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-6 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-6 ("VR-6") non-geostationary orbit ("NGSO") spacecraft in low-Earth orbit ("LEO"), to transport and deploy multiple, separate customer payloads, and to conduct testing.[1]

VR-6 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). Additionally, for up to a seven-day period after deployment, VR-6 will operate a beacon in the UHF frequency band (with a center frequency 400.5 MHz) to facilitate the acquisition of the satellite, thereby reducing the probability that Momentus will not be able to communicate with the spacecraft because of lack of accurate orbital information, which could result from an anomaly. VR-6 is scheduled to be deployed from a Space Exploration Technologies Corporation ("SpaceX") Falcon 9 launch in February 2023, and the mission is expected to have a duration of approximately 250 days.

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[1] *See* 47 C.F.R. § 25.114.

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.

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, permanently 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

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

thruster ("MET"), which is designed to be a non-toxic and low-pressurized 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-6 will transport and directly deploy a number of third-party payloads from VR-6. 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-6 and the launch vehicle and provide evidence of such authorizations to Momentus.

The VR-6 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.5 below.

VR-6 has a planned launch on a Falcon 9 rideshare presently scheduled for February 2023. VR-6 will be affixed directly to the Falcon 9 vehicle and deployed into a targeted sun-synchronous orbit with approximately a 97 +/- 1 degree inclination and an insertion orbit between 480 to 520 km circular orbit.[3] VR-6 will then conduct a series of maneuvers, during which VR-6 will make minor inclination changes while staying within the 96 +/- 1 degree range.

After separation from the launch vehicle, VR-6 will undergo commissioning and conduct maneuvers to a 495 km circular orbit, *i.e.*, the "Second Orbit." Upon completion, VR-6 will deploy all of the customer payloads.[4]

After the payload deployments, VR-6 will conduct two sets of maneuvers to test the capabilities of the propulsion system. First, VR-6 will conduct LTAN change maneuvers by transferring to a maximum 547 km x 547 km orbit, dwelling for approximately 30 days, and returning to approximately a 495 km orbit.

Second, VR-6 will conduct a 180° phase change maneuver by transferring to a maximum 515 km orbit, dwelling for approximately 5 days, and returning to approximately a 495 km orbit. VR-6 will then deploy a demonstration solar array (distinct from the solar arrays used on the vehicle for nominal power generation) and conduct testing of the demonstration solar array.

Upon completion of the demonstration solar array testing, VR-6 will relocate to a final 410 km x 350 km elliptical end-of-life orbit. *See* Table 1 below (summarizing the relevant orbital parameters for the mission). Momentus calculates that VR-6 will have sufficient

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[3] For the purposes of this application, Momentus assumed a 520 km maximum insertion orbit based on information from the launch provider.

[4] *See* Exhibit 5. As explained in the attached ODAR, VR-6 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-6 bus experiences a failure and Momentus is unable to command the deployment. *See* Exhibit 2.

propellant remaining at the conclusion of the mission to conduct further perigee reduction maneuvers, which could reduce to months the demise of the VR-6.

As demonstrated in the attached ODAR (*see* Exhibit 2), a 520 km circular sun-synchronous orbit would be the worst-case scenario in the assessment of orbital debris risk, and VR-6 would re-enter the Earth's atmosphere in approximately 11 years from that altitude.[5] At the target final orbit, 410 km x 350 km, Momentus calculates that VR-6 will de-orbit within approximately 2 months, which complies with the FCC's proposed new de-orbit requirements.[6]

B. Technical Specifications

1. Orbital Parameters

The VR-6 concept of operations ("CONOPS") is as follows:

1. Launch vehicle arrives at insertion orbit (maximum 520 km altitude circular sun-synchronous orbit ("SSO")).
2. VR-6 separates from launch vehicle.
3. VR-6 undergoes commissioning and preliminary testing.
4. VR-6 conducts orbit maneuvers to its second (operational) orbit (495 km circular SSO).
5. VR-6 deploys all customer payloads.[7]
6. VR-6 conducts LTAN change maneuvers.
7. VR-6 conducts 180-degree phase change maneuvers.
8. VR-6 deploys a demonstration solar array and conducts testing.
9. VR-6 relocates to end-of-life orbit (410 km x 350 km elliptical). Momentus will ensure that its maneuvers through the orbits of inhabitable spacecraft will not create risk to other spacecraft.

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[5] Momentus is aware that the FCC has adopted new orbital debris mitigation rules requiring that satellites in low Earth orbit be disposed no later than five years following completion of the mission. *See Space Innovation; Mitigation of Orbital Debris in the New Space Age*, Second Report and Order, IB Docket Nos. 22-272, 18-313, FCC 22-74 (September 30, 2022).

[6] *Id*.

[7] The CONOPS reflect nominal conditions. *See* supra note 4 (discussing the off-nominal failsafe deployment).

	Insertion Orbit	Second Orbit[8]	LTAN Change Maneuver[9]	Phase Change Maneuver	Third Orbit	Final Orbit
Apogee Altitude	520 km (max)	495 km	547 km (max)	515 km (max)	495 km	410 km
Perigee Altitude	520 km (max)	495 km	547 km (max)	515 km (max)	495 km	350 km
Inclination	~97°+/-1°	~96°+/-1°	~96°+/-1°	~96°+/-1°	~96°+/-1°	~96°+/-1°
Period	95 mins	94 mins	95 mins	95 mins	94 mins	94 mins
Argument of Perigee	N/A	N/A	N/A	N/A	N/A	N/A
Local Time of the Ascending Node (LTAN)	1030am	1028am	1026am	1000am	0958am	0840am
Maximum De-Orbit Life	~ 11 years[10]	~ 1 year[11]	~ 4 years[12]	~ 2 years[13]	~ 1 year[14]	~ 2 months

Table 1: Orbital Parameters

2. Frequency Bands

VR-6 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 2 below. However, Momentus will also downlink imagery generated from one or

[8] The second orbit is the VR-6 operational orbit; the LTAN and Phase change maneuvers are conducted at higher altitudes to change parameters temporarily.

[9] After the LTAN change maneuver, VR-6 will return to the second (operational) orbit before conducting the phase change maneuver.

[10] This is the deorbit duration, if VR-6 fails after deployment.

[11] This is the deorbit duration, if VR-6 achieves a 495 x 495 km orbit, deploys the demonstration solar array and then the propulsion system fails.

[12] This is the deorbit duration, if VR-6 achieves a 547 x 547 km orbit and then the propulsion system fails.

[13] This is the deorbit duration, if VR-6 achieves a 515 x 515 km orbit and then the propulsion system fails.

[14] This is the deorbit duration, if VR-6 achieves a 495 x 495 km orbit and then the propulsion system fails.

more on-board cameras to confirm successful deployment of the payloads and perform mission assurance functions.[15]

	Uplink (Earth-to-space)	Downlink (space-to-Earth)	Beacon
Center Frequency	2075.0 MHz[16]	8200 MHz	400.5 MHz
Bandwidth (max.)	0.1 MHz	1 MHz	20 kHz
Data Rate[17]	50 kbps	500 kbps	9.6 kbps
Modulation & Coding[18]	BPSK	OQPSK	2GFSK
Transmit RF Power	9.4 dBW	-3.7 dBW	4.3 dBW
Transmit Antenna	4.5m (dish)	Patch (6 dBiC)	5.2 dBi
Transmit Antenna EIRP	47.4 dBW	2.3 dBW	9.5 dBW
Receive Antenna	Patch (7 dBiC)	Dish (51 dBiC)	16.2 dBi
Receive Antenna G/T	-26 dB/K	26.7 dB/K	-10.5 dB/K

Table 2: Radio Frequency Plan

Although the associated Schedule S identifies the use of multiple bandwidths, there will be at most a single S-band uplink transmission (with a representative center frequency at 2075.0 MHz) at any given time and a single X-band downlink transmission (with a representative center

[15] Momentus holds a commercial remote sensing license issued by the National Oceanic and Atmospheric Administration ("NOAA") for the operations of imaging sensors. *See* NOAA Licensees, https://www.nesdis.noaa.gov/commercial-space/regulatory-affairs/licensing/noaa-licensees (last visited December 10, 2021).

[16] 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.

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

[18] Links may include forward error correction.

frequency at 8200 MHz) 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 that its reduction in the bandwidth at every operating orbital altitude will not result in VR-6 exceeding applicable PFD limits, as discussed in more detail below. Under nominal conditions, Momentus would expect to transmit at the maximum bandwidth.

a. S-band and X-band Frequencies

Momentus is aware that there are federal and other operations in these frequency bands and intends to coordinate its proposed operations with affected operators prior to operations. Provided as Exhibit 6 is an interference analysis demonstrating that the X-band operations will not cause harmful interference to authorized spectrum operations.

Attached to this application in Exhibit 3 are the antenna gain contours for 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.[19] The peak gain value for the X-band transmit beam is 6 dBi. The peak gain value for the S-band receive beam is 7 dBi.

VR-6 will also include a demonstration X-band radio and patch antennas, built by Momentus, called CHIRP. The CHIRP demonstration has the same RF characteristics as the primary X-band radio and antenna. CHIRP will only transmit while VR-6 is over Momentus' identified ground stations and when the primary X-band radio is not transmitting.

[19] *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.

b. X-band Interference Analysis

VR-6 meets the International Telecommunication Union ("ITU")-established power flux density ("PFD") limits on the Earth's surface and at the geostationary arc and adequately limits emissions in the adjacent band frequencies.

i. 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.[20] However, Table 21-4 of the ITU Radio Regulations ("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;
- $-150 + 0.5(\delta - 5)$ 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-6 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-6. 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-6 is below 350 km and until as low as 150 km, as VR-6 is de-orbiting. In that event, Momentus will reduce the power levels of its transmissions to maintain compliance with the PFD limits.

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

[20] 47 C.F.R. § 25.208.

will operate at the maximum EIRP level of 2.3 dBW. Because VR-6 operates over a range of 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.

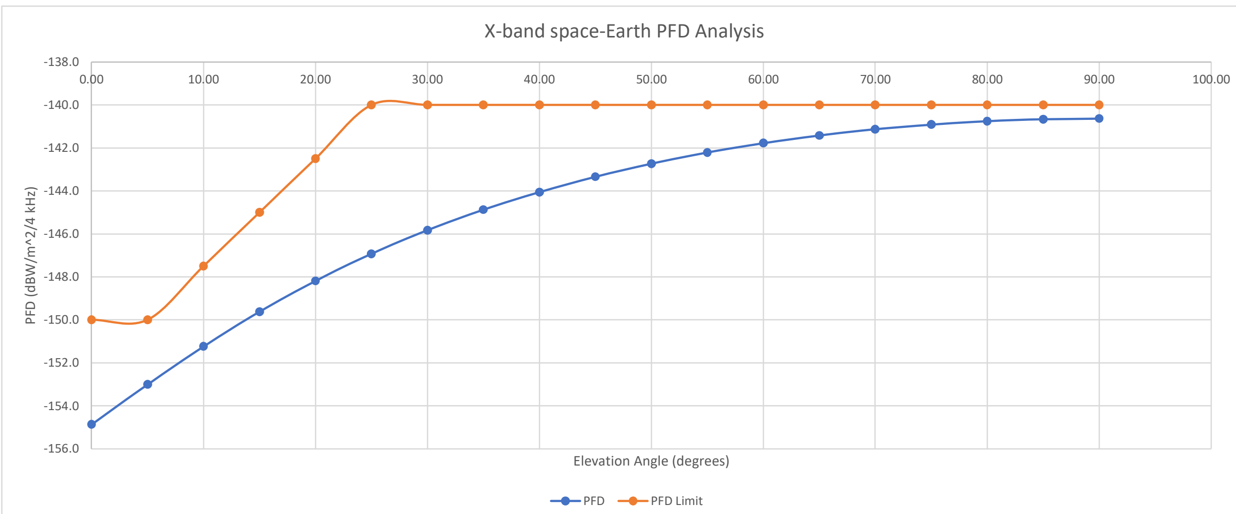

Figure 2: X-band PFD from 500 km Orbital Altitude

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.

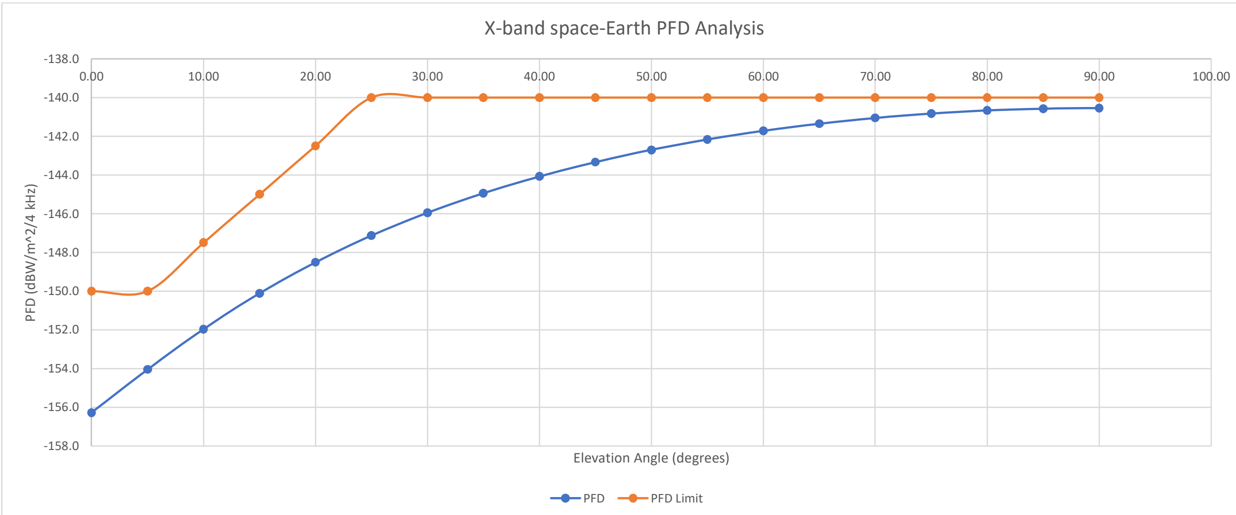

Figure 3: X-band PFD from 350 km Orbit Altitude

The X-band payload may continue to operate as the perigee is lowered below 350 km. However, either the EIRP will be reduced or payload transmissions will be limited to times when the instantaneous orbital altitude is above 350 km.

ii. 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 547 km altitude for VR-6, 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
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EIRP = 2.3 dBW
EIRP Density = -16.6 dBW per 4.0 kHz Ref BW
θ = 0°
D = 35261.0 km
PFD = -177.6 dBW/m^2 @ 4.0 kHz Ref BW

iii. Protection of authorized X-band satellite operators

The Momentus VR-6 mission plans to use a 1-megahertz channel (8199.5-8200.5 MHz) in the X-band Earth-Exploration Satellite Service allocation (space-to-Earth) on an unprotected and non-interference basis for Space Operations services. The attached report included as Exhibit 6 demonstrates that the VR-6 spacecraft operations will not cause unacceptable levels of interference to authorized satellite systems in these X-band frequencies and, further, by maintaining a 3-degree avoidance angle with other co-frequency satellite operators will ensure protection of those systems.[21]

iv. 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.[22] 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.[23] The maximum interference PSFD was calculated as follows:

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[21] *See* Exhibit 6.

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

[23] *Id.*

VR-6 maximum PFD (at 350 km altitude)[24] = -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)

c. UHF Frequencies

VR-6 will include a 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 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 Deadhorse, Alaska 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, 1-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.

[24] 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-6 is below 350 km and until as low as 150 km, as VR-6 is de-orbiting. In that event, Momentus will reduce the power levels of its transmissions to maintain compliance with the limit.

The operator can power off the beacon at any time via command from the ground.[25] Momentus will manually turn off the beacon as soon as the company is able to obtain accurate tracking information, which could be as soon as one day after launch.[26]

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.[27] 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.[28] 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.

3. Schedule S Clarifications

Momentus notes that the minimum and maximum Saturation Flux Density ("SFD") values in the Schedule S are generally relevant only to GSO, bent-pipe communication links. Nonetheless, Momentus calculates minimum and maximum SFD values for this NGSO

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[25] 47 C.F.R. § 25.207.

[26] 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 1-week timer. Momentus would not reset the beacon without obtaining additional FCC authorization.

[27] 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.

[28] 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.

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.

4. 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-6'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-6 complies with 47 C.F.R. § 25.207.

5. 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-6. To that end, TT&C transmissions will be sent using packetized protocols incorporating end-to-end AES256 encryption.[29] Provided in Exhibit 8 is a table identifying the ground stations that Momentus intends to use with the VR-6 spacecraft.[30] 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

[29] 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-6.

[30] 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-6) 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.

relevant Federal operators. Momentus will maintain an updated list of coordinated earth stations in the license application docket.[31]

6. Microwave Electrothermal Thruster

VR-6 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 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.[32] The power

[31] *See, e.g.,* Stamp Grant, Loft Orbital, 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, 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, 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.").

[32] *See* 47 C.F.R. § 2.106.

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.[33] 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.[34]

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.

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)[35]
PFD = -221.78 dBW/m^2 @ 4.0 kHz Ref BW

C. Orbital Debris Mitigation

Momentus has conducted an ODAR in compliance with NASA-STD-8719.14, which is attached as a separate exhibit (Exhibit 2). As discussed in the submitted ODAR, VR-6 is compliant with all applicable orbital debris requirements.

VR-6 is planned to operate with an approximately 10% margin of propellant, in addition to the propellant necessary to achieve the operational concept. Momentus calculates that this

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[33] *See* ITU Radio Regulations 21.16.

[34] Due to the operation of the equipment as part of the spacecraft, Momentus believes the VR-6 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.

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

reserve will be sufficient to support all contingencies during the VR-6 mission, including orbital debris and object avoidance maneuvers throughout the mission life. Additionally, Momentus calculates that it would have sufficient propellant remaining at the conclusion of the mission to conduct further perigee reduction maneuvers which could reduce to months the demise of the VR-6.

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 no later than 4 months prior to the launch date. Alternatively, Momentus may replace a customer payload with a mass dummy, which would not be deployed on orbit, as discussed in the attached ODAR.[36] 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 any payload with a mass dummy, as necessary, is key to the ongoing certification of the VR-6 mass properties to the launch service provider and ensuring orbital debris compliance for the mission.

III. Waiver Requests

The Commission may waive any of its rules if there is "good cause" to do so.[37] 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.[38] Generally, the Commission will grant a waiver of its rules in a particular case if the

[36] *See* Exhibit 2.

[37] *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).

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

relief requested would not undermine the policy objective of the rule in question and would otherwise serve the public interest.[39] 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

1. 2025-2110 MHz TT&C Uplink

This band is allocated to Space Operations and Earth-Exploration Satellites Services ("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 that any use may not cause harmful interference to authorized operations.[40] Accordingly, to the extent necessary, Momentus requests waiver of the Table of Allocations to use the 2025-2110 MHz band (Earth-to-space) for TT&C. Given the limited use of the frequencies during the brief 250-day mission, Momentus' commitment to coordinate use of these frequencies, and the public interest justification supporting the mission, Momentus submits that waiver is warranted.

2. 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-6, the 8025-8400 MHz band is, as discussed above, to be used primarily

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

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

for TT&C and some satellite imaging.[41] 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).[42]

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

- limit operations to approximately 250 days;
- transmit only over identified ground stations, many of which are located in regions not typically used for earth-exploration satellite service systems;
- 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, as necessary to ensure protection of those systems; and
- pre-coordinate operations with potentially affected federal operators.

In analogous situations, the FCC has granted similar use of the X-band.[43] For these reasons, Momentus submits that waiver is warranted.[44]

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[41] Such use will include transmission of limited imagery of the payloads during deployment primarily to provide mission assurance and, to a limited degree, selected images for publicity or marketing purposes.

[42] *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).

[43] *See, e.g.,* 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).

[44] 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 22,645, 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 13,952, at ¶ 11 (IB 1996); *see also supra* note 43.

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.[45] 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.[46]

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.[47] Momentus' spectrum use would be limited in time and location, and Momentus is 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.[48] The Commission's bond requirements have been developed to prevent licenses from warehousing spectrum.[49] Momentus does not seek mutually exclusive use of the

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[45] 47 C.F.R. § 25.158.

[46] 47 C.F.R. §§ 25.156 and 25.157.

[47] 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).

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

[49] *See Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Second Report and Order, 30 FCC Rcd 14713, ¶ 53 (2015) (citing, *e.g.*, *TMI Communications and Company, Limited Partnership and TerreStar Networks Inc.*, *Application for Review and Request for Stay*, Memorandum

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.[50] Here, the mission life for VR-6, a single spacecraft, is expected to be less than one year. Indeed, the FCC has not historically imposed a bond requirement on limited-duration, in-orbit deployment missions.[51]

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.[52] 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

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Opinion and Order, 19 FCC Rcd 12603, 12604, ¶ 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, 11537-38, ¶ 12 (2001)).

[50] *In the Matter of Streamlining Licensing Procedures for Small Satellites*, Notice of Proposed Rulemaking, 33 FCC Rcd 4152, ¶ 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).

[51] *See, e.g.*, 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); *cf.* Application of Spaceflight, IBFS File No. SAT-LOA-20220111-00007 (granted May 10, 2022) (imposing a bond requirement for an in-orbit spacecraft that would be hosting a commercial radiofrequency payload for 1 year).

[52] *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, ¶¶ 28-31 (2004).

launch and operate."[53] 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 an extremely 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.

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 to VR-6. 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.[54] 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.[55]

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.

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

[54] *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).

[55] *Id* ¶ 45.

Respectfully submitted,

<u>/s/ Paul Ney</u>

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Dated: October 9, 2022

EXHIBIT 1

ITU Cost-Recovery Declaration

October 9, 2022

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-6 Satellite Network Operating in Non-geostationary Orbit in the Non-Planned Frequency Bands. (VIGORIDE-6)

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-6 satellite network. Please address all cost-recovery inquires, and ITU correspondence and filings, related to the VIGORIDE-6 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-6 Spacecraft

Orbital Debris Assessment Report (ODAR)

Rev 1

09/30/2022

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	Randy Yount	09/30/22

Table of Contents

Randy Yount

Randy Yount
Regulatory Technical Lead, Vigoride-6
Momentus

Orbital Debris Self-Assessment Evaluation

Reqm't #	Launch Vehicle: Compliant or N/A	Launch Vehicle: Not Compliant	Launch Vehicle: Std. Non-Compliant	Launch Vehicle: Incomplete	Spacecraft: Compliant or N/A	Spacecraft: Not Compliant	Spacecraft: Incomplete	Comments *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-6 ("VR-6") 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-6 spacecraft. Sections 9 through 14 of the NASA standard apply to the launch vehicle ODAR and are not covered here.

I. Program Management and Mission Overview

Project Manager:

- Andrew Reys

Foreign Government or space agency participation:

- None

Schedule of Upcoming Mission Milestones:

- Launch – February 2023

Mission Overview:

This ODAR evaluates the Momentus VR-6 mission, which is targeted to launch on a SpaceX Falcon 9 rocket in February 2023. For the mission, VR-6 will exhibit the capacity to transport and deploy multiple payloads. Each deployed payload is a third-party 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.

Launch Vehicle:

- Falcon 9

Expected Launch Site:

- Vandenberg Air Force Base, California

Operational Mission Duration:

- Planned for approximately 250 days.

[1] General information regarding the payloads is provided in Exhibit 5 to the application. 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 no later than 4 months prior to the launch date. Alternatively, Momentus may replace a customer payload with a mass dummy, which would not be deployed on orbit. Any such mass dummies to replace Momentus customer payloads 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 VR-6 nominal concept of operations is as follows:

1. Launch vehicle arrives at insertion orbit (maximum 520 km altitude circular sun-synchronous orbit (“SSO”)).
2. VR-6 separates from launch vehicle.
3. VR-6 undergoes commissioning and preliminary testing.
4. VR-6 conducts orbit maneuvers to its second (operational) orbit (495 km circular SSO).
5. VR-6 deploys all customer payloads.[2]
6. VR-6 conducts LTAN change maneuvers.
7. VR-6 conducts 180-degree phase change maneuvers.
8. VR-6 deploys a demonstration solar array and conducts testing.
9. VR-6 relocates to end-of-life orbit (410 km x 350 km elliptical). Momentus will ensure that its maneuvers through the orbits of inhabitable spacecraft will not create risk to other spacecraft.

VR-6 is planned to operate with an approximately 10% 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-6 mission, including orbital debris and object avoidance maneuvers throughout the mission life. Additionally, our calculations suggest VR-6 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-6.

[2] *See* Exhibit 5 to the application.

Table 1. Orbital Parameters

	Insertion Orbit	Second Orbit[3]	LTAN Change Maneuver[4]	Phase Change Maneuver	Third Orbit	Final Orbit
Apogee Altitude	520 km (max)	495 km	547 km (max)	515 km (max)	495 km	410 km
Perigee Altitude	520 km (max)	495 km	547 km (max)	515 km (max)	495 km	350 km
Inclination	~97°+/-1°	~96°+/-1°	~96°+/-1°	~96°+/-1°	~96°+/-1°	~96°+/-1°
Period	95 mins	94 mins	95 mins	95 mins	94 mins	94 mins
Argument of Perigee	N/A	N/A	N/A	N/A	N/A	N/A
Local Time of the Ascending Node (LTAN)	1030am	1028am	1026am	1000am	0958am	0840am
Maximum De-Orbit Life	~ 11 years[5]	~ 1 year[6]	~ 4 years[7]	~ 2 years[8]	~ 1 year[9]	~ 2 months

Failsafe Deployment:

VR-6 includes a failsafe deployment timer, which has a battery backup 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

[3] The second orbit is the VR-6 operational orbit; the LTAN and Phase change maneuvers are conducted at higher altitudes to change parameters temporarily.
[4] After the LTAN change maneuver, VR-6 will return to the second (operational) orbit before conducting the phase change maneuver.
[5] This is the deorbit duration, if VR-6 fails after deployment. Momentus is aware that the FCC has adopted new orbital debris mitigation rules requiring that satellites in low Earth orbit be disposed no later than five years following completion of the mission. *See Space Innovation; Mitigation of Orbital Debris in the New Space Age*, Second Report and Order, IB Docket Nos. 22-272, 18-313, FCC 22-74 (September 30, 2022).
[6] This is the deorbit duration, if VR-6 achieves a 495 x 495 km orbit, deploys the demonstration solar array and then the propulsion system fails.
[7] This is the deorbit duration, if VR-6 achieves a 547 x 547 km orbit and then the propulsion system fails.
[8] This is the deorbit duration, if VR-6 achieves a 515 x 515 km orbit and then the propulsion system fails.
[9] This is the deorbit duration, if VR-6 achieves a 495 x 495 km orbit and then the propulsion system fails.

the deployable customer payloads after 7 days. In the event that the VR-6 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-6 has the following subsystems: Propulsion, Structures, Mechanisms, Electric Power, and Avionics.

VR-6 includes a primary and a secondary structural assembly with: Propellant Tanks, Microwave Electrothermal Thruster (MET), Reaction Control System thrusters, Solar Array Assemblies, a launch vehicle separation ring, a deployable solar array demonstration, and 3 12U CubeSat deployers.

VR-6 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-6 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-6 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	386 kg	Includes 51 kg of propellant.
Spacecraft Launch Dry Mass	335 kg	Includes 38 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	0.94x1.21x1.61 m^3, stowed solar arrays body configuration 13.61x1.21x6.3 m^3, with demonstration solar array deployed	Body dimensions

Deployed Solar Array Dimensions	2.68x1.41x0.01m^3	Dimensions per solar array wing.
Demonstration Solar Array Dimensions	12.93x1.24x0.01m^3	Single array
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-6 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	None	
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.	

Propulsion System Description

The Vigoride-6 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-6 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 eight reaction control thrusters each with an estimated maximum thrust of 30 mN and specific impulse of 120 seconds. These reaction control thrusters are also redundant 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 18 psig. 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-6 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.

III. Spacecraft Debris Released during Normal Operations

Payload Re-Contact Mitigation

Momentus will plan to support at least three re-contact mitigation strategies for deployments from VR-6:

- 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-6 vehicle under nominal deployment conditions. If VR-6 is unable to maintain attitude control during deployment (such as in the event of the triggering of the failsafe deployment timer), the analysis estimates a 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.

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-6.

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 End of Mission, 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 (18 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 tanks is at least 2. For the pressurant tanks, 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-6 will reduce stored energy in the battery by limiting power generation capability of the solar arrays at EOL. 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 EOL to conduct further perigee reduction maneuvers. Even if the propellant is not fully depleted,

liquid water propellant has low stored energy (at 18 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 tanks have a maximum pressure of 250 psi resulting in a factor of safety of more than 500 at EOL. There will not be enough stored energy in the pressurant tank to penetrate or break apart the spacecraft structure. Moreover, the Nitrogen pressurant tanks are 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-6 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-6 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.[10] Furthermore, the proposed operation of the VR-6 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.

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-6 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 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.

[10] The Momentus assessment of the VR-6’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%.

Table 3: Planned Actions in Response to CDM Messages

Probability of Collision (PoC)	Planned Actions[11]
> 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.[12]

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 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-6 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[13] within 24 hours of the time of closest approach ("TCA") should

[11] 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.

[12] *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.

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

reduce the PoC to much less than 1E-5 and by at least one and one-half orders of magnitude.[14] 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-6 would produce more than 1 m/s of delta V.[15]

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**

Protection of International Space Station ("ISS")

VR-6 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 above. Additionally, when VR-6's perigee drops below the orbit of the ISS, Momentus will contact the NASA JSC Flight Operations Director (FOD) Human Space Flight Conjunction Assessment Operations to ensure that the ISS has a point of contact for the VR-6 spacecraft.

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[14] *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 (March 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 (March 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).

[15] 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:**
  - Insertion Orbit (520 x 520 km) 3.8381E-5; COMPLIANT.
  - Maximum Orbit Altitude (547 x 547km) 4.8213E-5; COMPLIANT
  - Demo Solar Array Deployment Orbit (495 x 495 km) 4.2139E-5; COMPLIANT
  - Final Orbit (410 x 350 km) 2.3246E-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 postmission disposal requirements is less than 0.01 (Requirement 56507).
- **Small-Object Impact and Debris Generation Probability:**
  - Not Applicable since VR-6 can deorbit passively within 25-years under all analyzed conditions; COMPLIANT

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

- None are specifically required, but the propulsion system is expected to be used for a postmission 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:

- VR-6 will de-orbit naturally by atmospheric reentry without any intervention. However, VR-6 will attempt a de-orbit maneuver (discussed below) to reduce the time to atmospheric reentry.

Plan for any spacecraft maneuvers required to accomplish postmission disposal:

- No maneuvers are required for postmission disposal. However, VR-6 will attempt a de-orbit maneuver 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:

Worst-Case Orbit Insertion (520km x 520km, prior to solar array deployment)

- Spacecraft Final Mass: 386 kg
- Cross-sectional Area: 2.3 m^2 (estimated average area in tumbling assuming Momentus Solar Array and Demo Solar Array Payload stowed)
- Area to mass ratio: 0.005957 m^2/kg

Worst-Case Orbit Altitude (547km x 547km, following solar array deployment)

- Spacecraft Final Mass: 376 kg
- Cross-sectional Area: 6.1 m^2 (estimated average area in tumbling assuming Momentus Solar Array Deployed but Demo Solar Array Payload stowed)
- Area to mass ratio: 0.016166 m^2/kg

Initial Demo Solar Array Payload Deployment (495km x 495km)

- Spacecraft Final Mass: 346 kg
- Cross-sectional Area: 12.678 m^2 (estimated average area in tumbling assuming Momentus Solar Array and Demo Solar Array Payload deployed)
- Area to mass ratio: 0.036642 m^2/kg

Final Demo Solar Array Payload Deployment (410km x 350km)

- Spacecraft Final Mass: 346 kg
- Cross-sectional Area: 12.678 m^2 (estimated average area in tumbling assuming Momentus Solar Array and Demo Solar Array Payload deployed)
- Area to mass ratio: 0.036642 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)

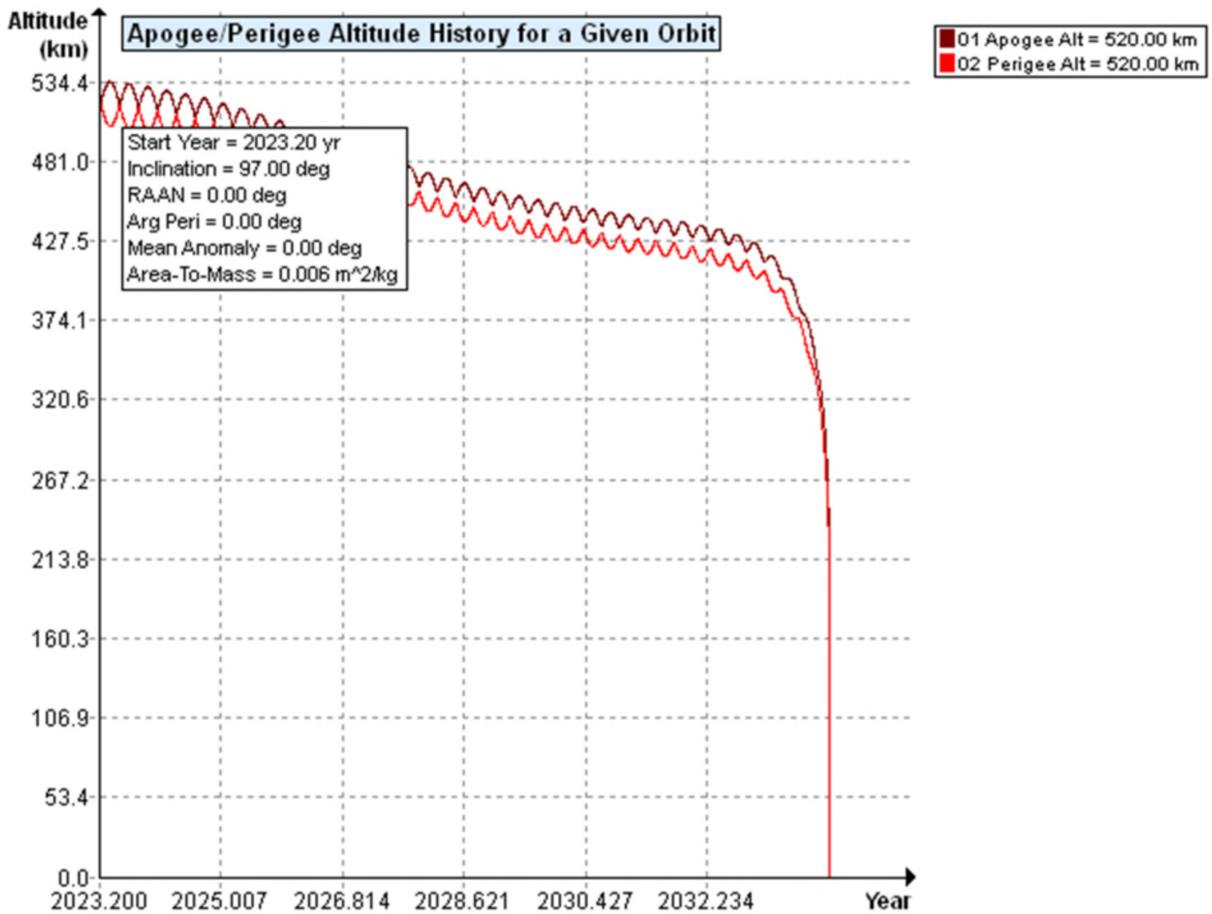
1. Atmospheric reentry option:
    a. Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
    b. Maneuver the space structure into a controlled de-orbit trajectory as 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:

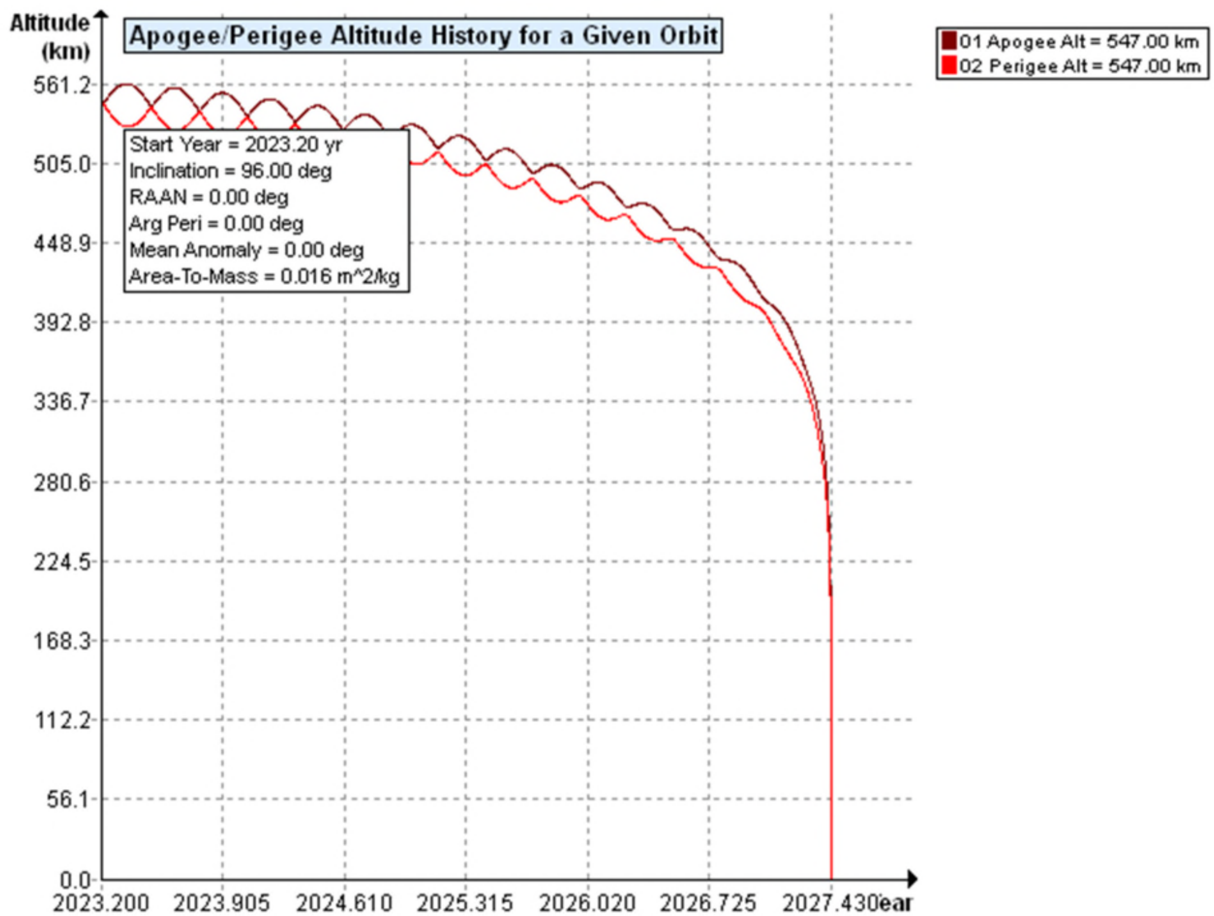
VR-6 will follow a concept of operations to ensure safe disposal within 25 years of the end of the mission under all scenarios.

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

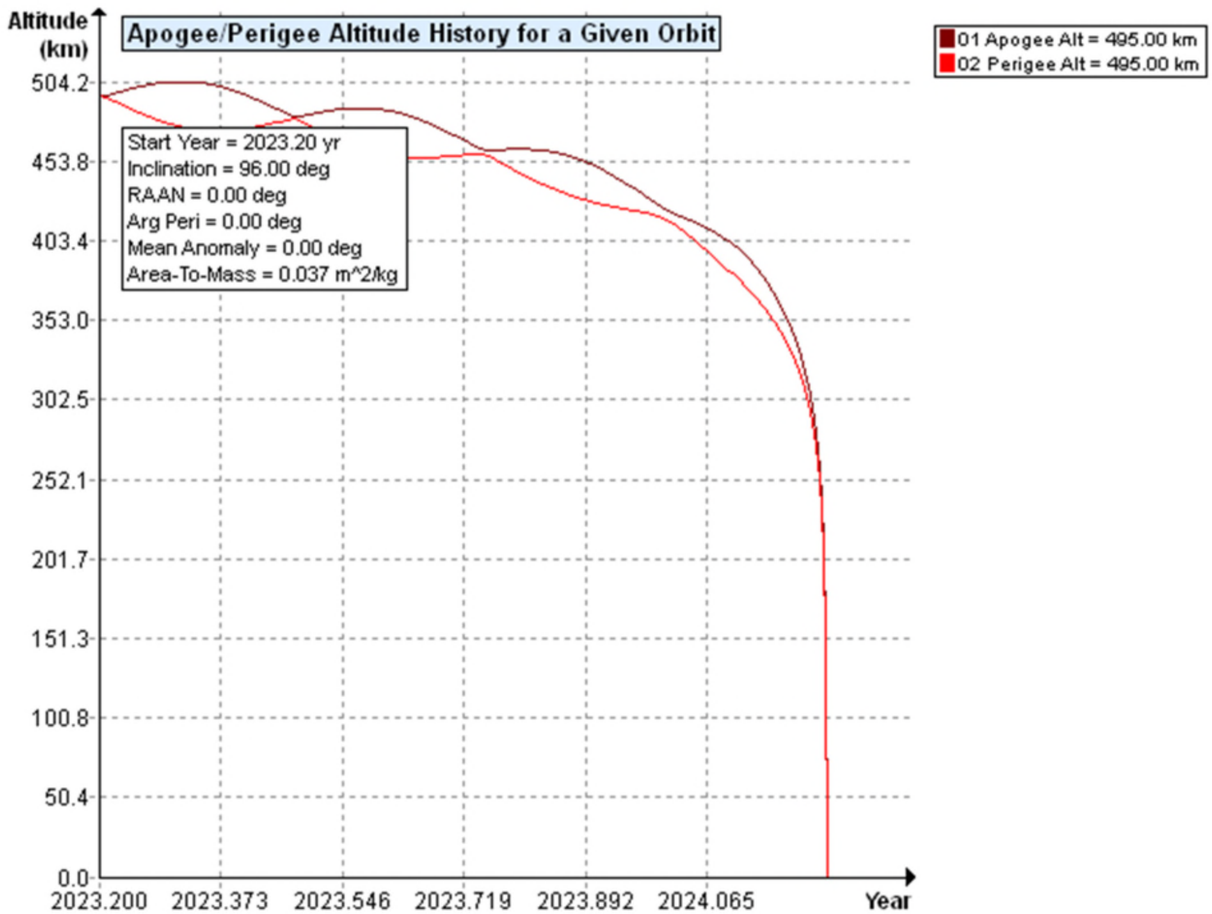
Orbital Decay for VR-6 Failure at 520x520 km



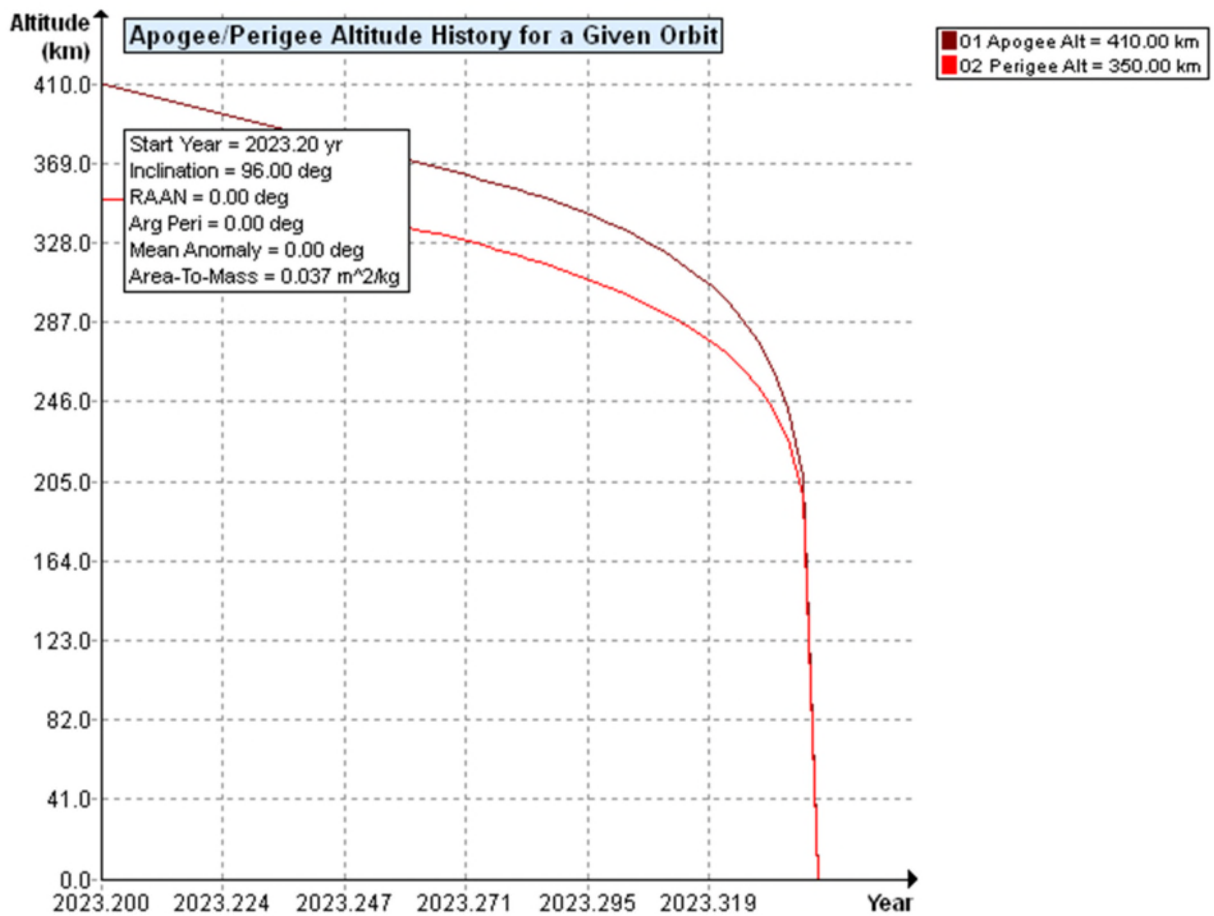
Orbital Decay for VR-6 Failure at 547x547 km



Orbital Decay for VR-6 Failure at 495x495 km



Orbital Decay for VR-6 at 410x350 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-6 is compliant with the requirement with no risk of human casualty. As shown below, only one VR-6 component is expected to survive reentry, and the associated impacting kinetic energy is less than 15 joules.

Analysis using DAS v3.2.3:

09 30 2022; 15:10:44PM Processing Requirement 4.3-1: Return Status : Not Run

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No Project Data Available

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

09 30 2022; 15:10:47PM Processing Requirement 4.3-2: Return Status : Passed

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

No Project Data Available

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

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

09 30 2022; 15:30:59PM Processing Requirement 4.5-1: Return Status : Passed

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

Run Data

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

INPUT

Space Structure Name = Vigoride-6-1

Space Structure Type = Payload

Perigee Altitude = 547.000 (km)

Apogee Altitude = 547.000 (km)

Inclination = 96.000 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0162 (m^2/kg)

Start Year = 2023.200 (yr)

Initial Mass = 376.000 (kg)

Final Mass = 297.000 (kg)

Duration = 1.000 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

OUTPUT

Collision Probability = 4.8213E-05

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

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

INPUT

Space Structure Name = Vigoride-6-2

Space Structure Type = Payload

Perigee Altitude = 520.000 (km)

Apogee Altitude = 520.000 (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 = 0.0060 (m^2/kg)

Start Year = 2023.200 (yr)

Initial Mass = 386.000 (kg)

Final Mass = 297.000 (kg)

Duration = 1.000 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

OUTPUT

Collision Probability = 3.8381E-05

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

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

INPUT

Space Structure Name = Vigoride-6-3

Space Structure Type = Payload

Perigee Altitude = 495.000 (km)

Apogee Altitude = 495.000 (km)

Inclination = 96.000 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0366 (m^2/kg)

Start Year = 2023.200 (yr)

Initial Mass = 346.000 (kg)

Final Mass = 297.000 (kg)

Duration = 1.000 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

OUTPUT

Collision Probability = 4.2139E-05

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

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

INPUT

Space Structure Name = Vigoride-6-4

Space Structure Type = Payload

Perigee Altitude = 350.000 (km)

Apogee Altitude = 410.000 (km)

Inclination = 96.000 (deg)

RAAN = 0.000 (deg)

Argument of Perigee = 0.000 (deg)

Mean Anomaly = 0.000 (deg)

Final Area-To-Mass Ratio = 0.0366 (m^2/kg)

Start Year = 2023.200 (yr)

Initial Mass = 346.000 (kg)

Final Mass = 297.000 (kg)

Duration = 1.000 (yr)

Station-Kept = False

Abandoned = True

Long-Term Reentry = False

OUTPUT

Collision Probability = 2.3246E-06

Returned Message: Normal Processing

Date Range Message: Normal Date Range

Status = Pass

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

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

09 30 2022; 15:33:06PM Project Data Saved To File

09 30 2022; 15:33:11PM Requirement 4.5-2: Compliant

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

09 30 2022; 15:33:13PM Processing Requirement 4.6 Return Status : Passed

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

Project Data

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

INPUT

Space Structure Name = Vigoride-6-1

Space Structure Type = Payload

Perigee Altitude = 547.000000 (km)

Apogee Altitude = 547.000000 (km)

Inclination = 96.000000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.016166 (m^2/kg)

Start Year = 2023.200000 (yr)

Initial Mass = 376.000000 (kg)

Final Mass = 297.000000 (kg)

Duration = 1.000000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = 523.720166 (km)

PMD Apogee Altitude = 552.348535 (km)

PMD Inclination = 95.973523 (deg)

PMD RAAN = 284.263961 (deg)

PMD Argument of Perigee = 74.580521 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 523.720166 (km)

Suggested Apogee Altitude = 552.348535 (km)

Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2027 (yr)

Requirement = 61

Compliance Status = Pass

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

INPUT

Space Structure Name = Vigoride-6-2

Space Structure Type = Payload

Perigee Altitude = 520.000000 (km)

Apogee Altitude = 520.000000 (km)

Inclination = 97.000000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.005957 (m^2/kg)

Start Year = 2023.200000 (yr)

Initial Mass = 386.000000 (kg)

Final Mass = 297.000000 (kg)

Duration = 1.000000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = 500.506470 (km)

PMD Apogee Altitude = 529.837495 (km)

PMD Inclination = 96.994178 (deg)

PMD RAAN = 336.219841 (deg)

PMD Argument of Perigee = 79.901099 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 500.506470 (km)

Suggested Apogee Altitude = 529.837495 (km)

Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2034 (yr)

Requirement = 61

Compliance Status = Pass

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

INPUT

Space Structure Name = Vigoride-6-3

Space Structure Type = Payload

Perigee Altitude = 495.000000 (km)

Apogee Altitude = 495.000000 (km)

Inclination = 96.000000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.036642 (m^2/kg)

Start Year = 2023.200000 (yr)

Initial Mass = 346.000000 (kg)

Final Mass = 297.000000 (kg)

Duration = 1.000000 (yr)

Station Kept = False

Abandoned = True

PMD Perigee Altitude = 388.903567 (km)

PMD Apogee Altitude = 405.469362 (km)

PMD Inclination = 95.964046 (deg)

PMD RAAN = 295.982455 (deg)

PMD Argument of Perigee = 68.628279 (deg)

PMD Mean Anomaly = 0.000000 (deg)

Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 388.903567 (km)

Suggested Apogee Altitude = 405.469362 (km)

Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2024 (yr)

Requirement = 61

Compliance Status = Pass

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

INPUT

Space Structure Name = Vigoride-6-4

Space Structure Type = Payload

Perigee Altitude = 350.000000 (km)

Apogee Altitude = 410.000000 (km)

Inclination = 96.000000 (deg)

RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)

Area-To-Mass Ratio = 0.036642 (m^2/kg)

Start Year = 2023.200000 (yr)

Initial Mass = 346.000000 (kg)

Final Mass = 297.000000 (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 = 410.000000 (km)

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

Released Year = 2023 (yr)

Requirement = 61

Compliance Status = Pass

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

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

09 30 2022; 15:33:15PM *********Processing Requirement 4.7-1

Return Status : Passed

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

Item Number = 1

name = Vigoride-6-1

quantity = 1

parent = 0

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

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 = 20

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 = 20

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

quantity = 4

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 1

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 26.000000

Thermal Mass = 26.000000

Diameter/Width = 0.400000

Length = 0.600000

Height = 0.400000

name = 12U Cubesat Deployer 2

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 26.000000

Thermal Mass = 26.000000

Diameter/Width = 0.400000

Length = 0.600000

Height = 0.400000

name = ISIS Cubesat Deployer 3

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 26.000000

Thermal Mass = 26.000000

Diameter/Width = 0.400000

Length = 0.600000

Height = 0.400000

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 = Solar Array Demo Structure

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 20.000000

Thermal Mass = 20.000000

Diameter/Width = 0.380000

Length = 1.430000

Height = 0.140000

name = Solar Array Demo Boom

quantity = 1

parent = 1

materialID = 8

type = Cylinder

Aero Mass = 20.000000

Thermal Mass = 20.000000

Diameter/Width = 0.130000

Length = 1.230000

name = Beacon

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

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

Item Number = 1

name = Vigoride-6-1

Demise Altitude = 77.998237

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Primary Radiator Segment

Demise Altitude = 75.969629

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Secondary Radiator

Demise Altitude = 76.551512

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Side Radiator Plate

Demise Altitude = 76.482707

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Corner Brackets

Demise Altitude = 77.185898

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Comms Panel

Demise Altitude = 76.740355

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Lower Payload Deck Segment

Demise Altitude = 76.239354

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Structure

Demise Altitude = 75.928014

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Propellant Tank

Demise Altitude = 74.080638

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Water Propellant

Demise Altitude = 66.806960

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Launch Vehicle Adapter

Demise Altitude = 76.805304

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Solar Array Panel

Demise Altitude = 77.256500

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Battery Assembly

Demise Altitude = 73.166767

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Power Supply Unit

Demise Altitude = 76.482790

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Microwave Source Box

Demise Altitude = 75.365715

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Feed System Box

Demise Altitude = 77.107300

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Power Distribution Unit

Demise Altitude = 75.994334

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank Middle

Demise Altitude = 77.661674

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank End 1

Demise Altitude = 77.649198

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank End 2

Demise Altitude = 77.649198

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Diaphragm Tank Liner

Demise Altitude = 76.713735

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Plumbing Lines

Demise Altitude = 77.514471

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Plumbing Fittings

Demise Altitude = 72.891152

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Thruster

Demise Altitude = 66.659138

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Window

Demise Altitude = 0.000000

Debris Casualty Area = 0.316329

Impact Kinetic Energy = 0.855605

****

name = Reaction Control Thruster

Demise Altitude = 72.253435

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = RCS Fasteners

Demise Altitude = 75.602919

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = 12U Cubesat Deployer 1

Demise Altitude = 73.794168

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = 12U Cubesat Deployer 2

Demise Altitude = 73.794168

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = ISIS Cubesat Deployer 3

Demise Altitude = 73.794168

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Payload Interface Adapter

Demise Altitude = 76.923636

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Structural Fasteners

Demise Altitude = 75.970365

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Microwave Filament

Demise Altitude = 74.910836

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Beacon Radio

Demise Altitude = 77.000085

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Beacon Antenna

Demise Altitude = 77.704033

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Solar Array Demo Structure

Demise Altitude = 75.075935

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Solar Array Demo Boom

Demise Altitude = 72.219928

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Beacon

Demise Altitude = 77.000085

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

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

Item Number = 2

name = Vigoride-6-2

quantity = 1

parent = 0

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

name = V

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

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

Item Number = 2

name = Vigoride-6-2

Demise Altitude = 77.998292

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = V

Demise Altitude = 65.947838

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

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

Item Number = 3

name = Vigoride-6-3

quantity = 1

parent = 0

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

name = V

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

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

Item Number = 3

name = Vigoride-6-3

Demise Altitude = 77.998237

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = V

Demise Altitude = 65.915111

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

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

Item Number = 4

name = Vigoride-6-4

quantity = 1

parent = 0

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

name = V

quantity = 1

parent = 1

materialID = 8

type = Box

Aero Mass = 297.000000

Thermal Mass = 297.000000

Diameter/Width = 1.230000

Length = 1.560000

Height = 0.970000

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

Item Number = 4

name = Vigoride-6-4

Demise Altitude = 77.998237

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = V

Demise Altitude = 65.915111

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

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

VIII. Special Classes

Not applicable.

EXHIBIT 3

Antenna Gain Plots

Vigoride-6 Spacecraft
NGSO Antenna Gain Plots

10/09/2022

Momentus Space LLC

3901 N. First Street

San Jose, CA 95134

+1 (650) 564-7820

MOMENTUS

Table of Contents

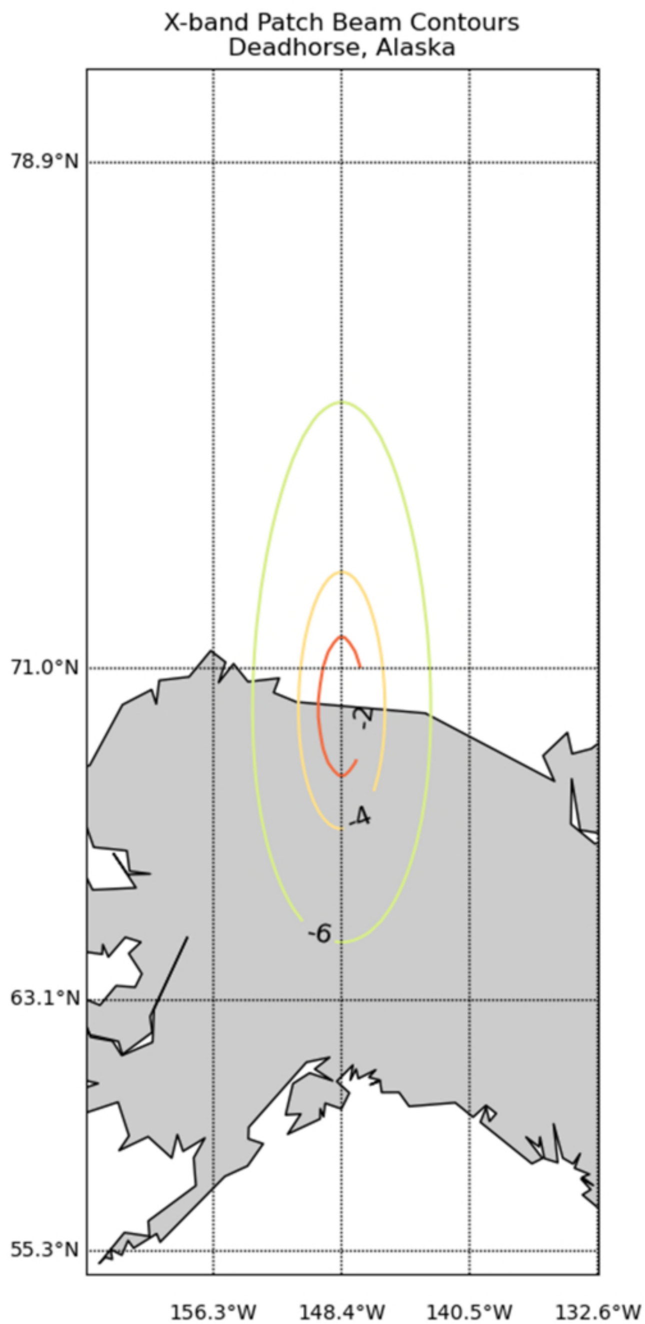
I. Introduction

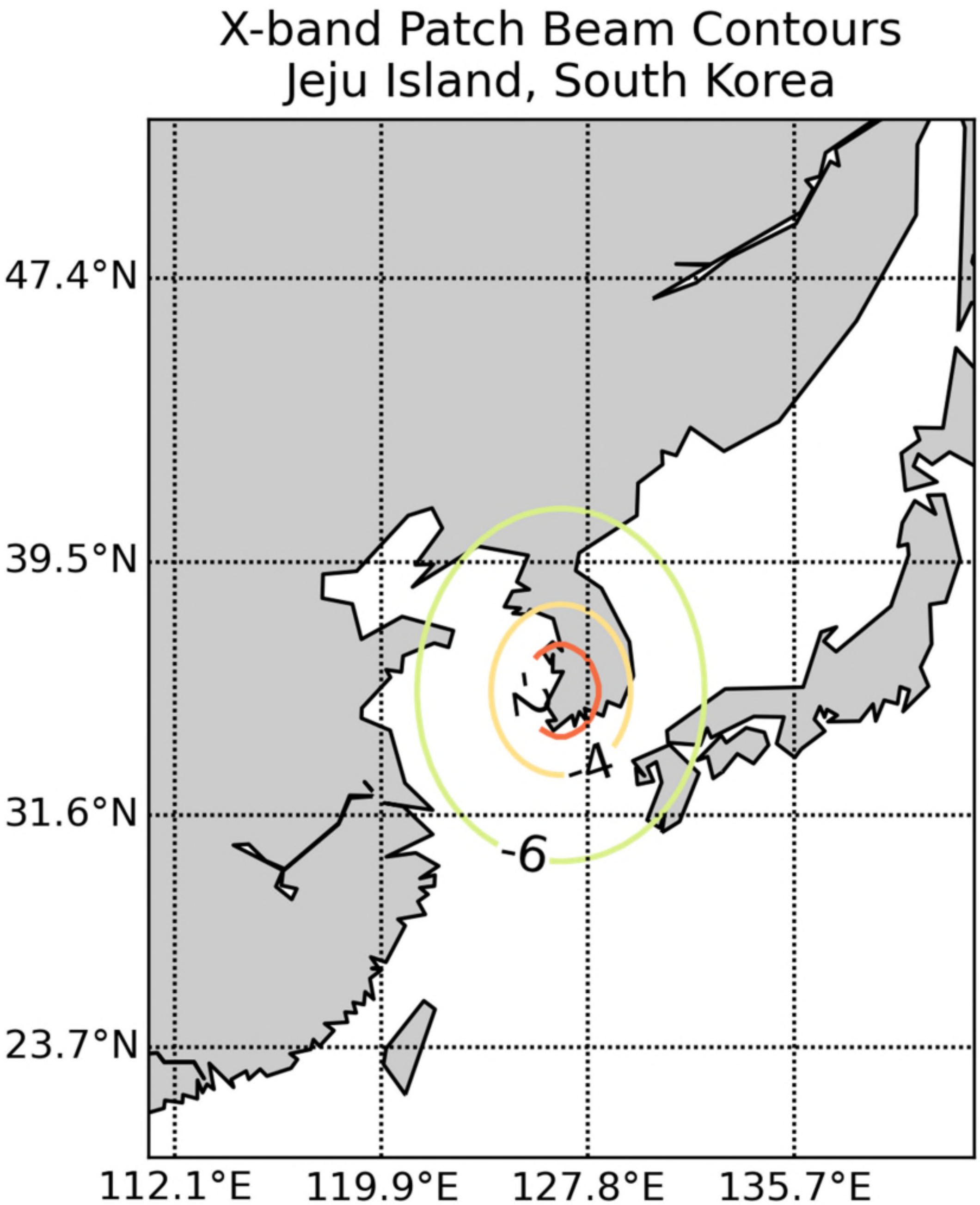
Momentus plans to operate with earth stations located in various locations. This exhibit provides sample uplink and downlink antenna gain contour maps for several of the earth stations identified in the application, as well as more general maps to reflect the antenna gain contours for a representative earth station.

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.

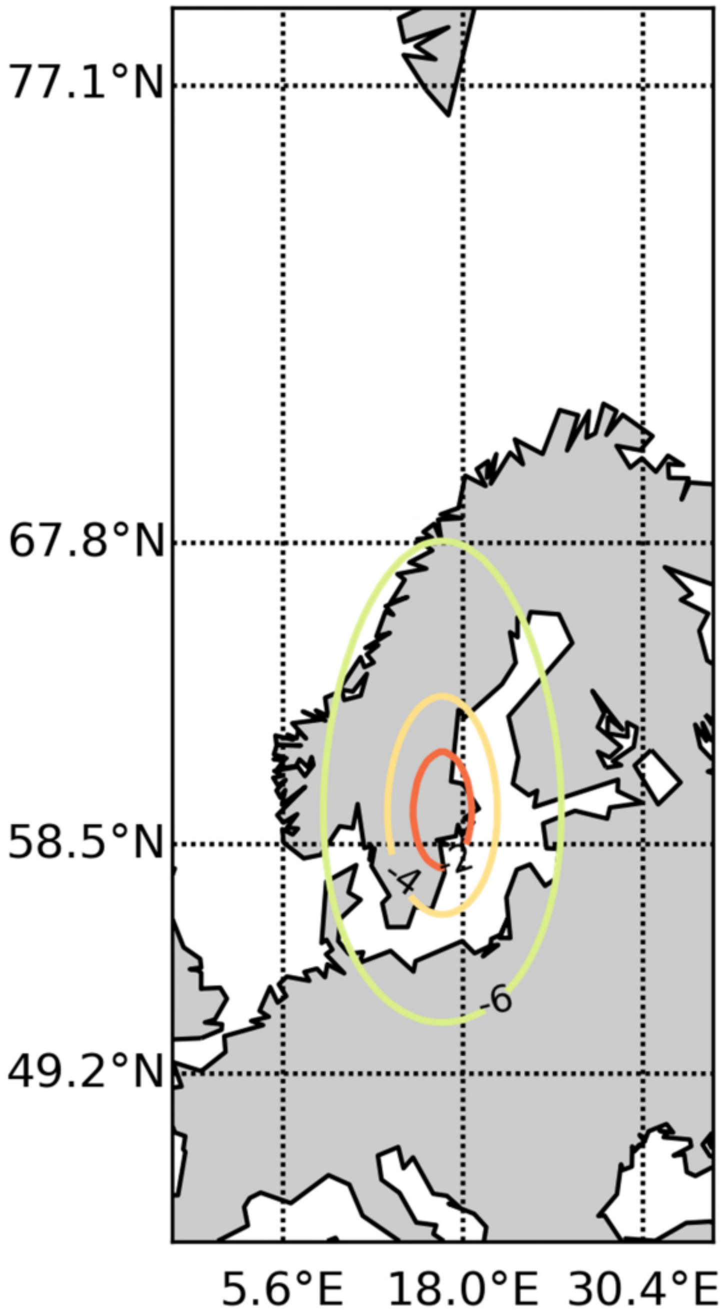
Note that for some gain contour plots, lower gain (greater than 6 dB below the peak) is beyond the horizon and is not shown in the plots.

II. Sample Downlink Gain Contour Plots

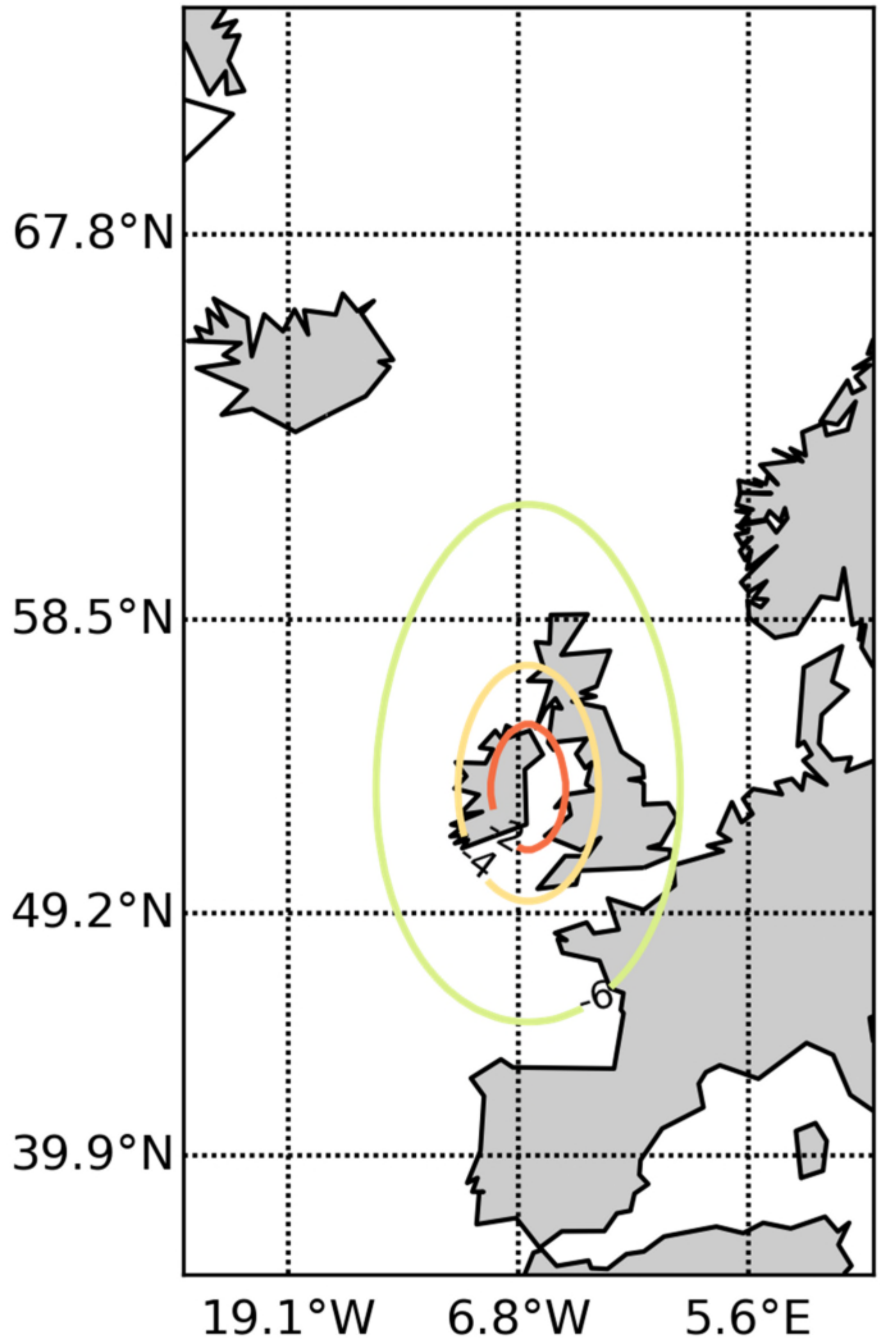


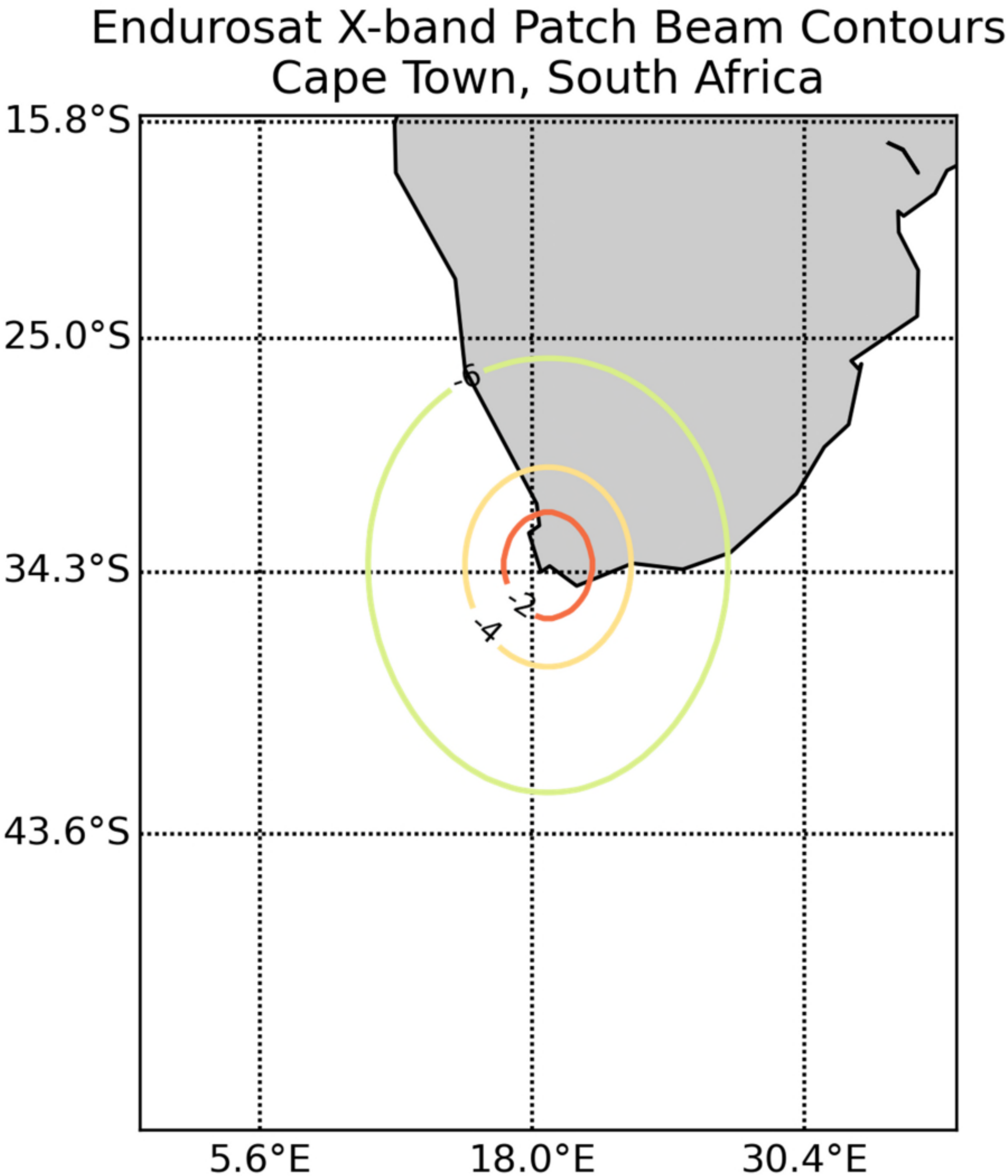

X-band Patch Beam Contours
Jeju Island, South Korea
47.4°N
39.5°N
31.6°N
23.7°N
112.1°E
119.9°E
127.8°E
135.7°E
-4
-6

Endurosat X-band Patch Beam Contours
Stockholm, Sweden

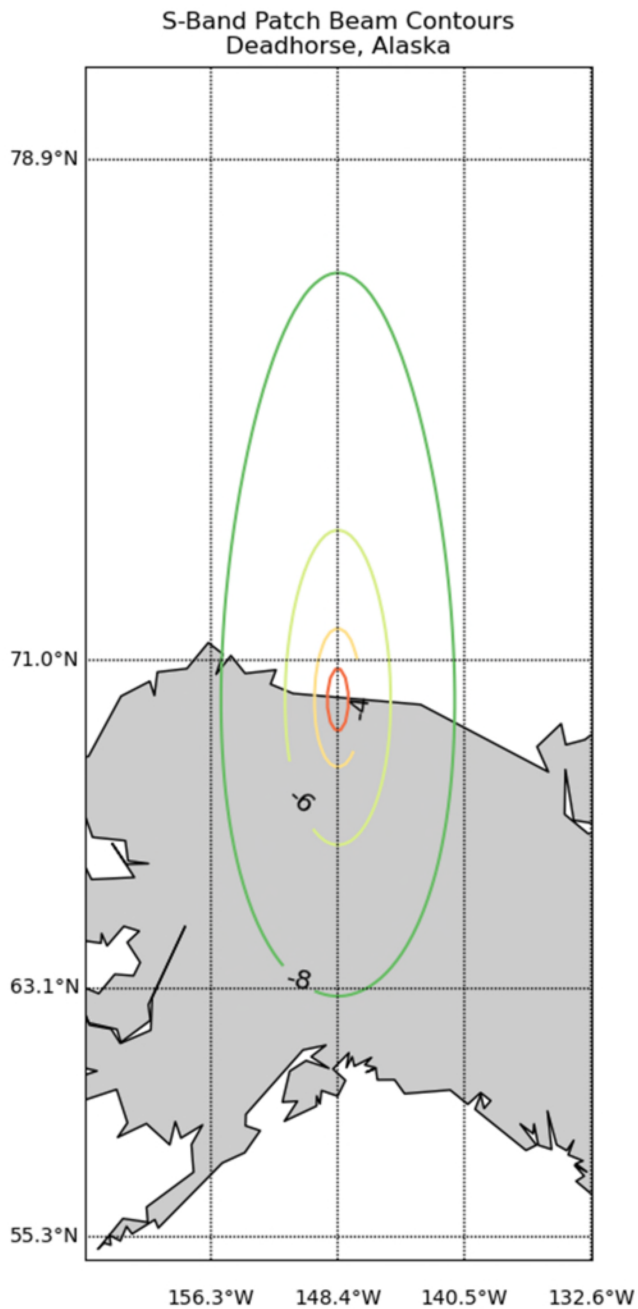


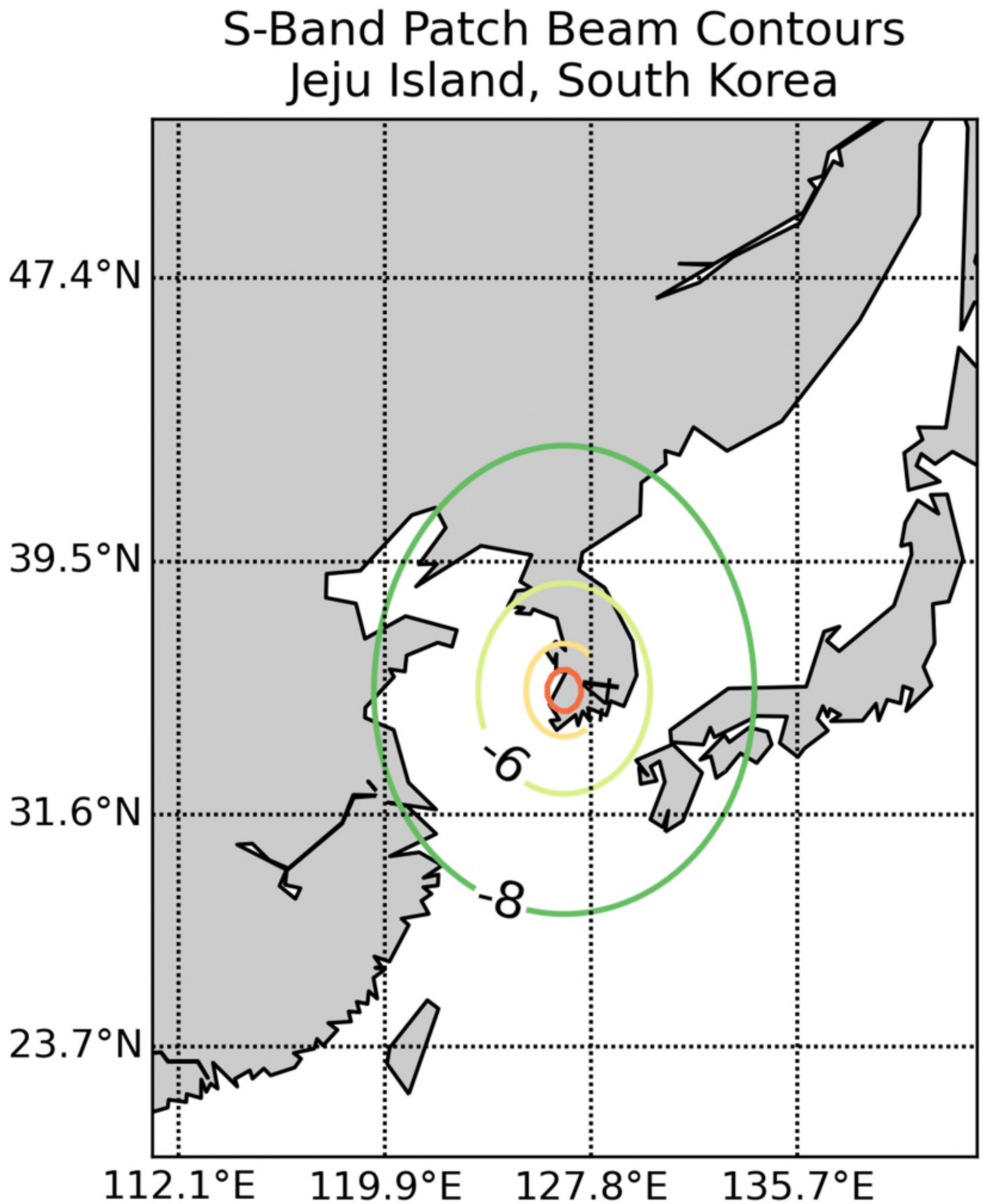
Endurosat X-band Patch Beam Contours
Dublin, Ireland

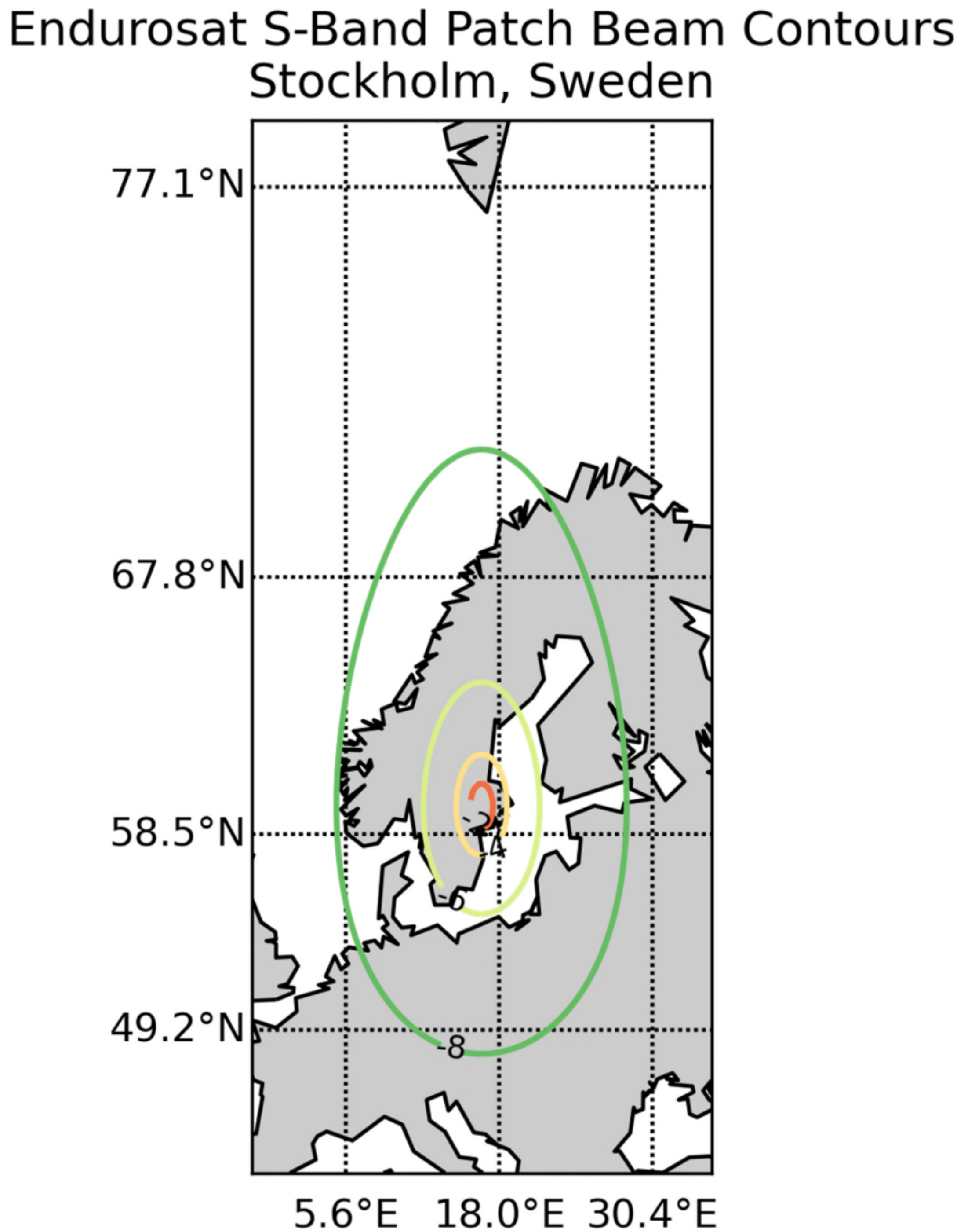



Endurosat X-band Patch Beam Contours
Cape Town, South Africa
15.8°S
25.0°S
34.3°S
43.6°S
5.6°E
18.0°E
30.4°E
-6
-4
-2

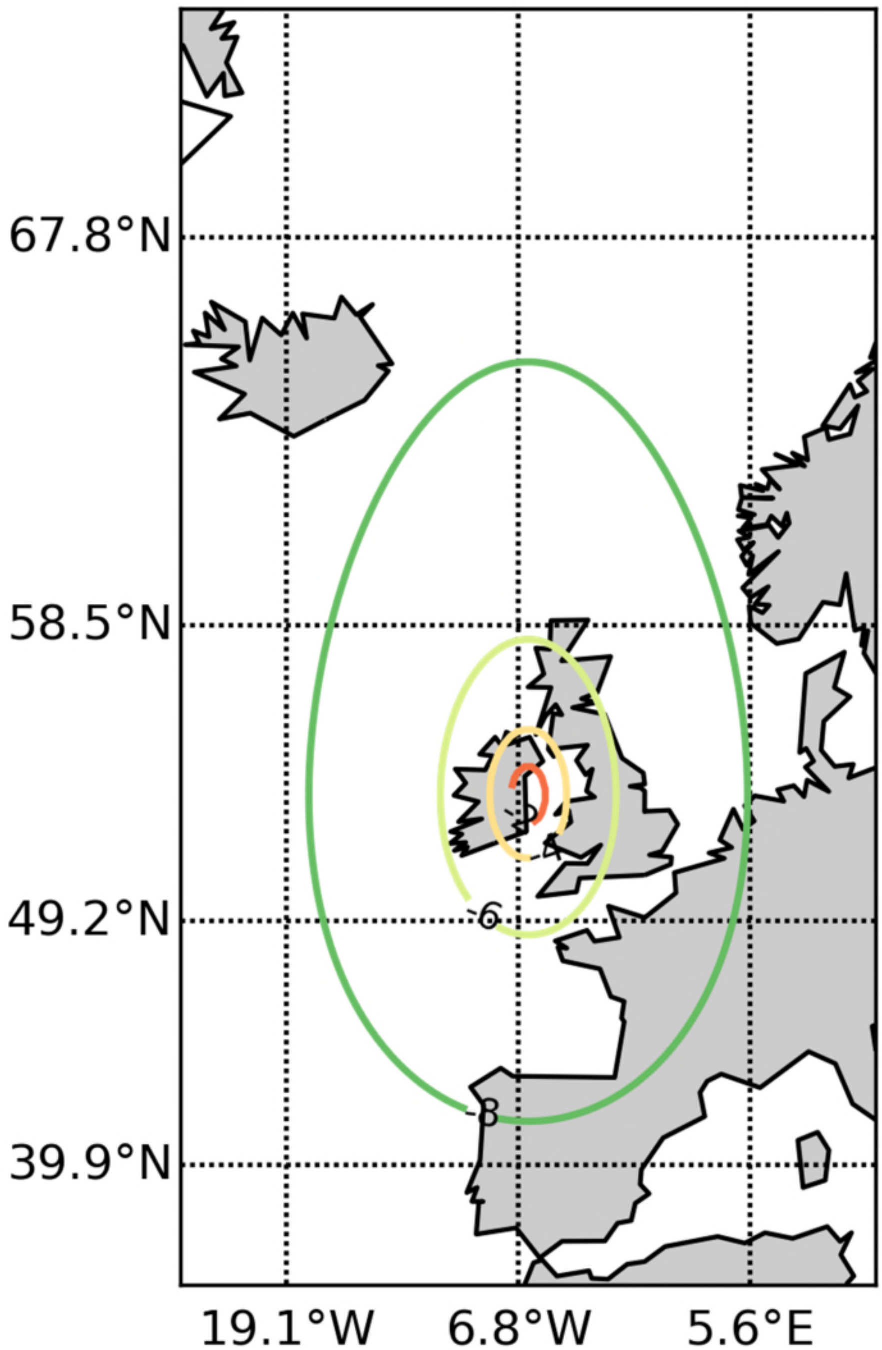
III. Sample Uplink Gain Contour Plots



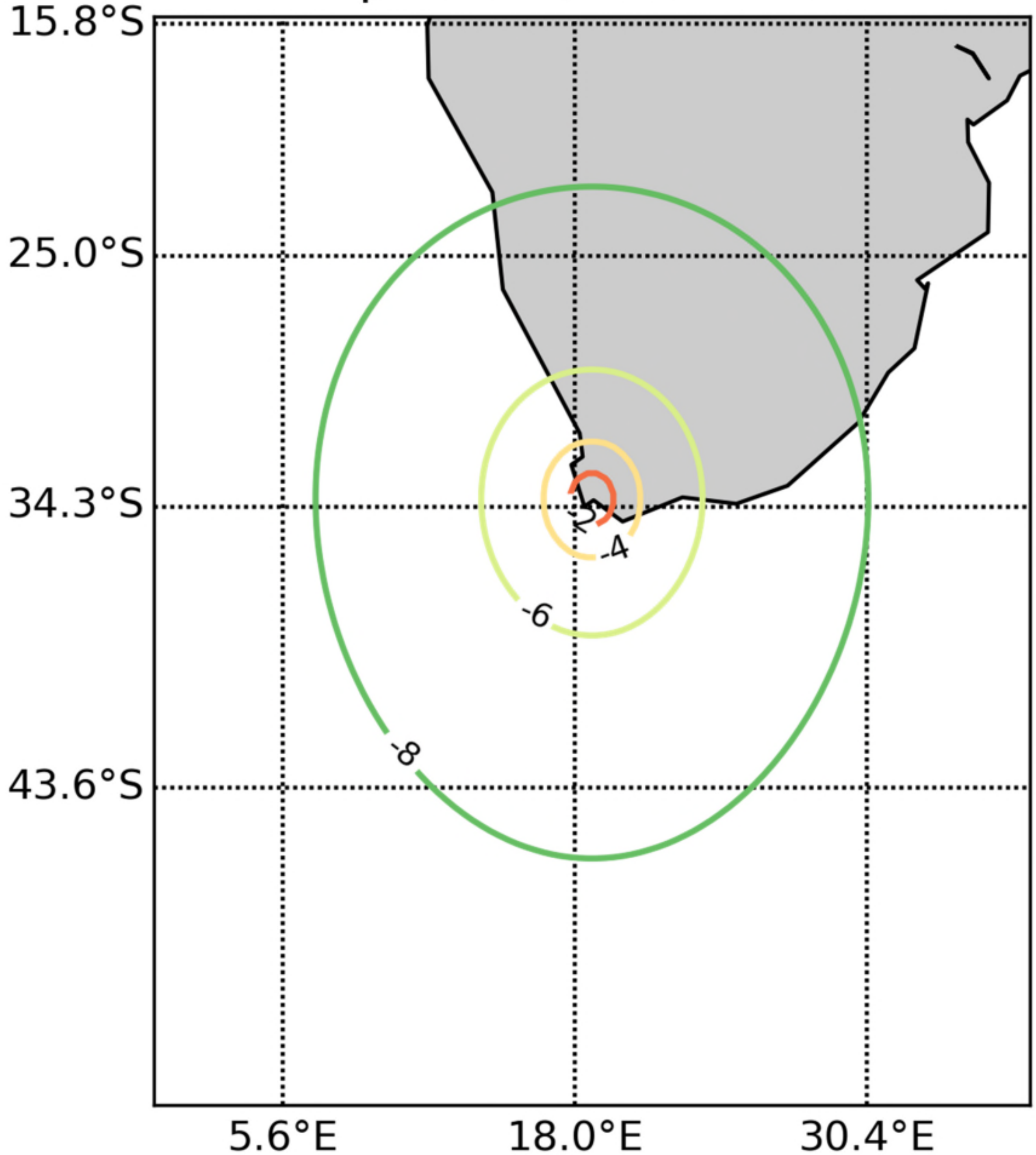

S-Band Patch Beam Contours
Jeju Island, South Korea
47.4°N
39.5°N
31.6°N
23.7°N
112.1°E
119.9°E
127.8°E
135.7°E
-6
-8


Endurosat S-Band Patch Beam Contours
Stockholm, Sweden
77.1°N
67.8°N
58.5°N
49.2°N
5.6°E
18.0°E
30.4°E
-8
-6
-4
-2

Endurosat S-Band Patch Beam Contours
Dublin, Ireland



Endurosat S-Band Patch Beam Contours
Cape Town, South Africa



IV. Representative Gain Contour Plots

X-band downlink

S-band Uplink

UHF Beacon Downlink

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 31.16%[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

[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 June 30, 2022. *See* Statement of Changes in Beneficial Ownership, https://www.sec.gov/Archives/edgar/data/1781162/000106299322014678/xslF345X03/form4.xml.

Director

4. Linda Reiners
Director

5. Brian Kabot
Director

6. Kimberly Reed
Director

7. Victorino Mercado
Director

8. Paul Ney
Chief Legal Officer, Corporate Secretary

9. Dawn Harms
Chief Revenue Officer

10. Jikun Kim
Chief Financial Officer

11. Rob Schwarz
Chief Technology Officer

EXHIBIT 5

VR-6 Payload Customers

Payload Name	Payload Owner	Licensing Jurisdiction	Size	Mass (kg)	Effective Drag Area[1] (m)	Maximum Deployed Dimensions (m)
REVELA	ARCA	Italy	3U	~3.4	0.118 x 0.119 x 0.3405	0.825 x 0.954 x 0.493
SMPOD03	ARCA	Italy	3U Deployer	~1.55	0.134 x 0.1464 x 0.4317	0.134 x 0.146 x 0.564
DISCO-1	Aarhus University	Denmark	1U	~0.95	0.1 x 0.1 x 0.1	0.202 x 0.202 x 0.202
STORK-7	SatRevolution	Poland	3U	<6	0.1 x 0.1 x 0.3405	0.340 x 0.438 x 0.374
VIREO	CS3	Hungary	3U	~4.2	0.1153 x 0.1172 x 0.3405	0.326 x 0.415 x 0.456
OreSat 0.5	Portland State	USA	2U	~2	0.100 x 0.100 x 0.150	0.309 x 0.309 x 0.931
LLITED-1	NASA	USA	1.5U	~2.5	0.1 x 0.1 x 0.15	0.1 x 0.173 x 0.347
LLITED-2	NASA	USA	1.5U	~2.5	0.1 x 0.1 x 0.15	0.1 x 0.173 x 0.347

[1] Effective drag area assumes tumbling.

EXHIBIT 6

X-band Interference Analysis

X-band Interference Analysis

Overview

The Momentus Vigoride-6 (“VR-6”) 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 for Space Operations services.[1] This report demonstrates that the VR-6 spacecraft operations will not cause unacceptable levels of interference to authorized satellite systems in these X-band frequencies and, further, by maintaining a 3-degree avoidance angle with other co-frequency satellite operators will 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 incidental imaging and mission assurance purposes (*e.g.*, the deployment of customer payloads). *See* Application Narrative, at 6.

[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 presented results 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.

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.-band 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-6 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-6, 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-6 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-6 spacecraft will be operating in a variety of orbital configurations during its 6-month operational life. The six "nominal" operational orbits are listed below.

- 520 km x 520 km SSO (LTAN 10:30)
- 495 km x 495 km SSO (LTAN 10:28)
- 515 km x 515 km SSO (LTAN 10:00)
- 547 km x 547 km SSO (LTAN 10:26)
- 495 km x 495 km SSO (LTAN 9:58)
- 410 km x 350 km, ~96-degree inclination

Because VR-6 is a secondary payload, the launch parameters could change, and the spacecraft will be maneuvering for most of brief mission lifetime, representative simulations were conducted at six representative orbits, 520 km x 520 km, 495 km x 495 km, 515 km x 515 km, 547 x 547 km, 495 km x 495 km (different LTAN), and 410 km x 350 km,[6] in order to simulate the envelope of potential operational altitudes. In general, the interference curves look very similar.

Simulation Results

Simulations were conducted for each of the satellite systems listed in Table 2**Error! Reference source not found.** above operating with their respective Alaska GW ES site to determine the interference power statics caused by VR-6 downlinking to the Deadhorse, AK GW ES site and comparing the results against the defined short-term protection criterion. The VR-6 spacecraft was assumed to attempt to communicate with the Deadhorse, AK GW ES site any time it is

[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 same 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 same interference analysis for the Vigoride-5 spacecraft).

within line of sight and above a minimum elevation angle of 5-degrees. This is another conservative assumption, translating to ~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.

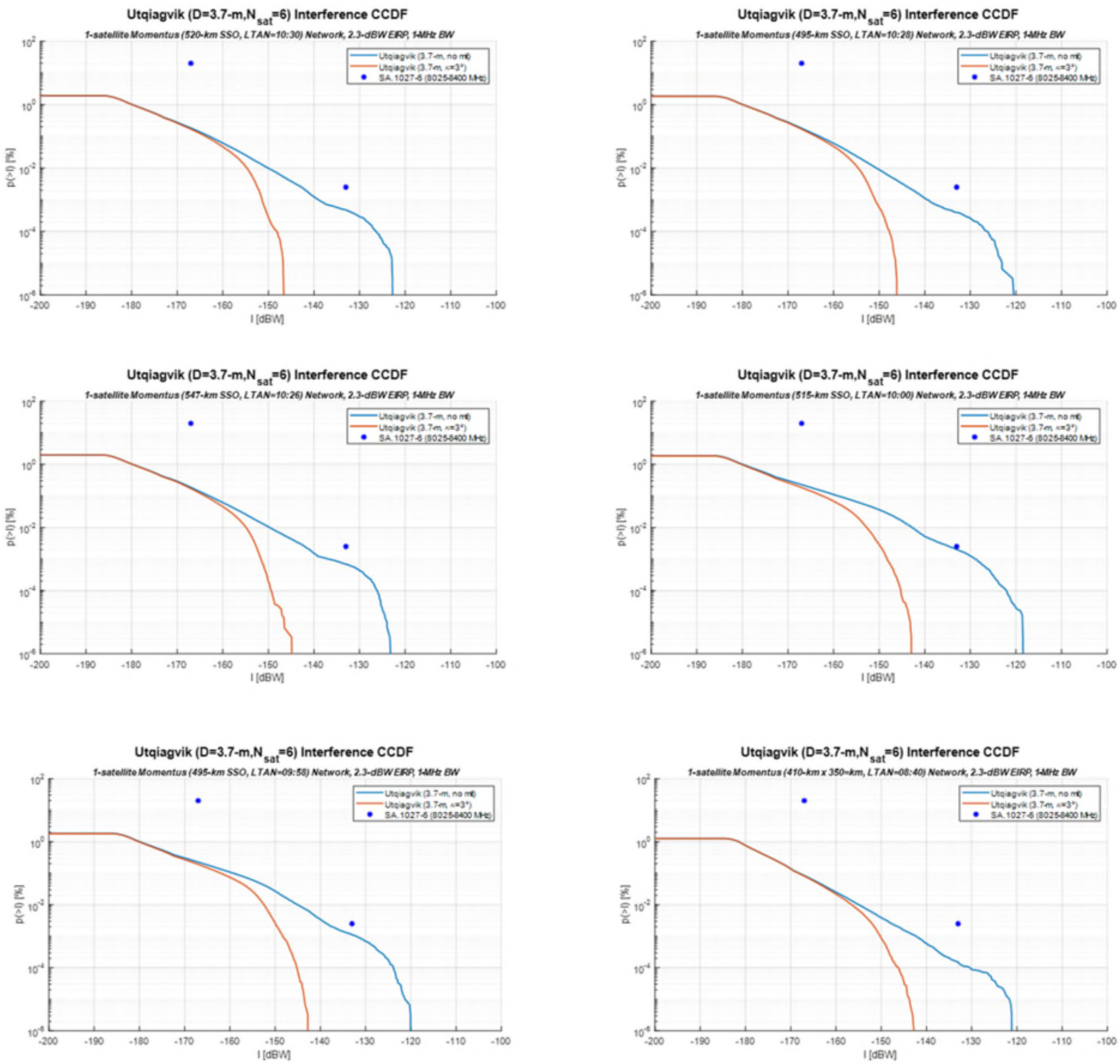


Figure 2: X-band Spectrum Sharing Simulation – ICEYE at Utqiagvik, AK

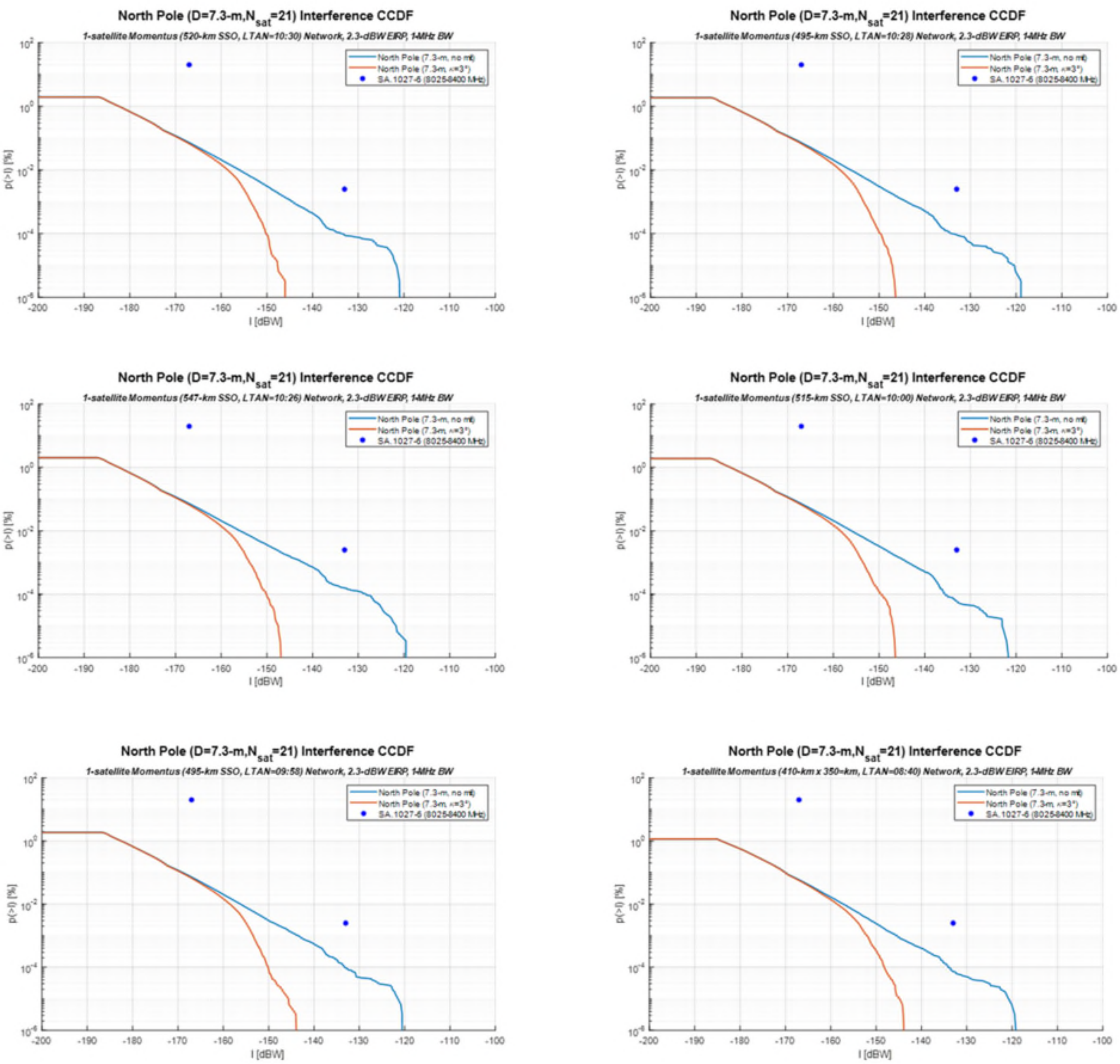


Figure 3: X-band Spectrum Sharing Simulation – Blacksky, WorldView & GeoEye at North Pole, AK

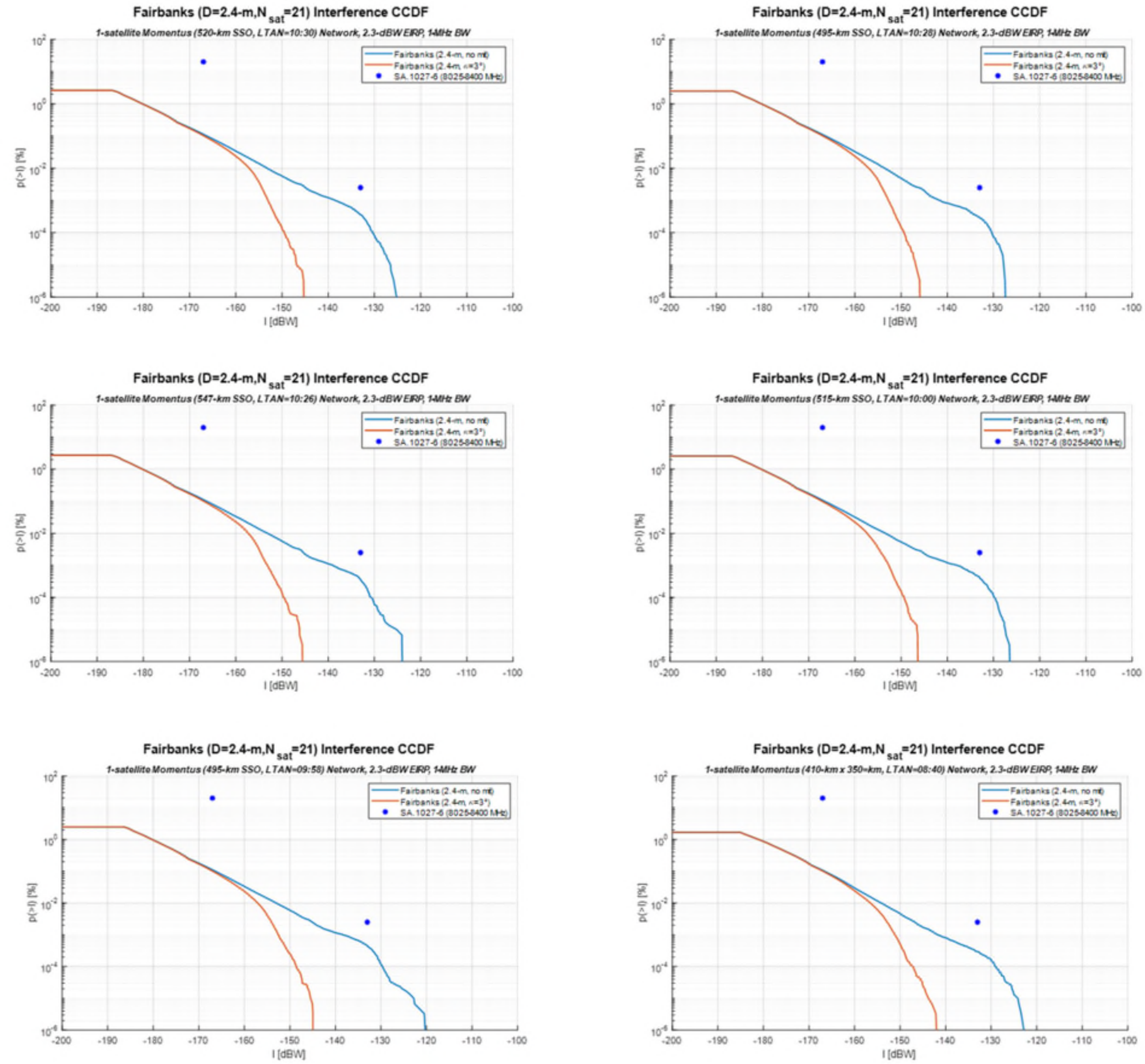


Figure 4: X-band Spectrum Sharing Simulation – Planet SkySat at Fairbanks, AK

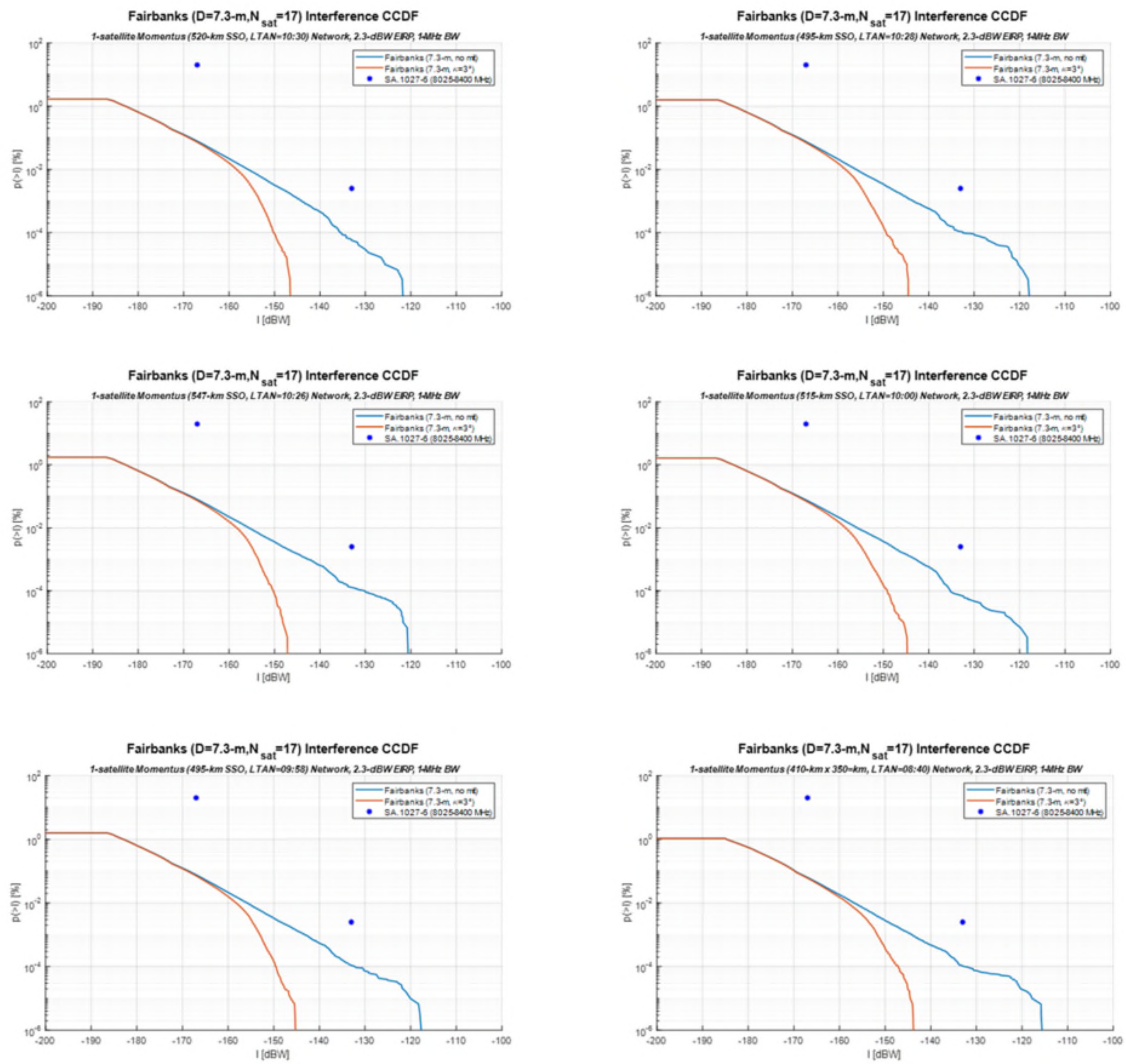


Figure 5: X-band Spectrum Sharing Simulation – WorldView, GeoEye and Legion at Fairbanks, AK

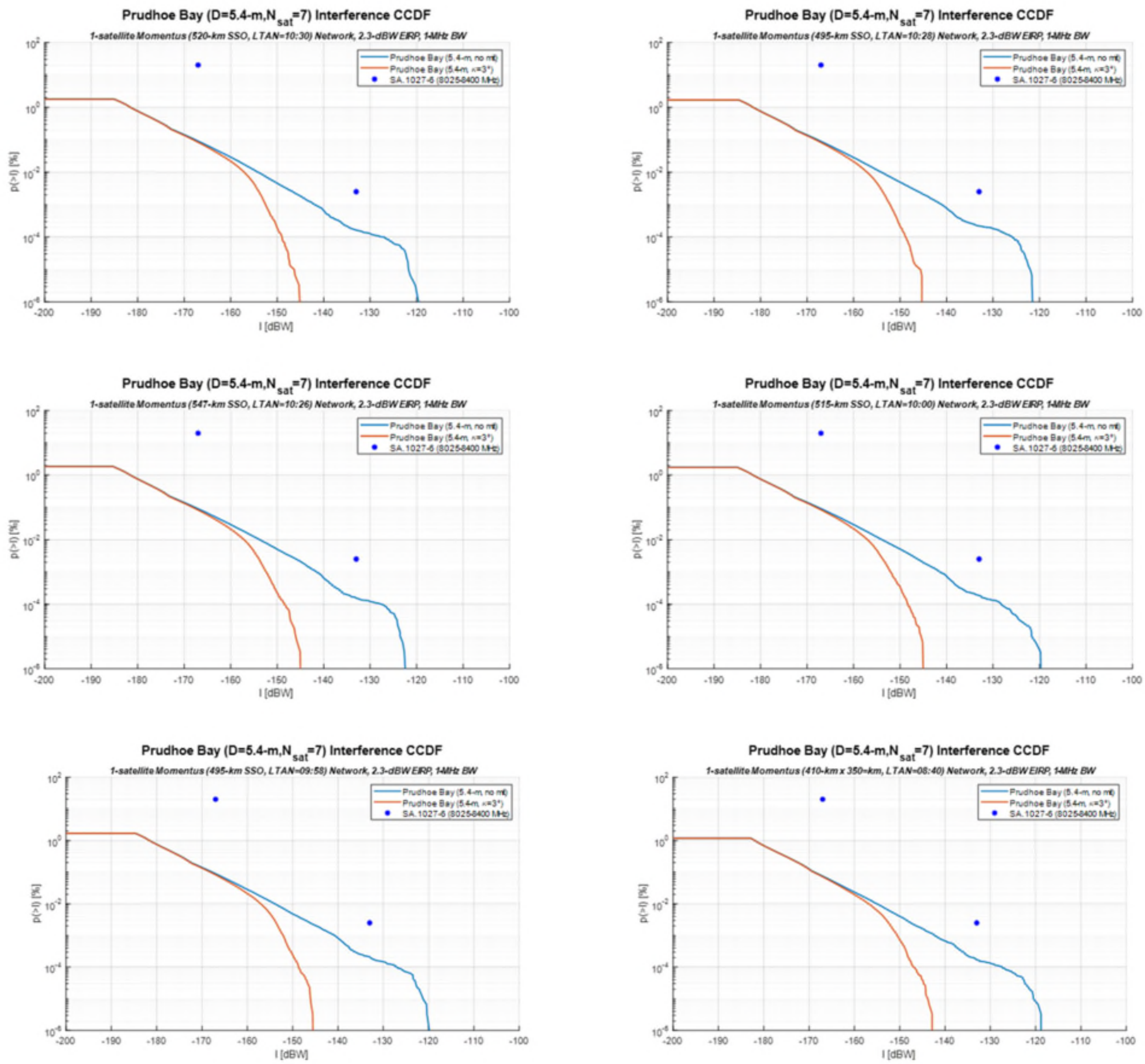


Figure 6: X-band Spectrum Sharing Simulation – WorldView, GeoEye and QuickBird at Prudhoe Bay, AK

Conclusions

The X-band spectrum sharing simulations show that VR-6 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-6 satellite would most likely not exceed the protection criteria.

Nevertheless, out of an abundance of caution, Momentus intends to avoid authorized EESS satellite operators in the X-band spectrum whenever they are within 3-degrees of an inline interference event. As can be seen from the simulations results, when a 3-degree avoidance angle is applied, the maximum interference power stays ~5-6 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 ~1-2% reduction in access opportunities for the VR-6 downlink, ensuring that the VR-6 will not be unduly constrained operationally.

Next Steps

Having demonstrated, via simulations at the U.S.-based GW ES in Deadhorse, AK, that authorized users of X-band spectrum (space-to-Earth) can be fully protected by applying a 3-degree inline interference avoidance angle, the next step will be to expand the U.S.-based analysis to identify all authorized co-frequency users of this spectrum band. To collect this data, Momentus has determined that there are ~200 ITU-notified non-geostationary-satellite orbit systems and 4 ITU-notified geostationary-satellite orbit systems in this band. Momentus intends to analyze each of these ITU notifications to determine which satellite systems have both spectrum and service area overlap. Momentus will engage in coordination with the identified systems to understand which satellites each system has in operation, collect TLE information for all applicable space stations that must be avoided and establish relationships to receive notifications when new space stations are added to the constellations. Momentus will analyze inline-interference events (within 3-degrees) and modify the satellite contact plan to cease X-band emissions (space-to-Earth) as part of the satellite contact plan.

EXHIBIT 7

Technical Certification

I, Randy Yount, 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/ Randy Yount /
Head of Flight Operations
Momentus Space LLC
3901 N. First Street
San Jose, CA 95134
650-564-7820

Date: October 9, 2022

EXHIBIT 8

Ground Station List

Location	Latitude °	Longitude °
RBC **Deadhorse, Alaska**	70°12’36” N	148°00’00” W
RBC **Jeju Island, South Korea**	35°32’24” N	126°00’00” E
RBC **Stockholm, Sweden**	59°39’00” N	16°34’48” E
RBC **Dublin, Ireland**	53°24’36” N	6°13’12” W
RBC **Cape Town, South Africa**	34°1’39” S	18°43’7” E
KSAT **Svalbard, Norway**	78°13’47” N	15°24’28” E
KSAT **Troll, Antarctica**	72°1’00” S	2°31’60” E