surpassed the FCC's threshold of 0.001, an inquiry state is placed on the operator's license. In this review state, the operator must design and submit a risk abatement plan to the FCC. This plan can include on-orbit services such as tugs, repair, refueling, or active removal, among other options to reduce Pc risk. The fifth satellite in the constellation remains operational.

Year five: The second failed satellite has not yet re-entered, but its Pc has fallen to 0.0001. Additionally, the third and fourth failed satellites' Pc have fallen to 0.0005. The operator in this scenario did not implement any action in its plan to decrease the aggregate Pc risk. Because the aggregate Pc of the constellation as a whole is above the threshold of 0.001 for the second review period (in this example, yearly) in a row, the Inquiry state is upgraded to a hold state on the operator's license. The hold state may include penalties or other Commission/ USG enforcement mechanisms.

Year six: The second failed satellite has re-entered, but the fifth and final satellite has failed. The hold/inquiry state remains because the aggregate Pc risk remains above the FCC threshold of 0.001.

Regardless of whether a real-time failed satellite check-in scheme is adopted, for all deorbit mitigation techniques, they should be considered in tandem with overall aggregate collision risk. Post-mission disposal reliability will still be a critical element of orbital debris mitigation; both shortening time in orbit after operations have ended and ensuring post-mission disposal reliability together yield an ideal solution for lowering the risk of debris creation.