ATTACHMENT B - TECHNICAL DESCRIPTION

Myriota is amending its petition for declaratory ruling to access the U.S. market using its non-voice, non-geostationary ("NVNG") mobile-satellite service ("MSS") system (the "Myriota System") of small satellites to provide low-power Internet of Things ("IoT") services in the 137-138 MHz (space-to-Earth) and 148-150.05 MHz (Earth-to-space) bands (the "*NVNG VHF Petition*").[1] This Technical Description provides the Federal Communications Commission ("Commission") with information regarding changes to the Myriota System as required by 47 C.F.R. §§ 25.116 and other relevant sections of Part 25 of the Commission's rules.

A.1 INTRODUCTION

Myriota intends to improve the Myriota System by: (i) using Spire Global, Inc.'s ("Spire") Low Earth Multi-Use Receiver ("LEMUR") 3U CubeSat platform, equipped with active propulsion, to increase reliability and space safety; and (ii) adjusting the system's orbital architecture including number of satellites, and certain operational parameters to provide more uniform coverage without increasing the potential for interference. Information regarding the satellites and updated orbital architecture is provided herein and in the attached Schedule S.[2]

This amendment does not involve changes to the Myriota NVNG VHF payload, the fundamental operational characteristics of which were described in the *NVNG VHF Petition*. As a result, this Technical Description focuses on use of the LEMUR 3U CubeSat and spectrum compatibility issues associated with adjusting the orbital architecture and number of satellites of the system.

A.2 THE MYRIOTA SATELLITE

A.2.1 General Description

The Myriota System will be comprised of LEMUR satellites manufactured by Spire. The satellite bus is technically equivalent to that of LEMUR 3U CubeSats previously licensed and granted U.S. market access by the Commission.[3] Myriota hereby incorporates by reference the information previously submitted to the Commission regarding the LEMUR 3U CubeSat bus

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[1] *See* Myriota Pty. Ltd., *Petition for Declaratory Ruling to Access the U.S. Market in Non-Voice, Non-Geostationary ("NVNG") Satellite System in the 137-138 MHz and 148-150.05 MHz Bands*, File No. SAT-LOI-20191118-00135, Call Sign S3057 (filed Nov. 18, 2019) ("*NVNG VHF Petition*").

[2] In the context of its partnership with Spire, the Myriota satellites will have certain capabilities that are not directly related to the provision of NVNG VHF services in the U.S. market. Myriota includes information regarding these additional capabilities, for which it does not seek U.S. market access, in the interest of full disclosure, out of an abundance of caution, and to the extent relevant to the Commission's public interest considerations.

[3] *See* Spire Global, Inc., *Order and Authorization*, File No. SAT-PDR-20190321-00018, Call Sign S3045 (grant stamp October 17, 20219) (grant-in-part of market access for Spire Luxembourg-licensed MINAS satellites, which are technically identical to the U.S.-licensed LEMUR-2 satellites); *see also* Spire Global, Inc., File No. SAT-LOA-20151123-00078 *et. seq.*, Call Sign S2946 (grant stamp Nov. 28, 2018) (LEMUR-2 satellite license). For the avoidance of doubt and as discussed herein, Spire's separate U.S. market access grant is not being used in the context of Myriota's operations.

and highlights additional information herein, as appropriate.

A.2.2 Myriota Satellite Structure

Each Myriota satellite has a total mass of no more than 8.3 kilograms[4] and an outer stowed envelope of approximately 120mm x 120mm x 380mm, which is modestly larger than LEMUR 3U CubeSats previously considered by the Commission. The Myriota versions of the LEMUR CubeSats will include:

- upgraded and more efficient internal electronic components (none of which materially affect orbital debris mitigation compliance or demise characteristics);
- the Myriota IoT payload using NVNG UHF and VHF frequencies, the latter with antenna characteristics and power levels as described in the *NVNG VHF Petition*;
- UHF, S-Band, and X-Band communications systems for telemetry and data transmission used only for communications outside the United States;
- four deployable, automatic dependent surveillance-broadcast ("ADS-B") antennas that will not be used for Myriota's NVNG VHF operations; and
- one of two active propulsion systems that will be attached to "Z" end of the spacecraft and used for station-keeping, collision avoidance, and, if fuel remains at end-of-life, de-orbiting.

A.2.3 Active Propulsion System

Each Myriota satellite will have one of two propulsion systems onboard for station-keeping, collision avoidance, and possible use for de-orbit (assuming fuel remains at satellite end-of-life): the Morpheus MultiFEEP (3U - Low T) system or the Thrustme I2T5 system.[5] The fundamental performance characteristics of these propulsion systems are set forth below.

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[4] The satellite mass depends on component selection unrelated to Myriota's NVNG operations. For example, there are two suitable propulsion systems with different total mass. The maximum mass listed is includes the wet mass of the heavier propulsion system.

[5] Additional information regarding the Morpheus MultiFEEP (3U – Low T) system can be found here: https://morpheus-space.com/products/multifeep/. Additional information regarding the Thrustme I2T5 system can be found here: https://www.thrustme.fr/products/i2t5.

Table 1. Propulsion Module Characteristics

	Morpheus MultiFEEP (3U - Low T)	**Thrustme I2T5**
Thrust	0.1 mN	0.2 mN
Specific Impulse	3600 s	20 s
Total Impulse	13,000 Ns	32 Ns
Total Size (LxWxH)	100 x 50 x 50 mm	100 x 100 x 50 mm
Total wet mass	0.3 kg (Gallium)	0.9 kg (Iodine)

A final determination has not yet been made regarding how many satellites will be equipped with each propulsion system. However, all satellites in an orbital plane will have the same propulsion system, so at least six satellites will have each type of system. Myriota will update the Commission with the final propulsion system decision for each set of six satellites to the extent required by the Commission.

The contemplated propulsion systems have sufficient performance to conduct anticipated in-orbit collision avoidance maneuvers. The updated Myriota System has a planned initial deployment altitude of 525 km (+/- 25 km). As explained in the *NVNG VHF Petition*, Myriota proposes operational altitudes with a lower limit of 400 km to ensure sufficient operational flexibility.[6] If there is sufficient fuel remaining at satellite end-of-life, the propulsion system will also be used for end-of-life de-orbiting maneuvering. Even with assisted de-orbit, however, the orbits will naturally decay well within the required 25-year time frame.

The use of either active propulsion system is superior to the more limited maneuvering capabilities associated with differential drag initially contemplated for Myriota's satellites. Thus, the Commission may consider the benefits of active propulsion on Myriota satellites as part of the *NVNG VHF Petition*, as amended, without definitive information regarding the number of Myriota satellites with each type of propulsion system.

A.2.4 Spectrum Usage

A.2.4.1 NVNG VHF Payload

Myriota will provide satellite-based IoT services in the 137-138 MHz (space-to-Earth) and 148-150.05 MHz (Earth-to-space) bands in the United States. The fundamental characteristics of Myriota's NVNG VHF operations were described in the *NVNG VHF Petition* and will not change as a result of the Myriota System improvements described herein.

A.2.4.2 Spectrum Use Outside the United States

Myriota is not requesting U.S. market access for satellite operations that will be conducted independently by Spire outside the United States in the context of operating the LEMUR satellite bus or providing services separate from Myriota's NVNG VHF offering. However, in

[6] The Commission routinely grants similar operational ranges for NGSO systems. *See, e.g.,* File No. SAT-AMD-20200504-00041 (grant Dec. 7, 2020).

the interest of full disclosure, these radiofrequency capabilities are described briefly below.[7]

The satellites will operate in the 2020-2025 MHz band and 8025-8400 MHz band for data downlink and TT&C, and in the 402-403 MHz band for data uplink and TT&C. For redundancy purposes, the LEMUR 3U CubeSats will also use the 402-403 MHz band for emergency backup downlink (*i.e.*, only in the event the primary communications link is lost, as a result of improper pointing or another anomaly). Use of the 402-403 MHz band will be on a non-conforming, non-harmful interference basis. These essential capabilities are part of the basic LEMUR satellite design and operations will be conducted by Spire, as satellite bus operator, outside the United States under authority granted by the Luxembourg administration.

The satellites will be equipped with an ADS-B receive antenna unrelated to Myriota operations. Spire is leveraging the additional 36-satellite Myriota System to support its global ADS-B offering. ADS-B capabilities are part of the basic LEMUR satellite design and operations will be conducted by Spire under authority granted by the Luxembourg administration.

The satellites will also be equipped with ISLs which will operate in the S-band space operations spectrum. Such operations will be conducted by Spire under authority granted by the Luxembourg administration and in accordance with domestic and international rules. Myriota understands that Spire is separately seeking Commission authority for similar ISL operations in connection with its U.S.-licensed satellites, the technical information for which is hereby incorporated by reference.[8]

A.3 NUMBER OF SATELLITES AND ORBITAL ARCHITECTURE

The orbital parameters of the Myriota System were described in the *NVNG VHF Petition*, accompanying materials, and additional information submitted in the proceeding. This amendment reduces the number of orbital planes from eighteen (18) at various inclinations to only six (6) equally spaced, sun-synchronous planes inclined at 97.55°.[9] Six (6) LEMUR CubeSats will be equally spaced within each orbital plane. Thus, the total number of satellites in the Myriota System will be 36 rather than 26 as originally planned.

With a target deployment altitude range of approximately 525 km (+/- 25 km), the satellites will be well within the altitude range recognized in the *NVNG VHF Petition* and *NVNG UHF Grant*.[10] Each Myriota satellite will be equipped with active propulsion capabilities for station-keeping. The orbital planes will be separated by two hours of local time of the descending node ("LTDN"), with target LTDNs of 07:00, 09:00, 11:00, 13:00, 15:00, and 17:00, and an

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[7] *See* 47 C.F.R. § 24.114(d)(1).

[8] *See* Spire Global, Inc., File No. SAT-MOD-20200603-00065 (granted-in-part May 14, 2021).

[9] Myriota previously indicated the Myriota System would include 18 planes (6 planes @ 97.7°, 12 planes @ 54°). *See NVNG VHF Petition* at 1 (*citing NVNG UHF Petition*, Technical Description at Section A.2). The updated inclination angle of 97.55° reflects an orbital altitude of 550 km. The satellites are in a sun-synchronous orbit and, therefore, the inclination angle is set by altitude. Because the *NVNG VHF Petition* sought to operate with an orbital altitude range of 400-600 km, the updated orbital parameters are well within those previously contemplated.

[10] *See NVNG UHF Grant* at ¶¶ 1-2.

orbital period of about 95 minutes.

The Myriota satellites will meet the National Aeronautics and Space Administration ("NASA") orbital debris guidelines[11] and an updated Orbital Debris Assessment Report ("ODAR") is attached below. Myriota, in cooperation with Spire (as operator of the satellite buses), acknowledges the need to coordinate the physical operation of the satellites with other satellite operators. Myriota also acknowledges the need to work, in cooperation with Spire, with the 18th Space Control Squadron to effectively address potential conjunction risks. Private services and industry associations such as LeoLabs and SDA will also be engaged, to facilitate information sharing and provide a safe a non-geostationary orbit ("NGSO") low-Earth orbit ("LEO") operational environment.

A.4 SPECTRUM COMPATIBILITY

Myriota demonstrated in the *NVNG VHF Petition* (i) the operational characteristics of the Myriota System that will allow it to operate in a manner that will not cause harmful or unacceptable interference to any NVNG MSS system; (ii) the power flux-density ("PFD") produced by its system at the Earth's surface in the 137-138 MHz band to demonstrate that no coordination with terrestrial systems is necessary; (iii) how it would protect the radioastronomy service in the 150.05-153 MHz band from harmful interference from unwanted emissions; (iv) compliance with applicable emission limitations; and (v) its commitment to coordination with Federal government users.[12] This amendment has no impact on these demonstrations.

The discussion of spectrum compatibility below discusses the impact of increasing the number of satellites and decreasing in the number of orbital planes on the use of NVNG VHF spectrum and, thus, on other authorized NVNG VHF systems in the United States. These changes extend average daily single-satellite coverage and decrease multiple-satellite coverage throughout much of the United States. Specifically, with the exception of Alaska, the increase average daily single-satellite coverage in the United States is effectively offset by a greater reduction in multiple-satellite coverage. In Alaska, Myriota will control satellite operations to ensure that the spectrum impact of the Myriota System is no greater than that of its original constellation design.

A.4.1 Other NVNG VHF Operators

Two NVNG MSS systems are authorized to operate in the NVNG VHF bands: ORBCOMM License Corp. ("ORBCOMM") and Swarm Technologies, Inc. ("Swarm"). ORBCOMM is the only remaining original licensee in the NVNG VHF bands.[13] Swarm, which is licensed to operate in a portion of the NVNG VHF spectrum, is the only other participant in the current NVNG VHF processing round.[14]

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[11] *See* NASA TECHNICAL STANDARD 8719.14, Process for Limiting Orbital Debris (Dec. 2011).

[12] *See* 47 C.F.R. § 25.142(a)(1)-(3).

[13] ORBCOMM License Corp., *Order and Authorization*, DA Docket No. 08-633 (rel. Mar. 2, 2008) at ¶ 2.

[14] Swarm Technologies, Inc., File No. SAT-LOA-20181221-00094, Call Sign S3041 (granted Oct. 17,

Myriota understands the need to avoid causing harmful interference to ORBCOMM's licensed NVNG VHF operations authorized in prior processing rounds. Myriota's advanced spectrum sharing capabilities will ensure that Myriota is able to operate harmoniously with ORBCOMM, and it will otherwise coordinate with ORBCOMM to the extent necessary to ensure that operation of the Myriota System does not cause harmful interference. These efforts will be facilitated by the Myriota System's more traditional orbital architecture. With the requested amendment, Myriota System coverage will be more uniform and the time associated with irregular multiple-satellite coverage is reduced in most areas of the United States, because a number of orbital planes and differences in inclinations are being eliminated.

Myriota and Swarm have reached a global coordination agreement for operations throughout the entire 137-138 MHz (space-to-Earth) and 148-150.05 MHz (Earth-to-space) bands on an operator level. Given this coordination, the changes described herein will not increase the potential for harmful interference to Swarm.

The changes described herein create more uniform coverage in low- to mid-latitude regions but result in greater beam overlap at higher latitudes as satellites approach the poles. Myriota will control satellite operations in high-latitude regions (*i.e.*, Alaska). Myriota's operating parameters are flexible. For example, the Myriota System can vary its power levels and reduce duty cycles and can dynamically select channels to minimize beam overlap on the same frequency. By applying these and/or other approaches, Myriota can control high-latitude operations to ensure an interference environment that is the same as or better than with the 26-satellite system as originally planned.

A.4.2 Equivalent Uplink and Downlink Transmissions

Myriota previously described in detail its ability to share spectrum with other NVNG VHF systems. Consistent with the Commission's rules, and under operator-to-operator coordination arrangements, the software-defined radios on Myriota's satellites can dynamically select channels depending on the availability of spectrum, vary the bandwidth of satellite emissions, and organize their emissions to accommodate sharing arrangements with other users of the band. This enables Myriota to ensure that operation of the 36-satellite system will not increase the potential for harmful interference in the United States.

Downlink transmissions can range in bandwidth anywhere between 10 and 100 kHz and can operate anywhere within the entire one-megahertz band. Downlink communications will operate at 10% system-wide duty cycle (*i.e.*, any location in the United States, on average, receives Myriota downlink transmissions for a given frequency range no more than 10% of the time). In other words, 90% of the time there are no Myriota downlink transmissions on that frequency at any such location.

The system-wide downlink duty cycle is independent of the number of satellites or potential coverage of the system, so changes in the latter characteristics will not alter its interference potential. Myriota will maintain the 10% system-wide duty cycle, ensuring that there will be no increase in the potential for harmful interference from downlink operations. As a result, although average daily coverage may increase, this daily downlink transmission time would

2019).

remain the same because the downlinks operate at no more than a 10% duty cycle (*i.e.*, 2.4 hours per day). And because all areas of the United States had more than seven times this coverage (*i.e.*, 17+ hours per day) with the 26-satellite system originally planned, the geographic coverage of the system would not change.

On the uplink, Myriota's IoT modules have a typical duty cycle of less than 0.02% (only occasionally up to 0.5%) and employ frequency hopping across the band with an emission bandwidth of just 2 kHz. Myriota's micro-gateways have a typical duty cycle of less than 0.5%, occasionally up to 5%, and an emission bandwidth ranging from 10-100 kHz. These characteristics remain unchanged from the *NVNG VHF Petition*.

As with downlink operations, the change in orbital architecture will not increase the potential for harmful interference from Myriota uplinks. First, the number of Myriota modules and micro-gateways in the United States and their duty cycles dictate the amount of uplink transmissions (*i.e.*, more satellites do not result in more earth station uplinks). Second, the operating parameters of Myriota's IoT modules and micro-gateways remains the same. Third, additional average daily coverage allows uplink transmissions to be spread more evenly over time, reducing the probability of simultaneous co-frequency transmissions. Finally, because satellites are evenly distributed there are no "peak hour" loading or use concerns.

For these reasons, the changes described herein make Myriota System coverage more uniform and increase the average daily U.S. coverage but do not increase the potential for harmful interference. By covering its service area more uniformly, the changes decrease the system's multiple-satellite coverage over most of the United States and reduce the potential for harmful interference by spreading transmissions more evenly over time.

A.4.3 Increased Uniformity of Coverage and Reduction in Aggregate Coverage

Changes to the Myriota System involve increasing the constellation size to 36 satellites and decreasing the number of orbital planes from eighteen (18) in mid-latitude/polar inclinations to six (6) equally spaced, sun-synchronous planes inclined at 97.55˚. This more traditional orbital architecture results in more uniform coverage that is more evenly distributed over time.

Myriota has analyzed the average coverage per day and multiple coverage impacts of the changes described herein. Because the Earth spins underneath the constellation's orbits, longitudinal coverage may vary but averages out over time. Latitudinal coverage, however, varies as the spacing between planes is wider near the equator and narrower near the poles. This leads to increased time where satellite beams overlap (*i.e.*, multiple-satellite coverage) at higher latitudes and a reduction in multiple coverage for three or more satellites at lower latitudes.

To understand latitudinal differences, the average single-satellite coverage per day and multiple-satellite coverage of the original 26-satellite system and current 36-satellite system were examined in Analytical Graphics, Inc.'s Systems Tool Kit ("STK") at three representative U.S. locations with sufficient latitudinal difference: the geographic centers of Alaska, the contiguous United States, and Hawaii.[15] These locations are depicted in Figure 1, below.

FIGURE 1. Geographic Locations for Myriota 26 vs Myriota 36 Coverage Analysis

The average daily coverage and number of satellites covering each region, from highest to lowest latitude, are depicted in the following figures. Note that the coverage data is cumulative (*e.g.*, 2+ means two or more satellites covering the region).

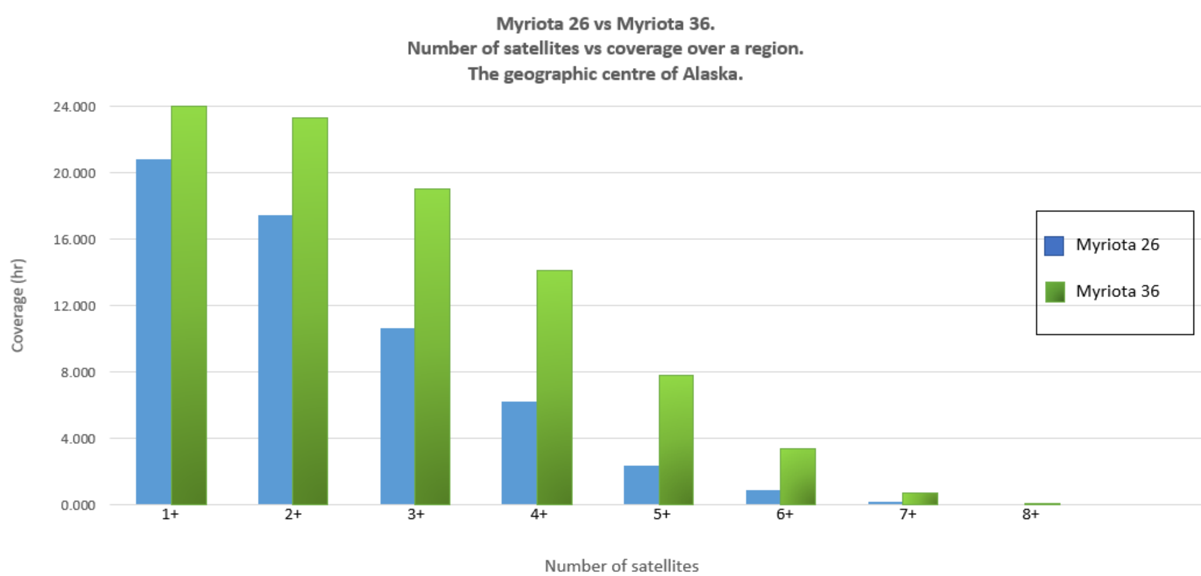

FIGURE 2. Myriota 26 vs Myriota 36 Coverage – Alaska

[15] Given their latitudes, these locations are also representative of lower-latitude Caribbean territories and mid-latitude Pacific territories of the United States.

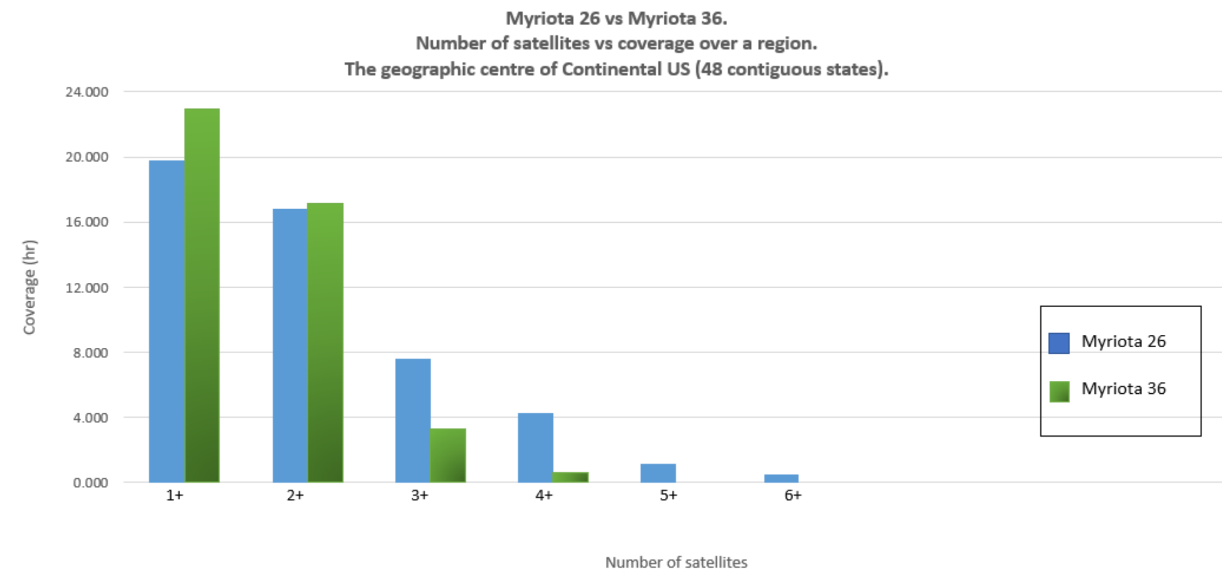

FIGURE 3. Myriota 26 vs Myriota 36 Coverage – CONUS

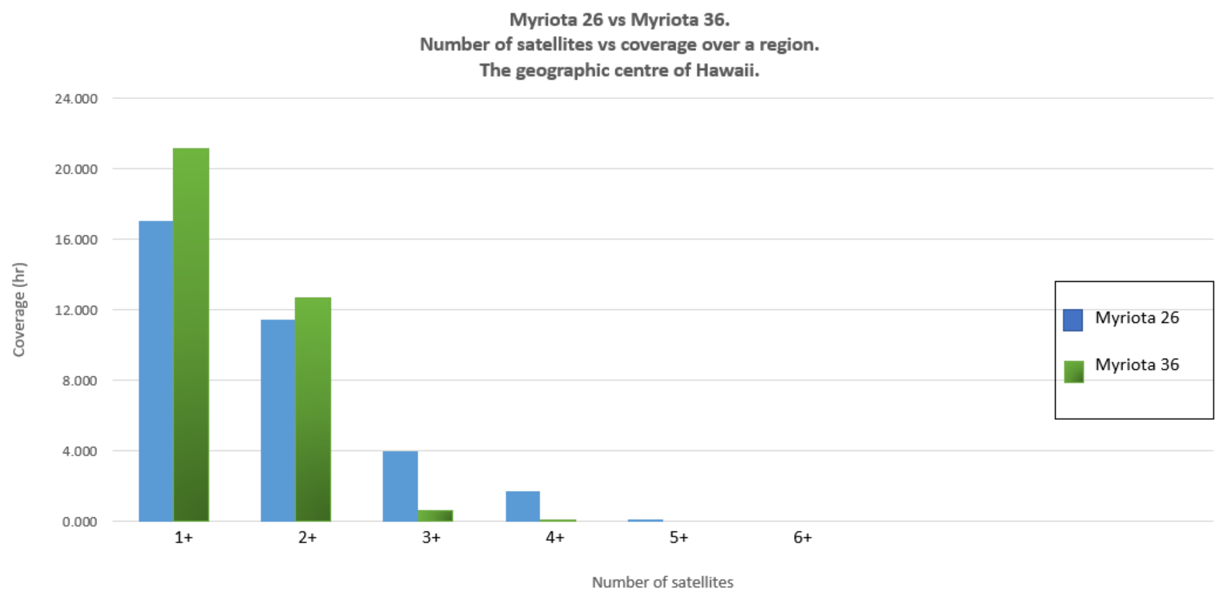

FIGURE 4. Myriota 26 vs Myriota 36 Coverage – Hawaii

The foregoing comparisons suggest that all three regions experience an increase in average daily coverage (*i.e.*, hours of 1+ satellite coverage) with the 36-satellite versus the 26-satellite system. In addition, high-latitude Alaska experiences increases in multiple-coverage for every number of satellites. However, the contiguous United States ("CONUS") and Hawaii regions experience similar 2+ coverage and decreased multiple-satellite coverage from three or more satellites. Thus, the increase in 1+ coverage is offset by the decrease in multiple-satellite coverage.

In addition to the cumulative satellite coverage analysis depicted above, Myriota analyzed the maximum aggregate U.S. coverage of the original 26-satellite and updated 36-satellite Myriota System in terms of total "satellite-hours" (*i.e.*, summing coverage multiplied by the number of satellites covering a U.S. location). By evaluating the original and updated Myriota System's U.S. coverage in this way, it is possible to assess the NVNG VHF spectrum access impacts of the system design changes described herein.

As indicated below, the total number of daily satellite-hours in CONUS and Hawaii decrease from approximately 84 to 78 while daily satellite-hours in Alaska increase from approximately 59 to 92.

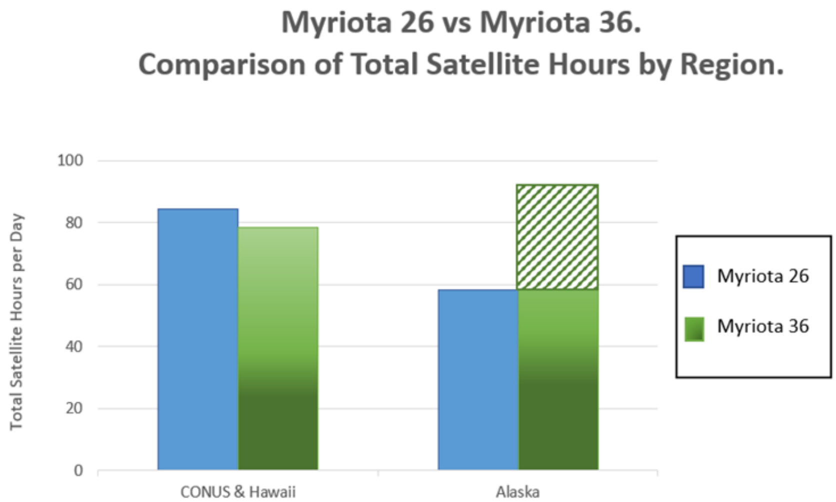

FIGURE 5. Myriota 26 vs Myriota 36 Daily Satellite-Hours

The decrease in satellite-hours in CONUS and Hawaii – and thus decrease in the spectrum access impact of the Myriota System in these areas – results from the improved orbital architecture even though the number of satellites is being increased from 26 to 36. To offset the satellite-hour increase in Alaska, Myriota will control Myriota System operations to ensure that the spectrum impact of the system is no greater than that of the original 26-satellite system design.

The Myriota System includes software-defined radios onboard Myriota's satellites and Myriota's IoT modules and micro-gateways, all of which are reconfigurable. Myriota delivers network information to modules and micro-gateways via the downlink. The network information instructs the devices on the availability and capability of each satellite in the constellation, including information on radio channels in both uplink and downlink directions and regional availability. This provides a sophisticated and highly flexible mechanism to control spectrum impact. Network information delivered to IoT modules and micro-gateways located in the Alaska region describes the operation of software-defined radios onboard Myriota's satellites when providing coverage to Alaska. It enables satellite coverage and frequency to be controlled to minimize beam overlap on the same frequency. This enables Myriota to control high-latitude operations to ensure the interference environment is the same as or better than the 26-satellite system as originally planned.

With the orbital architecture and operational controls contemplated herein, the maximum aggregate U.S. coverage and spectrum impact of the updated Myriota System is less than that of the original constellation design. Thus, the amendment would not increase the potential for interference to other NVNG VHF operations.

A.4.4 Power Flux Density at the Surface of the Earth

As was demonstrated in the *NVNG VHF Petition*,[16] Myriota's satellite emissions will not exceed -125 dB(W / m^2 / 4kHz) at the Earth's surface in U.S. territory. The amendment has no impact on this determination. Moreover, Myriota has the capability to control the satellite transmit power depending on satellite altitude in order to ensure this PFD level is not exceeded.

A.4.5 Coordination with U.S. Government Networks

Myriota's agile and spectrally efficient system will facilitate coordination with federal spectrum users and ensure that no harmful or unacceptable interference will be caused to such users. Myriota acknowledges that any grant of U.S. market access authority may be conditioned on coordinating with federal government operations, and Myriota will operate consistent with Commission requirements.

For all of the reasons discussed herein, the changes contemplated in the NVNG VHF Amendment will have no adverse interference impact on co-frequency Federal operations.

[16] *NVNG VHF Petition*, Technical Description at Section A.5.2.

A.5 ORBITAL DEBRIS ASSESSMENT REPORT

A.5.1 Program Management and Mission Overview

Table 2. Myriota System Mission Overview

ODAR Authors	Robert W. Sproles, Ph.D., Austin Ellis
Mission Description	The Myriota System will provide global IoT services in various non-voice, non-geostationary ("NVNG") mobile-satellite service ("MSS") bands. This orbital debris risk assessment covers 36 LEMUR satellites proposed to be launched and operated as part of the Myriota NVNG MSS System.
Foreign Government Involvement	None
Project Milestones	The 36 satellites will be launched into six (6) equally spaced, sun-synchronous orbital planes at a planned altitude between 500 and 550km, with the satellites ultimately equally spaced within each circular orbital plane and each orbital plane being separated by two (2) hours of LTDN. The launches will take place between June and December 2022 on a combination of rideshare and dedicated launch vehicles. It is anticipated that the launch vehicles will include the SpaceX Falcon 9 and the Astra Rocket v4. This is subject to revision based on launch availability, but the anticipated orbital parameters will not change. This analysis considers the range of representative orbits and includes a debris assessment of the worst-case altitude and lifetime in order to provide the most conservative results.
Proposed Launch Date	
Proposed Launch Vehicles	
Proposed Launch Sites	
Launch Vehicle Operator	
Mission Duration	The planned operational lifetime of each satellite is three (3) years following deployment from the launch vehicle. Replenishment strategies will be implemented to sustain the constellation once it is fully deployed to account for decommissioning of satellites.[17]
Selection of Orbit	Sun-synchronous (~98°) orbits with an anticipated deployment altitude range of 500-550 km.
Potential Physical Interference with Other Orbiting Objects	The satellites have propulsion systems onboard for station-keeping purposes. These systems can also be used for collision avoidance maneuvers. If there is sufficient fuel remaining at satellite end-of-life, the propulsion system will also be used for end-of-life de-orbiting maneuvering. In any event, the satellite orbits will naturally decay and the satellites will fully demise well within the required 25-year orbit dwell time. As detailed in Section A.5.5, the probability of physical interference between the satellites and other space objects complies with Requirement 4.5 of NASA-STD-8719.14A.

[17] *See* 47 C.F.R. § 25.165(e).

A.5.2 Spacecraft Description

The spacecraft is a 3U CubeSat, roughly 12cm x 12cm x 38cm in its stowed configuration. It has deployable solar arrays and antennas, as shown in Figure 6. Each satellite includes UHF, VHF, S-Band, and X-Band communications systems for telemetry and data transmission, and a 3-axis attitude determination and control system (“ADCS”). There is on-board propulsion for station-keeping, collision avoidance, and possible de-orbit purposes. The satellite is compatible with the Exolaunch NOVA “expanded envelope” CubeSat dispenser. This dispenser uses the standard CubeSat rail spacing, but has extra volume available between the rails for, in this case, deployable antennas. The satellite has a protruding antenna that uses the additional available ‘tuna can’ volume of standard CubeSat dispensers. Additional details can be seen in the table and drawings below.

In Figure 6, the dimensional envelope of the satellite is shown. For the purposes of collision analysis in Section 5, the largest dimensions from Fig. 1 are used. This is the worst-case (*i.e.*, largest) spacecraft area. For the purposes of orbit dwell time, various failure scenarios are modeled to represent a worst-case failure-to-deploy scenario where the surface area of the satellite is diminished. This is the worst-case (*i.e.*, smallest) spacecraft area for orbit dwell time.

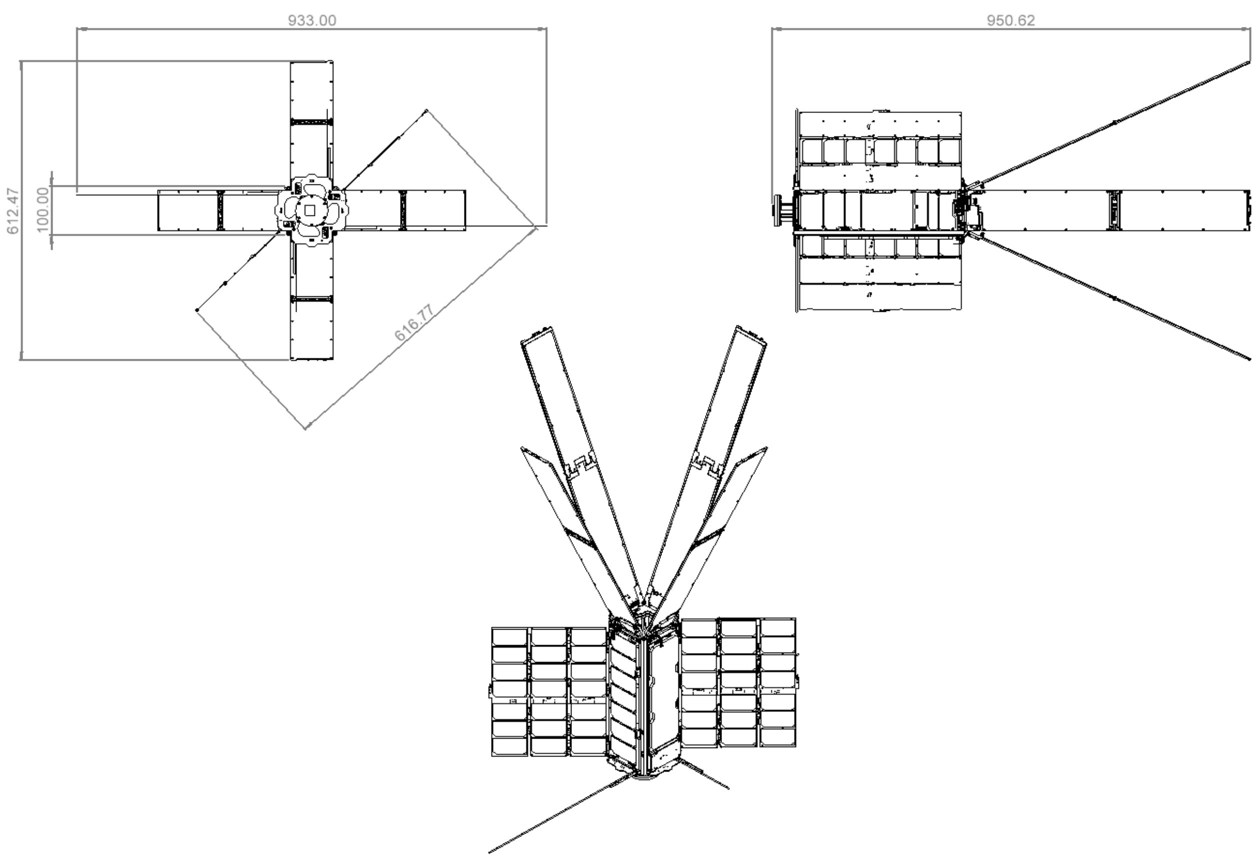

FIGURE 6. Dimensional Envelope (Fully Deployed in Mission Operation Configuration)

Table 3. Myriota Satellite Physical Description

Property	Value
Total Mass at Launch	8.3 kg maximum
Dry Mass at Launch	7.7 ~ 7.8 kg (depending on propulsion system used)
Form Factor	3U CubeSat, using "tuna-can" volume
COG	< 3 cm radius from geometric center
Envelope (stowed)	120mm x 120mm x 380mm
Envelope (deployed, max)	950.62mm x 933.00mm x 612.47mm
Propulsion Systems	ThrustMe I2T5 or Morpheus MultiFEEP
Fluid Systems	None
AOCS	Stabilization/pointing with up to 4x reaction wheels, desaturation + coarse pointing with magnetorquers, and GNSS navigation
Range Safety / Pyrotechnic Devices	None
Electrical Generation	Triple-junction GaAs solar panels
Electrical Storage	Rechargeable lithium-polymer battery pack
Radioactive Materials	None
Proximity Operations Planned	None

A.5.3 Assessment of Debris Released During Normal Operations

The satellites do not release objects during deployment or operation. Therefore, Requirements 4.3-1 and 4.3-2 of NASA-STD-8719.14A are not applicable.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:	
4.3-1a, All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release. 4.3-1b, The total object-time product shall be no larger than 100 object-years per mission. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to collectively follow the same 100 object-years per mission deployment limit.	N/A
4.3-2, Debris passing near GEO: For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degrees inclination), released debris with diameters of 5 mm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km or the perigee will not be lower than GEO + 200 km, and also ensures that the debris is incapable of being perturbed to lie within that GEO +/- 200 km and +/- 15 degree zone for at least 100 years thereafter. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to follow this requirement.	N/A

A.5.4 Assessment of Spacecraft Intentional Breakups and Potential for Explosions

Potential causes for spacecraft breakup:

While the satellites have propulsion onboard, they do not carry highly volatile propellant. The propulsion system is either an electric propulsion system (Morpheus) or cold gas thruster (ThrustMe), neither of which is stored at high pressure nor contains a chemical propellant that is burned to produce thrust. The only energy sources (kinetic, chemical, or otherwise) onboard the spacecraft are a lithium-polymer battery system and reaction wheels. Thus, three plausible causes for breakup of the satellites are identified:

1. energy released from onboard batteries,
2. mechanical failure of the reaction wheels, and
3. runaway torque event leading to solar panel breakup

Summary of failure modes and effects analysis of all credible failure modes, which may lead to an accidental explosion:

The battery module aboard the satellites contains eight (8) cells in a 2S-4P arrangement. Each has a capacity of 9.62 Wh, bringing the total to 76.96 Wh per satellite. These batteries represent the only credible failure mode during which stored energy is released. The main failure modes associated with lithium polymer batteries result from overcharging, overdischarging, internal shorts and external shorts.

One failure mode caused by the reaction wheel assemblies that could create debris would be the breakup of the wheels themselves due to mechanical failure while operating at a high angular rate.

A second failure mode caused by the reaction wheels could be a runaway torque event. In this scenario, high angular velocity could lead to the solar panels breaking up.

Risk Mitigation Plan:

The battery pack onboard the satellites has been designed and built to comply with all controls and process requirements identified in NASA Report JSC-20793 Section 5.4.3 to mitigate the chance of any accidental venting or explosion caused by the above failure modes.

The reaction wheels onboard the satellites are limited with respect to maximum rotational speed of the wheels and are contained within a sealed compartment, thus mitigating any risk of breakup of the wheels themselves into debris.

An analysis was performed to address the feasibility of a runaway torque event and the potential for solar panel shedding. Given the maximum stored momentum in the reaction wheels, the bending stress and shear stress at the solar panel hinges was calculated, and a factor of safety of over 20,000 was found against solar panel shedding.

A similar analysis to above was performed for the deployable antenna arrays deployed hinged at the -Z end of the satellite. Given the same maximum stored momentum in the reaction wheels, the bending stress and shear stress at the antenna array hinges was calculated, and a minimum Factor of Safety of over 1,800 was found against the antenna array shedding.

The reaction wheels cannot provide sufficient torque to cause solar panel or antenna array shedding, which is the most likely mechanical shedding through rotational motion.

Given the above analysis, the risk of a runaway torque event causing breakup of satellite hardware was deemed negligible.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:

There is no planned breakup of the satellites on-orbit.

Rationale for all items required to be passivated that cannot be due to design:

N/A

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:	
4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission (i.e., every individual free-flying structural object), the program or project shall demonstrate, via failure mode and effects analyses, probabilistic risk assessments, or other appropriate analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle does not exceed 0.001 (excluding small particle impacts).	COMPLIANT
4.4-2, Design for passivation after completion of mission operations while in orbit about Earth, or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability and a plan to either 1) deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or 2) control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft. The design of depletion burns and ventings should minimize the probability of accidental collision with tracked objects in space.	N/A
4.4-3, Limiting the long-term risk to other space systems from planned breakups for Earth and lunar missions: Planned explosions or intentional collisions shall: a. be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years. For example, if the debris fragments greater than 10cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup. b. Not generate debris larger than 1 mm that remains in Earth orbit longer than one year.	N/A
4.4-4, Limiting the short-term risk to other space systems from planned breakups for Earth orbital missions: Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10^{-6}.	N/A

A.5.5 Assessment of Spacecraft Potential for On-Orbit Collisions

Requirement 4.5-1 Probability for collision with objects larger than 10 cm:

The probability of a collision of any of the satellites with an orbiting object larger than 10 cm in diameter was calculated using the National Aeronautics and Space Administration's ("NASA's") Debris Assessment Software ("DAS") 3.1.0 software. The maximum cross-sectional surface area of the satellites is used for this analysis in order to produce the most conservative (worst case) results.

Table 4 below shows the risk for lifetime orbits at 600 km, which are 75 km above the target orbit for this constellation. These conservative assessments are well below the requirement of 0.001 probability of collision.

Five different area-to-mass ratio scenarios are analyzed, including:

- Dead-on-arrival or non-functional satellite (tumbling, no panels deployed)
- ADCS non-functional, one panel deployed
- ADCS non-functional, two panels deployed
- Operational, one panel deployed
- Fully operational, nominal deployment of solar panels

Table 4. Collision Risk with Objects Larger Than 10 cm
Run at Worst-Case Orbit of 650km SSO

	Maximum Mass Configuration (8.3 kg) 600 km, 98 degrees (Worst-Case Orbit)		
Satellite Operational State	**Effective A/M (m^2/kg)**	**Collision Risk Over Lifetime (years)**	**Collision Risk per NASA DAS Analysis**
Operational, Nominal	0.0391	12.7	4.2×10^{-6}
Operational, Partial Deploy	0.0244	14.3	5.7×10^{-6}
ADCS Nonfunctional, Fully Deployed	0.0389	13.9	4.2×10^{-6}
ADCS Nonfunctional, Partial Deploy	0.0254	18.9	5.2×10^{-6}
Satellite Nonfunctional	0.0076	18.9	5.1×10^{-6}

Requirement 4.5-2 Probability for collision with objects 10 cm or less:

Per the DAS User's Guide Section 3.6, Requirement 4.5-2 applies only to subsystems vital to completing post mission disposal.

Though the propulsion systems onboard can be used for collision avoidance maneuvers, there may not be sufficient fuel onboard to perform end-of-life de-orbit. Regardless, their orbits will naturally decay well within the required 25-year orbit dwell time, so the requirement 4.5-2 is listed as N/A.

Assessment of spacecraft compliance with Requirement 4.5-1 and 4.5-2:	
4.5-1, Limiting debris generated by collisions with large objects when in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter does not exceed 0.001. For spacecraft and orbital stages passing through the protected region +/- 200 km and +/-15 degrees of geostationary orbit, the probability of accidental collision with space objects larger than 10 cm in diameter shall not exceed 0.001 when integrated over 100 years from time of launch.	COMPLIANT
4.5-2, Limiting debris generated by collisions with small objects when operating in Earth orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post mission disposal maneuver requirements does not exceed 0.01.	N/A

Aggregate Collision Risk

While the analysis above satisfies requirement 4.5-1 for collision risk for an individual satellite, Aggregate collision risk for the Myriota constellation as a whole was also completed, based on planned launches.

The general aggregate risk (P_A) is summarized by Eq. 1, below:

$$P_A = [1 - (1 - P_1)^{N_1}] + [1 - (1 - P_2)^{N_2}] + \ldots + [1 - (1 - P_n)^{N_n}] \tag{1}$$

Where *N* is the number of satellites in a particular orbital plane and *n* is the number of orbital planes used for the analysis.

The Myriota constellation consists of 36 satellites in six (6) orbital planes, with six (6) satellites in each orbital plane. The orbital planes are circular, sun synchronous orbits with a planned deployment altitude of 525 km +/- 25 km, evenly spaced by two (2) hours of LTDN. The selected LTDNs are 07:00, 09:00, 11:00, 13:00, 15:00 and 17:00.

Using the value P in Table 5 and calculating the risk with Eq. 1, the resulting aggregate constellation risk is below.

Table 5. Orbital Plane Collision Risks for Aggregate Risk

Orbital Altitude Range	Worst-Case Single Satellite DAS Collision Risk (P)	Number of Satellites in Proposed Orbital Altitude (N)	Aggregate Collision Risk (P_A)
~550km	5.7×10^{-6}	36	2.05×10^{-4}

The foregoing aggregate collision risk is a conservative estimate not taking into account the capabilities of the onboard propulsion system. The expected aggregate collision risk would be significantly smaller.

A.5.6 Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

Description of disposal option selected:

Following its deployment, a satellite's orbit will naturally decay until it reenters the atmosphere. The re-entry will be uncontrolled and subject to the natural decay of the orbit. Table 6 describes the mission scenarios for which lifetime analysis of a satellite was considered and the effective area-to-mass ratio of the satellite in each scenario. The ratio was calculated using the external dimensions of the satellite and deployed arrays.

For purposes of Section A.5.6, drag area from deployed VHF and UHF dipole antennas, as well as the deployable ADS-B antenna, is omitted; as such, the effective area-to-mass calculated below is a conservative case. In addition, potential use of active propulsion for de-orbit has been omitted given the uncertainty that all satellites will have fuel remaining for de-orbit operations. To the extent that fuel remains at satellite end-of-life for de-orbit, the remaining orbital lifetime values in Table 6, below, may be considerably shorter.

Table 6. Area-to-Mass Ratio of Myriota Satellites in Various Mission Scenarios

Scenario	**Description**	**Effective Area/Mass Ratio** (m^2/kg) Maximum Mass 8.3 kg[18]
Operational, Nominal	▪ Spacecraft pointing, position is nominal, operational ▪ Solar arrays deployed	0.0149
Operational, Partial Deploy Failure	▪ Spacecraft pointing, position is nominal, operational ▪ half of solar arrays and deployable antennas deployed	0.0110
ADCS Non-functional Fully Deployed	▪ Spacecraft tumbling randomly ▪ All solar panels and antennas deployed	0.0117
ADCS Non-functional Partially Deployed	▪ Spacecraft tumbling randomly ▪ half of solar panels and antennas deployed	0.0071

[18] The satellite mass depends on component selection unrelated to Myriota's NVNG operations. For example, there are two suitable propulsion systems with different total mass. The maximum mass listed is includes the wet mass of the heavier propulsion system.

Satellite Non-functional	▪ Spacecraft tumbling randomly ▪ No solar panels nor antennas deployed	0.0022 for 5 years 0.0117 thereafter[2]

Table 7 below shows the simulated orbital dwell time for a satellite in typical orbits, including the worst-case scenario (longest time in orbit) of 600 km altitude.

Table 7. Orbit Dwell Time for Myriota Satellites in Representative Low Earth Orbits (8.3 kg)

	Maximum Mass (8.3 kg)			
Spacecraft Operational State	**Effective Area/Mass (m^2/kg)**	**400 km, 98 deg**	**500 km, 98 deg**	**600 km, 98 deg**
Operational, Nominal	0.0149	0.5 yr	2.4 yr	12.7 yr
Operational, Partial Deploy	0.0110	0.7 yr	3.0 yr	14.3 yr
ADCS Non-functional, Fully Deployed	0.0117	0.7 yr	2.9 yr	13.9 yr
ADCS Non-functional, Partial Deploy	0.0071	1.0 yr	4.5 yr	18.9 yr
Satellite Non-functional	0.0022	2.6 yr	14.9 yr	18.9 yr[19]

Identification of systems required for post mission disposal: None

Plan for spacecraft maneuvers required for post mission disposal: N/A

Calculation of final area-to-mass ratio if atmospheric reentry not selected: N/A

[19] To ensure the satellite exceeds the NASA requirement in all scenarios, a double fault-tolerant solar panel deployment mechanism is included, which will provide sufficient surface area and drag to comply with the NASA standard even if a satellite is non-functional upon deployment. The satellite's solar panels are part of a built-in, post-deployment sequence programmed into onboard software prior to launch, which requires no direction from the ground. If for some reason the onboard sequence fails, solar array deployment can be commanded from the ground. If a satellite is non-communicative, an entirely passive, redundant fail-safe is included on all satellites in the form of a burn wire. The tensile strength of the burn wire has been tested and verified to degrade to a breaking point after 3600 hours or 150 days of UV radiation exposure. The worst-case scenario for dwell time above conservatively models five (5) years of non-deployed solar panels and no loss of altitude during that period, followed by the dwell times for an ADCS non-functional satellite, even though a non-deployed solar panel satellite would still have some surface area that would cause some loss of altitude during that period. As such, this is a conservative worst-case scenario.

Assessment of Spacecraft Compliance with Requirements 4.6-1 through 4.6-4:	
4.6-1, Disposal for space structures in or passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2,000 km shall be disposed of by one of the following three methods: a. Atmospheric reentry option: (1) Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission or (2) Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission. b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude above 2000 km and ensure its apogee altitude will be below 19,700 km, both for a minimum of 100 years. c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.	COMPLIANT
4.6-2, Disposal for space structures near GEO: A spacecraft or orbital stage in an orbit near GEO shall be maneuvered at EOM to a disposal orbit above GEO with a predicted minimum perigee of GEO +200 km (35,986 km) or below GEO with a predicted maximum apogee of GEO – 200 km (35,586 km) for a period of at least 100 years after disposal.	N/A
4.6-3, Between LEO and Medium Earth Orbit (MEO): A spacecraft or orbital stage shall be left in an orbit with a perigee altitude greater than 2000 km and apogee altitude below 19,700 km for 100 years. Between MEO and GEO: A spacecraft or orbital stage shall be left in an orbit with a perigee altitude greater than 20,700 km and apogee altitude below 35,300 km for 100 years.	N/A
4.6-4, Reliability of post mission disposal maneuver operations in Earth orbit: NASA space programs and projects shall ensure that all post mission disposal operations to meet Requirements 4.6-1, 4.6-2, and/or 4.6-3 are designed for a probability of success as follows: a. Be no less than 0.90 at EOM, and b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty.	N/A

A.5.7 Assessment of Spacecraft Reentry Hazards

NASA DAS was used to test the major spacecraft components for re-entry hazards. The major components tested included:

- Solar panels and cells
- Various antennas
- Printed circuit boards
- Primary structure
- Reaction wheel assembly
- Electric propulsion payload

Summary of objects expected to survive an uncontrolled reentry (using DAS 3.1.0 software): No components are expected to survive reentry.

Calculation of probability of human casualty for expected reentry year and inclination: 0% (**1:164300**)

Assessment of spacecraft compliance with Requirement 4.7-1:	
4.7-1, Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules: a. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000). b. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from CONUS, U.S. territories, and the permanent ice pack of Antarctica. c. For controlled reentries, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000).	COMPLIANT

A.5.7.1 Assessment of Spacecraft Hazardous Materials

Summary of hazardous materials contained on spacecraft: None

A.5.8 Assessment for Tether Missions

Type of tether: N/A

Description of tether system: N/A

Determination of minimum size of object that will cause the tether to be severed: N/A

Tether mission plan, including duration and post mission disposal: N/A

Probability of tether colliding with large space objects: N/A

Probability of tether being severed during mission or after post mission disposal: N/A

Maximum orbital lifetime of a severed tether fragment: N/A

Assessment of compliance with Requirement 4.8-1:	
4.8-1, Mitigate the collision hazards of space tethers in protected regions of space: Intact and remnants of severed tether systems in Earth orbit shall limit the generation of orbital debris from on-orbit collisions with other operational spacecraft postmission. Tether systems should generally not remain deployed after the completion of their mission objectives. After mission objectives are met, such tethers should have provisions for disposal (full retraction/stowing and/or removal from Earth orbit) with a >0.90 probability of success, including an assessment of the reliability of the disposal system and accounting for the possibility of damage to or cutting of the tether prior to disposal.	N/A

ENGINEERING CERTIFICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this amendment, 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/

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