Before the
Federal Communications Commission
Washington, DC 20554

In the Matter of	)	
	)	
Momentus Space LLC	)	File No. SAT-LOA_________
	)	
Authority to Deploy and Operate the Vigoride-7 as a Non-Geostationary Orbit In-Space Transportation Spacecraft	))))	

APPLICATION

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APPLICATION

I. Introduction

By this application, Momentus Space LLC ("Momentus"), a wholly owned subsidiary of Momentus Inc., requests authority to deploy and operate the Vigoride-7 ("VR-7") non-geostationary orbit ("NGSO") spacecraft in low-Earth orbit ("LEO") for a period of one year, to transport and deploy multiple, separate customer payloads, and to demonstrate Rendezvous and Proximity Operations ("RPO") capabilities.[1] VR-7 is scheduled to launch in October 2023, and accordingly, Momentus requests that the Federal Communications Commission ("FCC") act expeditiously.

VR-7 will operate in the S-band (2025-2110 MHz) for space operations (Earth-to-space), in the X-band (8025-8400 MHz) for space operations (space-to-Earth), and in the UHF frequency band (with a center frequency of 916 MHz) for a receive-only inter-satellite link ("ISL") as part of its RPO demonstration. Additionally, for up to a fourteen-day period after deployment, VR-7 will operate a beacon in the UHF frequency band (with a center frequency of 400.5 MHz) to facilitate the acquisition of the satellite, thereby reducing the probability that

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[1] *See* 47 C.F.R. § 25.114.

Momentus will not be able to communicate with the spacecraft because of lack of accurate orbital information, which could result from an anomaly. Separately, Momentus will host a customer payload onboard VR-7 that will operate on the following center frequencies: 2214 MHz, 2220 MHz, and 2226 MHz (space-to-Earth) and 2038.725 MHz, 2044.25 MHz, and 2049.775 MHz (Earth-to-space).

Momentus is a U.S. commercial space company headquartered in San Jose, California, that trades on the NASDAQ Global Select market under the ticker symbol: MNTS.[2] Since its founding in 2017, Momentus has brought together a team of engineering, technology, and business experts united by the mission of providing the backbone infrastructure services to help people, industries, and companies use space in new ways. There are three infrastructure services that Momentus anticipates will be commonplace demands of the future: 1) in-space transportation to carry customer satellites to precise custom orbits; 2) hosted payloads to provide customers with continual power, orbit keeping, orientation, and communication services (also known as "Satellite as a Service"); and 3) in-orbit services like refueling, repositioning, repairing, and de-orbiting satellites. The company believes it can make these new ways of operating in space possible with its planned in-space transfer and service vehicles that will be powered by the company's innovative water plasma-based propulsion system that is under development. When these future services are available, space-faring customers can reap the benefits of investing more time in their payloads and technologies and rely on service-providers, like Momentus, to navigate the in-space logistics needed for mission success. For these reasons, Momentus submits that the public interest would be served by grant of the application.

[2] Ownership information for Momentus is provided in Exhibit 4 attached.

II. System Description

A. General System Description

The Vigoride spacecraft product line is comprised of self-propulsive, free-flying spacecraft designed to transport and deploy customer payloads, host customer payloads and, in future iterations, perform on-orbit services including rendezvous, proximity operations, and debris removal. Propelled primarily by a novel microwave electrothermal thruster ("MET"), which is designed to be a non-toxic, low-pressure water propellant system capable of providing orbit transfers, Vigoride spacecraft are designed to be capable of the transportation and deployment of dozens of individual payloads which may be scheduled for deployment at any point after orbital insertion and prior to deorbit.

Figure 1: Artist's rendering of Vigoride deploying a customer spacecraft

With respect to this application, VR-7 will transport and directly deploy third-party payloads from VR-7. Exhibit 5 provides a summary of the third-party payloads and related information, including effective drag area and maximum deployed dimensions.

Each of the payload owners is contractually obligated to obtain and certify that it has obtained all necessary authorizations for operation of its payload prior to integration with VR-7 and the launch vehicle and provide evidence of such authorizations to Momentus. If there are any changes to the customer manifest, Momentus may replace a customer payload with another customer payload with comparable mass and dimensions. Momentus will provide the FCC updates to its manifest list. Alternatively, Momentus may replace a customer payload with a mass dummy, which would not be deployed on orbit. Any such mass dummies would simulate the mechanical interfaces and mass of the customer spacecraft and allow Momentus to conduct a demonstration of the planned deployment without any deployment in fact occurring. The ability to replace a payload with comparable mass and dimensions, as necessary, is key to the ongoing certification of the VR-7 mass properties to the launch service provider and ensuring orbital debris compliance for the mission.

The VR-7 mission operations center ("MOC") is located at the company headquarters in San Jose, California. All primary telemetry and commanding will be handled through this facility, via commercial ground stations, using encrypted links. Additional information on the ground segment is provided in section II.B.4 below.

VR-7 will be affixed directly to the launch vehicle and deployed into a targeted sun-synchronous orbit with approximately a 97 +/- 1 degree inclination and a 525 km max circular insertion orbit.[3]

[3] For the purposes of this application, Momentus assumed a 525 km maximum insertion orbit based on information from the launch provider.

After separation from the launch vehicle, VR-7 will undergo commissioning and deploy each of the customer payloads.[4] VR-7 will subsequently conduct a series of RPO activities, which are discussed in detail in the Orbital Debris Assessment Report ("ODAR").[5] At the conclusion of the RPO activities, a six-month, dedicated hosted payload mission will commence that allows the LuxSpace Triton-X Genesis payload to collect attitude control system sensor data and communicate with a ground station in Spain once per day. As demonstrated in the attached ODAR (*see* Exhibit 2), Momentus complies with the FCC's orbital debris mitigation rules.

B. Technical Specifications

1. Frequency Bands

VR-7 will operate in the S-band (2025-2110 MHz) for space operations (Earth-to-space) and in the X-band (8025-8400 MHz) for space operations (space-to-Earth). The use of the S-band and X-band frequencies will be primarily for telemetry, tracking, and command ("TT&C"). *See* Table 1 below. Momentus will also downlink imagery generated from on-board cameras to confirm successful deployment of the payloads and cooperatively conduct RPO activities with another spacecraft (TROOP-F2).[6] VR-7 includes a limited duration UHF beacon, as well as a receive-only ISL that will receive data from the TROOP-F2 vehicle and facilitate locating the spacecraft for the demonstration RPO activities.

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[4] *See* Exhibit 5. As explained in the attached ODAR, VR-7 includes a failsafe deployment timer. The timer system commences upon deployment and begins a countdown that will trigger the release of the deployable customer payloads after seven days, which is intended to ensure deployment in the event that the VR-7 bus experiences a failure and Momentus is unable to command the deployment. *See* Exhibit 2.

[5] *See* Exhibit 2 at 4-6.

[6] Momentus will submit an application with NOAA for authority to conduct the RPO activities. *See* NOAA Licensees, https://www.nesdis.noaa.gov/commercial-space/regulatory-affairs/licensing/noaa-licensees (last visited Dec. 10, 2021).

VR-7 also will host a non-deployable payload built by LuxSpace, called Triton-X Genesis. That payload will perform an in-orbit demonstration of key Triton-X subsystems, including sensors, and other technologies. The Triton-X Genesis will conduct transmissions, for demonstration purposes only, in the S-band frequencies and communicate with only a single ground station located in Spain.

Momentus is aware that there are federal and other operations in the S-band and X-band frequencies and intends to coordinate its proposed operations with affected operators prior to operations. Attached to this application in Exhibit 3 are the antenna gain contours for all the transmit and receive antenna beams, in 2 dB increments from 2 dB to 10 dB below max gain, and also 15 dB and 20 dB below max gain.[7]

[7] *See* Exhibit 3. For some gain contour plots, the contours at the lower gains are beyond the horizon (or do not exist) and are not shown in the plots.

	Uplink (Earth-to-space)	Downlink (space-to-Earth)	Beacon	ISL	Triton-X Genesis S-band uplink	Triton-X Genesis S-band downlink
Center Frequency	2075.0 MHz[8]	8200 MHz	400.5 MHz	916 MHz	2038.725 2044.25[9] 2049.775 MHz	2214 2220[10] 2226 MHz
Bandwidth (max.)	0.1 MHz	1 MHz	20 kHz	140 kHz	0.1 MHz	2 MHz
Data Rate[11]	50 kbps	500 kbps	9.6 kbps	9600 bps	64 kbps[12]	279.4-1119 kbps[13]
Modulation & Coding[14]	BPSK	OQPSK	2GFSK	GFSK	BPSK	BPSK, OQPSK[15]
Transmit RF Power	9.4 dBW	-3.7 dBW	4.3 dBW	-3.98 dBW (from TROOP-F2)	7.2 dBW	1.6 dBW
Transmit Antenna Gain	35-38 dBi	6 dBi	5.2 dBi	3 dBi (from TROOP-F2)	42.8 dBi	6 dBi
Transmit Antenna EIRP	47.4 dBW	2.3 dBW	9.5 dBW	-0.98 dBW	50 dBW	7.6 dBW
Receive Antenna Gain	7 dBi	47-51 dBi	16.2 dBi	3 dBi	6 dBi	42.1 dBi

[8] The identified center frequencies are representative frequency channels. As a result of coordination with federal operators, Momentus may select another channel within the identified frequency bands for its operations.

[9] 2044.25 MHz will be used as the primary frequency; 2038.725 MHz and 2049.775 MHz are backup frequencies.

[10] 2220 MHz will be used as the primary frequency; 2214 MHz and 2226 MHz are backup frequencies.

[11] Data rate is configurable from approximately 1 kbps up to a maximum listed.

[12] Able to be set as 8, 16, 32, or 64 kbps before launch.

[13] Selectable by telecommand.

[14] Links may include forward error correction.

[15] Selectable by telecommand.

Receive Antenna G/T	-26 dB/K	26.7 dB/K	-10.5 dB/K	-21.8 dB/K	-23.2 dB/K	18.0 dB/K
Max Transmission Duration per Pass	~10 minutes	~10 minutes	~6 seconds every 60 seconds	6 seconds every 60 seconds	~10 minutes, once per day	~10 minutes, once per day
Duty Cycle	~10%	~10%	~10%	10%	<1%	<1%

Table 1: Radio Frequency Plan

a. VR-7 S-band and X-band Use

The VR-7 spacecraft will operate in the 2025-2110 MHz band (Earth-to-space) band. This band is allocated to space operations and Earth exploration-satellite service ("EESS"), *inter alia*, in all ITU regions. In the United States, space operations are limited to federal operators, and EESS use by commercial operators is subject to conditions.[16] VR-7 will also operate in the 8025-8400 MHz band, which is allocated to EESS (space-to-Earth), *inter alia*, in all ITU regions and in the United States. As discussed in the waiver section below, to the extent necessary, Momentus requests a waiver of the Commission's rules to operate in these frequencies.[17]

Although the associated Schedule S identifies the use of multiple bandwidths for the VR-7 S-band uplink use, there will be at most a single uplink transmission (with a representative center frequency of 2075.0 MHz) at any given time and a single X-band downlink transmission (with a representative center frequency of 8200 MHz) from VR-7 at any given time. The Momentus network has adaptive coding transmission capabilities and can reduce the emission bandwidth for both the uplink and downlink as necessary to maintain or increase link margin.

The inclusion of more narrow bandwidths in the Schedule S for both links is intended to reflect sample technical parameters for such transmissions. In all cases, Momentus will ensure

[16] *See* 47 C.F.R. § 2.106 n. US347.

[17] *See infra* Section III.A.

that its reduction in the bandwidth at every operating orbital altitude will not result in VR-7 exceeding applicable power flux density ("PFD") limits, as discussed in more detail below. Under nominal conditions, Momentus would expect to transmit at the maximum bandwidth.

The S-band frequency use by the Triton-X Genesis payload is discussed below in Section II.B.1.d.

i. S-band PFD at the Earth's surface

The Commission's rules do not specify a PFD limit in the 2200-2290 MHz band; however, there are PFD limits specified in rule No. 21.16 of the International Telecommunication Union ("ITU") Radio Regulations ("ITU RR"). The maximum PFD levels for the VR-7 transmissions were calculated for the 2200-2290 MHz band and the results, which are provided in Schedule S, demonstrate that the downlink PFD levels of the VR-7 carriers do not exceed the limits specified in rule No. 21.16 of the ITU RR.

The figures below illustrate the S-band downlink PFD values in comparison with the ITU PFD limits in No. 21.16. When operating at orbital altitudes above 500 km, the full EIRP of 7.6 dBW can be used for an emission bandwidth of 2 MHz as shown in Figure 2. For narrower emission bandwidths, the EIRP is reduced to keep the EIRP density constant. As the orbit altitude drops below 500 km, the RF power is backed off to assure PFD limits are always observed. Figure 3 below demonstrates the case when the orbit altitude is down to 350 km, the EIRP has been reduced by 3 dB to 4.6 dBW, and the emission bandwidth is still 2 MHz. The PFD at the Earth's surface produced by VR-7 satisfies the PFD limits for all angles of arrival calculated at the 350 km orbital altitude, which is the lowest nominal operating orbital altitude for VR-7. To the extent possible and helpful for de-orbiting, Momentus will continue to conduct TT&C communications during the period when the perigee of VR-7 is below 350 km and until as low as 150 km, as VR-7 is de-orbiting. In that event, Momentus will further reduce the power levels of its transmissions to maintain compliance with the PFD limits or payload transmissions will be limited to times when the instantaneous orbital altitude is above 350 km.

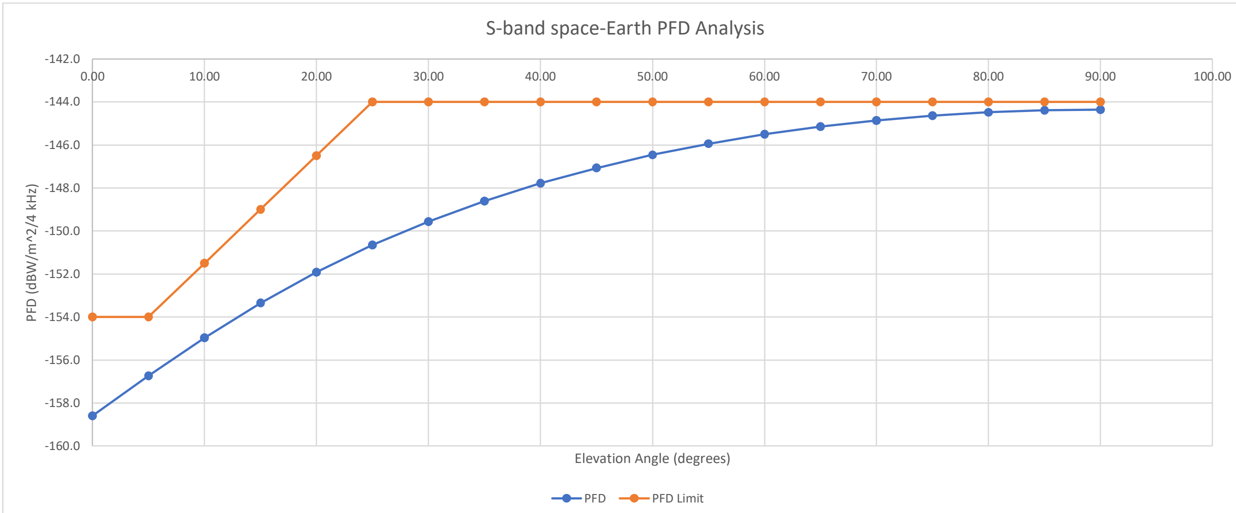

Figure 2 S-band PFD from 500 km Orbital Altitude

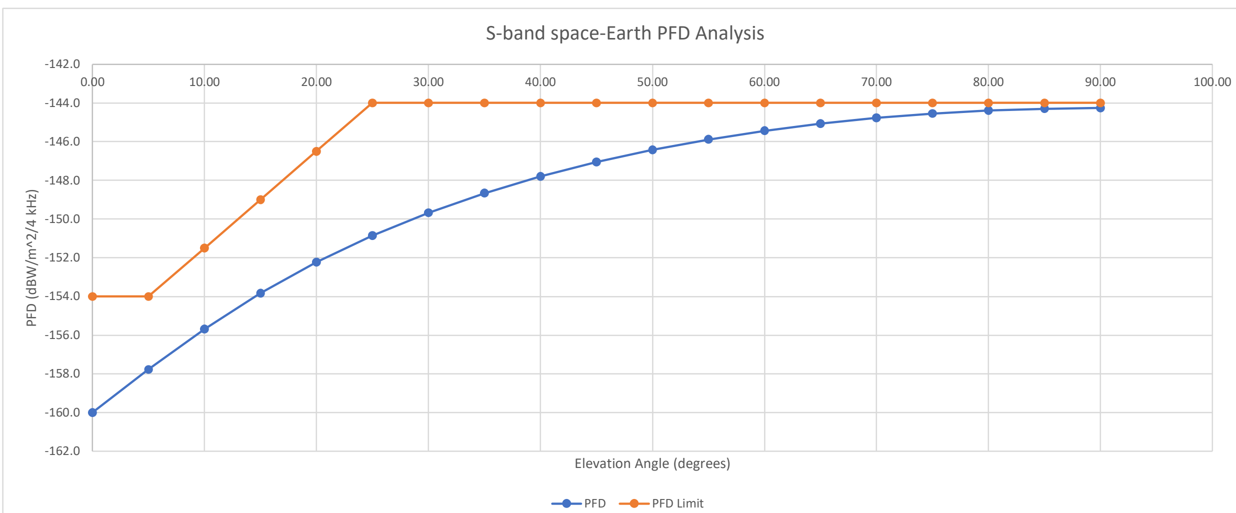

Figure 3 S-band PFD from 350 km Orbital Altitude

ii. X-band Interference Analysis

VR-7 meets the ITU-established PFD limits on the Earth's surface and at the geostationary arc and adequately limits emissions in the adjacent band frequencies, as discussed below. Additionally, provided as Exhibit 6 is an interference analysis demonstrating that the X-band operations will not cause harmful interference to other authorized X-band satellite spectrum operations under certain operational constraints.

iii. X-band PFD at the Earth's Surface

The Commission's rules do not contain limits on PFD at the Earth's surface produced by emissions from space stations operating in the 8025-8400 MHz band.[18] However, Table 21-4 of the ITU RR specifies that the PFD at the Earth's surface produced by emissions from a space station in the 8025-8400 MHz band, including emissions from a reflecting satellite, must not exceed the following values:

- -150 dB(W/m²) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
- -150 + 0.5(δ – 5) dB(W/m²) in any 4 kHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and
- -140 dB(W/m²) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

The PFD at the Earth's surface produced by VR-7 satisfies the PFD limits for all angles of arrival calculated at the 350 km orbital altitude, which is the lowest nominal operating orbital altitude for VR-7. To the extent possible and helpful for de-orbiting, Momentus will continue to conduct TT&C communications during the period when the perigee of VR-7 is below 350 km and until as low as 150 km, as VR-7 is de-orbiting. In that event, Momentus will reduce the power levels of its transmissions to maintain compliance with the PFD limits or payload transmissions will be limited to times when the instantaneous orbital altitude is above 350 km.

Reduced emission bandwidths will typically be employed either early in the operational lifetime or in cases where additional link margin is necessary. Typically, the X-band transmitter will operate at the maximum EIRP level of 2.3 dBW. Because VR-7 operates over a range of

[18] 47 C.F.R. § 25.208.

orbital altitudes, the minimum emission bandwidth that can be employed at maximum EIRP will change as a function of orbital altitude to ensure the PFD limits are met. For orbital altitudes with perigee above 500 km, the minimum emission bandwidth that can support the maximum EIRP is 250 kHz. The PFD for a 2.3 dBW EIRP within 250 kHz at 500 km orbital altitude is shown in the figure below.

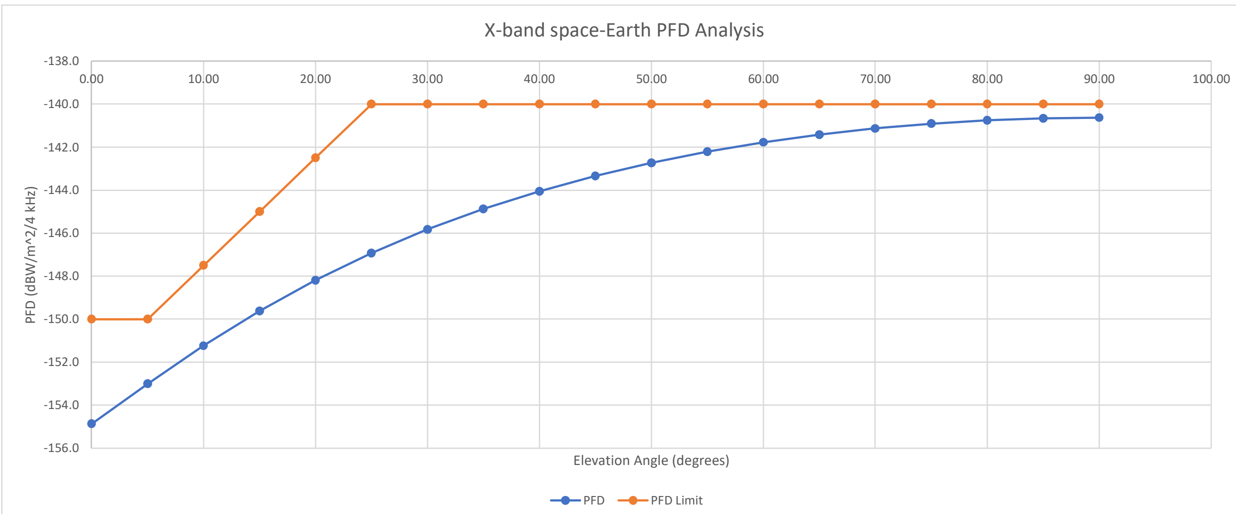

Figure 4 X-band PFD from 500 km Orbital Altitude

The minimum orbital altitude at which the payload will transmit in X-band at full EIRP is 350 km. At orbital altitudes from 500 km down to 350 km, the maximum EIRP can only be used with emission bandwidths down to 500 kHz. The PFD for a 2.3 dBW EIRP within 500 kHz at 350 km orbital altitude is shown in the figure below.

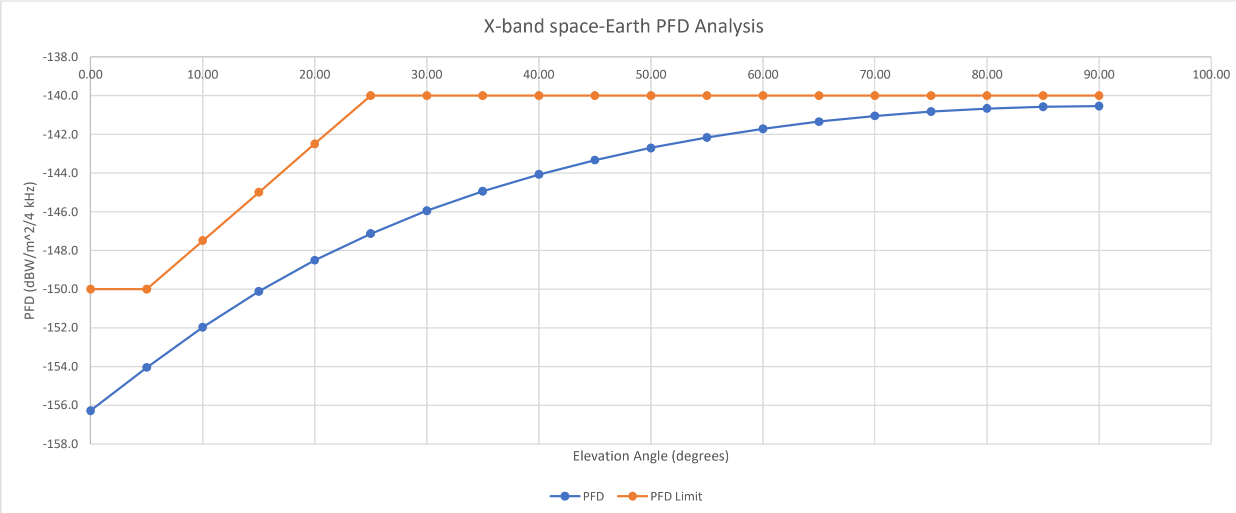

Figure 5 X-band PFD from 350 km Orbit Altitude

The X-band payload may continue to operate as the perigee is lowered below 350 km, as discussed above.

iv. PFD at the Geostationary-Satellite Orbit

ITU RR 22.5 states that in 8025-8400 MHz band "the maximum power flux-density produced at the geostationary-satellite orbit by any Earth exploration-satellite service space station shall not exceed −174 dB(W/m^2) in any 4 kHz band." At the maximum 525.2 km altitude for VR-7, assuming the spacecraft is pointed directly at geostationary orbit, the PFD would be approximately -177.6 dBW/m^2, which complies with the limit.

PFD Calculation
================
EIRP = 2.3 dBW
EIRP Density = -15.6 dBW per 4.0 kHz Ref BW
θ = 0°
D = 35261.0 km
PFD = -177.6 dBW/m^2 @ 4.0 kHz Ref BW

v. Protection of authorized X-band satellite operators

The Momentus VR-7 mission plans to use a 1-megahertz channel (8199.5-8200.5 MHz) in the X-band EESS allocation (space-to-Earth), to the extent necessary, on an unprotected and non-interference basis for space operations services. The attached report, included as Exhibit 6, demonstrates that the VR-7 spacecraft operations will not cause unacceptable levels of interference to authorized satellite systems in these X-band frequencies.[19]

vi. Out-of-band emissions in the 8400-8450 MHz band

ITU-R Recommendation SA-1157-1 specifies a maximum allowable interference power spectral flux density level ("PSFD") at the Earth's surface to protect ground receivers in the deep-space research band operating in the 8400-8450 MHz frequencies.[20] Momentus complies with this requirement by using a combination of baseband digital filtering and hardware radio frequency filtering, which is projected to provide 80 dB of filtering. Moreover, Momentus' highest band edge is approximately 200 megahertz below the lowest band edge for the 8400–8450 MHz band, which would result in further attenuation.

Momentus calculates a maximum PSFD at the Earth's surface of -256.5 dB(W/m^2 / Hz), which is below the maximum allowable interference power spectral flux-density level at the Earth's surface of -255.1 dB(W/m^2/Hz) at 8.4 GHz.[21] The maximum interference PSFD was calculated as follows:

VR-7 maximum PFD (at 350 km altitude) = -140.5 dB(W/m^2*4 kHz)
Total Attenuation at 8.4 GHz relative to 8.2 GHz (filtering and guard band) = at least 80 dB

PSFD = PFD - 10*log(4000) – Attenuation
PSFD = -140.5 dB(W/m^2/4000 Hz) - 10*log(4000) dB - 80 dB
PSFD = -256.5 dB(W/m^2/Hz)

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[19] *See* Exhibit 6.

[20] *See* Recommendation ITU-R SA.1157-1 (Protection criteria for deep-space research) (2006).

[21] *Id.*

b. UHF Beacon Frequencies

VR-7 will include a limited-duration UHF beacon. The beacon transmissions will contain data from GPS receivers onboard the spacecraft and will be used to facilitate the acquisition of the satellite in the two-week period after deployment, thereby reducing the probability that Momentus will not be able to communicate with the spacecraft as a result of any anomalies. Momentus expects to receive the data from the beacon transmissions at the Brøstadbotn, Norway ground station identified in Exhibit 8. The beacon will have the following technical parameters:

Center Frequency: 400.5 MHz
Bandwidth: 20 kHz
Antenna Gain: 5.2 dBi
Modulation: 2GFSK
RF Output Power: 9.5 dBW EIRP

The beacon will be set to begin automatically transmitting 120 seconds following separation from the launch vehicle. The duty cycle of the transmissions will be 6 seconds every 60 seconds. As a failsafe to ensure termination of the beacon, there is a built-in, two-week timer that is stored in triple-voted, non-volatile memory. Once the timer expires the processor in the beacon will turn the radio off.

The operator can power off the beacon at any time via command from the ground.[22] Momentus will manually turn off the beacon as soon as the company is able to reliably obtain accurate tracking information.[23]

The 400.15-401 MHz band (space-to-Earth) band is allocated internationally and in the United States for federal and non-federal mobile-satellite and space research use on a primary basis as well as for federal and non-federal space operations use on a secondary basis.[24] Momentus' use of these frequencies to transmit data from GPS receivers and to facilitate acquisition of the satellite is consistent with the space operations allocation under the U.S. Table of Frequency Allocations.[25] Given the anticipated brief use of the beacon over the life of the mission and the low duty cycle when in use, Momentus submits that the beacon is unlikely to cause harmful interference to other authorized operations.

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[22] 47 C.F.R. § 25.207. In the particular case where the beacon is powered off prior to the initial 14-day maximum period and the spacecraft restarts or otherwise reinitiates its software, the beacon will power on and commence transmitting for the <u>remaining portion of the 14-day period</u>, calculated from the time Momentus separated from the launch vehicle. In such instances, Momentus would send a beacon shut-down command, as soon as practicable. To be clear, unless commanded to power on, the beacon would not transmit at any time after the 14th day from the launch vehicle separation regardless of any spacecraft restarts.

[23] The beacon does not automatically re-activate after it has been shut off. The operator can reset the beacon via command from the ground. In such event, the beacon will commence transmitting again with another 2-week timer. Momentus would not reset the beacon without obtaining additional FCC authorization.

[24] In order to protect NOAA radiosondes operations in the United States, operations in the UHF frequencies will not exceed the long-term interference criteria limits specified in Table 2 (Type C) of Recommendation ITU-R RS.1263-2.

[25] Momentus is aware that the FCC established an October 15, 2019, cut-off deadline for requests to operate, *inter alia*, in the 400.15-401 MHz band for the provision of Mobile-Satellite Service. *See Cut-off Established for Additional NVNG MSS Applications or Petitions for Operations in the 399.9-400.05 MHz and 400.15-401 MHz Bands*, Public Notice, DA 19-779 (August 15, 2019). Momentus' proposed use of this band for space operations on a secondary basis is limited and not mutually exclusive with other operations on a long-term basis. Accordingly, the request to use these frequencies should be treated as consistent with the 400.15-401 MHz processing round.

c. UHF ISL Frequencies

VR-7 includes a receive-only ISL (with a center frequency of 916 MHz) that will receive telemetry data from TROOP-F2 to facilitate the RPO activities between the spacecraft. Near Space Launch Inc., the operator of the TROOP-F2 vehicle, is separately seeking a Part 5 authorization to operate the spacecraft.[26] The 902-928 MHz band is designated for industrial, scientific, and medical applications and other applications, including federal radiolocation, federal fixed and mobile services, amateur, and location and monitoring services.[27] As discussed in the waiver section below, Momentus requests a waiver of the Commission's rules to receive communications in these frequencies.[28]

d. Triton-X Genesis S-band Uplink

As discussed above, the LuxSpace Triton-X Genesis payload will operate in the 2025-2110 MHz band (Earth-to-space). This band is allocated to space operations and EESS, *inter alia*, in all ITU regions. In the United States, space operations are limited to federal operators, and EESS use by commercial operators is subject to conditions. [29] As discussed in the waiver section below, to the extent necessary, Momentus requests a waiver of the Commission's rules to operate in these frequencies.[30]

[26] *See* Application of Near Space Launch, Inc. ELS File No. 0309-EX-CN-2023 (filed February 18, 2023).

[27] 47 C.F.R. § 2.106.

[28] *See infra* Section III.A.4.

[29] See 47 C.F.R. § 2.106 n.US347.

[30] *See infra* Section III.A.1

e. Triton-X Genesis S-band Downlink

The Triton-X Genesis payload will operate in the 2200-2290 MHz band (space-to-Earth). This band is allocated internationally for EESS, space research, and space operations.[31] In the United States, this band is allocated primarily for Federal EESS, space research, and space operations. As discussed below, to the extent necessary, requests a waiver of the Commission's rules to operate in these frequencies.[32]

2. Schedule S Clarifications

The minimum and maximum Saturation Flux Density ("SFD") values in the Schedule S are generally relevant only to geostationary-orbit ("GSO"), bent-pipe communication links. Nonetheless, Momentus calculates minimum and maximum SFD values for this NGSO spacecraft with regenerative links and provides in the Schedule S the range of PFD values expected at the satellites over the full range of operational orbital altitudes, gateway Earth station EIRP levels and elevation angles. Additionally, because the ISLR beam entry represents the reception of an inter-satellite link that supports RPO, the SFD values provided in the Schedule S system for that entry are placeholder values to enable submission through the system.

3. Frequency Tolerance and Emission Limitations

Momentus will comply with the frequency tolerance requirements of 47 C.F.R. § 25.202(e) and the emission limitations of 47 C.F.R. § 25.202(f). In addition, VR-7's transmitter does not turn on automatically (except as discussed with respect to the UHF beacon), and manual commands from the ground are required to initiate communications from the spacecraft. Accordingly, VR-7 complies with 47 C.F.R. § 25.207.

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[31] *See* 47 C.F.R. § 2.106.

[32] *See infra* Section III.A.2.

4. Ground Stations

All operational communications between the Momentus MOC and ground stations will be protected by levels of encryption appropriate to secure control over the VR-7. To that end, TT&C transmissions will be sent using packetized protocols incorporating end-to-end AES256 encryption.[33] Provided in Exhibit 8 is a table identifying the ground stations that Momentus intends to use with the VR-7 spacecraft.[34] The company may expand its future ground station network to include stations inside and/or outside the United States. Momentus will coordinate all non-U.S. ground stations with Federal operators in the relevant bands prior to operating any such stations and requests authority for such communications subject to coordination with relevant Federal operators. Momentus will maintain an updated list of coordinated earth stations in the license application docket.[35]

5. Microwave Electrothermal Thruster

VR-7 uses a radiofrequency generator that emits electromagnetic energy at a maximum theoretical power level of 750 watts to operate the thruster. This generator uses a magnetron to efficiently produce this level of power output, which, in turn, is delivered via a bolted waveguide

[33] The ground station operator will not receive any keys necessary to decrypt or otherwise manipulate any packetized TT&C instructions sent from the MOC to VR-7.

[34] Except for the Triton-X Genesis payload, which communicates only with a single ground station located in Spain, Momentus expects that it will have, as a minimum, between four to five passes per day over each of the identified ground stations (*i.e.*, four to five opportunities per day per station to communicate with VR-7) but may nominally have in excess of nineteen such passes in any given day. Each communication window presents an average of approximately ten minutes contact time.

[35] *See, e.g.,* Stamp Grant, Loft Orbital Solutions Inc., IBFS No. SAT-LOA-20200907-00105, at Condition 14 (granted May 28, 2021) ("[Licensee] shall provide the FCC with an updated list of coordinated earth stations within ten business days following any changes to the list."); Stamp Grant, Astro Digital US, Inc., IBFS File No. SAT-MOD-20210319-00036, at Condition 17 (granted May 28, 2021) ("[Licensee] must provide the FCC with a list of such earth stations and any operating condition as a result of coordination with the Federal agencies within ten business days of completing coordination."); Stamp Grant, Planet Labs Inc., IBFS File No. SAT-MOD-20200615-00076, Call Sign S2912 (granted March 18, 2021) ("[Licensee] shall provide the FCC with a list of coordinated earth stations, and shall provide the FCC with an updated list within ten business days following any changes to the list.").

connection to the thruster chamber. The location of the generator and the application of shielding mitigates the radiation of emissions outside of the thruster. The emission frequency generated by the magnetron is fixed and operates at 5750 MHz +/- 250 MHz. Electromagnetic interference emission levels from the flight thruster payload have been measured in an anechoic facility, indicating emissions of less than 10 uV/m at a distance of 300 meters. In addition, there is expected to be further attenuation given the aluminum structure surrounding the thruster, which has no gaps larger than the wavelength (~5 cm).

Momentus' proposed thruster operations will not cause harmful radiofrequency interference to incumbent services. The narrow frequency range around 5750 MHz is used on a primary basis by Radiolocation and Fixed-Satellite (Earth-to-space) and is used on a secondary basis by the Amateur and Amateur-Satellite radio services in all three ITU regions.[36] The power flux density at the Earth's surface from 150 km, the estimated closest operational distance to the satellite, is far below the PFD threshold specified in the ITU Radio Regulations.[37] At the calculated emission levels, no emissions will be detectable (by a very large margin) by radar, mobile, fixed, or amateur systems. All other emissions from the thruster (*e.g.*, harmonics and sub-harmonics) will be further attenuated by at least an additional 20 dB.[38]

More specifically, per our calculations, the PFD at the Earth's surface is approximately -221 dB(W/m^2/4 kHz), which meets the limits specified in ITU RR 21.16 for all angles of arrival.

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[36] *See* 47 C.F.R. § 2.106.

[37] *See* ITU Radio Regulations 21.16.

[38] Due to the operation of the equipment as part of the spacecraft, Momentus believes the thruster should not be characterized as Industrial, Scientific or Medical equipment. *See* 47 C.F.R. §18.101, *et. seq.* In any event, as discussed above, due to the low calculated emissions levels, the frequency range within which the thruster will operate, and the operations of the equipment in space, the emissions from the propulsion system are unlikely to cause harmful interference to any authorized services.

PFD Calculation
===============
PFD = P*G/(4*π*D^2)
P = -7.27 dBW/4kHz Ref BW (750W)
θ = 0°
D = 150.0 km (worst case - decommissioning)
G = 1E-10 (as measured)[39]
PFD = -221.78 dBW/m^2 @ 4.0 kHz Ref BW

III. Waiver Requests

The Commission may waive any of its rules if there is "good cause" to do so.[40] In general, waiver is appropriate if (1) special circumstances warrant a deviation from the general rule; and (2) such deviation would better serve the public interest than would strict adherence to the rule.[41] Generally, the Commission will grant a waiver of its rules in a particular case if the relief requested would not undermine the policy objective of the rule in question and would otherwise serve the public interest.[42] Here, the development of efficient, flexible and non-toxic space transportation infrastructure, and the benefits such a service provide – including, critically, the potential to assist in orbital debris risk mitigation – represent a special circumstance warranting waiver of the FCC rules.

A. U.S. Table of Frequency Allocations

Section 25.112(a)(3) of the Commission's rules provides that an application is defective if an applicant does not seek a waiver request for authority to operate a space station in a frequency band that is not allocated under the ITU Radio Regulations for such operations. The Commission has specifically stated, with respect to waiver requests to permit non-conforming

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[39]As measured, there is a gain of less than -100 dBi within the 5670-5725 MHz range.

[40] *See* 47 C.F.R. § 1.3; *Northeast Cellular Tel. Co. v. FCC*, 897 F.2d 1164 (D.C. Cir. 1990); *WAIT Radio v. FCC*, 418 F.2d 1153 (D.C. Cir. 1969).

[41] *See Northeast Cellular*, 897 F.2d at 1166.

[42] *See WAIT Radio*, 418 F.2d at 1157.

uses, that it will grant such waivers when there is little potential for interference into authorized services and when the non-conforming operator accepts any interference from authorized services.[43] The Commission's standard for permitting non-conforming use and waiver of the rule has been applied to both operations that do not conform to the U.S. Table of Allocations and those that do not conform to ITU allocations.[44] As discussed below, because Momentus has demonstrated that its proposed uses will not cause harmful interference and that it will accept any interference from other systems authorized to use the requested spectrum, waiver of the rule is appropriate in all cases requested below.

1. 2025-2110 MHz TT&C Uplink

This band is allocated to space operations and EESS, *inter alia*, in all ITU regions. In the United States, space operations are limited to federal operators, and EESS use by commercial operators is subject to conditions as may be applied on a case-by-case basis and the limitation

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[43] *Application for Modification of License to Authorize a Second-Generation NGSO MSS Constellation by Iridium Constellation LLC*, Order and Authorization, 31 FCC Rcd. 8676 at ¶ 21 (IB 2016); *see also Applications by Orbcomm License Corp. for Authority to Modify its Non-Voice, Non-Geostationary Satellite System et al.*, Order and Authorization, 23 FCC Rcd. 4804 at ¶ 15 (IB & OET 2008); *The Boeing Company*, Order and Authorization, 16 FCC Rcd. 22645 at ¶ 12 & n.48 (IB & OET 2001) (citing *Fugro-Chance, Inc.*, Order and Authorization, 10 FCC Rcd. 2860 at ¶ 2 (IB 1995); *Motorola Satellite Communications, Inc.*, Order and Authorization, 11 FCC Rcd. 13952 at ¶ 11 (IB 1996)).

[44] *See supra* note 43; *see also* Stamp Grant, Loft Orbital Solutions Inc., IBFS File Nos. SAT-LOA-20190807-00072 and SAT-AMD-20200527-00063, at Conditions 8-9 (Oct. 8, 2020) (granting waiver of 47 C.F.R. § 2.106 to allow use of commercial mobile-satellite service spectrum for intersatellite navigation correction service; granting waiver of 47 C.F.R. § 2.106 to allow use of commercial mobile-satellite service spectrum for intersatellite service on an unprotected, non-interference basis); Stamp Grant, Astro Digital US Inc., IBFS File No. SAT-LOA-20170508-00071 at n. 3 (granted in part Dec. 14, 2017) (granting use of commercial mobile-satellite service frequencies for intersatellite service based on showing of non-harmful interference); Stamp Grant, Spaceflight, Inc., IBFS File No. SAT-LOA-20220111-00007, at Condition 7 (granted in part May 10, 2022) (granting waiver of 47 C.F.R. 25.112(a)(3) to permit use of frequencies for space operation service in a frequency band allocated for other services, conditioned on operations on a non-interference, unprotected basis); *c.f. The Boeing Company Application for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in the Fixed-Satellite Service*, Order and Authorization, IBFS File Nos. SAT-LOA-20170301-00028, SAT-AMD-20170929-00137, SAT-AMD-20180131-00013 ¶¶ 12- 15 (rel. Nov. 3, 2021) (denying waiver of 47 C.F.R. § 25.112(a)(3) where applicant failed to provide sufficient technical information demonstrating that it could operate on a noninterference, unprotected basis).

that any use may not cause harmful interference to authorized operations.[45] For VR-7, the 2025-2110 MHz band is to be used primarily for TT&C and some satellite imaging, including RPO activities and marketing. Similarly, the Triton-X Genesis payload will operate, for in-orbit demonstration purposes only, in this band to communicate with only a single ground station located in Spain. Accordingly, to the extent necessary, Momentus requests waiver of the Table of Allocations and 47 C.F.R. § 25.112(a)(3)[46] to use the 2025-2110 MHz band (Earth-to-space) for TT&C and testing as discussed above.[47] Given the limited use of the frequencies during the brief mission, Momentus' commitment to coordinate use of these frequencies, and the public interest justification supporting the mission, Momentus submits that waiver is warranted.

2. 2200-2290 MHz Triton-X Genesis Downlink

As discussed above, the Triton-X Genesis payload will operate in the 2200-2290 MHz band (space-to-Earth). This band is allocated internationally for EESS, space research, and space operations.[48] In the United States, this band is allocated primarily for Federal EESS, space research, and space operations. The Triton-X Genesis S-band downlink will only communicate with one ground station, which is located in Spain. Momentus will pre-coordinate with Federal operators in this band to ensure no harmful interference would be caused to their operations by

[45] *See* 47 C.F.R. § 2.106 n. US347.

[46] *See supra* Section III.A.

[47] Waivers of the U.S. Table of Frequency Allocations are generally granted "when there is little potential for interference into any service authorized under the Table of Frequency Allocations and when the nonconforming operator accepts any interference from authorized services." *The Boeing Company*, Order and Authorization, 16 FCC Rcd. 22645 at ¶ 12 & n.48 (IB & OET 2001) (citing *Fugro-Chance, Inc.*, Order and Authorization, 10 FCC Rcd. 2860 at ¶ 2 (IB 1995); *Motorola Satellite Communications, Inc.*, Order and Authorization, 11 FCC Rcd. 13952 at ¶ 11 (IB 1996)).

[48] *See* 47 C.F.R. § 2.106.

such transmissions. To the extent necessary, requests a waiver of the Table of Allocations and to operate in these frequencies.[49]

3. 8025-8400 MHz TT&C Downlink

This band is allocated to EESS (space-to-Earth), *inter alia*, in all ITU regions and in the United States. For VR-7, the 8025-8400 MHz band is, as discussed above, to be used primarily for TT&C and some satellite imaging, including for RPO activities and marketing. Accordingly, to the extent necessary, Momentus requests waiver of the U.S. Table of Frequency Allocations and 47 C.F.R. § 25.112(a)(3).[50]

Momentus intends to engage in the following activities that will mitigate the potential for harmful interference:

- limit operations to approximately one year;
- transmit only over identified ground stations;
- limit use to a (maximum) one-megahertz bandwidth channel using OQPSK modulation;
- operate on an unprotected and non-harmful interference basis;
- maintaining a 3-degree avoidance angle with other co-frequency satellite operators, where necessary to address coordination requests; and
- pre-coordinate operations with potentially affected federal operators.

[49] *See supra* note 47.

[50] *See* 47 C.F.R. § 25.112(a)(3)(an application will be unacceptable for filing if it requests authority to operate a space station in a frequency band that is not allocated internationally for such operations under international radio regulations); *supra* Section III.A; *supra* note 47.

In analogous situations, the FCC has granted similar use of the X-band.[51] For these reasons, Momentus submits that waiver is warranted.[52]

4. 902-928 MHz Receive-Only ISL

The 902-928 MHz band is designated for industrial, scientific, and medical applications and other applications, including federal radiolocation, federal fixed and mobile services, amateur, and location and monitoring services.[53] This band will be used, as discussed above, for an ISL to transmit data from TROOP-F2 to VR-7, conveying telemetry of TROOP-F2 to facilitate the RPO activities between the spacecraft.

Momentus requests a waiver of the U.S. Table of Frequency Allocations[54] and 47 C.F.R. § 25.112(a)(3).[55] Momentus' proposed use of these frequencies is limited to space-to-space communications for a brief duration RPO demonstration and will not cause harmful interference

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[51] *See, e.g.,* Stamp Grant, Momentus Space LLC, IBFS File No. SAT-LOA-20221009-00131 (granted Feb. 27, 2022, reissued Mar. 29, 2023); Stamp Grant, Momentus Space LLC, IBFS File No. SAT-STA-20211216-00195 (granted April 28, 2022); Stamp Grant, Spaceflight, IBFS File No. SAT-STA-20210205-00017 (granted May 28, 2021); Stamp Grants, Momentus Space LLC, IBFS File Nos. SAT-LOA-20220504-00047, SAT-AMD-20220729-00075 (granted November 15, 2022); *see also Expediting Initial Processing of Satellite and Earth Station Applications*, Notice of Proposed Rulemaking, IB Docket Nos. 22-411, 22-271 (December 22, 2022).

[52] The Commission has specifically stated, with respect to waiver requests to permit non-conforming uses, that it will grant such waivers "when there is little potential for interference into any service authorized under the Table of Frequency Allocations and when the non-conforming operator accepts any interference from authorized services." *Application for Modification of License to Authorize a Second-Generation NGSO MSS Constellation by Iridium Constellation LLC*, Order and Authorization, 31 FCC Rcd. 8676 at ¶ 21 (IB 2016); *see also Applications by Orbcomm License Corp. for Authority to Modify its Non-Voice, Non-Geostationary Satellite System et al*., Order and Authorization, 23 FCC Rcd. 4804 at ¶ 15 (IB & OET 2008); *The Boeing Company,* Order and Authorization, 16 FCC Rcd. 22645 at ¶ 12 & n.48 (IB & OET 2001) (citing *Fugro-Chance, Inc.,* Order and Authorization, 10 FCC Rcd. 2860 at ¶ 2 (IB 1995); *Motorola Satellite Communications, Inc.,* Order and Authorization, 11 FCC Rcd. 13952 at ¶ 11 (IB 1996); *see also supra* note 51.

[53] 47 C.F.R. § 2.106.

[54] 47 C.F.R. § 2.106.

[55] *See* 47 C.F.R. § 25.112(a)(3) (an application will be unacceptable for filing if it requests authority to operate a space station in a frequency band that is not allocated internationally for such operations under international radio regulations); *see supra* Section III.A.

to existing or future authorized operations on the ground or in orbit.[56] Momentus will accept any interference from other authorized services in the band. Grant of the waiver for limited use of these frequencies for a single demonstration mission will enhance Momentus' ability to conduct RPO activities with TROOP-F2 vehicle and facilitate development in this field. For these reasons, grant of a waiver to allow limited use of these frequencies, as proposed in this application, is warranted.[57]

B. Modified Processing Round Rules

Momentus requests that this application be processed pursuant to the first-come, first-served procedure adopted for "GSO-like satellite systems" under Section 25.158 of the Commission's rules.[58] To the extent necessary to allow for such processing, Momentus also requests waiver of Sections 25.156 and 25.157 of the Commission's rules, which stipulate the processing of "NGSO-like satellite systems" under a modified processing round framework.[59]

The Commission has not required modified processing rounds and essentially allowed similar in-orbit servicing missions to be processed on a first-come, first-served basis on multiple occasions.[60] Momentus' spectrum use would be limited in time and location, and Momentus is

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[56] *See* Application of Near Space Launch, Inc. ELS File No. 0309-EX-CN-2023, TROOP-F2 EMC Analysis (filed April 26, 2023) (demonstrating that the ISL use will not interfere with terrestrial stations because the expected maximum field strength received at a station is 11.3 dBµV/m, which is below the minimum non-interference requirement of 15 dBµV/m).

[57] *See supra* note 47.

[58] 47 C.F.R. § 25.158.

[59] 47 C.F.R. §§ 25.156 and 25.157.

[60] Application of Spaceflight, IBFS File No. SAT-STA-20210205-00017 (granted May 28, 2021); Application of Spaceflight, IBFS File No. SAT-STA-20180523-00042 (granted October 12, 2018); Application of Spaceflight, IBFS File No. SAT-STA-20150821-00060 (granted October 26, 2016); Application of Momentus Space LLC, IBFS File No. SAT-STA-20211216-00195 (granted April 28, 2022); Application of Momentus Space LLC, IBFS File No. SAT-LOA-20220504-00047 (granted November 15, 2022); Application of Momentus Space LLC, IBFS File No. SAT-LOA-20221009-00131 (granted Feb. 27, 2022, reissued Mar. 29, 2023);.

capable of both sharing the spectrum on which it proposes to operate and operating on a non-interference basis. A grant of Momentus' requested authorization would not preclude later grants of applications for the same spectrum. Accordingly, the underlying basis of the processing round rules would not be served by applying them under these circumstances here.

C. Milestone and Bond Requirements

Momentus requests waiver of the Commission's milestone and bond requirements for NGSO systems.[61] The Commission's bond requirements have been developed to prevent licenses from warehousing spectrum.[62] Momentus does not seek mutually exclusive use of the spectrum used, as discussed above. A grant of Momentus' requested authorization would not preclude other operators from seeking authorization to use the frequency bands proposed by Momentus. Accordingly, there is no basis to impose the milestone or bond requirements.

Additionally, as the Commission has recognized, the anticipated time period for implementation and overall length of time that individual satellites are expected to operate are relevant considerations with regards to public interest benefits of bond requirements.[63] Here, the mission life for VR-7, a single spacecraft, is expected to be one year. Indeed, the FCC has not historically imposed a bond requirement on limited-duration, in-orbit deployment missions,

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[61] *See* 47 C.F.R. §§ 25.164, 25.165.

[62] *See Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Second Report and Order, 30 FCC Rcd. 14713 at ¶ 53 (2015) (citing, *e.g.*, *TMI Communications and Company, Limited Partnership and TerreStar Networks Inc.*, *Application for Review and Request for Stay*, Memorandum Opinion and Order, 19 FCC Rcd. 12603 at ¶ 2 (2004); *PanAmSat Licensee Corp.*, A*pplication for Authority to Construct, Launch, and Operate a Ka-Band Communications Satellite System in the Fixed-Satellite Service at Orbital Locations 58° W.L. and 125° W.L.*, Memorandum Opinion and Order, 16 FCC Rcd. 11534 at ¶ 12 (2001)).

[63] *In the Matter of Streamlining Licensing Procedures for Small Satellites*, Notice of Proposed Rulemaking, 33 FCC Rcd. 4152 at ¶ 51 (2019). The ultimate rule adopted by the Commission for small satellites provides that individual satellites must have a lifetime from deployment of six years or less. 47 C.F.R. § 25.123(b)(2).

including prior Momentus missions.[64] Given the approaching scheduled launch date of VR-7 and consistent with prior Momentus missions, Momentus requests the Commission waive the bond and milestone requirements by requiring Momentus to post a surety bond within 90 days of grant, rather than the 30 days provided by rule.[65]

Another consideration that underlies the Commission's bond requirements is the Commission's concern not to impose a cost that is disproportionate to the overall cost of the mission.[66] The Commission has stated: "we note that the cost of maintaining a $3 million or $5 million final bond during satellite construction is nominal in comparison with the cost to implement licensed space stations, which generally cost several hundred million dollars each to launch and operate."[67] For NGSO constellations with costs to construct and launch measured in the billions, a $5 million bond and associated fees might indeed be viewed as "nominal." But, for a single satellite with a limited mission duration, the bond and associated fee, even for a short period of time, would be excessive and would be a disproportionate and unfair cost. For these reasons, Momentus submits that waiver of the milestone and bond requirements is justified.

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[64] *See, e.g.*, Application of Momentus Space LLC, IBFS File No. SAT-LOA-20221009-00131 (granted Feb. 27, 2022, reissued Mar. 29, 2023); Application of Momentus Space LLC, IBFS File Nos. SAT-LOA-20220504-00047, SAT-AMD-20220729-00075 (granted November 15, 2022); Application of Spaceflight, IBFS File No. SAT-STA-20210205-00017 (granted May 28, 2021); Application of Spaceflight, IBFS File No. SAT-STA-20180523-00042 (granted October 12, 2018); Application of Spaceflight, IBFS File No. SAT-STA-20150821-00060 (granted October 26, 2016); Application of Momentus Space LLC, IBFS File No. SAT-STA-20211216-00195 (granted April 28, 2022).

[65] *See* Stamp Grant, Momentus Space LLC, IBFS File No. SAT-LOA-20221009-00131, at Condition 9 (granted Feb. 27, 2022, reissued Mar. 29, 2023); Stamp Grant, Momentus Space LLC, IBFS File Nos. SAT-LOA-20220504-00047, SAT-AMD-20220729-00075, at Condition 10 (granted November 15, 2022).

[66] *See In the Matter of Amendment of the Commission's Space Station Licensing Rules and Policies*, First Order on Reconsideration and Fifth Report and Order, 19 FCC Rcd. 12637 at ¶¶ 28-31 (2004).

[67] *In the Matter of Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Second Report and Order, 30 FCC Rcd. 14713 at ¶ 60 (2016).

D. Annual Regulatory Fee

For the same reasons stated above, Momentus also requests that the FCC waive in advance any application of the FCC's annual satellite fee for NGSO systems. Given the brief duration of the mission, the potential assessment of hundreds of thousands of dollars in annual fees would be excessive, disproportionate, and unfair.[68] Moreover, the Commission itself recently concluded that assessing annual fees for in-orbit service providers was premature and invited comments on adopting a fee category for such service providers.[69]

IV. ITU Compliance

Momentus has prepared the ITU Advance Publication Information submission for its proposed system and is contemporaneously providing this information to the FCC under separate cover. Attached as Exhibit 1 to this application is a signed ITU cost-recovery declaration.

Respectfully submitted,

/s/ Paul Ney

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Dated: May 1, 2023

[68] *See In the Matter of Assessment and Collection of Regulatory Fees for Fiscal Year 2022*, Report and Order and Notice of Proposed Rulemaking, ET Docket No. 22-223, FCC 22-68 (September 2, 2022).

[69] *Id.* at ¶ 45.

EXHIBIT 1

ITU Cost-Recovery Declaration

May 1, 2023

Marlene H. Dortch
Office of the Secretary
Federal Communications Commission
45 L Street, N.E.
Washington, D.C. 20554

Subject: ITU Cost Recovery Declaration for the VIGORIDE-7 Satellite Network Operating in Non-geostationary Orbit in the Non-Planned Frequency Bands. (VIGORIDE-7)

Dear Ms. Dortch,

Momentus Space LLC ("Momentus") is aware that in accordance with Resolution 88 of the International Telecommunication Union's (ITU) Plenipotentiary Conference (Marrakech, 2002), and ITU Council Decision 482, as modified, cost-recovery fees will apply to satellite network filings received by the Radiocommunications Bureau after November 7, 1998. As a consequence, Commission applicants are responsible for any and all fees charged by the ITU to process their satellite network filings. Momentus hereby states that it is aware of this requirement and unconditionally accepts all cost recovery responsibilities associated with the ITU filings for the VIGORIDE-7 satellite network. Please address all cost-recovery inquiries, and ITU correspondence and filings, related to the VIGORIDE-7 satellite network to the following point of contact. We understand that should there be any change in the point of contact information, we will inform the Commission within 30 days of the foreseen event.

Point of Contact Name: Paul Ney

Organization Name: Momentus Space LLC

Address: 3901 N. First Street
San Jose, CA 95134

E-Mail: paul.ney@momentus.space

Telephone Number: (650) 564-7820

Momentus understands that it must remit payment of any resultant cost-recovery fee to the ITU by the due date specified in the ITU invoice, unless an appeal filed prior to the due date is pending with the ITU. We fully understand that a license granted in reliance on such a commitment will be conditioned upon discharge of any such cost-recovery obligation. We also acknowledge that, in accordance with 47 C.F.R. § 25.111, should we have an overdue ITU cost-recovery fee and have no appeal pending with the ITU, the Commission may dismiss any application associated with that satellite network.

Sincerely,

/s/Paul Ney/

Paul Ney
Chief Legal Officer

EXHIBIT 2

Orbital Debris Assessment Report

Vigoride-7 Spacecraft

Orbital Debris Assessment Report (ODAR)

Rev 1

5/01/2023

Momentus Space LLC

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Document contains no ITAR or otherwise export-restricted data.

DAS Software Version used in Analysis: v3.2.3

Revision History

Revision Number	Updates	Page #	Author	Date
1	Initial Release	All	Rudy Opperman	05/01/23

Table of Contents

Rudy Opperman
Regulatory Technical Lead, Vigoride-7
Momentus

Orbital Debris Self-Assessment Evaluation

Reqm't #	Launch Vehicle				Spacecraft			Comments
	Compliant or N/A	Not Compliant	Std. Non-Compliant	Incomplete	Compliant or N/A	Not Compliant	Incomplete	*For all incompletes, include risk assessment (low, medium, or high risk) of non-compliance & Project Risk Tracking #*
4.3-1.a *MRD 25-year limit*	☑	☐	☐	☐	☑	☐	☐	See comment 1. No debris released.
4.3-1.b *MRD<100 object x year limit*	☑	☐	☐	☐	☑	☐	☐	See comment 1. No debris released.
4.3-2 *GEO MRD*	☑	☐	☐	☐	☑	☐	☐	See comment 1. No debris released.
4.4-1 *<0.001 Explosion Risk*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.4-2 *Passivate Energy Sources*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.4-3 *Limit Intentional BU*	☑	☐	☐	☐	☑	☐	☐	See comment 1. No intentional breakups.
4.4-4 *Limit Intentional BU*	☑	☐	☐	☐	☑	☐	☐	See comment 1. No intentional breakups.
4.5-1 *<0.001 10cm Impact Risk*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.5-2 *<0.01 Small MMOD Impacts*	☐	☐	☐	☐	☑	☐	☐	See comment 1.
4.6-1a-c *LEO Disposal*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.6-2 *Storage or Earth-escape*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.6-3 *Long-term Reentry*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.6-4 *Disposal Reliability*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.7-1 *Reentry Risk*	☑	☐	☐	☐	☑	☐	☐	See comment 1.
4.8-1 *Special Classes*	☐	☐	☐	☐	☑	☐	☐	No special classes.

Comment 1. This ODAR analyzes only the Vigoride-7 ("VR-7") spacecraft and provides representative information regarding the customer payloads. The launch vehicle and other launch vehicle payloads are not considered in this ODAR.

Assessment Report Format

ODAR Technical Sections Format Requirements: This ODAR follows the format recommended in NASA-STD-8719.14, Appendix A.1, and includes the content indicated at a minimum in sections 2 through 8 for the VR-7 spacecraft. Sections 9 through 14 of the NASA standard apply to the launch vehicle and are not covered here.

I. Program Management and Mission Overview

Project Manager:

- Sean Burch

Foreign Government or space agency participation:

- None

Schedule of Upcoming Mission Milestones:

- Launch – scheduled October 2023

Mission Overview:

This ODAR evaluates the Momentus VR-7 mission, which is targeted to launch on a SpaceX Falcon 9 rocket. For the mission, VR-7 will exhibit the capacity to transport and deploy multiple payloads. Each deployed payload is a commercial smallsat individually licensed and authorized to operate by its respective national jurisdiction.[1] The necessary de-orbit and debris analysis for each deployed payload will be addressed through the licensing process for the relevant payload. As demonstrated in this ODAR, VR-7 is compliant with all applicable orbital debris requirements.

Launch Vehicle:

- Falcon 9

Expected Launch Site:

- Vandenberg Air Force Base, California

Operational Mission Duration:

- Approximately 1 year.

The VR-7 nominal concept of operations ("CONOPS") is as follows:

1. Launch vehicle arrives at insertion orbit (maximum 525 km altitude circular sun-synchronous orbit ("SSO")), with approximately 97 +/- 1 degree inclination.
2. VR-7 separates from launch vehicle.
3. VR-7 undergoes commissioning and preliminary testing.

[1] General information regarding the payloads is provided in Exhibit 5 to the application.

4. VR-7 deploys each of the customer payloads, except TROOP-F2.
5. VR-7 commissions the LuxSpace Triton-X hosted payload, which is not deployed.
6. VR-7 releases TROOP-F2, the target vehicle for VR-7's demonstration, and performs a close-approach Rendezvous and Proximity Operation ("RPO") with TROOP-F2.[2]
7. VR-7 completes a 180-day LuxSpace hosted payload mission.
8. VR-7 relocates to end-of-life orbit (380 km x 350 km elliptical).

A. Rendezvous and Proximity Operations

The focus of the RPO demonstration mission will be to validate the proposed architecture for rendezvous. The demonstration will test and validate sensor capability, navigation capability, and rendezvous/proximity operations. The demo mission will use a 6U CubeSat, TROOP-F2, to test and validate the RPO capability. The target cubesat will be onboard VR-7 and then deployed from VR-7. TROOP-F2 will have technology elements onboard that are required for rendezvous and proximity operations (e.g., LEDs, fiducials, inter satellite radio link) and will be separately licensed by Near Space Launch Inc.[3]

RPO CONOPS:

1. At insertion orbit, after completion of LuxSpace commissioning, VR-7 deploys TROOP-F2, the client object.
2. TROOP-F2 dampens out any rotation rates and relays client object health, position, and attitude information to VR-7 via Inter Satellite Link (ISL).
3. VR-7 conducts maneuvers to drift approximately 20 km away from client object and calibrates camera sensors.
4. After approximately 23 days, VR-7 conducts maneuvers[4] to decrease distance with client object, decreases closing rates at approximately 1 km separation, and calibrates camera sensors while holding relative position.
5. VR-7 performs a series of maneuvers[5] to enter a co-elliptic nearfield relative trajectory and reach a hold point at approximately 250 m separation.

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[2] *See infra*, RPO Concept of Operations.
[3] *See* Application of Near Space Launch Inc., ELS File No. 0309-EX-CN-2023 (filed February 28, 2023).
[4] Specifically, VR-7 will lower its altitude by approximately 150-200 m to increase its speed relative to TROOP-F2, then VR-7 will raise its orbit when it approaches approximately 1 km away from TROOP-F2, decreasing its relative speed.
[5] As part of this process, VR-7 may need to abort its close approach and reset its relative distance to TROOP-F2. In that event, VR-7 would raise its orbital altitude above TROOP-F2 by approximately 200 m, reducing its speed relative to TROOP-F2, and return to the 1 km separation distance. Accordingly, the worst case orbital altitude for the VR-7 mission is 525.2 km.

6. VR-7 approaches client object along velocity vector via safety corridor until approximately 100 m separation and holds.
7. VR-7 transits 1 km away from client object and recalibrates camera sensors if needed.
8. VR-7 repeats steps above, with a modification to reach 10 m separation and holds.
9. VR-7 performs its final approach to a best case 2 m (nominal 10 m) capture box separation and then retreats to 1 km separation.
10. VR-7 repeat steps 5 through 9, as propellant reserves and schedule allow.

Table 1. Orbital Parameters

	Insertion, Checkout and Payload Deployment Orbit	TROOP-F2 RPO and LuxSpace Orbit	Final Orbit
Apogee Altitude	525 km (max)	525.2 km (max)[6]	380 km (max)
Perigee Altitude	525 km (max)	525.2 km (max)	350 km
Inclination	97° +/- 1°	97° +/- 2°	97° +/- 1°
Period	~95.1 mins	~95.1 mins	~91.8 min
Argument of Perigee	N/A	N/A	N/A
Local Time of the Ascending Node (LTAN)	11:30 AM	11:30 AM	-
Maximum De-Orbit Life	~ 2.8-13.0 years years[7]	~ 2.81 years	< 3 months[8]

[6] *See supra* note 5.
[7] This is the deorbit duration, if VR-7 fails after deployment. The range is based upon the following three cases: if VR-7 fails before solar array deployment, then the time to deorbit is 13 years; if VR-7 fails after solar array deployment but before it has released all of the deployable payloads, then the time to orbit is 4.5 years; and if VR-7 fails after solar arrays deploy and the deployable payloads are released, then the time to deorbit is 2.8 years.
[8] This is the deorbit duration, if VR-7 achieves a 380 x 350 km orbit and then the propulsion system fails.

Failsafe Deployment:

VR-7 includes a failsafe deployment timer for the Payload Management Unit to ensure customer payloads deploy in off-nominal situations. The timer system commences upon deployment and begins a countdown that will trigger the release of the deployable customer payloads after 14 days. In the event that the VR-7 bus experiences a failure and Momentus is unable to command the deployment of the customer payloads, the timer system provides a failsafe deployment mechanism. Re-contact analysis is provided below in Section III.

II. Spacecraft Description

Physical Description:

VR-7 has the following subsystems: Propulsion, Structures, Mechanisms, Electric Power, and Avionics.

VR-7 includes a primary and a secondary structural assembly with: Propellant/Pressurant Tanks, Microwave Electrothermal Thruster (MET), Reaction Control System thrusters, Solar Array Assemblies, a launch vehicle separation ring, a deployable solar array, and 7 CubeSat deployers, 4 12U deployers, 2 6U and 1 16U deployer.

VR-7 includes two 4-panel 800W deployable solar arrays which are deployed using a Hold Down and Release Mechanism (HDRM), which releases no debris. The solar array deployment is controlled by a software timer via the flight computer.

The VR-7 customer payloads are fully stowed in deployers and their power is inhibited prior to on-orbit deployment. The payloads will follow the form and mass characteristics of a standard CubeSat of the relative U-size of the payload. The VR-7 spacecraft platform components all have their power inhibited until launch vehicle separation occurs.

Figure 1. Artist rendering of Vigoride deploying a customer spacecraft.

Table 2. General Spacecraft Description

Criteria	Description	Notes
Spacecraft Total Launch Mass	475 kg	Includes ~51 kg of propellant.
Spacecraft Launch Dry Mass	424 kg	Includes 156.2 kg of deployable payloads
Propulsion System	Redundant MET and reaction control thrusters. See *Propulsion System Description*.	Propulsion system operates using non-toxic and low-pressure liquid water propellant.
Body Dimensions	1.08x1.21x1.62 m^3, stowed solar arrays body configuration	Body dimensions
Deployed Solar Array Dimensions	2.68x1.41x0.01m^3	Dimensions per solar array wing.
Identification of all Fluids	• Liquid/vapor water mixture (propellant) • Nitrogen Gas (tank pressurant) • Dynalene HC-50 (Potassium Formate/H2O Solution – for cooling) See *Fluids Description*.	
Fluids in Pressurized Batteries	None. VR-7 uses unpressurized lithium-ion cells.	
Attitude Determination and Control	Attitude Determination • Star Trackers • Sun Sensors • Gyroscopes Attitude Control • Reaction Control Thrusters See *Attitude Determination and Control System Description*.	

Range Safety or Pyrotechnic Devices	Two separation system initiators	Single use part for separation from launch vehicle. No pyrotechnic devices used throughout the duration of the mission.
Electrical Generation and Storage System	Two 800W solar array wings for power generation. Four 500 Wh batteries are included and charged prior to launch vehicle integration.	
Other Stored Energy	• Solar array spring energy stored in hinges. • Clampband separation system spring energy. • Payload deployer hinged door spring energy.	
Radioactive Materials	Not applicable.	
Rendezvous and Proximity Operations (RPO)	VR-7 will conduct proximity operations with TROOP-F2.	

Propulsion System Description

The VR-7 fully redundant propulsion system energizes distilled water into plasma using RF microwave energy. The plasma is expelled out of two identical thrusters using nozzles to produce thrust at a specific impulse (Isp) exceeding traditional chemical propulsion systems. The expected thrust and Isp will vary with input power levels but will not exceed 150 mN per thruster. The VR-7 mission will nominally include 51 kg of liquid water propellant at launch. The maximum expected total impulse is approximately 150 kNs.

In addition, there are thirty-two reaction control thrusters (eight assemblies of four thrusters) each with an estimated maximum thrust of 30 mN and specific impulse of 120 seconds. These reaction control thrusters are operated as two redundant sets of sixteen thrusters and use the same stored liquid water as a propellant.

Fluids Description

The propulsion system includes a single primary tank with liquid water propellant pressurized using inert gaseous Nitrogen. At spacecraft integration, the propellant tank is pressurized to 4 psia. The tank is expected to remain within 20% of this pressure during transportation to the launch site, during launch, and post launch until thruster operations.

Attitude Determination and Control System Description

The VR-7 spacecraft includes 3-axis control with reaction control thrusters. For attitude determination, the spacecraft includes redundant star trackers, sun sensors, and gyroscopes, providing nominally >1° pointing knowledge.

- A sun tracking mode allows for optimized solar power generation by the spacecraft. The spacecraft's body will be oriented in two axes, and onboard Solar Array Drive Assemblies (SADAs) will rotate the panels along the third axis.
- A targeted tracking mode will allow the thrust axis to be pointed in any direction in inertial space.

RPO Safety Considerations in the VR-7 Design:

The Momentus RPO mission has been designed from the ground up with safety in mind. Several concepts were implemented in the design, which were inspired from standard safety practices defined by NASA's International Space Station visiting vehicle requirements. They are as follows:

- Each approach maneuver, outside of a defined keep out sphere (KOS) of 200 m around the target vehicle is designed to be free drift safe. This concept allows for full loss of vehicle control/navigation after each maneuver is completed, and the resulting free drift trajectory will not result in conjunction with the target. The trajectory was designed using linear covariance analysis to account for burn execution errors and navigation errors to ensure resulting trajectory uncertainty ellipsoids after each maneuver that stay outside of 200 m for 6+ hours. Trajectories are free drift safe much longer than this in practice. Free drift trajectories are also analyzed via 6-DOF Monte Carlo simulation to ensure proper clearance to the KOS
- As such, if the vehicle needs to be commanded out of autonomous approach anywhere prior to the forced motion phase of flight (250 m to 2 m), it can be commanded to do so safely.
- Each maneuver has a maximum execution time to prevent overburn, and the vehicle will transition to passive abort

- On the velocity vector (vbar), while translating toward the target, an active abort strategy was designed.
    - All aborts are body fixed, as to not require navigation to execute.
    - Aborts are sized such that the vehicle can be pointed off of the target by 15 degrees and be effective.
    - Aborts are designed to "initiate and maintain" an opening rate while within the KOS. This means that the separation distance is designed to increase during an abort.
    - Aborts are analyzed via Monte Carlo simulation to ensure effectivity under dispersion.
- The relative navigation system is designed such that:
    - Two separate and distinct filters are operating all the time, one in "primary mode", which is used to seed guidance and control, and one in backup mode
    - The backup filter is always designed as a crosscheck and is not used in navigation/control.
    - The backup filter uses dissimilar measurements than the primary filter.
    - The state machine is designed to transition to abort if the primary filter covariance does not overlap the secondary one.
    - The primary filter faults after a configured threshold of consecutive measurement outages as defined by the propagation dynamics, and the vehicle is designed to abort on the vbar.
    - The primary filter faults after a configured threshold of residuals that exceed a threshold, and the vehicle is designed to abort on the vbar.

III. Spacecraft Debris Released during Normal Operations

Payload Re-Contact Mitigation

Momentus plans to support at least three re-contact mitigation strategies for deployments from VR-7:

- Each deployment group will be spaced apart by at least 2.5 full orbits.
- Momentus will optimize deployment orientation and sequence to minimize re-contact.
- On-board propulsion may also be used for maneuvers to minimize the risk of re-contact.

Momentus conducted Monte Carlo simulations (varying velocity and attitude) to assess the probability of re-contact under nominal and contingency deployment conditions. The analysis predicts a 0.0% probability of re-contact between the deployed payloads and the VR-7 vehicle under nominal deployment conditions. If VR-7 is unable to maintain attitude control during deployment (such as in the event of the triggering of the failsafe deployment timer), the analysis estimates an average probability of re-contact of less than 0.1%. Both the auto-deploy timer and nominal deployment CONOPS ensure at least 2.5 orbits between each release.

Method: Momentus re-contact analysis includes deployment interval optimization to ensure minimal opportunity for conjunction between payloads, along with a Monte Carlo analysis to compute probabilities of collision between each payload and with the host vehicle. Collision probability is calculated both for 'nominal' deployment and 'tumbling' deployment cases. Tumbling cases factor in dispersion variations for yaw and pitch upon initial payload deployment.

Assumptions for this analysis:

- Single 6U payload deploying
  - Payload mass: 7.0 kg
  - Payload deployment velocity: 1.1 m/s
- Deployment altitude: 525 km
- Deployment velocities considered (with respect to host velocity): Radial, In-track, Cross-track and anti-radial, anti-velocity, & opposite cross-track (i.e. RIC and -R,-I,-C)
- Monte Carlo parameters:
  - 200 runs
  - Deployment velocity standard deviation (std): 5.0%
  - Pitch angle std: 5 deg
  - Yaw angle std: 5 deg

Results: With one deploying payload, interval optimization minimized the probability of conjunction between the deploying payload and the host. Deployment analysis for VR-7 and its deploying payload shows 0.0% probability of collision for all nominal deployment cases, and up to 0.5% probability of collision for tumbling deployment cases, with the highest probability on conjunction one orbit after deployment. Average probability of collision was computed to be less than 0.1% over 30,000 different deployment directions.

Persistent Liquids and Propellant-Related Debris

During primary mission operations, any water released into space through the MET or the reaction control thrusters will be vaporized at sufficiently high temperatures (>500K) to prevent the formation of debris. In the off-nominal case of a leak or flow of liquid water, there is potential for the creation of small water ice crystals. Any generated water ice crystals are expected to sublimate within minutes of exposure to sunlight.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v3.2.3)

- **4.3-1, Mission Related Debris Passing Through LEO:** COMPLIANT
- **4.3-2, Mission Related Debris Passing Near GEO:** COMPLIANT

Momentus does not plan to intentionally release any debris from VR-7.

IV. Intentional Breakups and Potential for Explosions

Potential causes of spacecraft breakup during deployment and mission operations:

There are two potential scenarios that could potentially lead to a breakup of the spacecraft:

1) Rupture of the propellant tank or pressurant tank (H_20, N_2)
2) Lithium-ion battery cell failure

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

- In-mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the failure modes and effects analysis (“FMEA”) (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to an explosion.

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

- There are no planned breakups.

List of components which shall be passivated at End of Mission including method of passivation and amount which cannot be passivated:

- 200 Lithium-ion battery cells. At the EOM, the battery cell’s maximum charge voltage may be reduced.

Rationale for all items which are required to be passivated, but cannot be due to their design:

- None.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 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, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).

Supporting Rationale and FMEA details:

- **Pressure Tank Explosion:**
  - **Effect:** A rupture of one propellant or pressurant tank would release water and Nitrogen gas. Due to the low pressure of the propellant (21.7 psi), the penetrating energy of any debris would be relatively low. In addition, a Nitrogen pressurant tank (250 psi) rupture would be insufficient to penetrate the surrounding solid aluminum structural walls of the spacecraft. These aluminum walls would contain any released debris within the body of the spacecraft.
  - **Probability:** Very low. A structural failure of the tank would need to occur, and the mechanisms by which these failures occur are very well understood. The factor of safety for the propellant tank is at least 2. For the pressurant tank, it is estimated to be 40 at beginning of life and 500 at end-of-life. For the surrounding structure, it is greater than 2.
- **Battery explosion:**
  - **Effect:** All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, although the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy and multiple enclosures surrounding the batteries.
  - **Probability:** Extremely Low. Estimated to be less than 0.01% given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion).
  - **Failure Mode 1:** Internal short circuit.
    - *Mitigation 1:* All of the following tests have or will be performed prior to flight: qualification level sine burst, sine, and random vibration testing in all three axes, thermal vacuum cycling and extensive functional testing, system rate-limited charge and discharge cycles, and subsystem and component level functional testing. The testing helps prove that no internal short circuit sensitivity exists.
    - *Combined Faults Required for Realized Failure:* Environmental testing AND functional charge/discharge tests must both be ineffective in discovery of the failure mode.
  - **Failure Mode 2:** Internal thermal rise due to high load discharge rate.
    - *Mitigation 2:* Battery cells were tested in lab for high load discharge rates in a variety of flight-like configurations to determine the feasibility of an out-of-control thermal rise in the cell. Cells are also tested in a hot, thermal vacuum environment to test the upper limit of the cells’

capability. No failures were observed or identified via spacecraft telemetry or external monitoring circuitry.
    - *Combined Faults Required for Realized Failure:* Spacecraft thermal design must be incorrect AND external over-current detection and disconnect function must fail to enable this failure mode.
- **Failure Mode 3:** Excessive discharge rate or short-circuit due to external devices failure of terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).
    - *Mitigation 3:* Qualification testing of short circuit protection on each external circuit, design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, and observation of such other mechanical failures by protoflight level environmental tests (sine burst, random vibration, thermal cycling, and thermal-vacuum tests).
    - *Combined Faults Required for Realized Failure:* An external load must fail/short-circuit AND external over-current detection and disconnect function must all occur to enable this failure mode.
- **Failure Mode 4:** Inoperable vents.
    - *Mitigation 4:* Battery venting is not inhibited by the battery holder design or the spacecraft design. The battery can vent gases to the external environment.
    - *Combined Faults Required for Realized Failure:* The cell manufacturer OR the spacecraft integrator fails to install proper venting.
- **Failure Mode 5:** Crushing.
    - *Mitigation 5:* This mode is negated by spacecraft design with no moving parts in the proximity of the batteries.
    - *Combined Faults Required for Realized Failure:* A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit AND the spacecraft must be in a naturally sustained orbit at the time the crushing occurs.
- **Failure Mode 6:** Low-level current leakage or short-circuit through battery or short-circuit through battery pack case or due to moisture-based degradation of insulators.
    - *Mitigation 6:* The battery interface includes a printed circuit board and standoffs from any conductive materials, and operation in a vacuum ensures that no moisture can affect insulators.

    - *Combined Faults Required for Realized Failure:* Abrasion or piercing failure of circuit board coating or wire insulators AND dislocation of battery packs AND failure of battery terminal insulators AND failure to detect such failures in environmental tests must occur to result in this failure mode.
  - **Failure Mode 7:** Excess temperatures due to orbital environment and high discharge combined.
    - *Mitigation 7:* The spacecraft's thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that the batteries do not exceed normal allowable operating temperatures under a variety of modeled cases, including worst-case orbital scenarios. Analysis shows these temperatures to be well below temperatures of concern for explosions.
    - *Combined Faults Required for Realized Failure:* Thermal analysis AND thermal design AND mission simulations in thermal-vacuum chamber testing AND over-current monitoring and control must all fail for this failure mode to occur.

Requirement 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 to 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 control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

The batteries, propellant, and pressurant are the only stored sources of energy. These stored sources of energy are controlled to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft, as explained below.

- Compliance statement:
  - VR-7 will reduce stored energy in the battery by limiting power generation capability of the solar arrays at EOM. This is done by positioning the arrays away from the expected sun vector. In case of a battery failure, the cells are, at a minimum, doubly contained within aluminum structural walls to prevent debris generation.
  - Momentus intends to use the remaining propellant at EOM to conduct further perigee reduction maneuvers. Even if the propellant is not fully depleted,

liquid water propellant has low stored energy (at 21.7 psi) and is chemically stable.

- Momentus will hold a small reserve of propellant for collision avoidance, as necessary, during the perigee reduction maneuvers. As a result, it cannot vent the pressurant. However, venting the propellant is unnecessary. The Nitrogen pressurant tank has a maximum pressure of 250 psi resulting in a factor of safety of more than 500 at EOM. There will not be enough stored energy in the pressurant tank to penetrate or break apart the spacecraft structure. Moreover, the Nitrogen pressurant tank is fully enclosed in the spacecraft body and any rupture would not be expected to release debris into space or break apart the spacecraft.

Requirement 4.4-3: Limiting the long-term risk to other space systems from planned breakups:

- Compliance statement:
  - Not applicable. There are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:

- Compliance statement:
  - Not applicable. There are no planned breakups.

V. Spacecraft Potential for On-Orbit Collisions

While the calculated risk of on-orbit collision with large debris or other operational space stations is low, Momentus shall monitor VR-7 throughout the operational life of the spacecraft to ensure near real-time collision avoidance, as ground station availability allows, and orbital maintenance maneuvers are executed as needed. The VR-7 mission will launch with a substantial propellant reserve which is intended to provide sufficient propellant to perform contingency operations (e.g., as needed collision avoidance maneuvers) during the mission while also retaining ample propellant to execute de-orbit maneuvers necessary to achieve end-of-mission timeline targets. Additionally, this monitoring shall assess, on an ongoing basis, the accuracy with which the targeted orbital parameters are to be maintained.[9] Furthermore, the proposed operation of the VR-7 does not rely on or otherwise necessitate coordination with any other operational space stations and no assessment of successful coordination with such an operator has been performed to date.

A. Protection of International Space Station ("ISS")

Momentus will ensure that its maneuvers through the orbits of inhabitable spacecraft will not create risk to such spacecraft. VR-7 is planned to operate with an approximately 10%-15% margin of propellant, in addition to the propellant necessary to achieve the operational concept. Momentus calculates that this reserve will be sufficient to support all contingencies during the VR-7 mission, including orbital debris and object avoidance maneuvers throughout the mission life. Additionally, our calculations suggest VR-7 would have sufficient propellant remaining at the conclusion of the mission to conduct further perigee reduction maneuvers, which could reduce the demise of the VR-7.

VR-7 will not be placed in or otherwise operate within a 10 km sphere centered around the ISS. However, in the scenario where a conjunction occurs, Momentus will implement the collision avoidance maneuver process discussed below. Additionally, when VR-7's perigee drops below the orbit of the ISS, Momentus will contact the relevant NASA ISS personnel to ensure that the ISS has a point of contact for the VR-7 spacecraft.

B. Collision Avoidance Maneuver Process

In order to determine whether the risk of a close approach is high enough to warrant avoiding a potential collision by performing a maneuver, or some other trajectory modification, if Momentus receives a CDM message with a probability of collision ("PoC") greater than 1E-5, then Momentus will forecast VR-7 ephemeris at least 48 hours into the future to better assess the PoC and determine whether the risk of a close approach is high enough to warrant further

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[9] The Momentus assessment of the VR-7's accuracy for orbital parameter maintenance indicates performance will be within the following ranges: Apogee, ±200m; Perigee, ±200m; Inclination, <1%: and the Right Ascension of the Ascending Node(s), <1%.

actions. In this scenario, the conjunction will be reanalyzed using higher fidelity ephemeris from the Momentus asset and, if available, high-fidelity ephemeris from the other asset's owner/operator or a third-party source. Momentus is working with Kayhan Space to provide more detailed conjunction analysis, including higher fidelity ephemeris, and advanced warning services.

If the PoC is greater than 1E-4, Momentus will coordinate with the other owner operator on next steps. If the PoC is greater than 1E-3 and the conjunction has not been resolved by coordination (e.g., the owner/operator cannot be contacted), Momentus will work with the 18SPCS and perform an avoidance maneuver to decrease the PoC below 1E-5.

Table 3: Planned Actions in Response to CDM Messages

Probability of Collision (PoC)	Planned Actions[10]
> 1E-5	Refine PoC through detailed analysis. Begin maneuver planning.
> 1E-4	Coordinate with the other owner/operator.
> 1E-3	Perform avoidance maneuver described in Table 4 below to decrease the PoC below 1E-5.

Momentus will share planned maneuvers and as-measured ephemeris via onboard GPS with the 18SPCS via Space-Track.org and with operators with whom Momentus is conducting physical coordination. Data shared with 18SPCS will be uploaded as OPM files in accordance with the current protocols laid out in the Combined Force Space Component Command satellite operator safety handbook.[11]

The anticipated maximum duration to commence a collision avoidance maneuver is captured below. Once a CDM has been received, Momentus will use the most accurate available ephemeris data to generate a maneuver plan within 3 hours. Following this, Momentus will update the proposed maneuver plan to Space-Track.org and coordinate with the 18SPCS, which is expected to occur within 6 hours. After the 18SPCS confirms that the proposed maneuver resolves the CDM, Momentus anticipates updating its command scheduler within 3 hours. Momentus has analyzed the worst-case gap between Earth station passes to be 10

[10] The planned actions are cumulative. For example, for a PoC > 1E-3, Momentus would first refine PoC through detailed analysis, begin maneuver planning, and coordinate with the other owner/operator before performing avoidance maneuvers.
[11] *See* Spaceflight Safety Handbook for Satellite Operators: 18 SPCS Processes for On-Orbit Conjunction Assessment & Collision Avoidance, Version 1.5, August 2020. 18th Space Control Squadron, Combined Force Space Component Command, Vandenberg AFB.

hours. Lastly, once the maneuver has been scheduled during a pass, it is anticipated that the time from start to finish of the maneuver will be within 2 hours.

Momentus expects that VR-7 will be able to generate a 1 km change in orbital altitude within 2 hours. Literature surveys support the conclusion by Momentus that its ability to implement a 1 km orbit altitude maneuver[12] within 24 hours of the time of closest approach ("TCA") should reduce the PoC to much less than 1E-5 and by at least one and one-half orders of magnitude.[13] Additionally, as necessary for collision avoidance, Momentus could conduct up to a 2-km orbital altitude maneuver (such as an orbit raise) within 48 hours, during which VR-7 would produce more than 1 m/s of delta V.[14]

Table 4: Estimated Maneuver Duration

Task	**Estimated Duration**
Generate maneuver plan	3 hrs
Update proposed maneuver plan to Space-Track.org and receive confirmation from 18SPCS that maneuver resolves CDM	6 hrs
Update command scheduler to include proposed plan	3 hrs
Worst-case delay for Earth station availability	10 hrs
Estimated total time until maneuver completion	2 hrs
Total Time	**24 hrs**

[12] Momentus notes that radial distance is materially different from in-track or cross-track distances for collision avoidance purposes.

[13] *See* 18th Space Control Squadron, Combined Force Space Component Command, Vandenberg AFB, *Spaceflight Safety Handbook for Satellite Operators: 18 SPCS Processes for On-Orbit Conjunction Assessment & Collision Avoidance*, Version 1.5 at 9 (Table 3) (August 2020), *available at* https://www.space-track.org/documents/Spaceflight_Safety_Handbook_for_Operators.pdf (NASA will conduct conjunction screening for satellites in low-Earth orbit only for events within a 400 m radial miss distance at TCA minus 5 days); *id*. at 10 (Table 5) (NASA will report CDMs only where overall miss distance is less than or equal to 1 km at TCA minus 3 days); NASA, *NASA Conjunction Assessment Risk Analysis Update Requirements Architecture*, at 14 (August 2019), *available at* https://ntrs.nasa.gov/api/citations/20190029214/downloads/20190029214.pdf (providing examples of overall miss distances of ~800 m and ~1000 m suggesting Pc=0, where the radial miss distance is between 125 m and 163 m). *See also* Hedron Space Inc. Response to FCC Questions, Ref No. 67622, ELS File No. 0024-EX-CN-2022, at 3 (Mar. 3, 2022) (providing example avoidance maneuvers resulting in miss distances of slightly greater than 1 km resulting in Pc < 1E-05); HE360 Response to FCC Questions, IBFS File No. SAT-MOD-20210114-00010, at 2 (Mar. 31, 2021) (providing examples where the miss distance is increased from 105 m to 523 m and 438 m, respectively, resulting in the Pc reducing from 2.1E-05 to 1.34E-07 and 4.6E-10, respectively).

[14] Because the delta V would be achieved by two propulsive maneuvers (separated by ~24 hours), the in-track spacing would be changed by more than 70 km as a result of the orbit altitude change from the first maneuver.

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating 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 is less than 0.001 (Requirement 56506).
- **Large Object Impact and Debris Generation Probability:**
  - Maximum Insertion Orbit (525 x 525 km) 4.7192E-5; COMPLIANT.
  - Final Orbit (380 x 350 km) 2.8773E-6; COMPLIANT

Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar 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 requirements is less than 0.01 (Requirement 56507).
- **Small-Object Impact and Debris Generation Probability:**
  - The VR-7 spacecraft will deorbit naturally in under 5-years for all stages of the mission. Therefore, a showing for collision probability with small objects in not required.; COMPLIANT

Reliability of spacecraft to conduct deorbit maneuvers as necessary to meet the 5-year end of life deorbit requirement:

Since the VR-7 spacecraft will deorbit in under 5-years from any mission phase, there is not requirement to demonstrate a reliability analysis for spacecraft deorbit: COMPLIANT

Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering:

- The propulsion system is planned to be used for a post-mission de-orbit maneuver to decrease the time until atmospheric reentry. The flight computer, radio hardware, battery system, and control boards will be used to reduce stored energy.

VI. Spacecraft Postmission Disposal Plans and Procedures

Description of spacecraft disposal option selected:

- At the EOM operations, VR-7 will de-orbit naturally by atmospheric reentry without any intervention.

Plan for any spacecraft maneuvers required to accomplish postmission disposal:

- VR-7 will attempt a de-orbit maneuver after mission completion as a proof of concept for future missions. The maneuver will be performed using the onboard propulsion system to lower the orbital perigee below 350 km altitude. Note that there is no planned controlled reentry.

Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected:

Orbit Insertion (525km x 525km) - Fail Before Solar Array Deployment

- Spacecraft Initial Mass: 475 kg
- Cross-sectional Area: 1.564 m^2 (estimated average area while tumbling)
- Area to mass ratio: 0.0039566 m^2/kg

Orbit Insertion (525km x 525km) - Fail After Solar Array Deployment

- Spacecraft Initial Mass: 475 kg
- Cross-sectional Area: 5.02 m^2 (estimated average area while tumbling)
- Area to mass ratio: 0.010568 m^2/kg

Orbit Insertion (525.2km x 525.2km) - Fail After Payload Releases

- Spacecraft Initial Mass: 318.8 kg
- Cross-sectional Area: 5.02m^2 (estimated average area while tumbling)
- Area to mass ratio: 0.015747 m^2/kg

Final PMD Orbit (380km x 350km)

- Spacecraft Final Mass: 267.8 kg
- Cross-sectional Area: 5.02 m^2 (estimated average area while tumbling)
- Area to mass ratio: 0.018743 m^2/kg

Requirement 4.6-1. Disposal for space structures passing through LEO:

A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

1. Atmospheric reentry option:
    a. Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
    b. Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.
2. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.
3. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

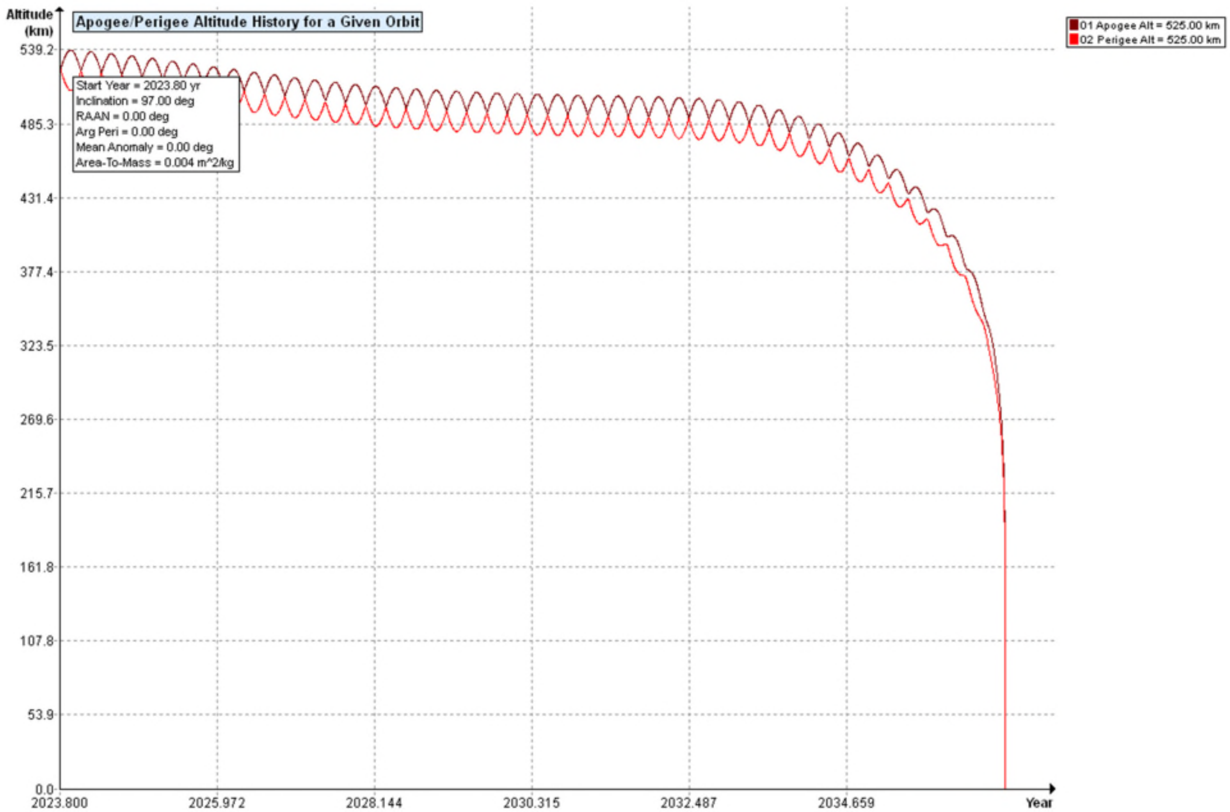
Analysis:

VR-7 will follow a concept of operations to ensure safe disposal within 5 years of the end of the mission under all scenarios. above provides the reentry timelines for the nominal mission, as well as scenarios involving propulsion failure at various points during the mission.

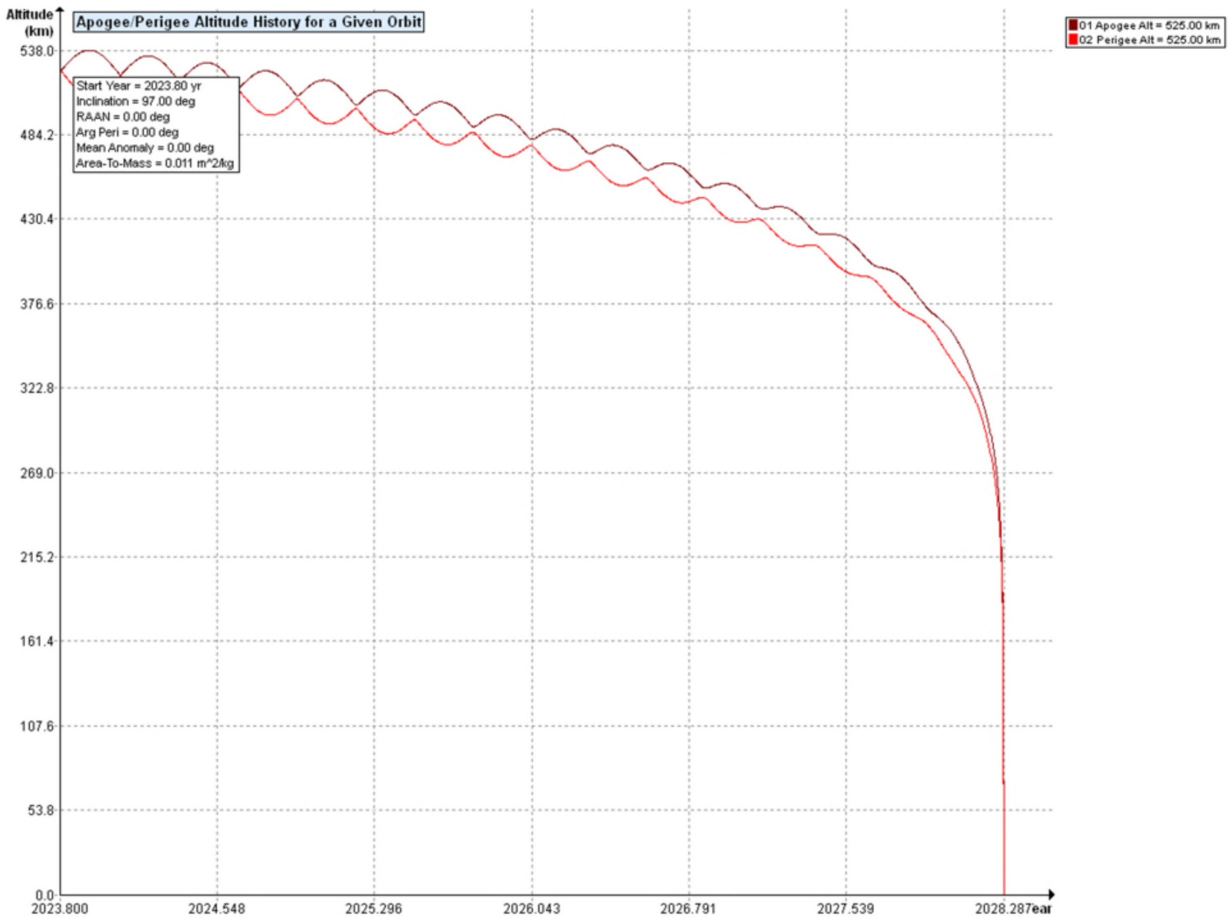
Table 1 above provides the reentry timelines for the nominal mission, as well as scenarios involving propulsion failure at various points during the mission.

The figures below show the Orbital Decay Timelines for various end of life scenarios.

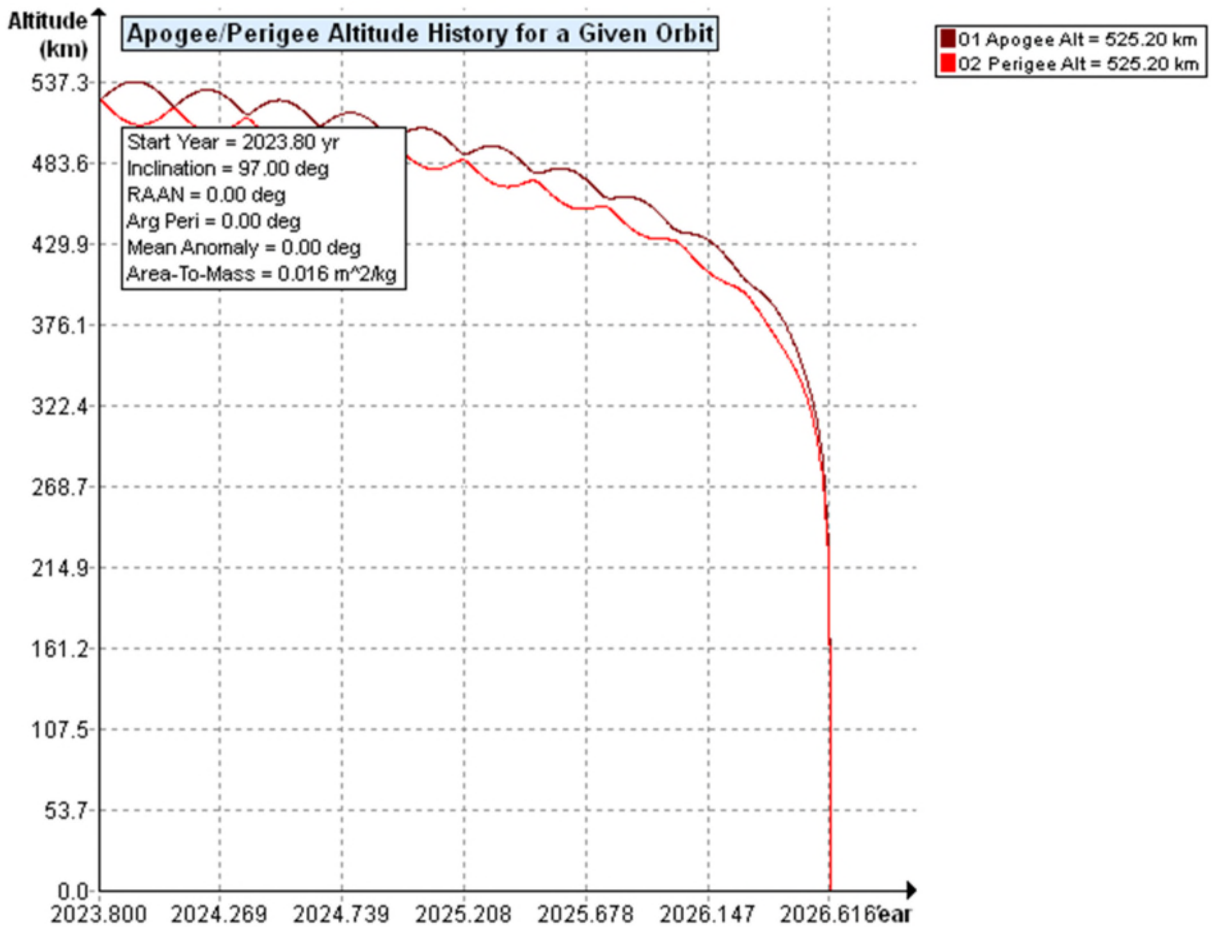
Orbital Decay for VR-7 Failure at 525x525 km – Before Solar Array Deployment



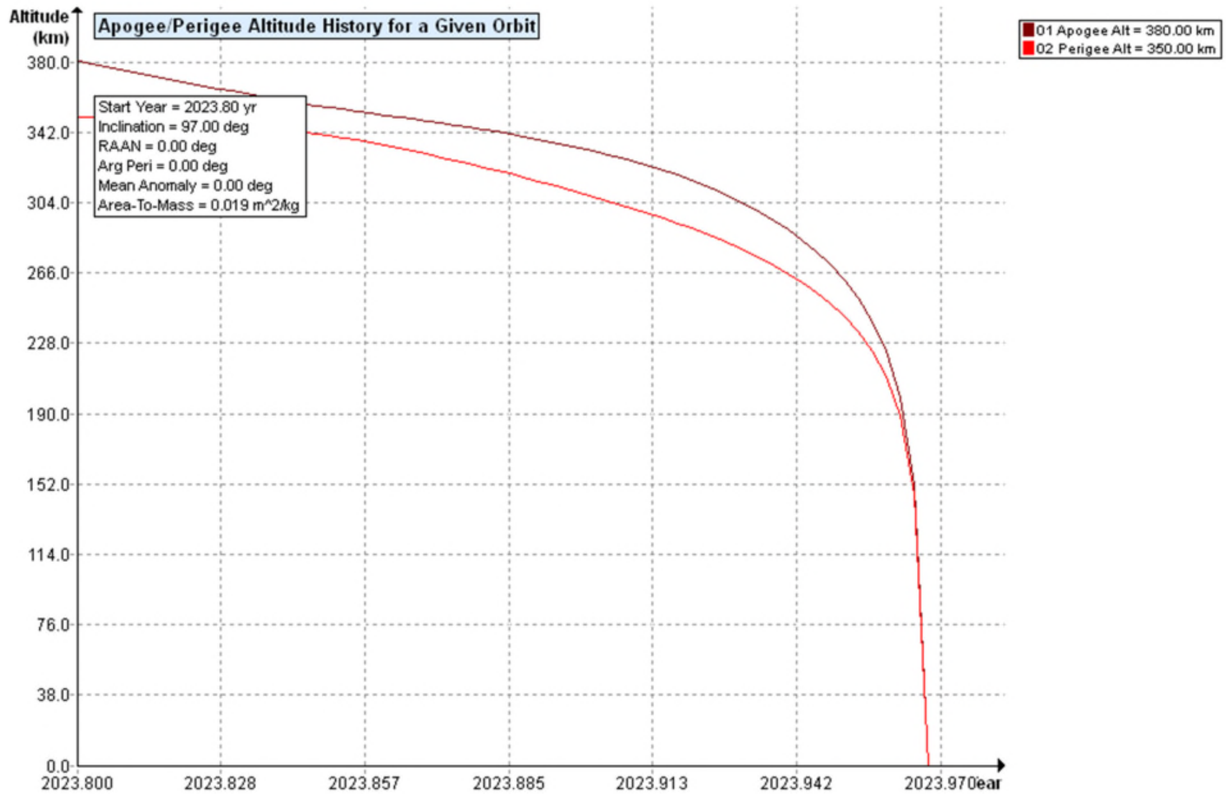
Orbital Decay for VR-7 Failure at 525x525 km – After Solar Array Deployment



Orbital Decay for VR-7 Failure at 525.2x525.2 km – After Payload Deployments



Orbital Decay for VR-7 at 380x350 km



Requirement 4.6-2. Disposal for space structures near GEO.

- Not applicable.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.

- Not applicable.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

- Not applicable. The spacecraft will reenter passively without post mission disposal operations within allowable timeframe.

VII. Spacecraft Reentry Hazards

Requirement 4.7-1. Limit the risk of human casualty:

The potential for human casualty is assumed for any object with impacting kinetic energy in excess of 15 joules:

1. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Summary Analysis Results: DAS v3.2.3 reports that VR-7 is compliant with the requirement with a 0 risk of human casualty. As shown below, one VR-7 component may survive reentry. In that case, the impacting kinetic energy is less than 15 joules.

- Alumina Window: 0.86J, 0.32m^2

If there are changes in the deployable customer payloads before launch, Momentus may replace some customer payloads with aluminum mass simulators.[15] To address this potential situation, the demise analysis assumes all deployable payloads have been replaced with mass simulators. This should reflect a worst-case scenario for the demise analysis.

Analysis using DAS v3.2.3:

04 25 2023; 07:43:04AM Project Data Saved To File

04 25 2023; 07:43:09AM Processing Requirement 4.3-1: Return Status : Not Run

=====================

No Project Data Available

=====================

=============== End of Requirement 4.3-1 ===============

04 25 2023; 07:43:12AM Processing Requirement 4.3-2: Return Status : Passed

[15] *See* Narrative at 4.

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No Project Data Available

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=============== End of Requirement 4.3-2 ===============

04 25 2023; 07:47:15AM Processing Requirement 4.5-1: Return Status : Passed

==============

Run Data

==============

INPUT

Space Structure Name = Vigoride-7-1

Space Structure Type = Payload

Perigee Altitude = 525.200 (km)

Apogee Altitude = 525.200 (km)

Inclination = 97.000 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0106 (m^2/kg)

Start Year = 2023.800 (yr)

Initial Mass = 475.000 (kg)

Final Mass = 475.000 (kg)

Duration = 1.000 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

OUTPUT

Collision Probability = 4.7192E-05

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

==============

INPUT

Space Structure Name = Vigoride-7-2

Space Structure Type = Payload

Perigee Altitude = 350.000 (km)

Apogee Altitude = 380.000 (km)

Inclination = 97.000 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0106 (m^2/kg)

Start Year = 2023.800 (yr)

Initial Mass = 475.000 (kg)

Final Mass = 475.000 (kg)

Duration = 1.000 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

OUTPUT

Collision Probability = 2.8773E-06

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

==============

=============== End of Requirement 4.5-1 ===============

04 25 2023; 07:47:21AM Project Data Saved To File

04 25 2023; 07:47:28AM Requirement 4.5-2: Compliant

=============== End of Requirement 4.5-2 ===============

04 25 2023; 07:47:30AM Processing Requirement 4.6 Return Status : Passed

==============

Project Data

==============

INPUT

Space Structure Name = Vigoride-7-1

Space Structure Type = Payload

Perigee Altitude = 525.200000 (km)

Apogee Altitude = 525.200000 (km)

Inclination = 97.000000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.010568 (m^2/kg)

Start Year = 2023.800000 (yr)

Initial Mass = 475.000000 (kg)

Final Mass = 475.000000 (kg)

Duration = 1.000000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = 496.725991 (km)

PMD Apogee Altitude = 524.581218 (km)

PMD Inclination = 96.957866 (deg)

PMD RAAN = 335.114626 (deg)

PMD Argument of Perigee = 80.920119 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 496.725991 (km)

Suggested Apogee Altitude = 524.581218 (km)

Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2028 (yr)

Requirement = 61

Compliance Status = Pass

==============

INPUT

Space Structure Name = Vigoride-7-2

Space Structure Type = Payload

Perigee Altitude = 350.000000 (km)

Apogee Altitude = 380.000000 (km)

Inclination = 97.000000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.010568 (m^2/kg)

Start Year = 2023.800000 (yr)

Initial Mass = 475.000000 (kg)

Final Mass = 475.000000 (kg)

Duration = 1.000000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = -1.000000 (km)

PMD Apogee Altitude = -1.000000 (km)

PMD Inclination = 0.000000 (deg)

PMD RAAN = 0.000000 (deg)

PMD Argument of Perigee = 0.000000 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 350.000000 (km)

Suggested Apogee Altitude = 380.000000 (km)

Returned Error Message = Reentry during mission (no PMD req.).

Released Year = 2024 (yr)

Requirement = 61

Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============

04 25 2023; 07:47:33AM *********Processing Requirement 4.7-1

Return Status : Passed

***********INPUT****

Item Number = 1

name = Vigoride-7-1

quantity = 1

parent = 0

materialID = 8

type = Box

Aero Mass = 475.000000

Thermal Mass = 475.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

name = Primary Radiator Segment

quantity = 4

parent = 1

materialID = 8

type = Flat Plate

Aero Mass = 3.500000

Thermal Mass = 3.500000

Diameter/Width = 0.400000

Length = 0.400000

name = Secondary Radiator

quantity = 1

parent = 1

materialID = 8

type = Flat Plate

Aero Mass = 3.400000

Thermal Mass = 3.400000

Diameter/Width = 0.500000

Length = 0.500000

name = Side Radiator Plate

quantity = 2

parent = 1

materialID = 8

type = Flat Plate

Aero Mass = 6.000000

Thermal Mass = 6.000000

Diameter/Width = 0.350000

Length = 1.200000

name = Corner Brackets

quantity = 4

parent = 1

materialID = 8

type = Box

Aero Mass = 1.100000

Thermal Mass = 1.100000

Diameter/Width = 0.100000

Length = 0.350000

Height = 0.100000

name = Comms Panel

quantity = 2

parent = 1

materialID = 8

type = Flat Plate

Aero Mass = 1.100000

Thermal Mass = 1.100000

Diameter/Width = 0.150000

Length = 0.350000

name = Lower Payload Deck Segment

quantity = 4

parent = 1

materialID = 8

type = Box

Aero Mass = 4.500000

Thermal Mass = 4.500000

Diameter/Width = 0.500000

Length = 0.500000

Height = 0.030000

name = Structure

quantity = 8

parent = 1

materialID = 8

type = Box

Aero Mass = 2.500000

Thermal Mass = 2.500000

Diameter/Width = 0.200000

Length = 0.350000

Height = 0.020000

name = Propellant Tank

quantity = 1

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 66.000000

Thermal Mass = 15.000000

Diameter/Width = 0.400000

Length = 0.400000

name = Water Propellant

quantity = 1

parent = 9

materialID = 75

type = Cylinder

Aero Mass = 51.000000

Thermal Mass = 51.000000

Diameter/Width = 0.400000

Length = 0.400000

name = Launch Vehicle Adapter

quantity = 1

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 4.000000

Thermal Mass = 4.000000

Diameter/Width = 0.600000

Length = 0.180000

name = Solar Array Panel

quantity = 6

parent = 1

materialID = 8

type = Box

Aero Mass = 3.400000

Thermal Mass = 3.400000

Diameter/Width = 0.350000

Length = 1.400000

Height = 0.020000

name = Battery Assembly

quantity = 5

parent = 1

materialID = 8

type = Box

Aero Mass = 4.000000

Thermal Mass = 4.000000

Diameter/Width = 0.150000

Length = 0.150000

Height = 0.100000

name = Power Supply Unit

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 1.200000

Thermal Mass = 1.200000

Diameter/Width = 0.100000

Length = 0.250000

Height = 0.050000

name = Microwave Source Box

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 4.000000

Thermal Mass = 4.000000

Diameter/Width = 0.200000

Length = 0.200000

Height = 0.200000

name = Feed System Box

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 0.500000

Thermal Mass = 0.500000

Diameter/Width = 0.100000

Length = 0.200000

Height = 0.030000

name = Power Distribution Unit

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 1.600000

Thermal Mass = 1.600000

Diameter/Width = 0.100000

Length = 0.250000

Height = 0.050000

name = Diaphragm Tank Middle

quantity = 2

parent = 1

materialID = 27

type = Cylinder

Aero Mass = 0.250000

Thermal Mass = 0.250000

Diameter/Width = 0.150000

Length = 0.300000

name = Diaphragm Tank End 1

quantity = 2

parent = 1

materialID = 27

type = Sphere

Aero Mass = 0.100000

Thermal Mass = 0.100000

Diameter/Width = 0.150000

name = Diaphragm Tank End 2

quantity = 2

parent = 1

materialID = 27

type = Sphere

Aero Mass = 0.100000

Thermal Mass = 0.100000

Diameter/Width = 0.150000

name = Diaphragm Tank Liner

quantity = 2

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 1.200000

Thermal Mass = 1.200000

Diameter/Width = 0.200000

Length = 0.200000

name = Plumbing Lines

quantity = 30

parent = 1

materialID = 59

type = Cylinder

Aero Mass = 0.030000

Thermal Mass = 0.030000

Diameter/Width = 0.005000

Length = 0.500000

name = Plumbing Fittings

quantity = 30

parent = 1

materialID = 59

type = Cylinder

Aero Mass = 0.050000

Thermal Mass = 0.050000

Diameter/Width = 0.020000

Length = 0.020000

name = Thruster

quantity = 1

parent = 1

materialID = 58

type = Cylinder

Aero Mass = 1.000000

Thermal Mass = 1.000000

Diameter/Width = 0.100000

Length = 0.070000

name = Window

quantity = 1

parent = 1

materialID = 1

type = Cylinder

Aero Mass = 0.010000

Thermal Mass = 0.010000

Diameter/Width = 0.050000

Length = 0.015000

name = Reaction Control Thruster - Assembly (4 thrusters each)

quantity = 8

parent = 1

materialID = 59

type = Box

Aero Mass = 0.160000

Thermal Mass = 0.160000

Diameter/Width = 0.030000

Length = 0.030000

Height = 0.030000

name = RCS Fasteners

quantity = 4

parent = 1

materialID = 66

type = Flat Plate

Aero Mass = 0.025000

Thermal Mass = 0.025000

Diameter/Width = 0.060000

Length = 0.060000

name = 12U Cubesat Deployer A (ISIS QP 2.XL)

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 24.900000

Thermal Mass = 24.900000

Diameter/Width = 0.274000

Length = 0.430000

Height = 0.273000

name = 12U Cubesat Deployer C (ISIS QP 2.3)

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 27.500000

Thermal Mass = 27.500000

Diameter/Width = 0.274000

Length = 0.405000

Height = 0.273000

name = ISIS Cubesat Deployer D (ISIS QP 4.XL)

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 27.900000

Thermal Mass = 27.900000

Diameter/Width = 0.274000

Length = 0.430000

Height = 0.273000

name = ISIS Cubesat Deployer F (ASTROFEIN 4.3)

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 28.700001

Thermal Mass = 28.700001

Diameter/Width = 0.277000

Length = 0.426000

Height = 0.266000

name = Payload Interface Adapter

quantity = 6

parent = 1

materialID = 8

type = Flat Plate

Aero Mass = 1.000000

Thermal Mass = 1.000000

Diameter/Width = 0.200000

Length = 0.300000

name = Structural Fasteners

quantity = 150

parent = 1

materialID = 57

type = Cylinder

Aero Mass = 0.010000

Thermal Mass = 0.010000

Diameter/Width = 0.010000

Length = 0.020000

name = Microwave Filament

quantity = 2

parent = 1

materialID = 43

type = Cylinder

Aero Mass = 0.005000

Thermal Mass = 0.005000

Diameter/Width = 0.010000

Length = 0.010000

name = Beacon Radio

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 0.500000

Thermal Mass = 0.500000

Diameter/Width = 0.100000

Length = 0.100000

Height = 0.100000

name = Beacon Antenna

quantity = 1

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 0.050000

Thermal Mass = 0.050000

Diameter/Width = 0.020000

Length = 0.200000

name = RPO Camera Sensor & Adapter Plate

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 10.000000

Thermal Mass = 10.000000

Diameter/Width = 0.290000

Length = 0.311000

Height = 0.219000

name = RPO Lidar Sensor

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 3.500000

Thermal Mass = 3.500000

Diameter/Width = 0.174000

Length = 0.206000

Height = 0.081000

name = RPOPayload Host Unit (PHU)

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 2.000000

Thermal Mass = 2.000000

Diameter/Width = 0.152000

Length = 0.188000

Height = 0.068000

name = RPO ACS Controller

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 1.000000

Thermal Mass = 1.000000

Diameter/Width = 0.104000

Length = 0.118000

Height = 0.035000

name = RPO ISL Radio

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 0.500000

Thermal Mass = 0.500000

Diameter/Width = 0.120000

Length = 0.120000

Height = 0.030000

name = RPO ISL Antenna

quantity = 1

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 0.050000

Thermal Mass = 0.050000

Diameter/Width = 0.020000

Length = 0.200000

name = RPO RCS Standoff

quantity = 4

parent = 1

materialID = 8

type = Box

Aero Mass = 2.500000

Thermal Mass = 2.500000

Diameter/Width = 0.085000

Length = 0.131000

Height = 0.082000

name = 16U Deployer (on the deck)

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 32.000000

Thermal Mass = 32.000000

Diameter/Width = 0.270000

Length = 0.561000

Height = 0.270000

name = 16U deployer interface plate (on the deck)

quantity = 1

parent = 1

materialID = 8

type = Flat Plate

Aero Mass = 4.790000

Thermal Mass = 4.790000

Diameter/Width = 0.380000

Length = 0.380000

name = HELLO Space PocketPod Deployer (on the deck)

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 4.000000

Thermal Mass = 4.000000

Diameter/Width = 0.150000

Length = 0.339000

Height = 0.090000

name = FOSSA PocketPod Deployer (on the deck)

quantity = 2

parent = 1

materialID = 8

type = Box

Aero Mass = 4.000000

Thermal Mass = 4.000000

Diameter/Width = 0.149000

Length = 0.320000

Height = 0.082000

name = LUXSPACE TRITON-X GENESIS Payload (on the deck)

quantity = 1

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 19.299999

Thermal Mass = 19.299999

Diameter/Width = 0.354000

Length = 0.441000

name = Deck RCS Manifold

quantity = 1

parent = 1

materialID = 59

type = Box

Aero Mass = 0.160000

Thermal Mass = 0.160000

Diameter/Width = 0.030000

Length = 0.030000

Height = 0.030000

name = Deck Cameras + Mounting plates

quantity = 3

parent = 1

materialID = 8

type = Box

Aero Mass = 0.500000

Thermal Mass = 0.500000

Diameter/Width = 0.100000

Length = 0.120000

Height = 0.070000

name = Payload Management Unit (PMU) (on the deck)

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 1.500000

Thermal Mass = 1.500000

Diameter/Width = 0.093000

Length = 0.134000

Height = 0.080000

*************OUTPUT****

Item Number = 1

name = Vigoride-7-1

Demise Altitude = 77.997547

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Primary Radiator Segment

Demise Altitude = 76.347371

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Secondary Radiator

Demise Altitude = 76.829838

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Side Radiator Plate

Demise Altitude = 76.771972

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Corner Brackets

Demise Altitude = 77.337765

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Comms Panel

Demise Altitude = 76.973167

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Lower Payload Deck Segment

Demise Altitude = 76.573282

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Structure

Demise Altitude = 76.314370

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Propellant Tank

Demise Altitude = 74.717620

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Water Propellant

Demise Altitude = 68.441907

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Launch Vehicle Adapter

Demise Altitude = 77.021633

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Solar Array Panel

Demise Altitude = 77.401603

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Battery Assembly

Demise Altitude = 74.002660

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Power Supply Unit

Demise Altitude = 76.763139

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Microwave Source Box

Demise Altitude = 75.844625

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Feed System Box

Demise Altitude = 77.271363

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Power Distribution Unit

Demise Altitude = 76.365365

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank Middle

Demise Altitude = 77.728244

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank End 1

Demise Altitude = 77.712310

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank End 2

Demise Altitude = 77.712310

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank Liner

Demise Altitude = 76.950679

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Plumbing Lines

Demise Altitude = 77.603627

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Plumbing Fittings

Demise Altitude = 73.730183

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Thruster

Demise Altitude = 67.910078

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Window

Demise Altitude = 0.000000

Debris Casualty Area = 0.316329

Impact Kinetic Energy = 0.855593

****

name = Reaction Control Thruster - Assembly (4 thrusters each)

Demise Altitude = 73.139286

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = RCS Fasteners

Demise Altitude = 76.222031

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = 12U Cubesat Deployer A (ISIS QP 2.XL)

Demise Altitude = 72.640465

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = 12U Cubesat Deployer C (ISIS QP 2.3)

Demise Altitude = 71.877971

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = ISIS Cubesat Deployer D (ISIS QP 4.XL)

Demise Altitude = 72.058930

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = ISIS Cubesat Deployer F (ASTROFEIN 4.3)

Demise Altitude = 71.790757

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Payload Interface Adapter

Demise Altitude = 77.121727

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Structural Fasteners

Demise Altitude = 76.335929

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Microwave Filament

Demise Altitude = 75.476023

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Beacon Radio

Demise Altitude = 77.186648

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Beacon Antenna

Demise Altitude = 77.758948

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = RPO Camera Sensor & Adapter Plate

Demise Altitude = 74.689199

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = RPO Lidar Sensor

Demise Altitude = 75.138687

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = RPOPayload Host Unit (PHU)

Demise Altitude = 76.013979

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = RPO ACS Controller

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Impact Kinetic Energy = 0.000000

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name = RPO ISL Radio

Demise Altitude = 76.937098

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = RPO ISL Antenna

Demise Altitude = 77.758948

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = RPO RCS Standoff

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Impact Kinetic Energy = 0.000000

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Demise Altitude = 72.325784

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Impact Kinetic Energy = 0.000000

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name = 16U deployer interface plate (on the deck)

Demise Altitude = 75.586338

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name = HELLO Space PocketPod Deployer (on the deck)

Demise Altitude = 75.820050

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name = FOSSA PocketPod Deployer (on the deck)

Demise Altitude = 75.636741

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Impact Kinetic Energy = 0.000000

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name = LUXSPACE TRITON-X GENESIS Payload (on the deck)

Demise Altitude = 73.403402

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Deck RCS Manifold

Demise Altitude = 73.139286

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Deck Cameras + Mounting plates

Demise Altitude = 77.169526

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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name = Payload Management Unit (PMU) (on the deck)

Demise Altitude = 75.916787

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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Length = 1.560000

Height = 0.970000

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quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 475.000000

Thermal Mass = 475.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

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Item Number = 2

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name = V

Demise Altitude = 62.810409

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

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=============== End of Requirement 4.7-1 ===============

04 25 2023; 07:47:33AM Project Data Saved To File

EXHIBIT 3

Antenna Gain Plots

Vigoride-7 Spacecraft

NGSO Antenna Gain Plots

5/01/2023

Momentus Space LLC

3901 N. First Street

San Jose, CA 95134

+1 (650) 564-7820

Table of Contents

I. Introduction

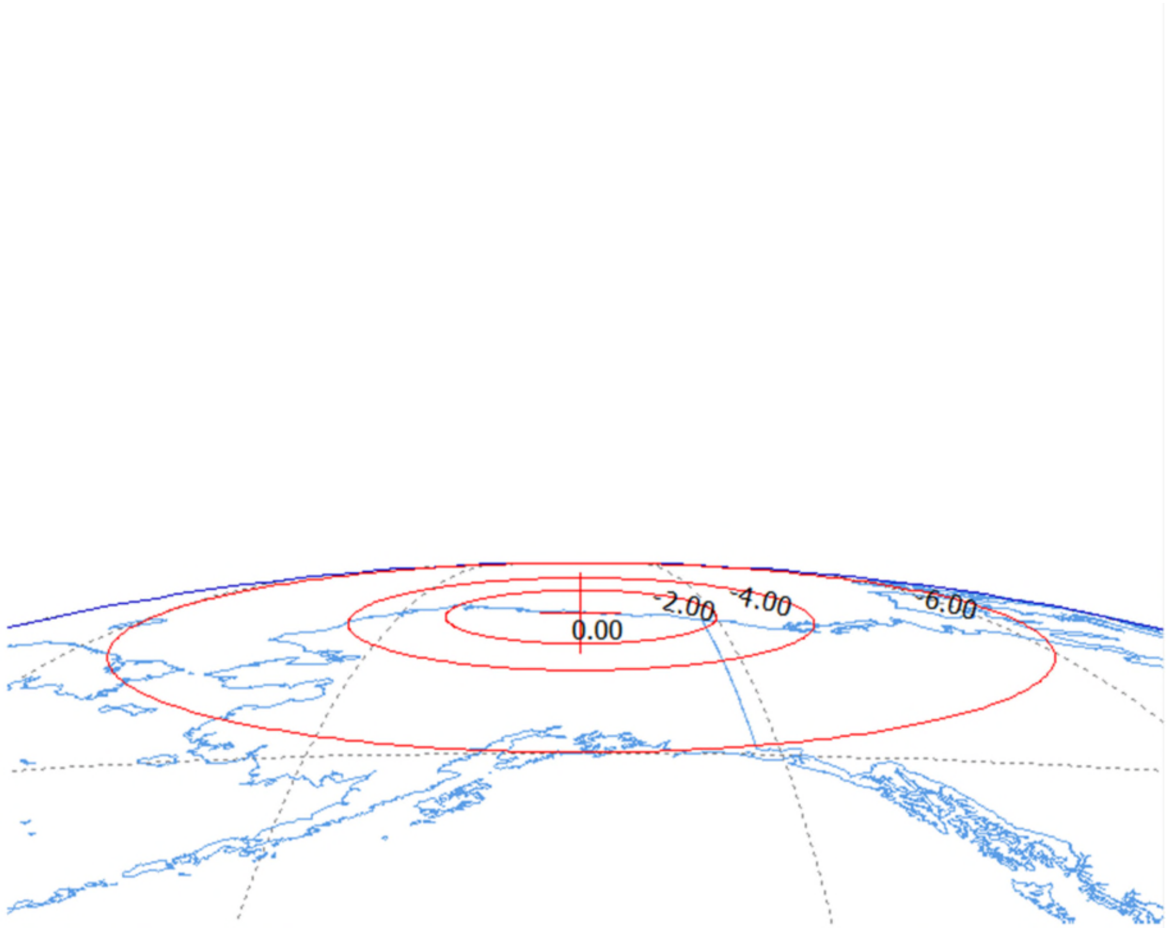
Momentus plans to operate with earth stations located in various locations. This exhibit provides general maps to reflect the antenna gain contours for representative earth stations.

All contour plots show a map of the Earth out to the horizon for each ground station and satellite antenna pair. The plot labels indicate antenna gain contours in 2 dB steps down to 10 dB below the peak gain. For instance, a contour label of “-2” indicates 2 dB below the maximum gain for that antenna.

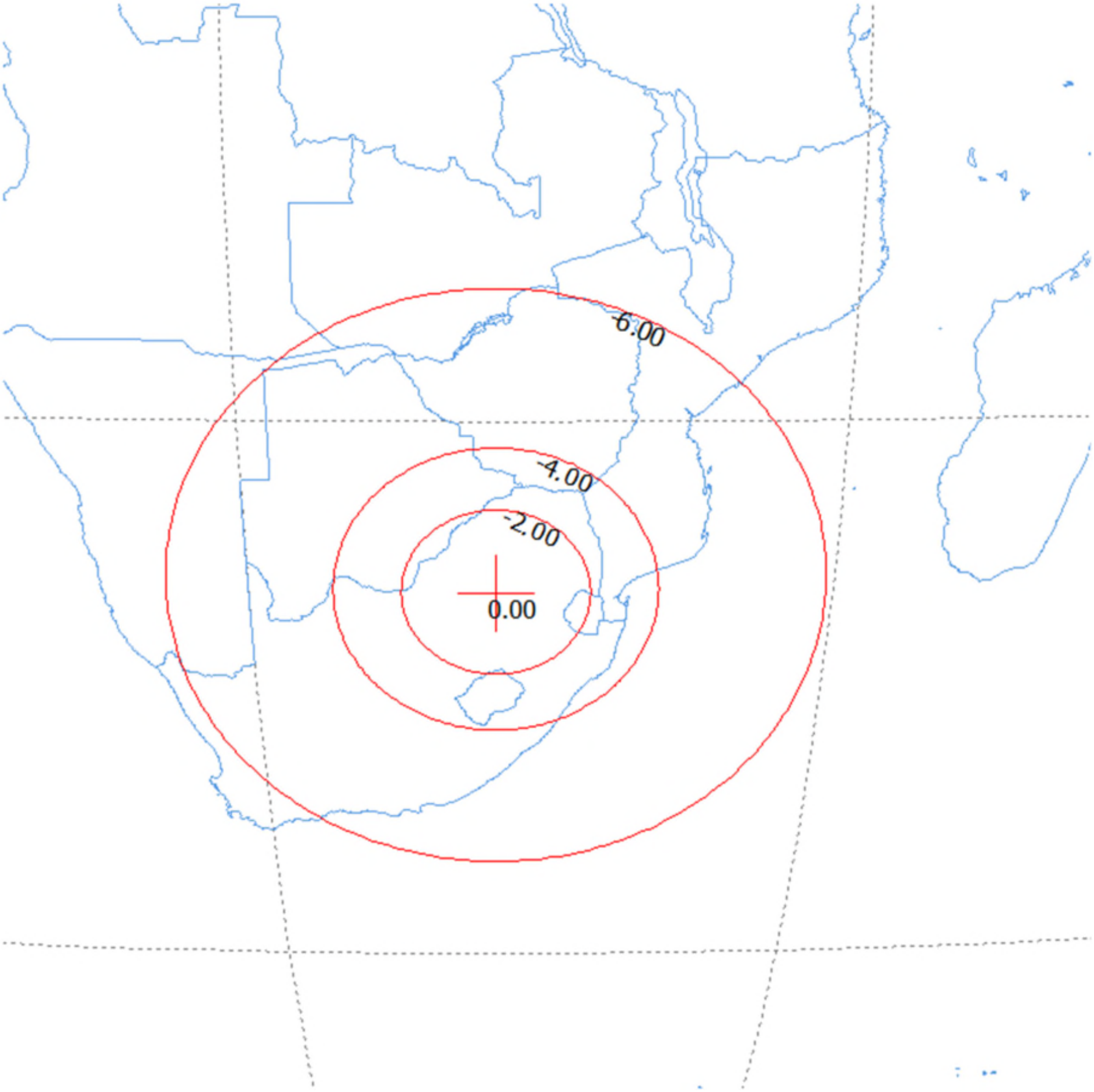
Note that for some gain contour plots, lower gain (greater than 6 dB below the peak) is beyond the horizon and is not shown in the plots.

II. Representative Gain Contour Plots

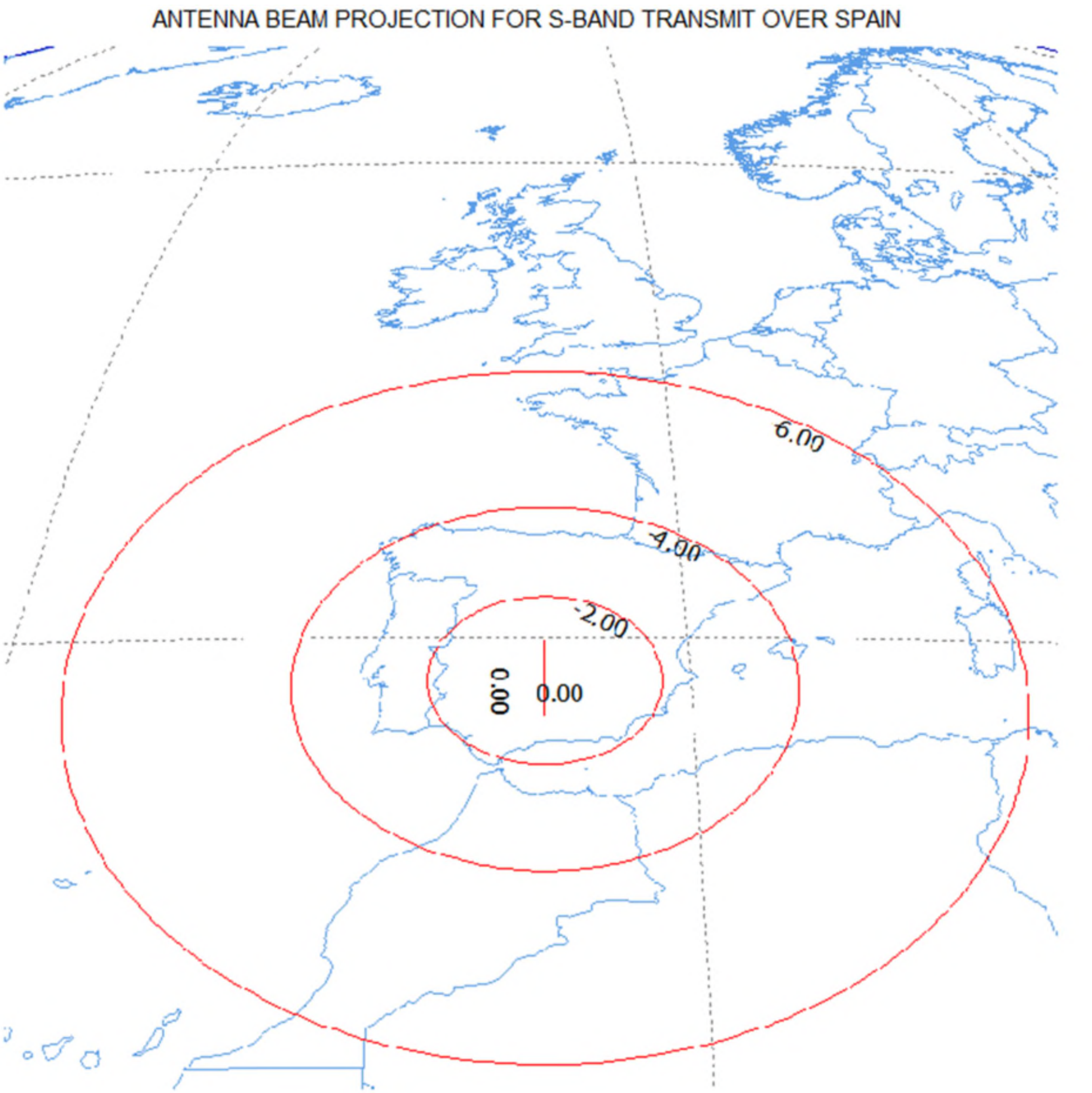
X-band downlink – Deadhorse, Alaska



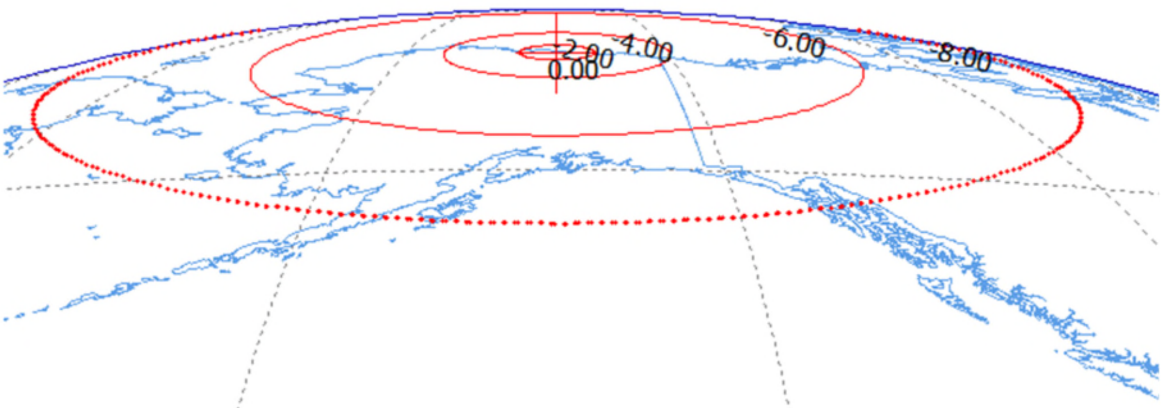
X-band downlink – South Africa



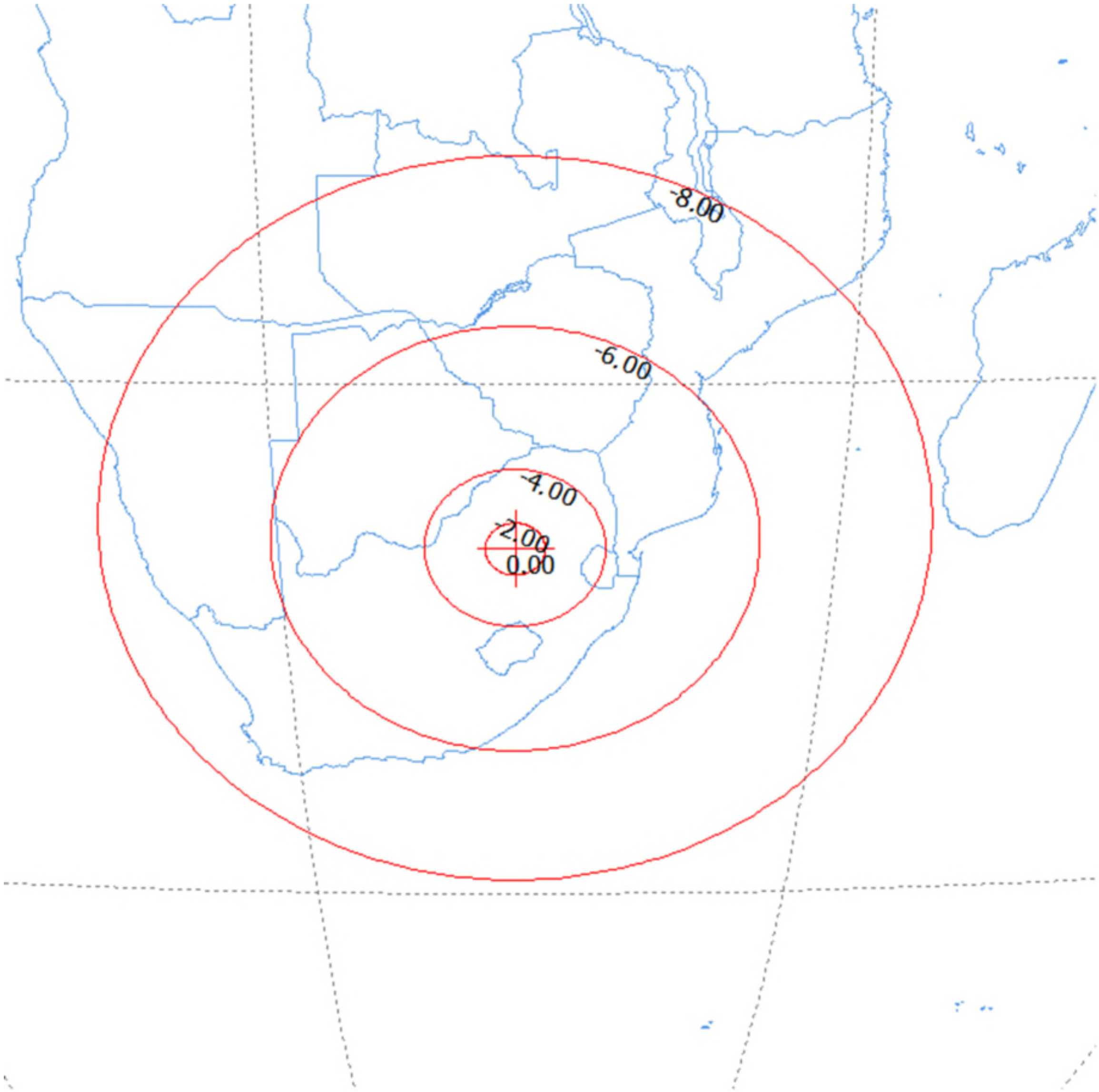
S-band Downlink – Triton-X - Spain



S-band Uplink – Deadhorse, Alaska



S-band Uplink – South Africa



S-band Uplink – Triton-X - Spain

UHF Beacon (400.5 MHz) Downlink – Brostadbotn, Norway

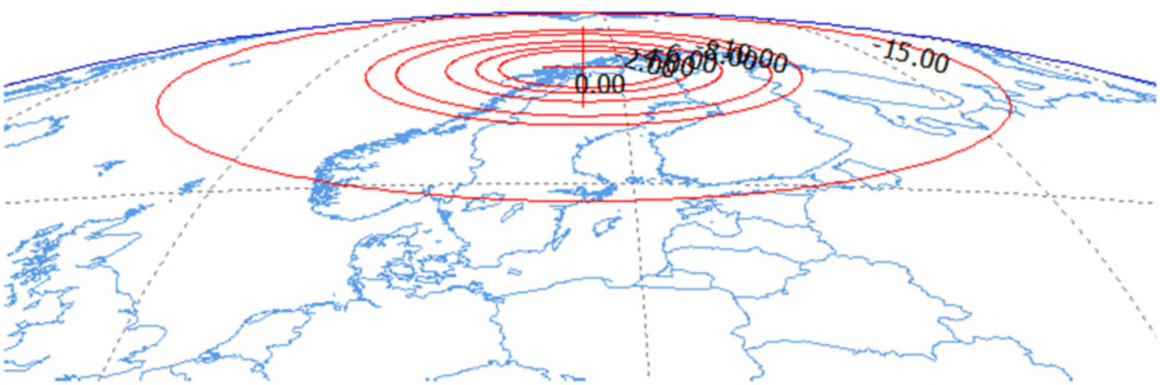


EXHIBIT 4

Momentus Space LLC Leadership and Ownership

OWNERSHIP INFORMATION

Momentus Space LLC ("Momentus") is a domestic Delaware limited liability company, wholly owned by its parent company Momentus Inc., a publicly held domestic Delaware corporation, which trades on the NASDAQ under the symbol MNTS. No foreign entities are known to hold, directly or indirectly, aggregated ownership of ten percent or more in MNTS. Should Momentus become aware of any new foreign ownership of MNTS which, in the aggregate, meets or exceeds the ten percent threshold, Momentus will notify the Commission.

As a publicly traded company, ownership is inherently fluid. Other than those entities listed below, Momentus is not aware of any owners of MNTS stock which would, in the aggregate, have more than a 10% or greater equity and/or voting interest in Momentus:

1. **Dakin Sloss**[1]
   General Partner, Prime Movers Lab ("PML")
   PO Box 12829
   Jackson, WY 83002
   PML Ownership Interest: approximately 27.9%[2]

OFFICERS AND DIRECTORS

All Momentus officers and directors listed below are, apart from Mr. Hadfield who holds Canadian citizenship, U.S. citizens, and may be reached at the following address:

c/o Momentus Space LLC
3901 N. First Street
San Jose, CA 95134

1. John Rood
Chief Executive Officer, Director

2. Mitch Kugler
Director

3. Chris Hadfield
Director

4. Linda Reiners
Director

[1] This ownership reflects the aggregated ownership of outstanding stock by Prime Movers Lab and its related entities.

[2] This ownership information is accurate as of April 20, 2023. *See* Schedule 14A, Proxy Statement, https://www.sec.gov/Archives/edgar/data/1781162/000114036123019344/ny20008814x1_def14a.htm.

5. Brian Kabot
Director

6. Kimberly Reed
Director

7. Victorino Mercado
Director

8. Paul Ney
Chief Legal Officer, Corporate Secretary

9. Dennis Mahoney
Interim Chief Financial Officer

10. Rob Schwarz
Chief Technology Officer

11. Eric Williams
Chief Financial Officer

EXHIBIT 5

VR-7 Payload Customers

VR-7 Payload Customers

Payload Name	Payload Owner	Licensing Jurisdiction	Size	Mass (kg)	Effective Drag Area[1] (m^2)	Maximum Deployed Dimensions (m)
TROOP-F2	SEOPS	USA	6U	~4.9	1.0005	0.727 x 0.880 x 0.394
CUAVA-2	Univ of Sydney	Australia	6U	~8.2	0.341	0.352 x 0.104 x 0.226
Waratah Seed	Univ of Sydney	Australia	6U	~9.2	0.341	0.352 x 0.104 x 0.226
HelloPod	Hello Space	Turkey	0.5U x8	~3.5	0.075	0.05 x 0.05 x 0.05
OREsat-0.5	PSAS	USA	2U	~3	0.2	0.2 x 0.1 x 0.1
Stork-7	SatRevolution	Poland	3U	~4	0. 25	0.3 x 0.1 x 0.1
JinjuSat-1	CONTEC	South Korea	2U	~2.5	0.2	0.2 x 0.1 x 0.1
Zeus-2	Qosmosys	Singapore	3U-XL	~2.5	0.28	0.36 x 0.1 x 0.1
WREN	C3S	Hungary	6U	~10	0.341	0.352 x 0.104 x 0.226
Lunasonde	Lunasonde	USA	1U	~1	0.15	0.1 x 0.1 x 0.1
Triton-X Genesis	LuxSpace	Luxembourg	Nano Sat	~19.3	N/A (does not separate from Vigoride)	0.354 x 0.441 x 0.354 (does not separate from Vigoride)

[1] Effective drag area assumes tumbling.

EXHIBIT 6

X-band Interference Analysis

X-band Interference Analysis

Overview

The Momentus Vigoride-7 ("VR-7") mission plans to use a 1-megahertz channel (8199.5-8200.5 MHz) in the X-band Earth-Exploration Satellite Service ("EESS") allocation (space-to-Earth) on an unprotected and non-interference basis primarily for space operations services.[1] This report demonstrates that the VR-7 spacecraft operations will not cause unacceptable levels of interference to authorized satellite systems in these X-band frequencies. Further, where necessary to address coordination requests, Momentus will maintain a 3-degree avoidance angle with other co-frequency satellite operators to ensure protection of those systems.

This analysis relies upon the protection criteria defined in ITU-R SA.1027-6.[2] This ITU Recommendation defines both long-term and short-term protection criteria. The long-term protection criterion defines an interference power level, which cannot be exceeded 20% of the time. Because the interfering system is a single non-geostationary low-Earth orbit ("LEO") satellite,[3] it is physically incapable of causing interference into any given gateway earth station ("GW ES") 20% of the time.

The short-term protection criterion limits the interfering signal power to -133 dBW/10 MHz for no more than 0.0025% of the time. The short-term protection criterion is the focus of this analysis because it reflects the protection criterion that could be exceeded by a single LEO interferer.

Frequency band (MHz)	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time		Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than *p*% of the time	
	Interfering signal path		Interfering signal path	
8 025-8 400	–167 dBW per 10 MHz	–150 dBW per 10 MHz	–133 dBW per 10 MHz $p = 0.0025$	–133 dBW per 10 MHz $p = 0.0050$

Figure 1: X-band EESS Protection Criteria - ITU-R SA.1027-6

[1] As stated in the application narrative, Momentus will also use this band for transmission of some imaging associated with rendezvous proximity operations and other mission assurance activities (*e.g.*, the deployment of customer payloads). *See* Application Narrative, at 24.

[2] *See* Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit, ITU-R SA.1027-6 (2019), *available at* https://www.itu.int/dms_pubrec/itu-r/rec/sa/R-REC-SA.1027-6-201908-I!!PDF-E.pdf.

[3] While Momentus intends to operate in the X-band on future missions, each mission is expected to have only a brief mission duration. Furthermore, as seen from the results presented below, the long-term protection criterion is met by roughly two orders of magnitude. Therefore, the long-term protection criteria would only be exceeded if over 100 Vigoride spacecraft were simultaneously operating, which is not presently a realistic operational scenario.

The goal of this simulation-based analysis is to demonstrate that Momentus will be able to maintain its operations in the X-band frequencies below the ITU-specified short-term protection criterion. This analysis focuses on the U.S.-based GW ES site to which Momentus will be conducting X-band downlink transmissions.[4] Further, Momentus will extrapolate these results, via analysis, to demonstrate that Momentus will be able to protect authorized X-band satellites operating at or near other GW ES sites Momentus will use.

Simulation Description

The Momentus U.S. GW ES site is listed below. The station has the receive antenna gain listed below and a system noise temperature of 200K. The emissions from the VR-7 space station were simulated as -3.7 dBW of RF power, spread over 1 MHz with a peak antenna gain of 6 dBi.

Simulated Momentus GW ES Site	**Location**	**Antenna Gain**	**Antenna Size**
Deadhorse, Alaska	148°24’29" W 70°12’45" N	48 dBi	4.5 m
Simulated “Victim” GW ES Sites	**Location**	**Antenna Gain**	**Antenna Size**
Utqiagvik, Alaska	156°48’22.0" W 71°16’30.4" N	50.9 dBi	3.7 m
North Pole, AK	147°32'10.0" W 64°47'37.0" N	53.0 dBi	7.3 m
Fairbanks, AK	147°44'0.2" W 64°48'47.4" N	43.5 dBi	2.4 m
Prudhoe Bay, AK	148°23'59.2" W 70°13'13.6" N	51.0 dBi	5.4 m
Fairbanks, AK	147°31'44" W 64°53'26.0" N	51.5 dBi	7.3 m

Table 1: Simulated GW ES Sites

Based upon a review of relevant GW ES and space station filings from IBFS that include space-to-Earth links to the U.S. GW ES site employed by VR-7, Momentus identified the following list of satellite systems that transmit co-frequency to the same or nearby GW ES sites (together, the “Simulated GW ES Sites”).[5] To be conservative, all satellite systems were assumed to operate co-frequency with full spectrum overlap. Because VR-7 only uses 1 megahertz of bandwidth in the 375 MHz EESS band, this assumption is very conservative and was made only for purposes

[4] The United States site was selected for this simulation effort because of the greater ease of access to the information necessary to conduct the analysis. Also, as discussed below, the U.S. ground station site is likely to be the worst-case scenario because the other ground station locations are not customarily used for EESS systems.

[5] As a conservative measure, Momentus treated GW ES sites in Alaska as nearby for purposes of the simulation.

of this simulation. During operations, spectrum overlap will be taken into account to avoid unnecessary operational constraints.

Satellite Constellation Name	**Number of Satellites**
BlackSky	18 (including 2 pathfinders)
Planet SkySat	21
Maxar WorldView	3
Maxar GeoEye	2
Ikonos	1
Quickbird-1	1
Maxar Legion	12
ICEYE XR	6

Table 2: Relevant Authorized X-band Satellite Systems

The Momentus VR-7 spacecraft will be operating in a variety of orbital configurations during its ~12-month operational life. The two "nominal" operational orbits are listed below.

- 500 km x 500 km SSO (LTAN 11:30)
- 380 km x 350 km, ~97-degree inclination

Because VR-7 is a secondary payload, the launch parameters could change, and the spacecraft will be maneuvering for most of its brief mission lifetime, representative simulations were conducted at two representative orbits, 500 km x 500 km and 380 km x 350 km,[6] in order to simulate the envelope of potential operational altitudes. In general, the interference curves are very similar and modest changes to the nominal operational orbits of +/- 10, 20, or 30 km would be immaterial.

Simulation Results

Simulations were conducted for each of the satellite systems listed in Table 2 above operating with their respective Alaska GW ES site to determine the interference power statistics caused by VR-7 downlinking to the Deadhorse, AK GW ES site and comparing the results against the defined short-term protection criterion. The VR-7 spacecraft was assumed to attempt to communicate with the Deadhorse, AK GW ES site any time it is within line of sight and above a minimum elevation angle of 5-degrees. This is another conservative assumption, translating to

[6] *See also* Application of Momentus Space LLC, IBFS File No. SAT-STA-20211216-00195, Letter from Tony Lin, Counsel to Momentus Space LLC, to Marlene Dortch, FCC, at Exhibit 2 (April 13, 2022) (conducting the X-band interference analysis for the Vigoride-3 spacecraft at the 525 km x 525 km, 537 km x 537 km, 550 km x 550 km, and 1050 km x 350 km orbits); Application of Momentus Space LLC, IBFS File No. SAT-LOA-20220504-00047, at Exhibit 7 (filed May 4, 2022) (conducting the X-band interference analysis for the Vigoride-5 spacecraft) Application of Momentus Space LLC, IBFS File No. SAT-LOA-20221009-00131, at Exhibit 6 (filed October 9, 2022) (conducting the X-band interference analysis for the Vigoride-6 spacecraft).

~92 minutes/day of contact time with Deadhorse, AK. By contrast, as an operational matter, Momentus anticipates averaging much closer to 20 minutes/day of contact time.

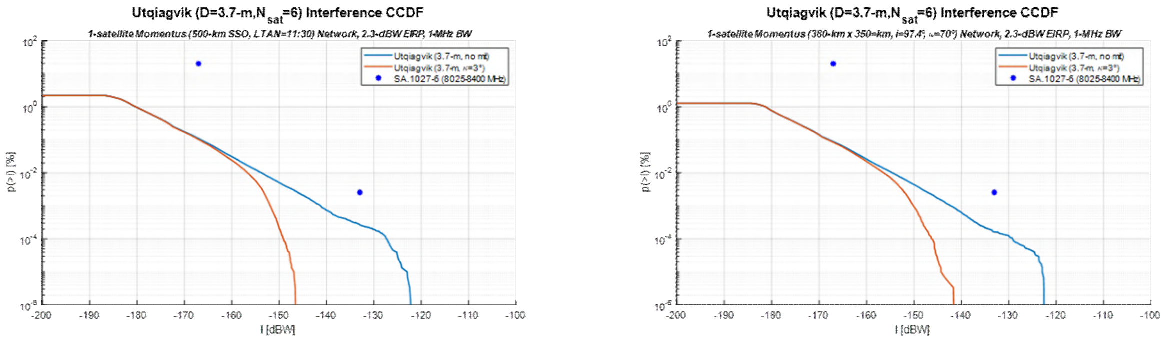


Figure 2: X-band Spectrum Sharing Simulation – ICEYE at Utqiagvik, AK

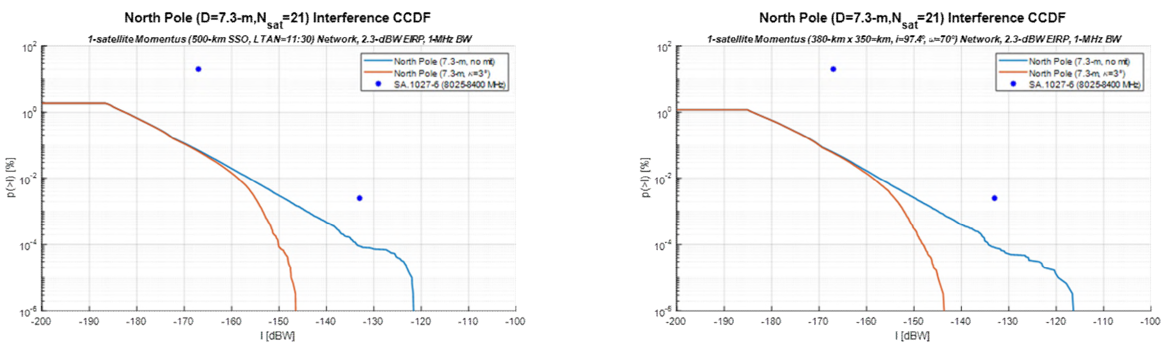


Figure 3: X-band Spectrum Sharing Simulation – Blacksky, WorldView & GeoEye at North Pole, AK

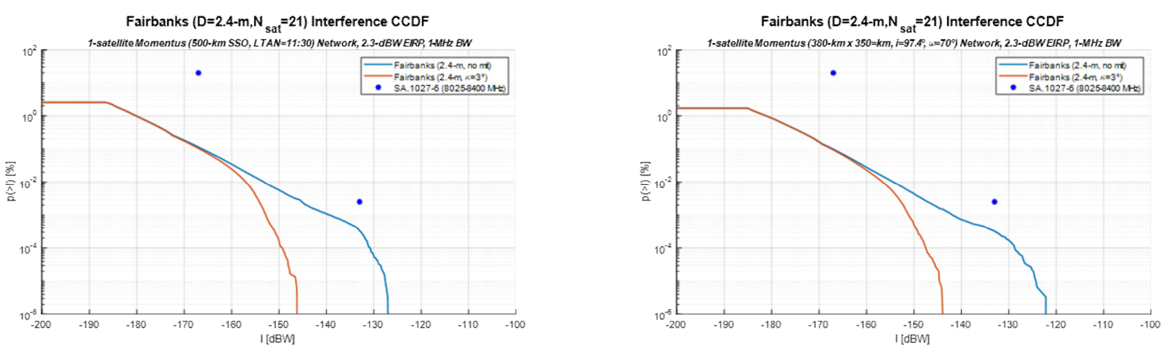


Figure 4: X-band Spectrum Sharing Simulation – Planet SkySat at Fairbanks, AK

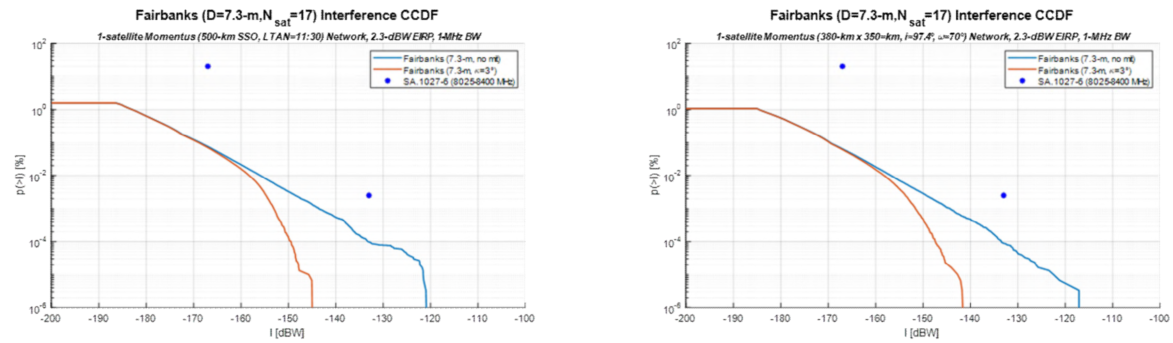


Figure 5: X-band Spectrum Sharing Simulation – WorldView, GeoEye and Legion at Fairbanks, AK

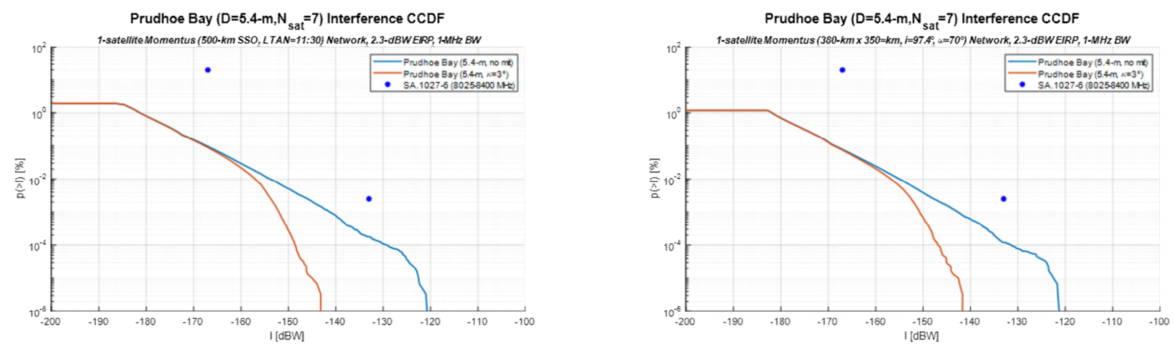


Figure 6: X-band Spectrum Sharing Simulation – WorldView, GeoEye and QuickBird at Prudhoe Bay, AK

Conclusions

The X-band spectrum sharing simulations show that VR-7 could operate without operational restrictions and meet the protection criteria specified by ITU-R SA.1027-6. The Deadhorse, AK GW ES site is the closest to either pole and therefore, given the highly inclined nature of the orbit, has the most opportunity each day for contact and, thus, will cause interference into other X-band downlinks the greatest percentage of time. Furthermore, the other Momentus GW ES sites were specifically selected in locations that are not in proximity to customary EESS GW ES sites. Therefore, the simulation results should, in fact, reflect the worst-case interference scenario into other X-band downlinks. Therefore, even if an authorized user of the X-band spectrum is not properly identified and included in the batch analysis process to modify the contact plan to avoid inline-interference events, the resultant interference CDF caused by the VR-7 satellite would most likely not exceed the protection criteria.

Nevertheless, Momentus will engage in coordination with affected co-frequency systems to understand which satellites each system has in operation, collect TLE information for all applicable satellites that must be avoided and establish relationships to receive notifications when new satellites are added to the constellations. In an abundance of caution, where necessary to address coordination requests, Momentus will maintain a 3-degree avoidance angle with other co-frequency satellite operators to ensure protection of those systems.

As can be seen from the simulations results, when a 3-degree avoidance angle is applied, the maximum interference power stays ~10 dB below the maximum interference level allowed by the short-term protection criterion. Since the maximum interference power remains safely below the maximum allowed interference level, any changes in the location of the victim GW ES would only affect the time-percentage statistics of the interference CDF (effectively only shifting the curve in the y-axis on each of the graphs). Therefore, by maintaining a 3-degree avoidance angle during operations, one can extrapolate these simulation results to any GW ES location supporting any number of authorized X-band satellites and never exceed the protection criteria.

Finally, the avoidance of inline interference event with all of the identified systems combined only results in <1% reduction in access opportunities for the VR-7 downlink, ensuring that the VR-7 will not be unduly constrained operationally.

EXHIBIT 7

Technical Certification

Technical Certification

I, David Morse, hereby certify, under penalty of perjury, that I am the technically qualified person responsible for the preparation of the engineering information contained in the technical portions of the foregoing application and the related attachments, that I am familiar with Part 25 of the Commission's rules, and that the technical information is complete and accurate to the best of my knowledge and belief.

/s/

David C. Morse, Ph.D.
Avaliant, LLC
Bellevue, WA USA
425-246-3080

Date: May 1, 2023

EXHIBIT 8

Ground Station List

Ground Station List

Location	**Latitude °**	**Longitude °**
RBC **Deadhorse, Alaska**	70°12’36” N	148°00’00” W
RBC **Dublin, Ireland**	53°24’36” N	6°13’12” W
RBC **Pretoria (Bronkhorstspruit), South Africa**	25°51'39.2" S	28°27'12.2" E
KSAT **Brøstadbotn, Norway**	69°5’19” N	17°41’34” E
KSAT **Svalbard, Norway**	78°13’47” N	15°24’28” E
KSAT **Troll, Antarctica**	72°1’00” S	2°31’60” E
RBC **Puertollano, Spain (for communications with LuxSpace Triton-X Genesis payload only)**	38°40’12” N	4°9’36” W