Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

Applications of	)	
	)	
SPACE EXPLORATION HOLDINGS, LLC	)	Call Signs S2983 and S3018
	)	
	)	File No. SAT-MOD-20200417-00037
For Modification of Authorization for the	)	
SpaceX NGSO Satellite System	)	

PETITION TO DENY OR DEFER OF VIASAT, INC.

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SUMMARY

SpaceX's third modification application seeks a material change to its existing authorizations for the Starlink NGSO system. This application raises fundamental issues with respect to space safety, shared use of space, and interference into other uses of the shared radio spectrum.

Many assertions in the modification application about safe space are unsubstantiated and conflict with other available information. Important interference issues remain unresolved. Moreover, the recently-disclosed failure rate of SpaceX's Starlink satellites, and evidence of how Starlink actually is being implemented, raise serious issues that warrant investigation.

The proposed modification would pack at least 10,000 Starlink satellites into densely-populated orbits that overlap with themselves, and with a number of other NGSO systems authorized (or to be authorized) by the Commission. Because this extremely large number of Starlink satellites now would occupy the same orbital space, along with thousands of other NGSO satellites, the reliability of the SpaceX satellites is far more critical than it ever was before. When Starlink satellites fail, and an alarming percentage have, the loss of maneuverability renders them uncontrollable and a collision risk to themselves, active satellites, as well existing and new orbital debris in space.

When authorizing the three prior iterations of Starlink, the Commission recognized the need to address the reliability of spacecraft in an NGSO constellation of this magnitude. However, the Commission deferred resolution of this critical space safety issue, and it conditioned the SpaceX authorizations on the outcome of future rulemakings.

Over two years later, one of those proceedings remains pending and many critical issues remain unresolved. As the Commission is aware, SpaceX opposed the adoption of collision

probability and reliability metrics for large NGSO constellations at the April Open Meeting. While the industry awaits further progress on the further NPRM on space safety and large NGSO constellations, SpaceX continues racing forward with launches of additional tranches of 60 (and possibly more) spacecraft at a time.

Now we know why SpaceX opposed the adoption of collision probability and reliability metrics for large NGSO constellations, and why it urges the immediate processing and grant of the modification application. *The aggregate risk of collisions between the modified SpaceX constellation and large space objects would be 17 (seventeen) to 200 (two hundred) times the probability that the Commission just proposed to apply to a large NGSO constellation as a whole*.[1]

Moreover, in the past two months, SpaceX disclosed the failure rate of its Starlink satellites. The 2% to 3% failure rate reported so far (depending on what satellites are included) is 2x to 3x the rate that SpaceX had assured the Commission its satellites would be "nowhere near." Just 1/10th into the lifetime of the satellites, the reported failure rate will only grow over the remaining lifetime. Moreover, this level of failure reveals that the assurances SpaceX provided to the Commission about the performance of its Starlink spacecraft during the licensing process have not become reality.

The increasing trend of SpaceX satellite failures also is a concern because at this rate hundreds, if not thousands, of Starlink satellites can be expected to become uncontrollable orbital debris that remain a source of collision risk for many years. Such collisions would be the type that:

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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 (2000), at ¶ 159.

- fragment spacecraft,
- create large debris clouds that can extend hundreds of kilometers and pollute other orbits,
- threaten the safe and reliable operation of all types of spacecraft for many years, if not decades, and
- add to the likelihood of "a space-asset destructive chain reaction, the so-called Kessler syndrome."[2]

The significant "densification" of orbits proposed in the modification application, coupled with the record of uncertainty (and failures) that surrounds the SpaceX collision avoidance system, calls into question the assumption made when authorizing prior versions of Starlink. That is, coordination among satellite operators does not mitigate the risk of collisions when failed spacecraft no longer are controllable.

Moreover, the modification application leaves unresolved a number of interference issues that go to the heart of the question whether this mega-constellation can effectively coexist and share the limited spectrum resource with other users, or whether it instead will end up monopolizing both physical access to space and effective access to radio spectrum.

The need to address all of these issues has never been more compelling than it is today. The time is long past for making assumptions about the risks presented by the Starlink constellation, relying on aspirational statements about what might be achievable, and waiting for the resolution of pending rulemakings. With the high SpaceX satellite failure rate, and the unfulfilled SpaceX commitments, there can be no doubt that consideration of this modification application requires the provision of substantiated facts and data, as well as rigorous analysis of

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2 Thompson, R., "A Space Debris Primer," in *Crosslink* (Aerospace Corporation, Fall 2015), p.26.

the issues raised in this petition and otherwise on the record. There no longer is time to rely on bald assertions and unsupported certifications about critical technical matters.

The Commission must investigate the issues surrounding SpaceX's failure rate, fully resolve the issues presented by its modification application, and exercise its authority to ensure appropriate and rigorous oversight over the Starlink system going forward. In doing so, the Commission should require the provision of ongoing operational data, and condition any grant of authority that the Commission ultimately may issue on the achievement and verification of appropriate reliability and collision probability metrics. Absent this approach, the consequences to safe space and the shared use of radio spectrum are too great.

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PETITION TO DENY OR DEFER
OF VIASAT, INC.

Viasat, Inc. requests that the Commission deny or defer consideration of the above-referenced modification application of Space Exploration Holdings, LLC. As detailed below, many assertions in the application about safe space are not substantiated, and conflict with other available information. Important interference issues remain unresolved. Moreover, the recently-disclosed failure rate of SpaceX's Starlink satellites launched to date, and evidence of how Starlink actually is being implemented, warrant investigation.

I. INTRODUCTION

This SpaceX modification application is the third such application since the Commission first authorized the Starlink constellation two years ago. This modification application is a material change that raises a number of fundamental issues with respect to space safety, shared use of space, and interference into other uses of the shared radio spectrum that must be fully addressed before the Commission can continue processing it.

When SpaceX first proposed its constellation (now consisting of 4,409 authorized active spacecraft) concerns were raised about the risk to safe space posed by a constellation the magnitude of which previously had not been contemplated. The Commission did not have a framework in place to address the issues associated with the deployment and operation of such a massive system; it thus deferred many issues for resolution in future rulemakings and conditioned the initial grant of authority on the outcome of those future proceedings. Over two years later, many of those issues remain unresolved. In the meantime, SpaceX has launched approximately 538 spacecraft and continues to launch additional tranches of approximately 60 spacecraft at a time.

Only in the past few months have the results of this science experiment started to trickle in publicly. Even those limited disclosures of SpaceX spacecraft failures to date reveal that many commitments made in the course of the Starlink licensing process have not been realized. Those failures also highlight the issues about spacecraft reliability that both the Commission and NASA recognized would be critical in the context of a constellation of this magnitude:

- *For large constellations such as the one proposed by SpaceX, NASA notes that the reliability of the design and fabrication of the spacecraft* and the reliability that the spacecraft can accomplish the post-mission disposal *are of particular interest from the perspective of keeping the orbital environment safe*. A design or fabrication flaw can potentially lead to malfunction or even explosion of many spacecraft during the deployment or mission operations of the constellation. … *[A] design and fabrication reliability on the order of 0.999 or better per spacecraft may be prudent to mitigate the risk of malfunction in a 4,000+ spacecraft constellation*.[3]

- [W]e agree with NASA that *the unprecedented number of satellites proposed by SpaceX* and the other NGSO FSS systems in this processing round *will necessitate a further assessment of the appropriate reliability standards of these spacecraft*.[4]

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3 Letter from Anne E. Sweet, NASA, to Marlene H. Dortch, Secretary, FCC, IBFS File No. SAT-LOA-20161115-00118, at 1-2 (filed June 26, 2017) (emphasis supplied).

4 *Space Exploration Holdings, LLC, Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, Memorandum Opinion, Order, and Authorization, 33 FCC Rcd 3391(2018), at ¶ 15 ("*SpaceX Initial Authorization*") (footnote omitted) (emphasis supplied).

Under the proposed modification, the once-large separation of the SpaceX satellites, touted as a benefit when the constellation was to be widely spread out in space,[5] no longer would be realized under a system design that packs an estimated 10,000 spacecraft (over 15 years)[6] into far-denser orbits that overlap with themselves, and with a number of other systems authorized (or to be authorized) by the Commission. Notably, many of those other systems do not employ propulsion as a means of collision avoidance.

That densification of orbits, coupled with the record of uncertainty (and failures) that surrounds the SpaceX collision avoidance system, calls into question the assumption previously made in the context of authorizing prior versions of Starlink that coordination among satellite operators will adequately mitigate the risk of collisions.[7] When Starlink satellites fail, and an alarming percentage have, the loss of maneuverability renders them uncontrollable and a collision risk to themselves, active satellites, as well as both existing and new orbital debris in space. Those collisions are the type that fragment spacecraft, create large debris clouds (that can extend hundreds of kilometers and pollute other orbits), and threaten the safe and reliable operation of other spacecraft for many years, if not decades.[8] Such collisions also add to the

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5 Letter from William M. Wiltshire, Counsel to SpaceX, to Jose P. Albuquerque, Chief, Satellite Division, FCC, IBFS File No. SAT-LOA-20161115-00118, at 1-2 (filed April 20, 2017) ("*April 20 Response*").

6 Letter from William M. Wiltshire, Counsel to SpaceX, to Jose P. Albuquerque, Chief, Satellite Division, FCC, IBFS File No. SAT-MOD-20200417-00037, at 6 (filed May 15, 2020) ("*May 15 Letter*"). Notably, this number could be higher if SpaceX replenishes its fleet at a faster rate due to failures.

7 *SpaceX Initial Authorization,* at ¶ 11; *Space Exploration Holdings, LLC, Request for Modification of the Authorization for the SpaceX NGSO Satellite System*, Order and Authorization, 34 FCC Rcd 2526, at ¶ 22 (2019) ("*SpaceX First Modification Order*").

8 A space object larger than 1 centimeter has the potential to completely fragment any object it hits. If that object is a large mass such as a satellite, the resulting collision will add tens of thousands of new space debris fragments to the population. Thompson, R., "A Space Debris Primer," in *Crosslink* (Aerospace Corporation, Fall 2015), p. 6.

likelihood of "a space-asset destructive chain reaction, the so-called Kessler syndrome."[9] The best way to mitigate that risk is to avoid littering space in the first instance with spacecraft not designed and proven to have a suitably-high level of reliability over their entire orbital lifetime.

Beyond the issues that SpaceX seems unable or unwilling to address, there is good reason to question SpaceX's willingness to protect others in a shared space environment. On September 2, 2019, the European Space Agency (ESA) raised the orbit of one of its satellites to pass over Starlink 44. As ESA stated at the time, "It is very rare to perform collision-avoidance manoeuvres with active satellites. The vast majority of ESA avoidance manoeuvres are the result of dead satellites or fragments from previous collisions."[10] Holger Krag, head of ESA's Space Debris Office, was notified by the Department of Defense of a possible collision. "Based on this, we informed SpaceX, who replied and said that they do not plan to take action," said Krag. "It was at least clear who had to react."[11]

This sort of response calls into question the judgment of a company with the ability to adversely affect the shared use of space for years to come. It also raises the question of whether SpaceX was in control of Starlink 44 at the time of its conjunction with the ESA satellite. Starlink 44 was part of SpaceX's initial launch. In its May 15, 2020 letter in this proceeding,[12]

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9 *Id.* at 26. As the Aerospace Corp has aptly explained: "In a landmark 1978 publication, NASA scientists Donald Kessler and Burton Cour-Palais concluded that collisions of satellites and spent rocket bodies would eventually form the dominant source of orbital debris in low Earth orbit (LEO). They predicted that debris from such collisions would collide with other satellites and rocket bodies and create even more debris. As a result of this chain reaction, the risk to satellites in certain regions of space would increase exponentially with time, even without further launches into those regions. In a 1991 paper, Kessler used the term 'collisional cascading' to describe this process. Since then, the term 'Kessler syndrome' has become widely used in the popular literature." *Id.* at 9.

10 Mike Wall, *European Satellite Dodges Potential Collision with SpaceX Starlink Craft*, Space.com, Sept. 3, 2019, *available at* https://www.space.com/spacex-starlink-esa-satellite-collision-avoidance.html (last visited July 12, 2020).

11 Jonathan O'Callaghan, *SpaceX Declined to Move a Starlink Satellite at Risk of Collision With a European Satellite*, Forbes, Sep. 2, 2019.

12 *May 15 Letter*, at 4.

SpaceX indicated that 6 satellites from that launch had lost maneuver capability above injection orbit, but did not identify which satellites are affected or when it lost maneuvering capability.

Moreover, the modification application leaves unresolved a number of interference issues that go to the heart of the question whether this mega-constellation can effectively coexist and share the limited spectrum resource with other users, or whether it instead will end up monopolizing both physical access to space and effective access to radio spectrum.

The time is long past for making assumptions about the risks presented by the Starlink constellation, relying on aspirational statements about what might be achievable, and waiting for the resolution of pending rulemakings on which SpaceX's prior authorizations remain conditioned. With the high SpaceX satellite failure rate, and the unfulfilled commitments discussed below, there can be no doubt that consideration of this modification application requires the provision of substantiated facts and data, as well as rigorous analysis of the issues raised in this pleading and otherwise on the record. There no longer is time for relying on bald assertions and unsupported certifications about critical technical matters.

The Commission must investigate the issues surrounding SpaceX's failure rate, fully resolve the issues presented by its modification application, and exercise its authority to ensure appropriate and rigorous oversight over the Starlink system going forward. In doing so, the Commission should require the provision of ongoing operational data, and condition any grant of authority that the Commission ultimately may issue on the achievement and verification of appropriate reliability and collision probability metrics. Absent this approach, the consequences to safe space and the shared use of radio spectrum are too great.

II. DISCUSSION

A. Collision risk

i. *The nature of the modified constellation design, coupled with SpaceX's experiential failures, warrants a fresh assessment of the risk to safe space*

As a threshold matter, an analysis of SpaceX's modification application[13] must account for all of the risks to safe space flight presented by the operation of the modified system in its entirety, over the 15-year license term, and considering the current and developing orbital environment. Regardless of what analysis was conducted on prior versions of the Starlink system, the stakes would be materially higher if (i) 4,408 active SpaceX spacecraft, and (ii) an untold number of inactive satellites (spare satellites, failed satellites, satellites in orbit-raising, and satellites in disposal orbits), were operating at effectively the same orbit, and in an increasingly-densified orbital environment shared with many other NGSO systems.

As detailed below, the proposed modification would significantly heighten the risks to safe space, particularly given SpaceX's experiential failure rates with its Starlink spacecraft, which renders them incapable of maneuvering effectively to avoid collisions. Those failure rates demonstrate that SpaceX is not achieving the level of reliability that it and the Commission originally envisioned to mitigate the risk of collisions that can endanger the continued safe use of space.

Before addressing the deficiencies in SpaceX's showing, Viasat takes the opportunity to address recent questions about whether orbital debris and safe space matters truly are issues that the Commission should consider in connection with modification applications such as the one

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13 Space Exploration Holdings, LLC, IBFS File No. SAT-MOD-20200417-00037; Call Signs S2983 and S3018 (filed Apr. 17, 2020), Application for Modification of Authorization for the SpaceX NGSO Satellite System ("Application").

before it. The answer is an unequivocal "yes," based on the Commission's appropriate exercise of authority over commercial satellite operations for 50 years.

Indeed, if the Commission does not require commercial entities to act in a responsible manner with respect to safe space flight, it should not authorize the launch and operation of fleets of many thousands of NGSO spacecraft, which present exponentially more risk than any other satellite systems licensed by the Commission. Consistent with its statutory responsibilities, the Commission cannot do what some in the industry would ask: (i) turn a blind eye toward the risks presented by certain designs of constellations of many thousands of NGSO satellites, (ii) fail to assess whether proposed mitigation techniques are likely to be, and actually are in practice, effective, (iii) authorize these NGSO systems to deploy, and (iv) just hope for the best.

The Commission has clear statutory authority over orbital debris and safe flight requirements for commercial satellite operators.[14] The Commission routinely employs this authority over the establishment and operation of space-based communications facilities to issue "launch and operate" authorizations that often impose limitations on the physical operations of spacecraft in a satellite system to ensure safe flight and avoid the risk of collisions that can fragment spacecraft and thus result in debris clouds that both endanger other spacecraft and have the potential to disrupt vital communications services, both near and long-term.

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[14] *Establishment of Domestic Communication-Satellite Facilities by Nongovernmental Entities*, Report and Order, 22 F.C.C.2d 86, app. C, at ¶ 1 (1970). The Commission has recognized that its broad authority under Title III encompasses the power to regulate not only satellite providers' use of radiofrequency but also providers' ability to "establish and operate" the "satellite facilities" that deliver communications services. In initially describing this authority, the Commission explained that, under Sections 301, 303, 307, 309, and other provisions of the Act, "[a] license from the Commission is required for all radio stations except Government-owned stations," *id.* at ¶ 3 (citing 47 U.S.C. §§ 301, 303, 305, 307, 308, 309), that "radio station" is defined as "a station equipped to engage in radio communication," *id.* (citing 47 U.S.C. § 153), and that and that "radio communication" in turn is defined "to include all instrumentalities, facilities, apparatus, and services incidental to the transmission," *id.* According to the Commission, "[t]hese all-inclusive definitions clearly include non-Government satellite and earth station facilities used for interstate communication or transmission of energy by radio." *Id.*

As the Commission previously found: "Because orbital debris could affect the cost, reliability, continuity, and safety of satellite operations, orbital debris issues have a bearing upon the 'larger and more effective use of radio in the public interest.'"[15] That is, because "orbital debris can negatively affect the availability, integrity, and capability of new satellite systems," "orbital debris and related mitigation issues are relevant in determining whether the public interest would be served by authorization of any particular satellite system, or by any particular practice or operating procedure of satellite systems."[16] Moreover, "[b]ecause robotic spacecraft are typically controlled through radiocommunications links, there is a direct connection between the radiocommunications functions [the Commission is] charged with licensing under the Communications Act and the physical operations of spacecraft."[17] Indeed, consistent with the Act's command to "promot[e] safety of life and property through the use of wire and radio communications,"[18] the Commission regularly accounts for safety considerations when exercising its Title III public interest authority, and courts have upheld this practice.[19] Thus, the Commission's jurisdiction over, and responsibility to address, the orbital debris and safe flight issues raised by this modification application are clear and compelling.[20]

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15 *Mitigation of Orbital Debris*, Second Report and Order, 19 FCC Rcd 11567 (2004), at ¶ 14 ("*2004 Orbital Debris Order*").

16 *Id.* (footnote omitted).

17 *Id.*

18 47 U.S.C. § 151(emphasis added).

19 *See 2004 Orbital Debris Order,* at ¶ 14 n.55 (collecting cases).

20 *See also* 47 U.S.C. § 303(r) (authorizing the Commission to "[m]ake such rules and regulations and prescribe such restrictions and conditions, not inconsistent with law, as may be necessary to carry out the provisions" of Title III).

ii. *The proposed modification would increase collision risks within the SpaceX constellation, with other constellations, and with orbital debris in general*

The proposed modification of the Starlink system would significantly accelerate the densification of a lower orbital shell (~ 550 km) that overlaps the orbits of a number of other NGSO systems. For several reasons discussed below, this increased density of satellites within the SpaceX constellation poses an increased risk of collision both within the Starlink system and with respect to other NGSO systems. In addition, the recently disclosed in-orbit failure rate of satellites in the SpaceX system raises additional concerns about the risk of collisions with SpaceX spacecraft that no longer can be maneuvered to avoid collisions or to effectuate controlled post-mission disposal.

SpaceX currently is licensed to operate 2,825 active satellites between 1,110 km and 1,325 km orbital altitudes, and an additional 1,584 active satellites at 550 km. The modification application proposes to operate 4,408 active satellites (one fewer) at nominal altitudes between 540 km and 570 km. Over the 15-year license term, this constellation is expected to employ approximately 10,000 spacecraft in the aggregate.[21] This change in altitude of 2,285 active satellites would significantly increase the satellite density (*i.e.*, more satellites in a smaller volume) within those lower orbits. It also would undermine one of the key benefits that SpaceX touted under its original system design: the once-large separation of the SpaceX satellites when the constellation was to be widely spread out in space, which SpaceX claimed would reduce collision risk.[22] The proposed modified system design now would pack these 10,000 (or more)

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[21] *May 15 Letter*, at 6. Notably, this number could be higher if SpaceX replenishes its fleet at a faster rate due to failures.

[22] *April 20 Response*, at 1-2.

spacecraft into orbits that overlap with themselves, and with a number of other systems authorized, or to be authorized, by the Commission.

This proposed densification immediately raises concerns about the impact on the Starlink system itself. This is especially true given SpaceX's +/-30 km orbital tolerance for each of its 170 planes at altitudes nominally specified as 540 km, 550 km, 560 km, and 570 km.[23] With this tolerance, it is apparent that 4,408 active satellites could all operate at essentially the same altitude, with potentially many more inactive satellites (spare satellites, failed satellites, satellites in orbit-raising, and satellites in disposal orbits).

Increased densification of the Starlink system also poses a substantially increased risk of collision with other satellites in the same or similar orbital altitudes, including both those *with* maneuvering capabilities and those *without* maneuvering capabilities.[24] For example, the proposed Kuiper system will consist of 3,236 satellites in 98 orbital planes at altitudes of 590 km, 610 km, and 630 km.[25] In addition, the Kepler system, already authorized by the Commission, will consist of 140 spacecraft at altitudes of 500-650 km.[26] Other Commission-authorized systems are deploying cubesats at altitudes ranging from 400 to 650 km.[27] Given the

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[23] At 550 km, a +/- 30 km tolerance is +/- 5.5%, twice what it would be at a 1,100 km altitude.

[24] SpaceX asserts that a benefit of moving to a lower altitude is that it will increase the distance between the SpaceX constellation and constellations like OneWeb and Telesat. Application, at 7. SpaceX overlooks the fact that by lowering the altitude of its constellation it is actually increasing the chance of collision within its own system as more satellites are spaced closer together, as well as other constellations that are at those lower altitudes, especially given its wide orbital tolerances.

[25] Kuiper Systems, LLC, IBFS File No. SAT-LOA-20190704-00057; Call Sign S3051 (filed July 4, 2019), Legal Narr., at 2 ("*Kuiper Application*").

[26] Kepler Communications Inc., IBFS File No. SAT-PDR-20161115-00114; Call Sign S2981 (filed Nov. 15, 2016), Legal Narr., at 5; *see also* Kepler Communications Inc., IBFS File No. SAT-PDR-20200526-00059, Call Sign S3070 (filed May 26, 2020), Exhibit A, at i (consisting of 360 satellites in 12 orbital planes at an altitude of 600 +/- 50 km).

[27] *See, e.g.*, Astro Digital US, Inc., Grant Stamp, IBFS File No. SAT-LOA-20170508-00071 (granted Aug. 1, 2018); Spire Global, Inc., 2019 Annual Report, IBFS File No. SAT-LOA-20151123-00078 (June 26, 2019); *Swarm Technologies, Inc.*, 34 FCC Rcd 9469 (2019), at ¶ 2.

Starlink system orbital tolerances, significant overlap will exist with both the Kuiper system and the Kepler system, and many of the cubesat systems. This all has a significant impact on the SpaceX Starlink orbital debris analysis, and it requires careful review by the Commission.

iii. *SpaceX's orbital debris analysis does not assess all relevant risks*

As Viasat has previously indicated,[28] serious concerns exist about the analytical tools that SpaceX has been employing in its orbital debris analysis. SpaceX originally relied on an outdated version of NASA's Debris Assessment Software ("DAS"), version 2.0.2, and other undisclosed proprietary software.[29] NASA DAS 2.0.2 was released on December 1, 2011, and its 2.0 version of the underlying Orbital Debris Engineering Model ("ORDEM") was released in 2001. As explained in NASA's release notes for DAS,[30] a logic error in DAS versions before version 2.1.1 produces an invalid calculation of large object collision risk probability.

Using a more current version of DAS with an updated version of the Orbital Debris Engineering Model ("ORDEM"), Viasat has been unable to replicate the results that SpaceX provided to the Commission in its letter in this proceeding dated May 15, 2020,[31] which is unsurprising considering the flaws in the earlier version of DAS that SpaceX used. Now, just six days before comments are due on its modification application, SpaceX has altered the basis for its orbital debris assessment, apparently abandoning the use of proprietary software, and it now

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28 *See* Letter from Christopher J. Murphy, Associate General Counsel, Viasat, to Jose P. Albuquerque, Chief, Satellite Division, International Bureau, FCC, IBFS File No. SAT-MOD-20200417-00037 (filed June 8, 2020).

29 SpaceX claimed that its proprietary software uses the debris flux tables obtained from DAS 2.0.2 using the "Debris Impacts vs. Orbit Altitude" tool in the "Science and Engineering" utilities at all operational inclinations. Letter from William M. Wiltshire, Counsel to SpaceX, to Jose P. Albuquerque, Chief, Satellite Division, FCC, IBFS File No. SAT-MOD-20200417-00037, at 3 (filed June 4, 2020).

30 https://orbitaldebris.jsc.nasa.gov/library/das3_0/das3.0_release_notes.txt.

31 *May 15 Letter*, at 2.

relies on a current version of DAS and the ORDEM,[32] as Viasat recommended. *But in doing so, SpaceX still has failed to disclose the underlying assumptions in its analysis that would allow the Commission or third parties to validate anything SpaceX has asserted*.

Notably, the results SpaceX now provides show a greater collision risk than before (in some cases 50% or more greater), but SpaceX's results still do not match the results that Viasat obtains when running the current DAS tools.

Table 1 below compares the values SpaceX provided in its modification application using DAS 2.0.2, the values provided in its July 7 letter using DAS 3.1.0, and the values computed by Viasat using DAS 3.1.0 for the current satellite design "maintained"[33] case. For its calculation, Viasat used the 0.0733 m^2/kg area to mass ratio value that SpaceX provided in an earlier application[34] and a start year of 2020.[35] Notably, these calculated values exceed the recent SpaceX-calculated DAS 3.1.0 values *by a factor of greater than 2*.

Altitude (km)	SpaceX Calculation Using DAS 2.0.2	SpaceX Calculation Using DAS 3.1.0	Viasat Calculation Using DAS 3.1.0
540	0.000042	0.000069	0.000190
560	0.000109	0.000139	0.000347
570	0.000087	0.000138	0.000296

Table 1: Comparison of SpaceX and Viasat DAS Calculations

32 Letter from William M. Wiltshire, Counsel to SpaceX, to Jose P. Albuquerque, Chief, Satellite Division, FCC, IBFS File No. SAT-MOD-20200417-00037 (filed July 7, 2020).

33 SpaceX provided two values in Table 1 *Collision Risk Assuming No Maneuver Capability*. One value is for attitude "maintained" and the other is for "tumbling." *Id.,* Table 1.

34 Space Exploration Holdings, LLC, IBFS File No. SAT-LOA-20170726-00110, Attachment A, at 30 (filed July 26, 2017).

35 DAS results vary depending on start year of the mission due to solar cycle variations. SpaceX has not provided a start year assumption for its calculations. Viasat selected 2020, which provides near minimum (optimistic) values.

As the Commission is aware, these values represent the risk of a *single* SpaceX satellite operating at a given altitude colliding with one of the pre-existing large objects (*i.e.*, >10 cm) represented in the NASA orbital debris environment model. In order to assess the risk presented by *the entire SpaceX constellation*, the individual values must be summed up, and a factor must be applied for the risk that a SpaceX satellite fails in orbit and no longer can be maneuvered to avoid a collision with one of the objects in the NASA debris model. The Commission has recently considered this information in the case of NGSO constellations, including in connection with one of SpaceX's modification applications,[36] and there is no valid reason not to consider the aggregate risk presented by the proposed modification, particularly given (i) the Commission's unique responsibility in this critical policy area, (ii) the public interest considerations regarding safe space that the Commission has recently affirmed, (iii) and the policy concerns the Commission has addressed about the lack of economic incentives for individual actors to act responsibly with respect the shared resource that is space.[37]

Because of the extremely large number of spacecraft in the Starlink system now proposed in essentially the same orbital shell (~550 km), the reliability of those spacecraft becomes an even more critical issue than it would be for smaller NGSO systems. Based on the constellation being proposed in this modification application, Viasat provides below an illustrative calculation

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[36] *See* Kuiper Systems LLC, IBFS File No. SAT-LOA-20190704-00057, Call Sign S3051, Letter from Jose P. Albuquerque, Chief, Satellite Division, FCC to C. Andrew Keisner, Lead Counsel, Kuiper Systems LLC, at 2 (filed Aug. 19, 2019); Space Exploration Holdings, LLC, IBFS File No. SAT-MOD-20181108-00083, Letter from William M. Wiltshire, Counsel to SpaceX, Harris, Wiltshire & Grannis LLP, to Jose P. Albuquerque, Chief, Satellite Division, FCC, at 2 (filed Mar. 13, 2019) (responding with additional information on collision risk of an incapacitated satellite as well as information on risk in the aggregate); Hiber, Inc., IBFS File No. SAT-PDR-20180910-00069, Call Sign 3038, Letter from Tony Lin, Counsel to Hiber, Inc., Hogan Lovells US LLP, to Marlene H. Dortch, Secretary, FCC, Attach., at 3-4 (filed April 15, 2019) (providing information on risk in the aggregate).

[37] *See generally Mitigation of Orbital Debris in the New Space Age*, Notice of Proposed Rulemaking, 33 FCC Rcd 11352 (2019); *see id.* at ¶¶ 88-89; *see also infra,* p. 36.

of aggregate large-object collision risk. Some very important qualifications on this illustrative calculation are in order:

- The failure rate discussion below takes at face value SpaceX's recently claimed failure levels for the 478 launched satellites.[38] As SpaceX noted at the time, it had not yet tested 58 of those satellites, and no information was provided about their performance.[39] If any of those 58 have failed, the actual failure rate would be higher.
- The failure rate discussed below ignores the impact of the first 60 satellites launched in May 2019 that have a reported 10% failure rate.[40]
- The 1.9% failure rate reported in SpaceX's *2020 Annual Report* is the absolute minimum failure rate for these additional 478 satellites over their lifetimes, because they were at the very early stage of their 5-year design life[41] when failures were assessed.[42] As discussed below, it is reasonable to expect that an additional number will fail during the significant remainder of their 5-year design life.

Viasat's calculation of the aggregate large-object collision risk for Starlink is based on the following parameters:

- 10,000 satellites launched during SpaceX's initial 15-year license term;[43]
- 0.0000877 blended probability of collision for a passive satellite in operational orbit calculated using DAS 3.1.0;[44] and
- Failure rate per satellite over its design lifetime.

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38 Letter from William M. Wiltshire, Counsel to SpaceX, Re: Space Exploration Holdings, LLC, Call Signs S2983/S3018 (filed June 23, 2020) ("*2020 Annual Report*") (reporting 9 satellites out of 478 Starlink v1.0 satellites launched since June 2019 as having have failed above injection orbit); *see infra,* pp. 21-25.

39 *Id.* at 1 ("Since its last annual report, SpaceX has launched a total of 478 Starlink satellites. It has completed testing of all but the last 58 satellites (which were launched ten days ago) ….").

40 *See May 15 Letter*, at 4-5.

41 *Id.* at 5 (Application, Schedule S, Satellite Information, Estimated Lifetime of Satellite(s) From Date of Launch, Response: 5 Years).

42 The 478 satellites at issue were launched in November 2019, and in January, February, March, April and June 2020 (nearly 2/3 of them in the prior 4 months before the June 23, 2020 report of the failures).

43 *May 15 Letter*, at 6.

44 Calculated as the weighted average of the DAS 3.1.0 collision probabilities for the proposed modified orbits based on an area-to-mass ratio of 0.0733 m^2/kg, a satellite mass of 260 kg, and a start date of 2020.

As to the failure rate parameter, SpaceX has reported an experiential value of 1.9% for its v1.0 satellites (9 of 478 failed).[45] However, these failures occurred over an average time of less than 5 months after being launched. If the SpaceX satellites continue to fail at 1.9% per 5 months once above injection orbit, then the failure rate per satellite over its 5-year lifetime would be 22.8%. While this may seem like a high value, it is not unreasonable considering that SpaceX reported a 1.9% failure rate (9 of 478 failed) just 5 weeks after reporting a 1.7% failure rate (6 of 360).[46] Bounding the failure rate per satellite over its design lifetime with (i) an optimistic value of 1.9%, and (ii) a potentially conservative, but not unrealistic, value of 22.8%, the aggregate collision risk for the SpaceX constellation ranges from 0.017 to 0.200.

These values are *17 (seventeen) to 200 (two hundred) times* the 0.001 probability that the Commission just proposed to apply to a large NGSO constellation as a whole in the pending *Mitigation of Orbital Debris* proceeding.[47]

To comply with the proposed requirement, SpaceX would need to reduce its failure rate to a maximum of 0.11%.[48] That is, SpaceX would need to achieve a reliability of at least 99.89% over orbital lifetime, which is consistent with the 99.9% level of reliability that NASA recommended in its 2017 comments on the original Starlink proposal.[49]

The number of additional non-maneuverable satellites (*i.e.,* new, passive debris objects) out of the 10,000 satellites SpaceX estimates launching is shown in the following Table 2, for

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[45] *2020 Annual Report*, at 1-2.

[46] *See 2020 Annual Report* (filed June 23, 2020), at 1; *May 15 Letter* (filed May 15, 2020), at 4. A failure rate growth of 0.2% per 5 weeks would result in a 10.4% failure rate per satellite over design lifetime.

[47] *Mitigation of Orbital Debris in the New Space Age,* Report and Order and Further Notice of Proposed Rulemaking 35 FCC Rcd 4156 (2020), at ¶ 159 ("*2020 Orbital Debris Order and FNPRM*").

[48] Calculated as 0.001 / (10,000 x 0.0000877).

[49] *See* Letter from Anne E. Sweet, NASA, to Marlene H. Dortch, Secretary, FCC, IBFS File No. SAT-LOA-20161115-00118, at 2 (filed June 26, 2017).

each of the failure rates discussed above. Note that having already experienced at least 15 failures out of 538 satellites launched,[50] *SpaceX can never achieve a 0.11% failure rate with 10,000 satellites launched, even if it does not experience any additional failures over the remainder of its license term*.

Failure Rate Per Satellite Over Design Lifetime	Number of Non-Maneuverable Satellites (Out of 10,000)
0.11%	11
1.9%	190
22.8%	2,280

Table 2: Additional Non-Maneuverable Satellites/New Passive Orbital Debris Objects

As ominous as the calculations above are, it bears emphasis that they are based on DAS 3.1.0 and do not fully assess the risk presented by the modified SpaceX constellation, including the debris flux changes resulting from future intra- and inter-system collisions, which are not accounted for by DAS, and which can result from collisions with spacecraft that have failed and no longer are maneuverable. As discussed below, assessing these issues (which is not done in the modification application) is especially important because of the large numbers of satellites being deployed in overlapping orbits and the increased probability of failures within and between NGSO systems in those orbits.

In this respect, Viasat illustrates once again how the risk associated with a constellation of many thousands of satellites scales compared to the risk associated with a single satellite, and why compliance with a suitable aggregate collision risk standard is essential. Table 3 below illustrates the expected numbers of collisions under the two different approaches in the case of

50 *See infra*, pp. 21-22 (this 15 comprises 6 satellites from the first tranche of 60, and 9 of the next 478 satellites).

large constellations, in each case based on a five-year individual satellite life, and calculated over a 15-year license term.

# of Satellites	Expected Accidental Collisions with Objects >10 cm (Fragmentation Events Generating Debris Clouds)					
	Under 0.001 *per Satellite Standard*			Under 0.001 *per Constellation Standard*		
	Probability	**Total Expected Number**	**Annual Expected Number**	Probability	**Total Expected Number**	**Annual Expected Number**
1	0.003	**0.003**	**0.0002**	0.001	**0.001**	**0.00007**
10	0.030	**0.03**	**0.002**	0.001	**0.001**	**0.00007**
100	0.259	**0.3**	**0.02**	0.001	**0.001**	**0.00007**
1,000	0.950	**3**	**0.2**	0.001	**0.001**	**0.00007**
5,000	>0.999	**15**	**1**	0.001	**0.001**	**0.00007**
10,000	>0.999	**30**	**2**	0.001	**0.001**	**0.00007**
50,000	>0.999	**150**	**10**	0.001	**0.001**	**0.00007**

Table 3: Expected Numbers of Large Object Collisions Under 0.001 Standards

The number of expected collisions in Table 3 is calculated in the absence of a satellite having effective and reliable maneuverability capabilities over its orbital lifetime. Any failure or impairment of those capabilities in a given number of satellites thus could result in the number of expected collisions reflected in Table 3. By way of example, such failures or impairments of maneuverability could result (i) from underlying spacecraft components failing or becoming unreliable (*e.g.*, command and control function, propulsion system), (ii) because insufficient propellant remains to effectuate collision avoidance, or (iii) because spacecraft are damaged by collisions with orbital debris or meteoroids of any size.

Notably, the NASA orbital debris environment model does not include any of the approximately 10,000 spacecraft expected to be deployed in the proposed SpaceX constellation,[51] or any of the thousands of other NGSO spacecraft planned to operate in overlapping orbits. The NASA tools are not designed with reference to the potential near-term introduction of constellations of thousands of NGSO spacecraft. Nor do they address the risk of collisions with objects smaller than 10 cm, which have been described as the "equivalent of being hit by a bus traveling at highway speed" and as having "the potential to cause catastrophic damage to an active satellite."[52] An estimated *26 times as many* space objects exist in the "medium object" range (1 cm to 10 cm), as in the "large object" range (>10 cm) [53] that is captured by the analysis that SpaceX conducted.

iv. *SpaceX spacecraft that cannot reliably maneuver cannot avoid collisions; they become additional, passive orbital debris that increases collision risk*

SpaceX has urged the Commission "to encourage investment in better technologies, such as by imposing responsibility on systems with limited propulsive abilities to *demonstrate how their constellations minimize the risk of collision*."[54] In its own modification application, however, SpaceX merely claims that because it has "invested in advanced propulsion capabilities for its satellites, collision risk is considered to be zero (or near zero)."[55] SpaceX does not even begin to address considerations that are relevant in determining whether these capabilities allow a Starlink

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51 *May 15 Letter,* at 6. Notably, this number could be higher if SpaceX replenishes its fleet at a faster rate due to failures.

52 Thompson, R., "A Space Debris Primer," in *Crosslink* (Aerospace Corporation, Fall 2015), pp. 5-6. ("An impact from a 5-centimeter object—the middle of the range—is the equivalent of being hit by a bus traveling at highway speed.") (Space debris in the 1 cm to 5 cm (and larger) range "has the potential to cause catastrophic damage to an active satellite.").

53 As of February 2020, ESA estimates that the debris population includes 34,000 objects greater than 10 cm in size, 900,000 objects greater than 1 cm and up to 10 cm in size, and 128 million objects greater than 1 mm and up to 1 cm in size. *See* European Space Agency, "Space Debris by the Numbers," https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers (last visited July 12, 2020).

54 Space Exploration Holdings, LLC, IBFS File No. SAT-MOD-20181108-00083, Consolidated Opposition to Petitions and Response to Comments of Space Explorations Holdings, LLC (filed Feb. 11, 2019), at 7 (emphasis supplied).

55 Application, at 11.

satellite to be maneuvered effectively, particularly in light of the failures of Starlink maneuverability capabilities to date.

v. *No assumptions about collision risk are warranted in this case*

The Commission has made a self-described "simplifying assumption" about the risk of collisions with large objects (>10 cm):[56]

> 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.[57]

Significantly, the Commission also indicated that it would not make this simplifying assumption in a case, like this, where evidence exists of SpaceX's experiential spacecraft failure rates, lost maneuverability capabilities on a number of its spacecraft, and the apparent lack of redundant systems that were promised to mitigate such risks (as discussed below):

> In individual cases, to the extent there is evidence that a particular system or operator is unable to effectively maneuver or is maneuvering only at risk thresholds that raise reasonable questions about its ability to meet the 0.001 collision risk metric even with some degree of maneuverability, this assumption will not be applied.[58]

As detailed below,[59] SpaceX's experiential failure rates (i) indicate that SpaceX is not achieving the level of reliability it assured the Commission it would achieve, (ii) raise questions about SpaceX's ability to maneuver effectively and meet the 0.001 large object collision risk metric, and (iii) thus present the type of circumstances in which the Commission no longer should make simplifying assumptions about the risk of collisions with large objects.

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[56] *2020 Orbital Debris Order and FNPRM,* at ¶ 35.

[57] *Id.,* at Appendix A, Final Rules, 47 C.F.R. § 25.114(d)(14)(iv)(A)(1) (emphasis supplied).

[58] *Id.,* at ¶ 35.

[59] *See infra,* pp. 21-25.

vi. *The modification application does not provide an assessment of whether Starlink satellites will be maneuvered effectively*

Determining whether a Starlink satellite in the proposed modified constellation "will be maneuvered effectively" over its orbital lifetime requires an assessment of the following types of information that are not addressed in the modification application:

- The *adequacy* of the maneuverability capabilities;
- The *reliability and effectiveness* of the maneuverability capabilities;
- *Failure rates* related to the maneuverability capabilities; and
- The impact of collisions with orbital debris and meteoroids in the 1 cm to 10 cm range on a spacecraft's ability to conduct collision avoidance maneuvers.

Exhibit 1 further details the type of information that should be examined before drawing any conclusions about SpaceX's maneuverability capabilities.

Stated another way, the issues to be examined in the SpaceX context include (i) whether its propulsion system is adequate for purposes of collision avoidance, and (ii) what happens when its collision avoidance systems fail or do not function as intended (*e.g.*, a software update results in loss of control of the spacecraft). Indeed, the SpaceX "backstop" of relying on coordination with other NGSO systems,[60] will be entirely ineffective if SpaceX is not able to maneuver to avoid an expected conjunction, particularly if neither satellite has effective and functioning maneuverability capabilities. Given the recently disclosed satellite failures in the Starlink system, it is important that the Commission seek more information from SpaceX and assess both (i) the maneuverability issues discussed above, as well as (ii) the impact of SpaceX's failures on the collision risk presented by the modified SpaceX constellation *as a whole*.

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[60] Application, at 11.

vii. ***Recently disclosed failure rates of Starlink spacecraft raise material questions about the reliability of the spacecraft that SpaceX is launching***

Recent filings by SpaceX in response to the Commission's questions about its launched spacecraft raise substantial questions about the reliability of the spacecraft that SpaceX is launching and what that means for the safe operation of an additional 2,825 spacecraft at the same altitude. In May 2020, SpaceX disclosed that 12 of the satellites that it had launched since *May 24, 2019* had become "non-maneuverable" above injection orbit.[61] While SpaceX attempts to minimize its experiential failure rate by ignoring the failures of 6 satellites that it deems a "prior version" (v0.9), SpaceX in no way explains (i) why those failures are irrelevant, (ii) how it has resolved the root cause(s) of those failures, (iii) what has changed to make this a "prior version" of what subsequently was launched, or (iv) why similar failures should not be expected in the future. One month later, in its June 23, 2020 Annual Satellite Report, SpaceX disclosed the loss of maneuvering capabilities on 9 satellites out of the 478 launched "*over the past year*," or 1.9% of those 478 satellites.[62] Based on a comparison with the failure list provided in May, these 9 apparently include only 6 of the same v1.0 satellites previously described as having "lost maneuver capabilities above injection orbit." Significantly, this June disclosure also reveals the existence of *3 additional failed v1.0 satellites*, which appears to bring to 15 the total of failed Starlink satellites. Notably, the June disclosure *does not account for* the 60 v0.9 satellites SpaceX launched on May 24, 2019 or the 6 failed satellites from that tranche; nor does it address whether more of those original 60 v0.9 satellites have failed.[63]

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61 *May 15 Letter*, at 4-5.

62 *See 2020 Annual Report*, at 1.

63 As of June 23, 2020, SpaceX had launched a total of 538 spacecraft, excluding the Tintin A and B test satellites. The June *2020 Annual Report* describes the status of 478 satellites launched "over the past year." SpaceX

Another way to look at this data, subject to the caveats above, is summarized in Table 4 below, which includes only the failures at altitudes "above injection" that SpaceX has reported to date:[64]

6 of 60 v0.9 satellites failed	10% failure rate
6 of 360 v1.0 satellites failed	1.7% failure rate
9 of 478 v1.0 satellites failed	1.9% failure rate
12 of 420 v0.9 & v1.0 satellites failed	2.9% failure rate
15 of 538 v0.9 & v1.0 satellites failed	2.8% failure rate

Table 4: SpaceX's Reported Failures as of June 23, 2020

The recently-disclosed upward failure-rate trend in the v1.0 design, from 1.7% to 1.9%, is troubling not only on its face, but also for the reasons discussed in Section II.B., below. Moreover, SpaceX has not actually achieved a "dramatic improvement" in the failure rate of its satellite maneuverability capabilities, as it claims.[65]

viii. *Space's experiential failure rates alter the collision risk analysis*

SpaceX's *May 15 Letter* describes its failed satellites as "non-maneuverable" and explains that they will be "passively de-orbited."[66] This statement suggests that SpaceX has lost control of these satellites. The inability to conduct active collision avoidance maneuvers means that failed satellites become a collision risk in their own right within the Starlink constellation,

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previously launched 60 satellites on May 24, 2019. The *2020 Annual Report* on failed satellites excludes satellites listed as numbers 1-6 that were included in the *May 15 Letter*, commences with spacecraft originally listed as numbers 7-12 in the *May 15 Letter*, and adds three more satellites listed as new numbers 7, 8 and 9.

64 *2020 Annual Report,* at 2, Table 1; *May 15 Letter* at 5, Table 2.

65 *May 15 Letter,* at 4.

66 *Id.*

with other constellations, and with existing orbital debris. Notably, this also means that (i) SpaceX is no longer able, as required, to coordinate the physical operations of the failed SpaceX satellites with other NGSO systems at similar orbital altitudes, and (ii) that those SpaceX satellites now pose an actual collision risk to other satellites in the same orbital region.[67] These risks are real. The Commission is already aware of the September 2, 2020 near-miss between one of the first 60 SpaceX satellites (which batch had a reported 10% loss of maneuverability capabilities) and an ESA satellite.[68]

SpaceX's statements on satellite failures alone are worthy of investigation by the Commission. Moreover, in the modification application, SpaceX disregards the fact that over a dozen of its satellites have already failed on-orbit (above injection) and simply asserts that reliability is expected to improve over time,[69] even though the available data indicates that the failure rate is trending upward, and even though the recent 1.9% failure rate for a number of satellites will likely grow over time because (i) their performance was measured very early in the satellite design lifetime, (ii) their performance can be expected to degrade over time, and (iii) 58 of the satellites in that group had not yet been tested.[70] Furthermore, even though its June 23, 2020 Annual Report provides material additional information with respect to the Commission's May 6, 2020 inquiry in this very proceeding, Viasat has seen no indication that Annual Report was filed in the docket of this proceeding.

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67 *SpaceX Initial Authorization,* at ¶ 11; *SpaceX First Modification Orde*r , at ¶ 22.

68 *See* Jonathan O'Callaghan, "*SpaceX Declined to Move a Starlink Satellite at Risk of Collision With a European Satellite*," Forbes, Sep. 2, 2019.

69 *See* Application, at 5.

70 *See supra,* pp. 14-16 (explaining that 1.9% is the absolute minimum failure rate for these 478 satellites, because they were at the very early stage of their 5-year design life when failures were assessed, and an additional number will fail during the significant remainder of their 5-year design life).

These developments raise several important questions that SpaceX should answer. What is the status of the currently non-maneuverable Starlink satellites? Are they in a predictable demise pattern? Are they actually non-operational? Are they orbiting in an uncontrolled manner? Has SpaceX determined what caused the anomalies that led to the non-maneuverability of those satellites? If the loss of maneuverability was a result of a design or software flaw, what steps has SpaceX taken to address that issue in subsequent satellite production or software updates? Is there redundancy designed into the system(s) that failed and left these spacecraft non-maneuverable? Does SpaceX have any analysis, accelerated life testing results, sample tests, or any other way to assess reliability other than in-orbit failures? The Commission and the public, including other operators in space, have a right to know the answers to these important questions to ensure that the root causes of these failures are being addressed before additional satellites are launched that may have the same flaws. These issues are addressed further in Section II.B. below.

SpaceX's experiential failure rate provides notice that, without substantial improvements in the reliability of its satellites, a significant number of additional satellites in the approximately 10,000 still-to-be-launched can be expected to become uncontrollable objects (and possibly more of those already launched). Such failed satellites would have no ability to avoid each other, avoid other NGSO systems in or near the same orbital altitude, or avoid other uncontrolled objects, such as non-propulsive satellites and orbital debris. As reflected in Table 2 above, anywhere from a few hundred to a few thousand additional failed and uncontrollable satellites can be expected out of the 10,000 Starlink satellites to be launched.[71] Each of those

[71] Again, this number could be higher if SpaceX replenishes its fleet at a faster rate due to failures.

uncontrollable satellites would pose a continued risk of collision until their orbits naturally decay and the spacecraft enter the Earth's atmosphere. As discussed above, these risks simply are not accounted for in the orbital debris risk analysis that SpaceX has provided. The Commission should thoroughly examine this issue in the context of this modification application proceeding.

As to the amount of time that the natural or passive deorbit of these numerous failed satellites would take, SpaceX's claims are inconsistent. While SpaceX claims that lowering the altitude of the satellites will reduce the de-orbit time to "less than five years (even under worst-case assumptions) to de-orbit,"[72] this assertion is not supported by Figure A.11-1 (Demise Time at Various Altitudes) in the modification application.[73] That figure clearly shows that at the highest proposed altitude of 570 km, the demise time exceeds 5 years for the "ADCS failure, solar low" case. That claim and figure also contradict SpaceX's separate claims in its *May 15 Letter* that its failed satellites "at the highest operational orbits will passively de-orbit in under two years on average,"[74] and in its *2020* Annual Report that those satellites that fail in operational orbit at 550 km "will passively de-orbit in under two years on average."[75] Again, these contradictory and inconsistent statements are among many reasons to call into question the credibility of SpaceX's many claims about the science experiment that is Starlink.

ix. *Material questions about the reliability of SpaceX's maneuverability capabilities remain unanswered*

Other critical issues that impact the effectiveness and reliability of Starlink spacecraft maneuverability and that are not addressed in the modification application include:

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72 Application, at 7.

73 Application, Attachment A, at 20.

74 *May 15 Letter,* at 4.

75 *2020 Annual Report,* at 1.

- How the system is designed to respond in circumstances that affect the ability to command collision avoidance maneuvers, such as when a spacecraft loses power, and when contact is lost with a spacecraft.
- Whether an automatic initiation of disposal occurs when communications with a spacecraft otherwise cease or become limited.
- The reliability of command link connectivity with the spacecraft.
- To the extent the satellites are to be maneuvered autonomously, the integrity of the database used and the security of the associated network.

In this respect, it bears emphasis that in most satellite systems, given the catastrophic results of a potential loss of control of the spacecraft, backup systems are built into the spacecraft to ensure redundancy in the case of loss of the primary command link. It is not clear how, if at all, SpaceX has addressed this issue in the Starlink system, or what happens when command links fail. SpaceX should be required to explain its plan when there is a loss of the command link.

B. SpaceX's experiential spacecraft failures warrant investigation and rigorous Commission oversight going forward

Particularly in a case like this, where an applicant's prior assurances in its applications have not matched the reality of system implementation, there is no basis for making licensing decisions on the types of unsubstantiated assertions made in the modification application. In fact, as detailed below, compelling reasons exist to examine the prior assurances on which SpaceX's existing authority is based.

i. *Material discrepancies exist between assurances made in SpaceX's various applications and the actual implementation of the Starlink system*

The Starlink licensing proceeding is replete with statements about how SpaceX intends to design and operate its large constellation in a manner that would avoid collisions with active satellites and orbital debris, and that otherwise would ensure a safe space environment.[76] The modification application includes similar assertions.[77] As detailed below, the actual implementation of Starlink appears to tell another story.

Before turning to that, it is important to understand what specific assurances SpaceX provided in order to obtain a grant of its initial authorization. In 2017, the Commission asked SpaceX to provide more information before its then-pending application could be processed further:

> Please provide an analysis of collision risk, assuming rates of satellite failure resulting in the inability to perform collision avoidance procedures of 10, 5 and 1 percent. This analysis should include *a study performed assuming all failures occur at the mission altitude,* but may also include additional studies specifying alternative assumptions concerning the orbital locations (such as injection altitude) at which failures might occur.[78]

In response, SpaceX provided the following assurances:

- "*Each satellite will include redundancy for critical components, as well as other attributes that enhance reliability and survivability*."[79]

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[76] *See, e.g.,* Space Exploration Holdings, LLC, SAT-LOA-20170726-00110 (filed July 26, 2017), Attachment A, at 25 (SpaceX's launch and space experience provides the *knowledge base for implementing an aggressive and effective space-debris mitigation plan*."), and at 27 ("SpaceX takes seriously the responsibility of deploying large numbers of satellites into space, and *intends to exceed best practices to ensure the safety of space*.") (emphasis supplied in each case).

[77] *See, e.g.,* Application, at iii ("SpaceX has repeatedly made clear that it *intends to conduct active maneuvers to avoid collisions* with both debris and other spacecraft throughout the life of its satellites."), at 10 ("SpaceX Will Avoid Collisions with Non-Propulsive Small Satellites and Already Employs the *Most Aggressive Collision Space Traffic Management in the Industry*) and at 11 ("SpaceX has made clear that it *intends to conduct active maneuvers to avoid collisions* with both debris and other spacecraft throughout the life of its satellites, *even though the de-orbit phase* until the spacecraft enters the atmosphere.") (emphasis supplied is each case).

[78] Space Exploration Holdings, LLC, IBFS File No. SAT-LOA-20161115-00118, Call Sign S2983, Letter from Jose P. Albuquerque, Chief, Satellite Division, FCC, to William M. Wiltshire, Counsel to SpaceX (March 21, 2017), at 1 (emphasis supplied).

[79] *April 20 Response,* at 4 (emphasis supplied).

- "Having taken such steps to reduce the risk of collision or malfunction, SpaceX views satellite failure to deorbit rates of 10 or 5 percent as unacceptable, and even a rate of 1 percent is unlikely."[80]
- "SpaceX *will construct its spacecraft to specifications and tolerances designed to ensure that failure rates are nowhere near the [1, 5 or 10 percent] levels postulated in this question.*"[81]
- "SpaceX will deploy its spacecraft incrementally over a long period of time" and "in the unlikely event that an unforeseen circumstance arises, *SpaceX would be able to defer further deployment until the problem has been identified and corrected before resuming launch of subsequent spacecraft*."[82]
- SpaceX "will continue to explore new technologies and implement upgrades in an iterative process to *ensure that its satellites are highly reliable* – a necessity not only for maintaining the continued safety of space, but also for delivering a high-quality service. SpaceX already has substantial experience engaging in such a process of continued improvement with its Dragon capsule, and this ongoing review would likely expose and correct any latent defect in system design. *This would enable SpaceX not only to avoid launching any more problematic spacecraft, but also to de-orbit any spacecraft already in orbit identified as at risk for similar issues.*[83]
- "In addition, unlike operators with a small number of large satellites, SpaceX's incentives to maintain the overall health of its constellation align well with SpaceX's and the Commission's goals of ensuring the continued safety of space."[84]

SpaceX also referred to the Commission's "assum[ed] satellite failure rate of 1 percent at mission altitude" as "unlikely" and said that its failure rate would be "nowhere near" that level.[85] SpaceX urged the Commission to make this very same type of inquiry to all NGSO applicants "to ensure that all systems that serve the U.S. meet the same high standard."[86]

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[80] *Id.*

[81] *Id.* (emphasis supplied).

[82] *Id.* at 5 (emphasis supplied).

[83] *Id.* (emphasis supplied).

[84] *Id.*

[85] *Id.* at 4.

[86] *Id.* at 7.

More generally, in the context of that very same proceeding, SpaceX stated that it "*intends to incorporate the material objectives set forth in this application into the technical specifications established for design and operation of the SpaceX System*."[87] As evidenced by the SpaceX failure rate detailed above, SpaceX's objective of meeting better than a 99% level of reliability has not been achieved in practice. In particular, SpaceX has disclosed that (depending on what satellites are included) approximately 2% to 3% of its satellites are "non-maneuverable," requiring that they "passively de-orbit."[88] As also discussed above, with this failure level, hundreds, if not thousands, of Starlink satellites can be expected to become uncontrolled objects and thus a source of unmitigated collision risk at operational orbit for many years.[89]

With the recent revelation that the actual failure rate of the Starlink satellites is 2x to 3x worse than the level that SpaceX deemed "unlikely" and said it would be "nowhere near," it should be apparent that what was promised at the Starlink application stage has not become reality. The design of SpaceX's implemented system in no way can be said to be achieving the expected performance that underpinned the grant of prior Commission authority. Only SpaceX can explain what changed along the way.

ii. *Public statements raise material doubts that SpaceX is honoring its commitments to the Commission*

A variety of statements that SpaceX has made strongly suggest that it is relying more on the ability to dispose of failed satellites, than designing them to be reliable in the first instance, as SpaceX assured the Commission it would do.

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87 Space Exploration Holdings, LLC, IBFS File No. SAT-LOA-20170726-00110 (filed July 26, 2017), Attachment A, at 25 (emphasis supplied). The subsequent grant of authority covered both this application and the one denominated IBFS File No. SAT-LOA-20161115-00118. *See SpaceX Initial Authorization*, at 1 n.1.

88 *See supra* pp. 21-22.

89 *See supra* pp. 15-16.

An STA request filed in April 2019 provides some insight into how SpaceX is really approaching spacecraft reliability.[90] In seeking STA for launch and early operations authority, SpaceX relied upon the need to "enhance the safety of space," explaining that the STA:

> would allow SpaceX to confirm the operational status of its satellites immediately upon insertion, *rather than waiting weeks while the satellites are orbit raising to ensure proper functioning*. This testing would yield a number of public interest benefits. For instance, SpaceX could act quickly in the unlikely event of a performance issue with one of its spacecraft *to identify and correct the problem even before the satellite reaches operational orbit*.

This strongly suggests an intention to employ a process of "weeding out" failed satellites at the injection orbit stage by deorbiting them without reporting the failures, particularly when considering that SpaceX has very carefully reported only those failures occurring "above injection altitude."

Indeed, SpaceX's recent reports on its satellite failures provide further reason to ask SpaceX if it indeed is relying on an approach based more on disposability than reliability. As noted above, SpaceX's 2020 Annual Report on "space stations not available for service" does not report on failures at injection orbit, but rather explains that satellites that fail at deployment in injection orbit "will demise in less than a month."[91] And in response to a question about "whether any of the satellites launched to date have permanently lost maneuver capabilities," SpaceX emphasizes its plan to "upgrade its satellites to drive reliability of the fleet throughout the license term as it de-orbits and replaces older satellites with upgraded models."[92]

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[90] Space Exploration Holdings, LLC, IBFS File No. SAT-STA-20190405-00023 (filed Apr. 5, 2019).

[91] *2020 Annual Report,* at 1; *see also May 15 Letter,* at 4-5.

[92] *May 15 Letter*, at 4-5.

An even more frank discussion of SpaceX's approach to disposability and reliability occurred in a recent Reddit "Ask Me Anything" session featuring SpaceX's software team. When asked about the redundancy strategies SpaceX employs, the company compared and contrasted its approach to Dragon and Starlink:[93]

- *On Dragon, we have a lot of redundancy on the hardware side (multiple computers, sensors, actuators, etc* [sic]*)* but also employ software to handle responses to faults. NASA requirements are such that our vehicle must be 2 fault tolerant (ie [sic], capable of being safely retreating from the space station and/or returning home safely for crewed vehicles) so we do both analysis and testing to ensure we meet this fault tolerance.

- *On Starlink, we've designed the system so that satellites will quickly passively deorbit due to atmospheric drag in the case of failure (though we fight hard to actively deorbit them if possible). We still have some redundancy inside the vehicle, where it is easy and makes sense, but we primarily trust in having system-level fault tolerance: multiple satellites in view that can serve a user.* Launching more satellites is our core competency, so we generally use that kind of fault tolerance wherever we can, and it allows us to provide even better service most of the time when there aren't problems.

Those statements speak volumes about the Starlink design: the primary strategy appears to be (i) disposability and replaceability (*i.e.*, redundancy in large numbers of satellites), rather than (ii) reliability and safety. Moreover, the redundancy needed to ensure *reliability* is employed where it is "easy."

In addition to these inconsistencies with the assurances that formed the basis for the grant of SpaceX's original application, it bears emphasis that many questions remain unaddressed and much information remains to be provided:

- SpaceX has not explained (i) the root cause(s) of its satellite failures, (ii) whether the promised redundant components were not included or did not work, or (iii) why it has experienced failure rates 2x to 3x the level that it assured the Commission were "unlikely" and that its satellites would be "nowhere near."

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[93] *See* https://www.reddit.com/r/spacex/comments/gxb7j1/we_are_the_spacex_software_team_ask_us_anything/ (last visited July 12, 2020) (emphasis supplied).

- SpaceX does not indicate that it ever "defer[ed] further deployment until the problem has been identified and corrected before resuming launch of subsequent spacecraft," even though at least 10% of its initial launch of 60 "v0.9" spacecraft "lost maneuverability."
- SpaceX has not disclosed the overall failure rate of its satellites, including those that failed at injection orbit, even though infant mortality (*i.e.*, early failure) is often a predictor of future failures.[94]

iii. *The Commission should investigate the circumstances surrounding SpaceX's failures, require operational and performance data, and suitably condition any resulting grant of authority*

As an initial matter, and discussed above,[95] circumstances such as these, where the reality of implementation does not match what was promised in an application, are the cases where the Commission should no longer make simplifying assumptions when processing an application about maneuverability capabilities and the associated risk of collisions with large objects.[96]

Moreover, these circumstances call for the Commission to take the types of more significant actions it indicated it would take when becoming aware of information that materially departs from assurances made at the application stage:

> The Commission could also require reporting as a result of information that comes to the attention of the Commission during the licensee's operations. In appropriate circumstances, the Commission could subsequently modify the license in accordance with Section 316 of the Communications Act *to address a rate of failure that departs materially from the expected reliability level, since that departure would affect the public interest assessment underlying grant of the license*.[97]

By way of example, the Commission should take the actions discussed in the following sections.

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[94] *See infra*, p. 34.

[95] *See supra,* pp. 14-16, 21-25.

[96] *See 2020 Orbital Debris Order and FNPRM,* at ¶ 35.

[97] *Id.* at ¶ 99 (footnotes omitted) (emphasis supplied).

a. Investigate the circumstances surrounding SpaceX's failures

Before processing this modification application further, the Commission should (i) investigate the issues discussed above in this Section II.B., including the apparent inconsistencies between SpaceX's assurances made at the application stage and the manner in which it is actually implementing Starlink, and also (ii) require SpaceX to answer the unaddressed questions, and provide the missing formation, detailed above.[98]

b. Require operational and performance data

The Commission also should require SpaceX, going forward, to provide actual operational data, to ensure that the reality of operating the Starlink NGSO system is consistent with the assurances made much earlier in its applications. In particular, a suitable spacecraft reliability analysis requires a baseline and subsequent operational performance data to develop the desired confidence in observing an appropriate level of failure-free in-orbit operations.

To state the obvious, and as calculated above,[99] when an estimated 10,000 (or more) spacecraft are to be operated over a license term, actual failure rates of spacecraft maneuvering capability must be kept very low in order to achieve a satisfactory, low large-object collision probability metric. Keeping these failure rates low includes ensuring the continued functioning of propulsion and satellite communications/command systems, and also ensuring the sufficiency of propellant.

- As shown above, individual satellite failures can evidence that an NGSO operator actually will not be able to meet the requisite large-object collision probability metric.
- The higher replenishment rates required after anomalous failures can alter the collision probability assessment on which the Commission originally issued an authorization (*i.e.,* more total satellites required in the constellation over 15 years)

98 *See supra,* pp. 24, 26, 31-32.

99 *See supra,* pp. 13-17.

- Failure can manifest itself in a variety of ways, including at injection orbit or during orbit raising, spacecraft maneuvering and station-keeping anomalies, and spacecraft that do not achieve stated mission life. Early failure may signal long-term reliability problems with other spacecraft in the constellation using similar designs or components, or those manufactured, tested or launched in the same lot.
- Early failure can be a "red flag" that expectations are not being met, and that suitable adjustments are required before more spacecraft are launched.
- The failure of a spacecraft to achieve the 5-year design life described in the applications similarly is a sign that expectations are not being met.
    - In this case, the SpaceX failures warrant further examination of the reliability assured at the application stage.
- Simply deorbiting failed satellites does not excuse or explain the cause of anomalous failure rates, or provide any assurance that other satellites of the same design will not fail later.

The Commission also should require SpaceX to timely submit data about spacecraft flight and performance that is relevant to assessing its ability to maneuver its satellites effectively, including:

- Spacecraft maneuvering failure and anomaly rates (*e.g.*, any failure to orbit raise).
- Original reliability predictions for all of the Starlink satellite already launched.
- Failure to maintain spacecraft communications and control.
- Unexpected in-orbit maneuvers, such as plane changes and phasing, including any maneuvers not in accordance with plans notified to the Commission in advance.
- Failure to maintain orbits within specified limits.
- Failure to maneuver to avoid pending conjunctions.
- A statistically anomalous record of exceptionally high-risk conjunctions.
- Failure to meet stated design life.

Only by taking these kinds of measures in light of the Starlink deployment thus far can the Commission ensure that improvements in spacecraft reliability occur and that a safe space environment is maintained for all.

c. Condition any further grants of authority

Viasat further urges the Commission, in any grant of authority that eventually may issue with respect to Starlink, to impose conditions to enable verification that SpaceX meets its commitments and obligations when deploying and operating its spacecraft, including:

- Conditioning any license grants on achieving periodic, statistically valid, in-orbit assessments that SpaceX will meet appropriate reliability and collision probability metrics over the license term.
- Requiring that the likelihood of satisfying such reliability and collision probability metrics going forward initially be verified by successful operation of a statistically significant portion of any additional satellites launched as part of the Starlink constellation, and conditioning the authority to launch additional satellites in that constellation on satisfying suitable operational showings.

Taking these actions would allow the Commission to obtain a level of confidence that the entire Starlink constellation will meet the required level of reliability and satisfy a suitable collision probability metric.

Doing so is especially important because changes in the space industry are removing incentives to achieve safe-space operations that previously existed. The cost of launch is dropping precipitously. Economies of scale that enable small, inexpensive payloads are driving investment in inexpensive and disposable spacecraft. When the cost of space is high, self-interest motivates high standards of care because the cost of failure is high. The term "space-qualified" once meant the industry's highest standards for quality and reliability, even in the harsh conditions of space. Those high costs and risks once fostered a safe space ecosystem, because the number of objects in space was limited, and the tools to manage them were adequate. With economic barriers gone, self-interest and the public good are quickly diverging. The cost of failure to an individual actor is far, far less than the collective risk of multiple individual failures – a long-anticipated "tragedy of the commons" in space.

The Commission discussed these very concerns in one of the still-pending rulemakings on which SpaceX's existing authority remains conditioned:[100]

> From an economic perspective, the earth orbital region of space can be viewed as essentially a "commons" …. A significant and fundamental problem with economic commons is the tendency of individuals to exploit the commons in a manner that is unsustainable long term and diminishing the usefulness for others. *In the context of the earth orbital environment, operators have an incentive to maximize the use of orbital resources for their own gain, which may result in an unsustainable level of activity for long term use of the same orbits.* … [O]nce a satellite reaches its end-of-life or otherwise ceases to operate, for example, it will become a piece of debris, posing a risk to the safe operations of other existing and future satellites.
>
> Debris generation by on-orbit activities is a negative externality, and is one which could lead to the degradation of the commons of the Earth orbital environment. Some unique, relevant aspects of debris include the fact that, particularly at higher orbits, the debris population will not naturally decrease with time even if no additional objects are launched into orbit, and that over time existing pieces of debris will tend to collide with other existing pieces of debris producing a "cloud" of debris which increases the likelihood of future collisions. *While the debris problem is a significant consideration for the long-term use of orbital resources, such considerations may not play a significant role in economic decision making in the short-term.* Individual satellite operators may have an interest in preserving the earth orbital environment for their continued operations, but a desire to avoid the short-term costs associated with deorbiting satellites to mitigate debris risk could override those long-term interests. *Given these incentives, in the long term, the debris population is likely to continue to grow and could result in an exponential increase in the debris population such that use of certain valuable orbital configurations may no longer be economically feasible.* This tendency of debris to generate yet more debris has come to be known as the "Kessler syndrome," a cascade in which so much debris is created that certain orbits can become unusable for decades or centuries, if ever.[101]

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[100] *SpaceX Initial Authorization*, at ¶ 40(r) ("This authorization is subject to modification to bring it into conformance with any rules or policies adopted by the Commission in the future. *Accordingly, any investments made toward operations in the bands authorized in this order by SpaceX in the United States assume the risk that operations may be subject to additional conditions or requirements as a result of any future Commission actions.*") (emphasis supplied); *SpaceX First Modification Order*, at ¶ 32(q) ("This authorization is subject to modification to bring it into conformance with any rules or policies adopted by the Commission in the future."); *Space Exploration Holdings, LLC, Request for Modification of the Authorization for the SpaceX NGSO Satellite System*, Order and Authorization, 34 FCC Rcd 12307 (2019), at ¶ 19(r) ("This authorization is subject to modification to bring it into conformance with any rules or policies adopted by the Commission in the future.").

[101] *Mitigation of Orbital Debris in the New Space Age*, Notice of Proposed Rulemaking, 33 FCC Rcd 11352 (2018), at ¶¶ 88-89 (emphasis supplied).

The risks about which the Commission expressed concern in November 2018 are now evidenced by SpaceX's approach to disposable spacecraft detailed above, under which (i) a "safe space" approach that requires careful engineering, rigorous testing, and space-qualification to ensure reliability over the design life of a spacecraft, would give way to (ii) a "system-level" fault tolerance that relies on launching more satellites to address failures, and deorbiting the disposable spacecraft. The "safe space" approach is good for the industry, as it facilitates competition, equal access to space, and choice for consumers. The SpaceX "system level" approach effectively results in a short-to-medium-term littering of space, and a negative externality that adversely affects others—a tragedy of the commons.

C. Interference issues

i. *SpaceX has not demonstrated the absence of significant additional interference from its proposed modified system*

In addition to the continued risks to safe flight discussed above, the proposed SpaceX modification presents significant risks of interference into GSO networks and NGSO systems that SpaceX has not addressed or mitigated. First, SpaceX has not shown that it will heed the EPFD limits that are designed to protect GSO networks from interference. Second, SpaceX has not shown that its operations would stay within the operating envelope with respect to other NGSO systems as defined by its initial 2018 authorization.[102]

Based on the analysis below, SpaceX has not met the burden of the *Teledesic* case,[103] and it has failed to explain in the modification application how it will do so. Viasat provides the

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[102] *Space Exploration Holdings, LLC, Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, Memorandum Opinion, Order, and Authorization, 33 FCC Rcd 3391 (2018).

[103] *Teledesic LLC, Minor Modification of License to Construct, Launch and Operate a Non-Geostationary Fixed Satellite Service System*, Order and Authorization, 14 FCC Rcd. 2261 (1999) ("*Teledesic Order*").

following to demonstrate why the modification should not be granted and urges the Commission to require SpaceX to respond to the questions raised below.

ii. *EPFD compliance has not adequately been established*

In the modification application, SpaceX asserts that its "NGSO constellation, as modified, will comply with the applicable equivalent power flux-density ("EPFD") limits set forth in Article 22 of the ITU Radio Regulations."[104] To support its claims, SpaceX includes in Annex 2 graphical information regarding asserted compliance with the applicable limits of Article 22. Compliance with these limits is essential in order to protect GSO operations in both the Ku-band segments that SpaceX intends to use for service links, as well as the Ka-band segments that SpaceX intends to use for feeder links. There are at least four reasons to closely examine the validity of this certification and question the assumptions underlying it.

First, in a recent request for special temporary authority (STA), SpaceX has indicated that it seeks permission to operate at significantly higher power density levels than it previously intended to use.[105] Namely, during launch, SpaceX seeks authority for its satellites to transmit at power levels that are 9 dB, or at about eight (8) times, higher than the levels it otherwise is authorized. Notably, SpaceX has not presented any interference analysis with respect to this proposed power increase.

Second, in the same STA request, SpaceX has clearly articulated that it does not intend to satisfy the EPFD protection levels all of the time. Rather, "SpaceX will *during almost all operations* observe the applicable EPFD limits set forth in Article 22 and Resolution 76 of the

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104 Application, Attachment A, at 15 (A.8.1).

105 Space Exploration Holdings, LLC, IBFS No. SAT-STA-20200610-00071 (filed June 10, 2020), Narrative, at 1-2.

ITU Radio Regulations and the applicable power flux-density ("PFD") limits set forth in the Commission's rules and Article 21 of the ITU Radio Regulations."[106] This is a surprising statement from SpaceX. It is not entirely clear when SpaceX does not intend to comply with these limits or the extent or duration of the exceedances. SpaceX needs to provide more information on this issue.

Third, SpaceX requests that the Commission grant authority in a "modified license for communications during transition phases before and after reaching authorized positions."[107] Viasat recognizes the need "to perform TT&C functions during orbit-raising and de-orbit maneuvers" but is concerned by SpaceX's request to include broad authority "for testing of the Ku- and Ka-band communications payloads during the orbit-raising process," even "on a non-protected, non-harmful interference basis."

As SpaceX notes, "there are over 4,000 [active] satellites in the constellation with a design life of five years" and "it is likely that SpaceX will be engaged in launch and de-orbit activities on an ongoing basis."[108] Currently, SpaceX is proposing up to two launches per month of 60 satellites during each launch and there does not seem to be any end in sight. Moreover, SpaceX will likely need to perform TT&C functions with an untold number of additional satellites beyond the 4,408 active ones (*i.e.*, spare satellites, any failed satellites which it still can control, satellites in orbit-raising, and satellites in disposal orbits). SpaceX has made no showing these Ku- and Ka-band emissions can be made on a non-interference basis, nor has it defined "non-harmful" in its proposal to operate "on a non-protected, non-harmful interference basis."

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106 *Id.*, Narrative, at 1.

107 Application, Attachment 1, at 4.

108 *Id.*

This is a particular concern given SpaceX's apparent view that it can exceed ITU EPFD limits without risking harm to other systems.[109]

SpaceX has not provided any EPFD analysis or masks to show that this "testing" can be conducted on a non-interference basis with GSOs, any I/N analysis showing that this "testing" can be conducted without increasing interference with other NGSO systems, nor any analysis showing that this "testing" would not cause additional interference to terrestrial fixed services. Viasat has found no precedent for a system to operate any given satellite anywhere within ~250 km of the intended altitude (whether operational or injection). And, with thousands of satellites, each with tens to as many as one hundred active beams per satellite, the complete mitigation of interference into GSOs, other NGSOs, terrestrial, and airborne systems is hard to imagine.

Fourth, it is unclear from its modification application whether SpaceX is basing its EPFD certification on the "single entry" value of its NGSO system as a whole, or whether instead, SpaceX is seeking to aggregate the single-entry EPFD levels of each of the constituent ITU NGSO system filings that comprise "Starlink." When SpaceX requested its license from the Commission, it expressed the intention to operate under network filings made on its behalf with the ITU by the administrations of the U.S. and Norway. SpaceX said: "*Taken together*, these U.S. and Norway network filings encompass all the frequencies SpaceX proposes to use in this application."[110]

To the extent that SpaceX's EPFD certification is based on the filings of the U.S. and Norway being "taken together" with the EPFD levels from multiple ITU NGSO system filings,

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[109] *See* Space Exploration Holdings, LLC, IBFS No. SAT-STA-20200610-00071 (filed June 10, 2020), Narrative, at 2.

[110] Space Exploration Holdings, LLC, SAT-LOA-20170726-00110 (filed July 26, 2017), Attachment A, at 24-25 (emphasis supplied).

doing so would constitute an impermissible attempt to emit more power than allowed under the ITU or FCC rules by claiming single-entry status from two or more SpaceX-controlled NGSO filings used as part of the same NGSO system.

In the Ka-band alone, at least 23 separate NGSO satellite filings have been made on behalf of SpaceX, along with two other filings through Norway that exhibit near-identical technical characteristics to two of their U.S. counterparts. While SpaceX has previously stated its intent to bring into use all of its ITU filings, it has not provided any technical analysis or evidence to show that the Starlink system would be capable of meeting the Article 22 single entry EPFD limits if the Starlink system operates under more than one of these filings.

Clarifying this issue is critical to determining EPFD compliance. To illustrate the concern, consider the aggregate EPFD implications should only two separate SpaceX ITU filings (USASAT-NGSO-3B-R and STEAM-2) be brought into use, each in accordance with the technical parameters specified in the modification application.[111] Even assuming that the system described in each filing operates cooperatively to avoid mutual interference, the EPFD level increases to the point where the combined system would no longer fit within the Article 22 single-entry limits. Figures 1-4 below illustrate the concern. While these examples are for Ka-band downlink EPFD with a specific reference antenna, operating a NGSO system under multiple ITU filings is a concern in all bands and directions, and under all reference parameters.

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[111] The current technical characteristics in ITU filings USASAT-NGSO-3B-R and STEAM-2 are nearly identical.

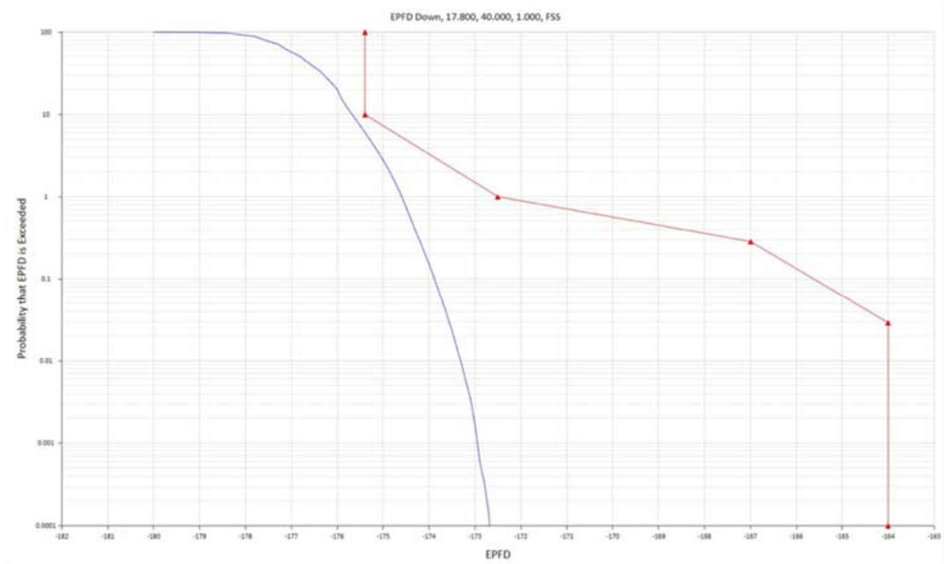

Figure 1: SpaceX EPFD down 17.8 GHz, 40 kHz, 1m FSS[112]

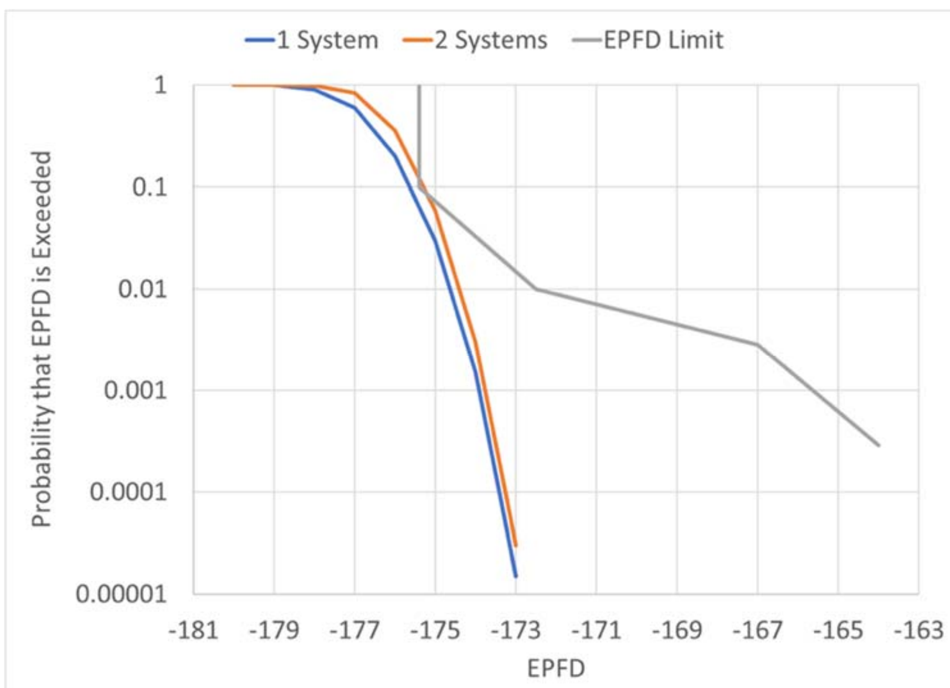

Figure 2: Same as Figure 1 with USASAT-NGSO-3B-R added

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112 Application, Attachment A, Annex 2, at A2-11.

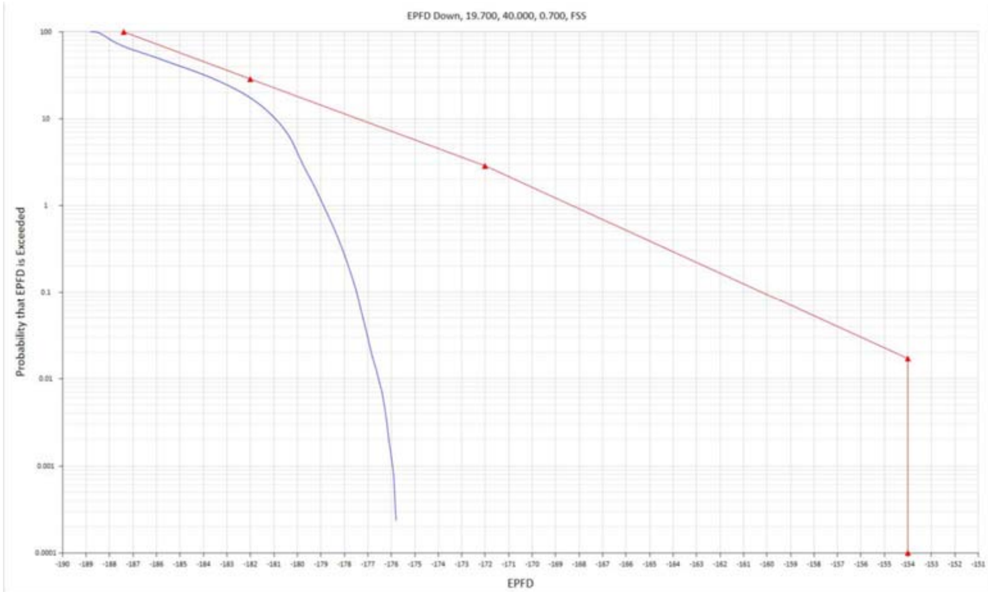

Figure 3: SpaceX EPFD down 19.7 GHz, 40-kHz, 0.7-m FSS

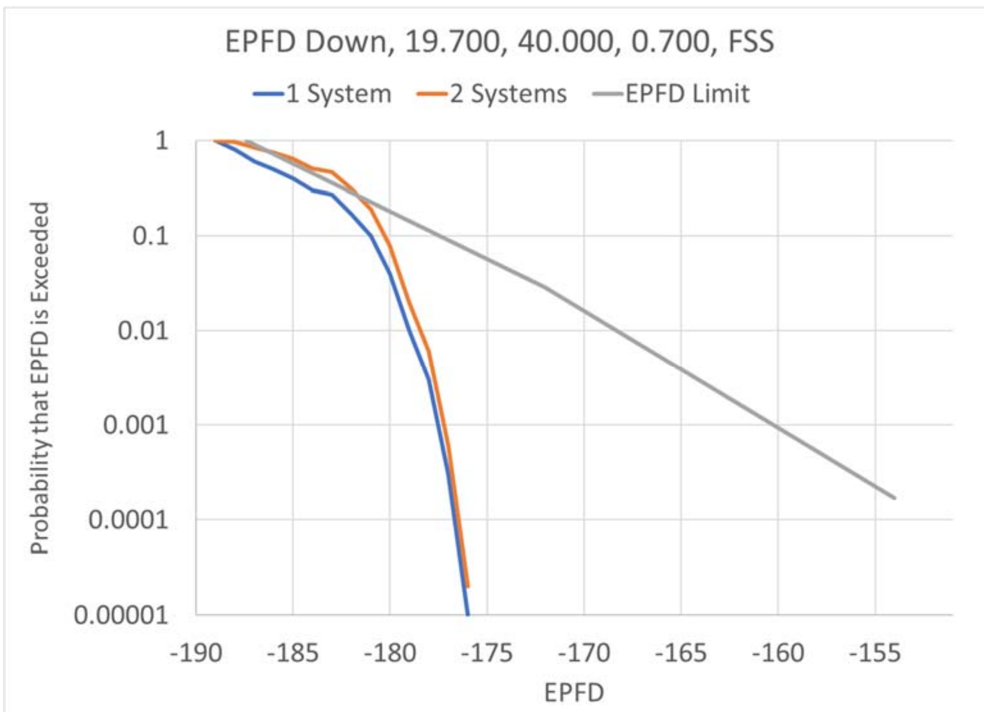

Figure 4: Same as Figure 3 with USASAT-NGSO-3B-R added

This initial analysis should be further expanded to consider the aggregate EPFD implications from the recent filings for 30,000 satellites made on SpaceX's behalf at the ITU in October 2019. If that analysis were undertaken, it may become even more evident why SpaceX should provide further technical analysis to demonstrate how it intends to attain EPFD compliance with ITU single entry EPFD limits for the Starlink system in accordance with ITU Radio Regulations and the Commission's requirements.

iii. *Potentially adverse changes in the NGSO-NGSO interference environment remain unresolved*

SpaceX addresses the potential for its proposed modification to increase the number of band splitting events with other NGSO systems authorized in the 2016/17 Commission processing rounds. Under the *Teledesic* decision, the Commission considers whether a modification would "create any significant interference problems to other systems or make sharing [with] other NGSO FSS systems significantly more difficult."[113] As reflected most recently in the *Viasat NGSO Authorization*, the determinative factor in a case such as this is "the number of times constellations will be required to reduce spectrum" as a result of the modification.[114]

In the modification application, SpaceX uses an analysis considering "the dynamic, time-varying interference expressed as a cumulative distribution function ('CDF') of the interference-to-noise ratio ('I/N'), for varying percentages of time."[115] Viasat agrees with SpaceX that such an analysis can be used to demonstrate that a proposed modification does not result in increased interference to other NGSO systems. Viasat also agrees that, in this case, the noise-dominated environment (I/N $\leq$ 0 dB) is the critical area for assessing harmful interference.

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113 *Teledesic Order,* at ¶ 7.

114 *Viasat, Inc., Petition for Declaratory Ruling Granting Access for a Non-U.S.-Licensed Non-Geostationary Orbit Satellite Network*, IBFS File Nos. SAT-PDR-20161115-00120, SAT-APL-20180927-00076, Order and Declaratory Ruling, FCC 20-56 (rel. Apr. 23, 2020), at ¶ 12.

115 Application, Attachment A, Annex 1, at A1-1.

SpaceX compares before (pre-mod) and after (post-mod) I/N CDF curves to demonstrate that the proposed modification does not increase interference, stating that "the new interference levels resulting with the modification are mostly less than (and at worst equal to) the interference levels that would have been experienced with the current constellation in the noise-dominated environment (*i.e.*, I/N ≤ 0 dB)."[116]

If this actually were the case, it would show that interference into other NGSO systems from the prior processing rounds has not increased. However, it appears that Figure A1-3. Downlink Comparison for Various Telesat Antennas at 75ºN (Ka-band) shows the opposite: in fact, interference would increase for the 55.4 dBi Telesat antenna.[117] This also appears to be the case in SpaceX's Figure A1-11. Uplink Comparison for Various O3B Antennas at 35ºN (Ka-band), this time for the 45 dBi O3B antenna.[118]

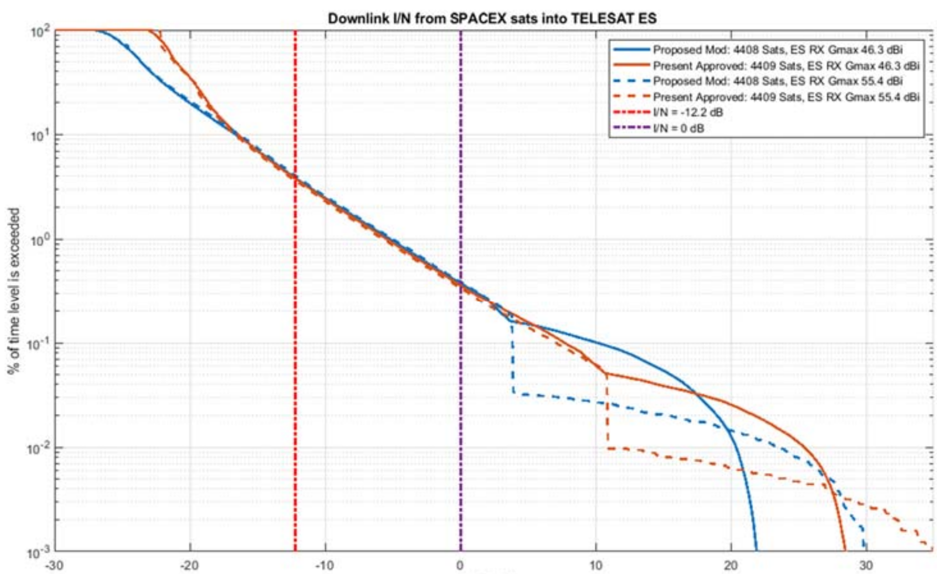

Figure A1-3. Downlink Comparison for Various Telesat Antennas at 75ºN (Ka-band)

[116] *Id.*

[117] Application, Attachment A, Annex 1, at A1-5.

[118] Application, Attachment A, Annex 1, at A1-9.

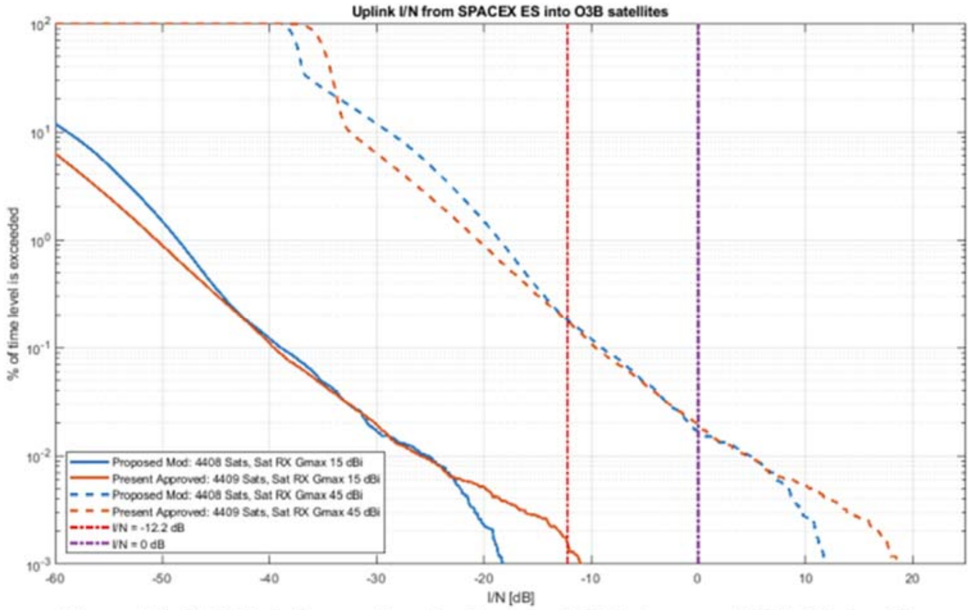

Figure A1-11. Uplink Comparison for Various O3B Antennas at 35ºN (Ka-band)

These figures from the modification application suggest that the proposed modification may result in some exceedances, but it is difficult to tell if that is just a result of the granularity of the figures provided. Therefore, Viasat requests that the Commission require SpaceX to file a table, similar to what Viasat provided in its recent modification application.[119]

Table E1-1. Probability of Exceeding 6% ΔT/T Threshold

Victim System	Uplink		Downlink	
	Current	Modified	Current	Modified
SpaceX Ka	0.691560	0.001775	0.276867	0.079498
SpaceX V	1.000000	0.005620	0.276320	0.078407
OneWeb	0.107556	0.000393	0.275247	0.081145
Telesat	0.005142	0.000295	0.276706	0.085481
O3b	0.000492	0.000182	0.300856	0.099939

119 Viasat, Inc., IBFS No. SAT-MPL-20200526-00056 (filed May 26, 2020), Exhibit B, Technical Annex, at 13.

D. Various other SpaceX claims do not bear scrutiny

SpaceX makes various unsubstantiated assertions throughout its application, seemingly in support of the public interest considerations that it believes are relevant. SpaceX's claims are unsubstantiated, do not bear scrutiny, and should not be used to justify the pending modification application.

SpaceX Assertion	Reality
Latency: SpaceX claims that the MOD will "accelerat[e] deployment of low-latency service to unserved and underserved Americans"[120] by providing service "to below 50 milliseconds."[121]	SpaceX does not substantiate this claim with any analysis or address the differences between the latency at the previous altitude and has never, to Viasat's knowledge, publicly demonstrated the ability to provide service to users with a latency under 50 milliseconds. Nor does SpaceX indicate whether this latency calculation includes all of the elements of the network from a user terminal, to an internet exchange point, and back to the user, consistent with the Commission's approach to measuring latency.
Hall-Effect Thrusters: SpaceX claims that it has demonstrated that the use of these thrusters has proven that they are capable of handling increased resistance at the lower altitude as a result of atmospheric drag.[122]	SpaceX does not explain how it has demonstrated this capability and should be required to provide the analysis as part of the technical certification of the modification application.
Coverage: SpaceX claims that operating at lower altitudes as proposed under the modification will "ensure that it has sufficient coverage to serve consumers, no matter where they are on Earth."[123]	The currently authorized SpaceX system already has the capability "to serve consumers, no matter where they are on Earth." The proposed modification is not required to do so.
Polar Region: SpaceX claims that the proposed modification will "move the satellites authorized to operate in polar orbits, which are similar to the orbits in which other large NGSO constellations hope to operate."[124]	SpaceX's licensed system has 1,225 satellites in high-inclination (greater than or equal to 70 degrees) orbits capable of providing service to polar areas. This modification is not required to provide polar service.

[120] Application, at 6.

[121] *Id.* at 7.

[122] *Id.* at 8.

[123] *Id.*

[124] *Id.* at 7.

Additional coverage: SpaceX claims that the proposed modification will allow it to serve customers in previously underserved and unserved areas particularly in polar regions.[125]	The currently-authorized SpaceX system already allows service to customers in previously underserved and unserved areas, including polar regions. The proposed modification is not required to do so.
Congestion in space: SpaceX suggests that one of the advantages of operating at lower altitude means that satellites will transit through fewer systems during orbit raising or end-of-life disposal.	The alleged gain is illusory. Satellites from other systems would now have to transit through the more-densely populated SpaceX orbits to get to their own orbital altitudes, and many would then have to transit back again through the SpaceX orbits to enter the Earth's atmosphere during end-of-life disposal.

III. CONCLUSION

As detailed above, SpaceX's modification application seeks a material change to its existing Starlink NGSO authorizations. The application raises fundamental issues with respect to space safety, shared use of space, and interference into other uses of the shared radio spectrum that must be resolved in the context of this proceeding, and not deferred to a rulemaking.

The recently-disclosed 2% to 3% failure rate of SpaceX's Starlink satellites, and evidence how Starlink actually is being implemented, raise serious issues that warrant investigation. Apart from calling into question the assurances SpaceX made during the licensing process, these reliability issues affect the collision risk presented by the modified constellation. As detailed above, the aggregate risk of collisions between the modified SpaceX constellation and large space objects would be *17 (seventeen) to 200 (two hundred) times* the probability that the Commission just proposed to apply to a large NGSO constellation as a whole.[126]

Moreover, these reliability issues raise the stakes associated with packing at least 10,000 Starlink satellites into densely-populated orbits that overlap with themselves, and with a number of other NGSO systems authorized (or to be authorized) by the Commission. When Starlink

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[125] *Id.* at 4.

[126] *2020 Orbital Debris Order and FNPRM,* at ¶ 159.

satellites fail, and an alarming percentage have, the loss of maneuverability renders them uncontrollable and a collision risk to themselves, active satellites, and the existing orbital debris in space. The Commission cannot assume any longer that coordination by SpaceX with other satellite operators would mitigate the risk of collisions.

Moreover, the modification application leaves unresolved a number of interference issues that go to the heart of the question whether this mega-constellation can effectively coexist and share the limited spectrum resource with other users, or whether it instead will end up monopolizing both physical access to space and effective access to radio spectrum.

The need to address all of these issues has never been more compelling that it is today. The Commission must investigate the issues surrounding SpaceX's failure rate, fully resolve the issues presented by its modification application, and exercise its authority to ensure appropriate and rigorous oversight over the Starlink system going forward. In doing so, the Commission should require the provision of ongoing operational data, and condition any grant of authority that the Commission ultimately may issue on the achievement and verification of appropriate reliability and collision probability metrics. Absent this approach, the consequences to safe space and the shared use of radio spectrum are too great.

Respectfully submitted,

/s/

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July 13, 2020

Exhibit 1

<u>The presence of a propulsion system does not ensure effective collision avoidance capabilities</u>

No basis exists to conclude that SpaceX would be able to meet the relevant collision probability metric merely based on the presence of a propulsion system or other maneuvering capability. Rather, it is critical that the effectiveness of proposed collision avoidance capabilities fully be evaluated as part of an application, and during actual operations.

- By way of example, propulsion systems sufficient for orbiting or de-orbiting may not be sufficient to avoid collisions generally or to do so over the entire orbital life.
    - The amount of propulsion needed to avoid a collision depends on many factors, including the amount of advance warning of the conjunction and the "cone of uncertainty" regarding the avoidance maneuver.
- The number of expected orbital maneuvers depends, among other things, on:
    - The mission (and orbital) life of the constellation.
    - The expected number of conjunctions with other systems—many of which are still to be launched but still must be accounted for in system design.
- The adequacy of the propellant onboard the spacecraft needed for expected avoidance maneuvers over orbital life may be greater than what is required for orbit raising or deorbiting alone.
- Recent failures of some small spacecraft that have lost communication capabilities, and a recent near-miss involving an operational small spacecraft and a larger one, further demonstrate that making any such assumptions is unwarranted.
- The design of the entire control system, communications chains, and response time must be evaluated.

An assessment at the application stage should take into account the following:

- The stated design life of the spacecraft.
- Nature and operational efficacy of the proposed means of collision avoidance during the stated intended mission life, including:
    - Whether the collision avoidance system is based on active detection or orbital data provided by others.
    - The response time of the collision avoidance system.
- Conjunction analysis for the constellation (*i.e.*, analysis of potential collision events), including:
    - The estimated number of conjunctions in increasingly congested orbits during the operation of the constellation.
    - The risk of maneuvering to avoid one conjunction event actually creating other potential collision events.
- Critical components and systems analysis.

    - The reliability of the underlying spacecraft components and control system used for collision avoidance, including factors such as:
        - The extent to which predicted reliability is based on suitable testing.
            - Established methods exist to ensure high reliability in space including reliability analysis under space conditions, parts screening and testing, ground testing, manufacturing process controls, and flight tests.
        - Experiential and projected failure rates of those critical components and systems.
        - Methods to ensure that the manufacturing process throughout the production of the constellation, as it is refreshed over time, is and remains appropriately rigorous.
        - As applicable:
            - The use of "off-the-shelf" or other parts not optimized for high levels of reliability in space.
            - The reliability risks associated with the mass production of spacecraft.
            - Constellation designs based on the use of "disposable" spacecraft designed to be replaced whenever they fail.
    - The resiliency of critical components and systems used for collision avoidance to collisions with small and medium-sized objects that cannot be tracked or avoided, such as fuel tanks, telemetry and command systems, thrusters, and flight computers.
        - The adequacy of any included redundancy to those critical components.
- Contingency planning.
    - How the system is designed to respond in circumstances that affect the ability to command collision avoidance maneuvers, such as when a spacecraft loses power, and when contact is lost with a spacecraft.
    - Whether an automatic initiation of disposal occurs when communications with a spacecraft otherwise cease or become limited.

DECLARATION OF MARK A. STURZA

I, Mark A. Sturza, hereby make the following declarations under penalty of perjury:

1. I am President of 3C Systems Company, which has acted as consultant to Viasat, Inc. ("Viasat") regarding the matters addressed in the foregoing Petition to Deny or Defer of Viasat ("Petition").

2. I have reviewed the Petition and certify that, to the best of my knowledge, information and belief, the factual assertions in the Petition are truthful and accurate.

3. I hereby declare that I am the technically qualified person responsible for preparation of the engineering information contained in the Petition, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted with the Petition, and that it is complete and accurate to the best of my knowledge, information and belief.

/s/

Mark A. Sturza
President
3C Systems Company

July 13, 2020

CERTIFICATE OF SERVICE

I, Elizabeth R. Park, hereby certify that on this 13th day of July, 2020, caused to be served a true copy of the foregoing Petition to Deny or Defer of Viasat, Inc. via first-class mail upon the following:

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/s/
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