June 30, 2020

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street S.W.
Washington, DC 20554

Re: Application for Modification of Authorization for the SpaceX NGSO Satellite System, SAT-MOD-20200417-00037, Callsigns S2983 and S3018

Dear Ms. Dortch,

Astroscale U.S. Inc. ("Astroscale") is writing to comment on the subject request for modification of the SpaceX NGSO constellation ("Starlink")[1][2]. As a leader in space sustainability, Astroscale is developing the technical, business and policy inputs to make space a safe and thriving environment. Broadband access via satellite is an important element of global and affordable connectivity and thus, generally, we support SpaceX and other operators' efforts to bring this service to unserved and underserved populations.

However, 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 this third modification request of the Starlink constellation in a thorough manner, understanding the specifics of modeling and measuring the total risk of licensing and maintaining oversight of 4,408 satellites within a 30 km shell surrounding Earth. Below, we have outlined several assessment issues and suggestions for further consideration associated with this modification.

[1] SAT-MOD-20200417-00037
[2] Astroscale U.S. Inc. is a wholly-owned subsidiary of Astroscale Holdings Inc.

Astroscale U.S. Inc.
1401 Lawrence Street, Ste 1600
Denver, Colorado, 80202
astroscale-us.com

Introduction

The proposed increase in mass and spatial density of the 540-570 km region of Earth's orbit requires a rigorous and complete demonstration of understanding the associated risks

In its third modification request, SpaceX seeks permission to move more than 2,800 satellites previously authorized to operate in a 215 km band between the altitudes of 1,110 km and 1,325 km to a smaller 30 km band between 540 km and 570 km: a span which already encompasses, among other spacecraft, the ongoing deployment of nearly 1,600 additional Starlink satellites[3]. To illustrate, we show the current amount of active of mass in orbit, as well as the proposed increase in mass due to moving all 4,408 Starlink satellites into the 540-570 km zone [figure 1]. The modified configuration would result in an orbital shell with over 8 times the mass that it has today. This is but one notable effect of condensing a constellation into a region that is roughly 11% of its original volume[4].

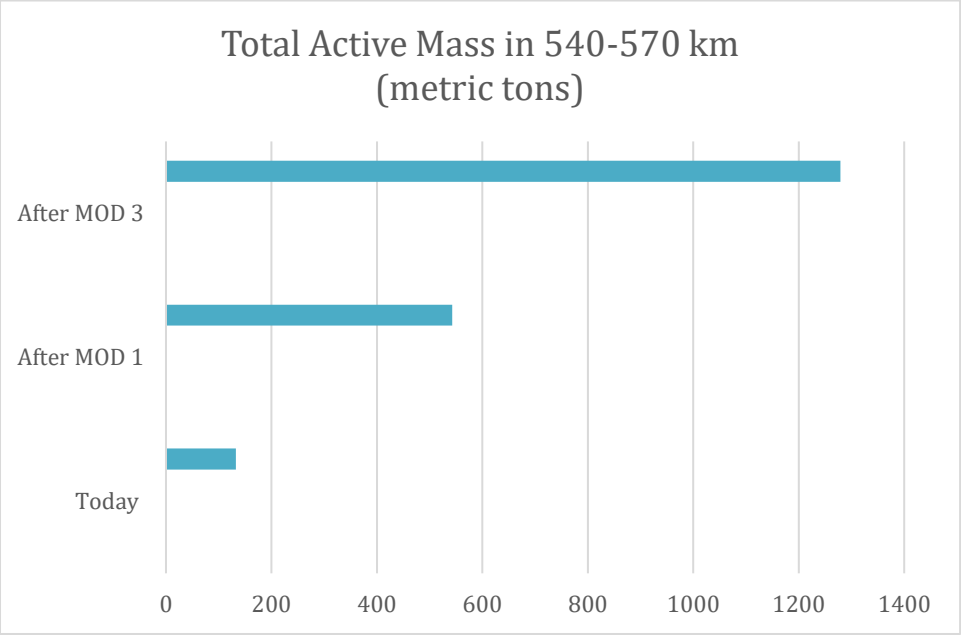

Figure 1: Mass of active satellites in the 540-570 km range: currently, after completion of the first Starlink modification, and after completion of the third Starlink modification[5]

[3] SpaceX states that "apogee and perigee will be maintained to within 30 km", SAT-MOD-20200417-00037 Technical Narrative, at 3.
[4] Comparing spherical shell volume
[5] Data of active mass in 540-570 km range from Union of Concerned Scientists (as of April 1, 2020) adding per Starlink satellite mass of 260 kg. Debris mass within the altitude band is not represented.

The increased density of the 540-570 km shell will not be without additional risk. Below, we highlight some key considerations for the Commission while this modification request is being assessed.

1. Maneuverable Satellites Present a Calculable Risk in Congested Orbits

The Commission should consider the potential increase in risk caused by more frequent close approaches involving maneuverable satellites due to the modification

In the Order and Authorization for SpaceX's first modification request, the Commission asserted that a functioning satellite with maneuverability causes zero, or near zero risk of collision, barring evidence to the contrary[6]. While this assumption was subsequently adopted in the Report and Order and Further Notice of Proposed Rulemaking[7], we feel it remains relevant to point out the material risk that comes with in-orbit operations notwithstanding maneuverability. Given the observed frequency and expected increase of conjunction events, even very low risks are substantially different from mathematical zero particularly because they will occur thousands of times, as is the case with systems involving multiple thousands of satellites [8].

Under the assumption that maneuverability negates all probability of collision, the number of close approaches involving any operable satellite would have zero bearing on risk and would therefore be irrelevant in assessing this modification. Unfortunately, close-approaches come with real and quantifiable risk, regardless of maneuverability, and in evaluating a modification which condenses thousands of satellites into a high-traffic region, the potential increase in the number of close-approaches must be appropriately taken into account. Collision risks do not become zero, or approach near zero, simply because a satellite has an *ability* to maneuver[9]. There are at least three reasons that demonstrate this fact. First, it should

[6] SAT-MOD-20181108-00083, Order and Authorization at 22.
[7] FCC 20-54 Report and Order and Further Notice of Proposed Rulemaking *In the Matter of Mitigation of Orbital Debris in A New Space Age*, at 35.
[8] For example, a simple calculation would show that accepting a $1x10^{-5}$ risk (below the typical conjunction threshold to take action) 10,000 times will have approximately a 9.5% chance of happening at least once. 1 - (1 - 0.00001)^10000 = 0.0952
[9] A good example of this is the Iridium33-Cosmos 2251 collision Feb 10, 2009.

not be assumed that all conjunction risks are detected, let alone accurately characterized and actionable[10]. Second, even if every conjunction risk above some undefined threshold were addressed in a timely manner by involved operators and thus mitigated, the effect would be a reduction, not elimination, of risk, thereby resulting in a probability not equal to mathematical zero. Third, all other conjunction risks below the same undefined threshold remain unmitigated and as such are not equal to mathematical zero.

Although the FCC requires certification that an applicant "[t]ake all possible steps" to assess collision risk as well as mitigate the collision risk if necessary[11], 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 satellites with maneuvering capabilities can and do regularly accept collision risks to varying and undisclosed degrees as was seen during a high profile conjunction between Starlink 44 and the European Space Agency's Aeolus satellite where it was clear that each party had differing risk thresholds[12].

This uncertainty in collision avoidance decision making extends to SpaceX's autonomous conjunction avoidance technology on Starlink satellites[13]. Such a technology is welcome in an increasingly congested orbital environment. However, few details have been made available to the Commission or to the public on the nature of the risk assessment, standards, or norms guiding the autonomous collision avoidance technology. More transparency would

[10] Objects 1 cm in size or larger and not tracked are called Lethal Non-Trackable debris (LNT). Conjunction assessment is not possible for these objects. Additionally, objects that may be tracked but without sufficient revisit time will not have accurate orbital predictions with which to compare a well-tracked object. Two examples of this would be newly launched objects without sufficient tracking data to be added to routine maintenance as well as any fragmentations that take several days (or more) to track and enter into a catalog.
[11] FCC 20-54 Report and Order and Further Notice of Proposed Rulemaking *In the Matter of Mitigation of Orbital Debris in A New Space Age*, page 101.
[12] https://spacenews.com/how-to-better-manage-space-traffic-aeolus-starlink-encounter-shows-emails-and-late-night-phone-calls-no-longer-cut-it/
[13] SAT-MOD-20200417-00037, Letter from Harris, Wiltshire, and Grannis LLP to FCC, May 15, 2020, page 3: "SpaceX believes it is the industry leader in collision avoidance mitigation and will continue to take a number of steps to ensure that its constellation does not unduly affect other NGSO systems. For example, SpaceX has implemented autonomous conjunction avoidance technology on its spacecraft and expects to continue to upgrade that capability as it gains operational experience."

benefit other satellite operators in coordinating avoidance maneuvers with Starlink spacecraft and would ultimately enhance space safety for all.

Certainly, better and more precise space situational awareness (SSA) will help to further drive down the full risk of an increase in conjunctions to a point. However, even if absolute perfect certainty in SSA data were available to all operators at all times, there would still be quantifiable risk remaining. Therefore, Astroscale requests the Commission to query SpaceX for their risk threshold for executing maneuvers, the targeted maximum residual risk for such maneuvers, and the resultant cumulative risk of both mitigated and unmitigated collision risks during full-scale operations, assuming defensible numbers of maneuverable and non-maneuverable objects. Before this information is made available, the Commission cannot adequately quantify or compare the actual levels of risk created by the proposed modification of the Starlink constellation, nor can it assume that SpaceX has done the same. While obtaining this type of information from all satellite operators would be helpful, it is critical with respect to SpaceX, which is proposing to operate multiple thousands of satellites within a relatively small 30 km shell surrounding Earth.

2. Orbital Debris Presents Multiple Risks in Congested Orbits, Regardless of Altitude

The self-cleaning properties of low-Earth orbit do not absolve the debris-creating risks associated with operating in a highly congested orbit

Astroscale commends the environmental risk awareness exhibited by SpaceX's desire to move to orbits with higher drag, thus reducing the long-term effects of individual failed satellites. Such orbits have been described as "self-cleaning" in that resident debris or non-maneuvering objects would experience faster natural decay at lower altitudes[14]. However, it is not evident whether or not this benefit outweighs the more near-term risks of a substantial increase in congestion within a smaller span of altitude.

[14] SAT-MOD-20181108-00083, Technical Narrative, p 41.

Hypervelocity impact studies and, unfortunately, real-life evidence show that a collision in space can spray trackable and lethal non-trackable debris over several hundred kilometers in altitude, putting at risk a wide range of satellite operations for years to come. In energetic collisions, such debris can be shed into higher orbits where they can take decades to deorbit while others can immediately endanger operations and astronaut lives in the 400 km region. The Iridium 33-Cosmos 2251 collision of 2009 resulted in approximately 2,000 trackable fragments spreading from an approximately 800 km altitude circular to apogees ranging up to 1,700 km [figure 2]. An Indian anti-satellite test in 2019, at a much lower altitude of 280 km, created approximately 250 trackable fragments of which a dozen were thrown above 1,000 km in apogee[15].

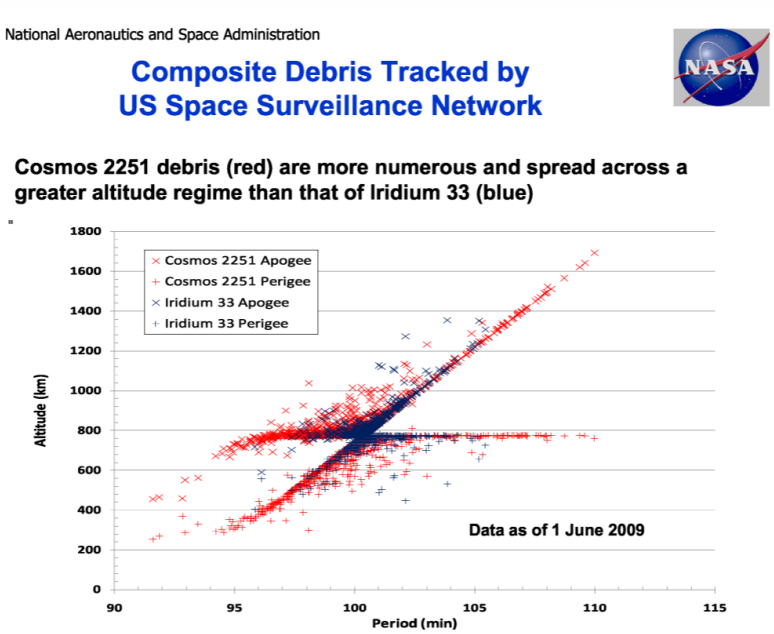

Figure 2: Spread of resulting debris after the Iridium 33-Cosmos 2251 collision Feb 10, 2009[16]

While Starlink satellites do appear to have very high area-to-mass ratios, contributing to reduced deorbit periods and higher-fidelity trackability, the fragments created from any potential collisions involving Starlink craft could have area-to-mass ratios significantly lower than their intact predecessors. In effect, this means that not only could fragments remain in

[15] Of note, any kinetic event between two objects in orbit, regardless of purpose or by accident, will result in a distribution of fragments. https://spacenews.com/india-asat-debris-spotted-above-2200-kilometers-will-last-a-year-or-more/ and https://www.youtube.com/watch?v=KYRHmEF1Azo

[16] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100002023.pdf and https://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf

orbit for several years, but this debris would be much more difficult to track by current Space Situational Awareness (SSA) methods -- and thus, unavoidable. While Astroscale agrees that fragments are inherently less risky at 550 km than at 1,325 km, when considered over the entirety of their respective lifetimes, a clear uncertainty remains as to whether the proposed modification would actually increase the likelihood of creating such fragments in the first place, especially over a 15-year term.

Post-mission disposal (PMD) reliability is an ineffective metric to limit risk for this modification request

SpaceX has stated that the Starlink constellation will achieve 100% post-mission reliability[17]. This is a rather specious statement because all satellites below a certain altitude threshold (around 600-650 km, depending on area/mass ratio) by default will achieve 100% post-mission disposal reliability over the current international norm of 25 years[18]. This means, in effect, even if each Starlink satellite 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.

The effective issue is the allowable increase in the number of failed or non-functional satellites from the Starlink constellation that could be in orbit at any given time, as compared to numbers resulting from the previously stated reliability of 99% or higher[19]. The lack of regulation which allows an unlimited number of satellites to drift uncontrolled through low Earth orbit for up to 25 years poses a major risk to space safety and would constitute negative impacts to the sustainability of not only low-Earth orbit (LEO), but also geostationary transfer (GTO) and highly-elliptical (HEO) orbits with perigees below 600 km[20]. To

[17] SAT-MOD-20200417-00037, Technical Narrative, p 20.
[18] See IADC Debris Mitigation Guidelines, at 5.3.2. https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf
[19] SAT-LOA-20161115001l8. Letter from William Wiltshire, Apr 20, 2017. “Specifically, SpaceX is designing the constellation to exceed NASA’s debris mitigation guidelines, which require a postmission disposal success rate of 90 percent, by *targeting a less than 1 percent rate of failure to deorbit from all causes*” (emphasis added).
[20] Worst case scenario, a defunct Starlink satellite will take a maximum 4.5 to 5.5 years to deorbit. SAT-MOD-20200417-00037, Technical Narrative, pg 19.

effectively manage and limit this risk, the Commission should condition any grant of the SpaceX modification upon keeping the number of non-functional satellites in orbit at any one time below an acceptable limit. In the context of this proposed modification, such a limit could be determined by using aggregate collision risk of the Starlink system as the relevant metric.

3. Ensuring a Holistic Risk Assessment for a Consequential Modification Request

The Commission should assess the aggregate collision risk of a complete Starlink constellation as proposed in this modification request

To date, SpaceX has shown only the risk of a *single* Starlink satellite against an outdated model of the orbital population[21]. A proper appreciation for the risks associated with deploying, operating, and replenishing a large constellation over several years, however, necessitates a quantification of not only a single satellite's risk, but the aggregate risk due to *all* satellites that will operate in close proximity to one another during an extended time period. An effort that is dedicated to meeting and exceeding safety standards needs to thoroughly demonstrate a holistic consideration and quantified understanding of all potential impacts to the space environment.

Astroscale asserts that if the goal is to achieve an accurate understanding of the impact of changing an entire system, as is requested through this modification, it is necessary to measure probability of collision in the aggregate of the complete system. Each object in space contributes to overall collision risk, and these contributions must be adequately quantified, understood, and appropriately limited. Simply put, total risk increases each time a discrete risk is taken. Failure to acknowledge fundamental principles of probability would impair any attempt to properly assess this modification. Therefore, Astroscale requests the Commission

[21] SAT-MOD-20200417-00037, Letter from William Wiltshire May 15, 2020 and Letter from William Wiltshire, June 4, 2020, indicating usage of NASA's Debris Assessment Software (DAS) version 2.0.2, released Dec 1, 2011. Newer versions of DAS are available with an update to the orbital debris environment model, starting with DAS 2.1 released Mar 31, 2016.
See https://orbitaldebris.jsc.nasa.gov/library/das3_0/das3.0_release_notes.txt

assess the aggregate probability of collision risk associated with this modification, ensuring transparency in how the risk is calculated.

4. NASA's Debris Analysis Software (DAS) Model assesses the minimal amount of risk

The Commission should expect the actual risk of collision by granting this modification will be greater than originally calculated

SpaceX has modified NASA's Debris Assessment Software to build in additional parameters. What is unknown is what changes and what assumptions were made to the DAS software that gives SpaceX confidence that these risk calculations are valid. Because SpaceX designates these changes and assumptions as proprietary in nature, the public and the Commission have no method of validating SpaceX's collision risk. Therefore, we encourage the Commission to address Viasat's Ex Parte letter regarding the proprietary assumptions used for SpaceX's risk assessment.

Astroscale would like to emphasize that the current version of NASA's DAS software does not take into consideration the future deployment of all licensed satellites, in either SpaceX's constellation or other pending constellations, into its collision probability estimates. Additionally, it is unclear from what starting date were the risk calculations performed, and how the results may change as future replacement satellites launch five or ten years later into an environment with increasing numbers of objects.

While imperfect, NASA's DAS software is available and free to users, which is a great benefit to all satellite operators and the public. Therefore, rather than discounting DAS in its entirety, the Commission should consider calculations garnered from DAS as 'bare minimum' representations of single-satellite risk only, and not as adequate indications of aggregate constellation risk, in light of the inadequate modelling of the future growth of low-Earth orbit populations. In other words, the presented results of SpaceX's collision risk calculations are, according to current publicly available information, very likely to be underestimations, and the Commission should treat them as such unless evidence is presented to suggest otherwise.

Conclusion

Astroscale believes that the connectivity gap in the United States can be mitigated through satellite services and applauds efforts to launch and operate constellations of satellites to close the gap, in a responsible and safe manner. 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[22]. The licensing process helps to ensure U.S.[23] satellite operators 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 ample information needed to assess the whole risk profile and make available this information such that other operators are able to predict the impact to their operations. Assessing whether a system is likely or not to create an unsafe and unsustainable orbit is in the public interest and requires factual and transparent information, such as described above.

It is clear that SpaceX has experience in ensuring safe operations. The company has been given responsibility of delivering cargo and humans to orbit. And, within this modification request, SpaceX has committed to "double down on the benefits of the lower altitude to even further enhance the already considerable space safety attributes of the constellation"[24]. SpaceX has repeatedly expressed its aim to exceed and enhance existing space safety standards in its conduct, rendering a new assessment that encompasses the full complement of risk posed by this modification both appropriate and, we expect, welcome. Indeed, ensuring transparency with the Commission, industry, and the public on a holistic risk profile will result in a safer and more secure space environment for all.

[22] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Article VI, 1967.
[23] And applicable market access applicants
[24] SAT-MOD-20200417-00037, Application Narrative at pages i and 5.

In summary, Astroscale recommends the Commission consider the following prior to grant of approval of this modification:

1. The Commission should query SpaceX on the risk threshold for executing maneuvers, the targeted maximum residual risk for such maneuvers, and the resultant cumulative risk of both mitigated and unmitigated collision risks during full-scale operations, assuming defensible numbers of maneuverable and non-maneuverable objects.
2. The Commission should condition any grant of the SpaceX modification upon keeping the number of non-functional satellites in orbit at any one time below an acceptable limit. In the context of this proposed modification, such a limit could be determined by using aggregate collision risk of the Starlink system as the relevant metric.
3. The Commission should assess the aggregate probability of collision risk associated with this modification, ensuring transparency in how the risk is calculated.
4. The Commission should address Viasat's Ex Parte letter regarding the proprietary assumptions used for SpaceX's risk assessment.
5. The Commission should consider calculations garnered from DAS as 'bare minimum' representations of single-satellite risk only.

Respectfully submitted,

___*Charity Weeden*___

Charity Weeden
Vice President, Global Space Policy
Astroscale U.S. Inc.
1401 Lawrence St, Ste 1600
Denver, CO, 80202

cc
Jose Albuquerque
Karl Kensinger
Merissa Velez

Certification of Service

I, Charity Weeden, hereby certify that, on June 29, 2020, a true and correct copy of the foregoing letter was sent by United States mail, first-class postage prepaid, to the following:

William M. Wiltshire
Paul Caritj
Harris, Wiltshire & Grannis LLP
1919 M Street, N.W.
Suite 800
Washington, DC 20036
Counsel to Space X

Patricia Cooper
David Goldman
Space Exploration Technologies Corp.
1155 F Street, NW
Suite 475
Washington, DC 20004

/s/ *Charity Weeden*
Charity Weeden