SPACEX NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT A

TECHNICAL INFORMATION TO SUPPLEMENT SCHEDULE S

A.1 SCOPE AND PURPOSE

SpaceX's first-generation ("Gen1") non-geostationary orbit ("NGSO") Fixed-Satellite Service ("FSS") constellation of 4,408 satellites at altitudes ranging from 540 km to 570 km, even partially deployed, is currently providing high-speed, low-latency satellite broadband service to Americans throughout even the most remote corners of the country.[1] With this application, SpaceX seeks to expand and improve its ability to serve consumers in the United States and worldwide by upgrading its satellite hardware to feature new capabilities that were developed following the deployment and operation of its first 3,800 satellites. Notably, SpaceX seeks to deploy technological improvements developed for its second-generation ("Gen2") system,[2] to enable the operation of upgraded hardware at the same orbits, altitudes and inclinations as licensed under its Gen1 license.

Typically, NGSO operators are not required to seek modification authority for changes to satellite equipment. Indeed, the Commission's rules expressly provide that "technically identical" satellites "need not . . . have the identical physical structure or microelectronics."[3] Instead, the legally relevant parameters are those specifically required under Sections 25.114(c) and (d) of the Commission's rules, which set the contours of an operator's license while permitting necessary

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1 *See Space Exploration Holdings, LLC*, 36 FCC Rcd 7995 (2021) ("*Current Authorization*"); *see also Space Exploration Holdings, LLC*, 34 FCC Rcd. 2526 (IB 2019) ("*First Modification*"); *Space Exploration Holdings, LLC*, 34 FCC Rcd. 12307 (IB 2019) ("*Second Modification*").

2 *See Space Exploration Holdings, LLC*, FCC 22-91 (rel. Dec. 1, 2022).

3 *Amendment of the Commission's Rules to Establish Rules and Policies Pertaining to a Mobile Satellite Service in the 1610-1626.5/2483.5-2500 MHz Frequency Bands,* 9 FCC Rcd. 5936, ¶ 182 n.250 (1994).

changes to address technological advances, supply chain issues, or steps to further improve the resilience of satellites. In this case, SpaceX seeks a modification because the changes proposed herein affect some of the relevant licensing parameters.

This modification to the *Current Authorization* will meet all required protection criteria for other systems operating in the same frequencies, and causes no material overall increase in radiofrequency interference to other systems. The modification will meet or exceed all space safety requirements including the Commission's rules for orbital debris mitigation.

This attachment contains the updated technical information with respect to the newly proposed operations required under Part 25 of the Commission's rules that cannot be fully captured by the Schedule S software. The accompanying Schedule S reflects only the modest changes requested in this application—most of which have no effect on the satellites' characteristics captured in Schedule S. Accordingly, SpaceX has provided only the minimum information needed to allow it to input the parameters that would be changed by this modification. SpaceX requests no other technical changes to its authorization at this time, and certifies that all other technical information provided in its previous Ku/Ka-band applications, as modified, remains unchanged.[4]

A.2 OVERALL DESCRIPTION

This information is generally available in Attachment A ("Technical Information to Supplement Schedule S") to the Previous Applications. Based on SpaceX's success in deploying and operating the first 3,800 satellites in its Gen 1 constellation to provide high-speed, low-latency

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4 *See* 47 C.F.R. § 25.117(c). *See also* Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System, IBFS File No. SAT-LOA-20161115-00118 (Nov. 15, 2016); Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System Supplement, IBFS File No. SAT-LOA-20170726-00110 (July 26, 2017); Application for Modification of Authorization for the SpaceX NGSO Satellite System, IBFS File No. SAT-MOD-20181108-00083 (Nov. 8, 2018); Application for Modification of Authorization for the SpaceX NGSO Satellite System, IBFS File No. SAT-MOD-20200417-00037 (Apr. 17, 2020). These applications are referred to collectively herein as the "Previous Applications."

broadband service to American users, SpaceX now proposes a modification to enhance its ability to serve Americans, while maintaining the considerable space safety attributes of its NGSO constellation. Under the modification proposed herein, SpaceX seeks to deploy an upgraded satellite design at the same orbits, altitudes and inclinations as currently authorized under its Gen1 license. Table A.2-1 below summarizes the configuration of SpaceX's currently authorized NGSO constellation.

SpaceX Current Authorization					
Orbital Planes	72	72	36	6	4
Satellites per Plane	22	22	20	58	43
Altitude	550 km	540 km	570 km	560 km	560 km
Inclination	53°	53.2°	70°	97.6°	97.6°

Table A.2-1. Summary of Currently Authorized Gen1 NGSO Constellation

Consistent with the *Current Authorization*, SpaceX generally will continue to use a minimum elevation angle as low as 25 degrees for user and gateway beams, although certain shells may use lower elevations for gateway communications in certain circumstances, consistent with its current authorization. Because this modification will not alter these elevation angles, SpaceX hereby incorporates by reference the information provided in its Previous Applications.

A.3 PREDICTED SPACE STATION ANTENNA GAIN CONTOURS

The antenna gain contours for the transmit and receive beams for a representative space station operating at 540 km, 545 km, 550 km, 560 km, and 570 km are embedded in the associated Schedule S, as required by Section 25.114(c)(4)(vi)(B). The methodology for their presentation is described in Attachment A to the Previous Applications.

A.4 GEOGRAPHIC COVERAGE

The Commission has found that the Gen1 constellation, when fully deployed, will satisfy all applicable geographic coverage requirements.[5] The proposed modification will not alter that conclusion.

A.5 TT&C CHARACTERISTICS

A complete description of the SpaceX TT&C subsystem is provided with the Previous Applications.[6]

A.6 CESSATION OF EMISSIONS

This information is available in Attachment A to the Previous Applications.

A.7 COMPLIANCE WITH PFD LIMITS

SpaceX will not alter its maximum PFD levels in Ku- or Ka-band. SpaceX plans to continue operating its modified Gen1 constellation satellites in a manner that complies with PFD limits applicable under its *Current Authorization*. Information regarding PFD limits is available in Attachment A to the Previous Applications and in Schedule S attached hereto.

A.7.1 PFD Limits in the Ku-Band

This information is available in Attachment A to the Previous Applications and in Schedule S attached hereto.

A.7.2 PFD Limits in the Ka-Band

This information is available in Attachment A to the Previous Applications and in Schedule S attached hereto.

A.8 INTERFERENCE ANALYSES

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5 *See Current Authorization* ¶ 33.

6 *See, e.g.*, Previous Applications, Sections A3.3, A.5, and Schedule S.

The Commission has recognized that a proposed modification to an NGSO authorization should be granted where it "does not present any significant interference problems and is otherwise consistent with Commission policies."[7] In this case, the modification will not have any impact on other users of the Ku- and Ka-band spectrum. The new beams operate with narrower beamwidths and a PFD no greater than the existing beams, and therefore SpaceX's previous analyses continue to provide a conservative assessment of the potential for interference.

A.8.1. Interference with Respect to GSO Satellite Systems

Pursuant to Section 25.146 of the Commission's rules, SpaceX hereby certifies that its Gen1 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, which have been incorporated by reference into the Commission's rules.[8] The Commission's rules contemplate that, prior to initiation of service, the ITU Radiocommunication Bureau will issue a "favorable" or "qualified favorable" finding regarding the constellation's compliance with those EPFD limits.[21] When the Commission granted the *Current Authorization*, it waived the requirement that SpaceX receive such a finding from the ITU *prior to* commencing operations, but retained the requirement that SpaceX receive such a finding at some point and adjust its operations as necessary to satisfy ITU requirements, essentially allowing SpaceX to proceed only at its own risk.[9] SpaceX will continue to proceed on that basis.

A.8.2 Interference with Respect to Other NGSO Satellite Systems

SpaceX has engineered its system with technical flexibility that will facilitate the necessary coordination with other NGSO satellite systems and is committed to achieving mutually

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7 *Current Authorization* ¶ 8 (quoting *Teledesic LLC*, 14 FCC Rcd. 2261, ¶ 5 (IB 1999)).

8 *See* 47 C.F.R. § 25.146(a)(2).

9 *See Current Authorization*, ¶ 41.

satisfactory agreements. The new beams operate with narrower beamwidths and a PFD no greater than the existing beams, and therefore SpaceX's previous analyses continue to provide a conservative assessment of the potential for interference. This information is available in Attachment A to the Previous Applications and in Schedule S attached hereto.

A.8.3 Interference with Respect to Terrestrial Networks

The new beams proposed herein operate with a PFD no greater than the existing beams. Accordingly, SpaceX's previous analyses continue to provide a conservative assessment of the potential for interference. This information is available in Attachment A to the Previous Applications and in Schedule S attached hereto.

A.8.4 Interference and Coordination with Respect to the Radio Astronomy Service

This information is available in Attachment A to the Previous Applications. In addition, SpaceX and the National Science Foundation have entered into a coordination agreement to protect radio astronomy sites, and SpaceX will operate its modified system in compliance with that agreement. Among other things, this coordination agreement protects Radio Astronomy facilities listed in Footnote US131 to the United States Table of Frequency Allocations.[10]

A.8.5 Coordination with GSO FSS Earth Stations in the 10.7-12.75 GHz Band

This information is available in Attachment A to the Previous Applications.

A.9 COORDINATION WITH U.S. GOVERNMENT OPERATIONS

This information is available in Attachment A to the Previous Applications.

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[10] 47 C.F.R. § 2.106 n.US131.

A.10 ITU FILINGS FOR SPACEX

SpaceX does not anticipate that the modification proposed herein will require any modification to its ITU satellite network filings.

A.11 ORBITAL DEBRIS MITIGATION

An overview of orbital debris mitigation information is available in Attachment A to the Previous Applications. Although many of the new orbital debris mitigation rules have not yet gone into effect,[11] SpaceX herein demonstrates compliance with those requirements as further evidence of its commitment to space safety.

Through detailed and conscientious mission planning, SpaceX has carefully assessed and limited the probability of its Gen1 system becoming a source of debris by collisions with small/large debris or other operational space stations. It will maintain the accuracy of its orbital parameters at a level that will allow operations to minimize the risk of conjunction with adjacent satellites in the constellation and other constellations. SpaceX has worked and will continue to work closely with the 18th and 19th Space Defense Squadrons, LeoLabs, and other relevant agencies and operators to perform effective collision avoidance. SpaceX has and will continue to regularly engage with operators of active satellites and constellations to ensure safe and coordinated space operations.

A11.1 Maneuverability

SpaceX intends to continue to perform collision avoidance procedures, including conjunction assessment, execution of avoidance maneuvers and trajectory planning for any planned alteration of satellite trajectory, and notification to other potentially affected operators of

[11] *See Mitigation of Orbital Debris in the New Space Age*, 35 FCC Rcd. 4156 (2020) ("*Orbital Debris Mitigation Update Order*"); *Space Innovation*, FCC 22-74 (Sept. 30, 2022) ("*Five Year Deorbit Order*"). The information collection involved in those rules must be approved by the Office of Management and Budget.

changes in our satellites' abilities to perform collision avoidance maneuvers. SpaceX will perform conjunction screening and avoidance maneuvers for all phases of operations, including any planned alteration of satellite trajectory, prior to passive disposal, after initial on orbit checks are complete. For this purpose, SpaceX satellites will continue to plan and execute collision avoidance maneuvers any time their onboard collision probability estimate is above 1e-5 (i.e., 0.001 percent). Satellites in the current SpaceX constellation execute approximately 12 avoidance maneuvers per year, which is only possible because of SpaceX's investment in autonomous collision avoidance algorithms and supporting software. Each satellite will have sufficient propellant and capability to perform collision avoidance maneuvers for all phases of the satellite's mission.[12]

SpaceX certifies that upon receipt of a space situational awareness conjunction warning, it will take all possible steps to assess the collision risk, and will mitigate the collision risk if necessary. SpaceX will continue to innovate to further reduce collision risk. An example of effective innovation is our "duck-to-dodge" technique. SpaceX satellites now further reduce collision probabilities by reorienting the solar array and presenting the smallest possible surface area to oncoming secondary objects at the time of closest approach any time the probability of collision exceeds 1e-7 (i.e., 0.00001 percent). This attitude-only change allows SpaceX satellites to continue serving customers while effectively reducing collision probability by a factor of 10, further reducing the constellation level risk posture. As appropriate, steps to assess and mitigate the collision risk may include, but are not limited to: contacting the operator of any active spacecraft involved in such a warning; sharing ephemeris and covariance data, maneuverability

[12] SpaceX is targeting active de-orbit operations down to an altitude of approximately 300 km. SpaceX will reserve at least 70 m/s of delta-V – a measure of the impulse required for a given maneuver or, here, the capability to perform those maneuvers if necessary – to deliver the described de-orbit functionality. The 300 km target does not account for a fuel margin stack-up reserved for other uses. In the vast majority of cases, any remaining margin would allow satellites to expedite demise.

status, conjunction data messages and other appropriate operational information with any such operator; and modifying space station attitude and/or operations.

A11.2 Satellite Tracking

Prior to deployment, SpaceX will register its satellites with the 18th Space Defense Squadron (or a successor entity). Following deployment, SpaceX will identify its satellites using a network of ground stations located around the world that will establish contact with the satellites and rapidly provide accurate position and velocity estimates to aid in the cataloging and tracking of our satellites. SpaceX certifies that each of its space stations will have a unique telemetry marker allowing it to be distinguished from other satellites or space objects. Because SpaceX satellites are larger than 10 cm in their smallest dimension, they are presumed to be trackable.[13] Nonetheless, SpaceX satellites autonomously estimate their own position using GNSS and other sensors and regularly report that information to enhance active tracking and for use in collision avoidance screening. SpaceX will share information regarding initial deployment, ephemeris, and planned maneuvers with the 19th Space Defense Squadron (or a successor entity) and other entities that engage in space situational awareness or space traffic management functions. SpaceX also shares propagated ephemeris and covariance data with anyone who has a space-track.org account and we continue to work to eliminate all access barriers, ensuring every operator and every nation has unfettered access.

A11.3 Collision Risk

SpaceX will continue to conduct active maneuvers to avoid collisions with both debris and other spacecraft throughout the life of its satellites, even through the de-orbit phase and until the spacecraft enters the atmosphere. As the Commission has recognized, because SpaceX has

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[13] *See Orbital Debris Mitigation Update Order*, ¶ 58.

invested in advanced propulsion capabilities for its satellites, collision risk with large objects is considered to be zero while a spacecraft is capable of maneuvering.[14] While SpaceX expects its satellites to perform nominally and deorbit actively as described below, in the unlikely event a vehicle is unable to finish its planned disposal maneuver, the denser atmospheric conditions at the low altitudes used by the Gen1 FSS system provide fully passive redundancy to SpaceX's active disposal procedures.

The natural orbital decay of a satellite at our operational altitudes will take on average between two and four years—less than the five-year deorbit requirement recently adopted (but not yet in effect) and faster than our currently authorized satellites.[15] Due to the unique design of our spacecraft, SpaceX achieves a high area-to-mass ratio on its vehicles. Combined with the natural atmospheric drag environment at lower altitude, this high ratio ensures rapid decay even in the absence of the nominally planned disposal sequence. Thus, even assuming an extreme worst-case scenario—i.e., the spacecraft fails while in the operational orbit, has no attitude control, and solar activity is at a minimum—the expected decay time is under three years, which will more than satisfy the goal recently set by the Commission for safe operation of large constellations.[16]

Nonetheless, SpaceX's nominal disposal plan using circular deorbit, which it anticipates for every spacecraft, will result in a lifetime of less than 70 days after SpaceX initiates disposal, an advantage of operating at the low altitudes proposed in this application.

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[14] *See, e.g., Current Authorization* ¶ 58.

[15] *See Five Year Deorbit Order*, ¶ 18.

[16] *See id.* ¶ 19 and new Section 25.114(d)(14)(vii)(D)(1) (establishing a "goal, for large systems, of a probability of success for any individual space station of 0.99 or better" and defining successful disposal as "atmospheric re-entry of the spacecraft as soon as practicable, but no later than five years following completion of the mission"). This new rule requires review and approval by the Office of Management and Budget before it will become effective. *Id.* ¶ 35.

These short demise times significantly limit the risk of collision and the consequence of a collision in the event that a satellite loses maneuverability while in operational orbit. Table A.11-1 below shows the demise time and probability of collision between a space object larger than 10 cm in diameter and a system satellite as modified herein at each of the operating altitudes proposed herein, assuming that the satellite has lost all maneuver capability and attitude control (i.e., is tumbling), as determined using the most recently released version of NASA's Debris Assessment Software ("DAS").[17]

DAS 3.2.3 - > Mean for all years 2023 through 2033					
		Passive Decay Time (yrs)		Passive Decay Collision Probability	
	A:M ->	0.075	0.0735	0.075	0.0735
Altitude	Inclination (deg)	F9	SSP	F9	SSP
540	53.2	1.74	1.71	3.33E-04	8.69E-04
550	53	2.33	2.11	4.00E-04	9.77E-04
560	97.6	2.18	2.33	7.09E-04	1.85E-03
570	70	2.50	2.66	7.69E-04	1.94E-03

Table A.11-1. Demise Time and Collision Probability Assuming No Maneuver Capability On-Orbit

Of course, even these collision risk calculations present an overly pessimistic picture as the vast majority of SpaceX satellites will not fail in orbit and will continue to maneuver to achieve an effective collision risk of zero.

Moreover, due to SpaceX's decision to minimize risk by using a low injection altitude when possible,[18] in the unlikely event any satellites after the initial launch experience immediate

17 Table A.11-1 presents information for the proposed form factors of SpaceX Gen1 satellites, one of which will be launched initially on Falcon 9 rockets and one that will be launched on Starship. For convenience, these satellites are labeled as F9 and SSP, respectively. Note that to better reflect a non-maneuverable satellite in a tumbling deorbit a scaling factor of 0.5 has been applied to the area-to-mass ratios used with DAS.

18 SpaceX intends to inject satellites into an elliptical orbit of approximately 210 km by 370 km. Though it is possible that injection parameters may vary slightly in a small number of cases, the maximum altitude is not planned to be more than 370 km.

failure upon deployment, they would decay to the point of demise very quickly even under worst-case conditions. Table A.11-2 below shows the demise time and probability of collision between a space object larger than 10 cm in diameter and a SpaceX satellite if rendered totally incapacitated immediately following orbital injection.

	Inclination (deg)	Demise Time (yrs)	Collision Risk
F9 Stowed Configuration	53, 53.2	0.74	4.91E-06
	70	0.75	5.64E-06
	97.6	0.72	7.40E-06
F9 Deployed Configuration	53, 53.2	0.07	4.11E-05
	70	0.08	4.59E-05
	97.6	0.07	6.13E-05
SSP Stowed Configuration	53, 53.2	1.02	1.03E-05
	70	1.04	1.20E-05
	97.6	1	1.56E-05
SSP Deployed Configuration	53, 53.2	0.08	1.01E-04
	70	0.08	1.12E-04
	97.6	0.07	1.50E-04

Table A.11-2. Demise Time and Collision Risk Assuming Incapacitated Satellite at Injection

Here again, SpaceX satellites typically satisfy the Commission's safety standard by several orders of magnitude even assuming failure upon injection.

SpaceX is aware of its existing obligation to engage in good-faith coordination of physical operations with other NGSO systems,[19] and that process is well underway for the Gen1 system. SpaceX will continue to comply with this requirement. Based on its experience to date, SpaceX continues to believe that physical coordination should be practicable, facilitated by the

[19] *See Current Authorization* ¶ 65.

maneuverability of its system and its willingness to share information on the operations of its system. SpaceX will carefully coordinate physical operations to ensure that the Gen1 and other satellite systems can coexist safely.

SpaceX is also aware of the possibility that its system could become a source of debris in the unlikely case of a collision with small debris or meteoroids that could either create jetsam or cause loss of control of the spacecraft and prevent post-mission disposal. SpaceX has continued to explore ways to make its spacecraft even more resistant to such strikes. For example, SpaceX has improved redundancy in the power and propulsion systems. As a result, SpaceX has maintained an overall probability of collision with small debris (down to one millimeter in diameter) sufficient to prevent compliance with post-mission disposal maneuvers of less than 0.01 for an individual Gen1 space station (as modified) during its mission lifetime.

A11.4 Post-Mission Disposal

Each satellite in the proposed satellite constellation is designed for a useful lifetime of five to seven years. SpaceX intends to dispose of satellites through uncontrolled atmospheric re-entry at end of life. As discussed above, SpaceX anticipates that its satellites will reenter the Earth's atmosphere within approximately 70 days after completion of their mission under normal circumstances, and even in a worst case would de-orbit within five years. Accordingly, the probability of successful disposal of each SpaceX satellite as defined by the Commission is deemed to be 100%—surpassing the goal set by the Commission for large NGSO systems.[20]

A.11.5 Casualty Risk Assessment

Each spacecraft's predominantly aluminum construction and the extreme engineering efforts they have undergone ensure SpaceX satellites maximize the likelihood of atmospheric

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[20] *See* note 16, *supra*.

demise on re-entry. To verify this, SpaceX used NASA's DAS to perform a re-entry survivability analysis. This analysis confirmed that all satellites (as modified) are fully demisable upon atmospheric re-entry, and no components would be expected to survive to reach the Earth's surface with a kinetic energy in excess of 15 joules. Accordingly, the calculated risk of human casualty is zero.

ENGINEERING CERTIFICATION

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

/s/ *David Goldstein*

David Goldstein, PhD
Principal Engineer
SPACE EXPLORATION TECHNOLOGIES CORP.

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