SPACE NORWAY

Technical Information to Supplement Schedule S Modification

1 Introduction

The ASBM (Arctic Satellite Broadband Mission) satellite system will provide broadband access for commercial and governmental users in the Northern hemisphere north of 55° N (primarily in the Arctic). The payloads will operate in both Ka- and X-band. The system will have no Ku-band payload.

Gateways have been built in Norway and will operate in Ka-band.

Satellite construction commenced July 2019 and the Critical Design Review milestone was passed in August 2020. Contracts have also been signed for launch services and ground segment operations.

The modifications to the original Schedule S submitted November 15th, 2016, are summarized below:

- Removal of Ku-band.
- Updating orbital parameters
- Updating the Ka-band frequency plan
- Updating service link description
- Updating feeder link description (for information only)

In addition to providing further technical information on the Schedule S item, this document also includes some of the requested updates to the orbital debris mitigation plan, as per requirements in the grant.

The modification only applies to the items covered in this document and Schedule S as provided; no other technical parameters of the ASBM System are modified.

2 Removal of Ku-band

The Space Norway Grant authorizes Space Norway to utilize the Ku- and Ka-bands to provide broadband Internet connectivity services to unserved and underserved communities in the Arctic region of the United States. Space Norway herein requests a modification to the Space Norway Grant by removing the use of Ku-band frequencies from the scope of the grant.

This change has materialized after deciding to host a payload on behalf of the U.S. Government, and subsequent careful analysis it was concluded that it is neither technically nor financially feasible for Space Norway to have more than one commercial payload on the

ASBM System. Following this process Space Norway has moved forward with Ka-band as the commercial payload of choice for the reasons set out in the application for modification.

To harmonize the Schedule S associated with the Application, Space Norway requests deletion of Transmitting Beam IDs TKU1, TKU2, TKU3, TKU4, TKU 5, TKU6 and TKU7 and Receiving Beam IDs RKU1, RKU2, RKU3, RKU4, RKU 5, RKU6 and RKU7 to reflect the removal of 10.70-12.75 GHz and 14.00-14.50 GHz, and further requests the deletion of Transmitting Channel IDs TKU1, TKU2, TKU3, TKU4, TKU 5, TKU6 and TKU7 and Receiving Channel IDs RKU1, RKU2, RKU3, RKU4, RKU 5, RKU6 and RKU7.

3 Orbital Parameters

3.1 Updated details

The constellation consists of two satellites in a 16 hour Highly Elliptical Orbit (HEO). The two satellites are in the same orbital plane, phased apart 180° mean anomaly. The orbit is illustrated in Figure 1 together with the geostationary orbit for illustrative purposes. The orbital parameters are given in Table 1. The orbital parameters will drift some over the course of the operational lifetime to conserve fuel. Details on how the elements will progress is provided in section 6.2.1

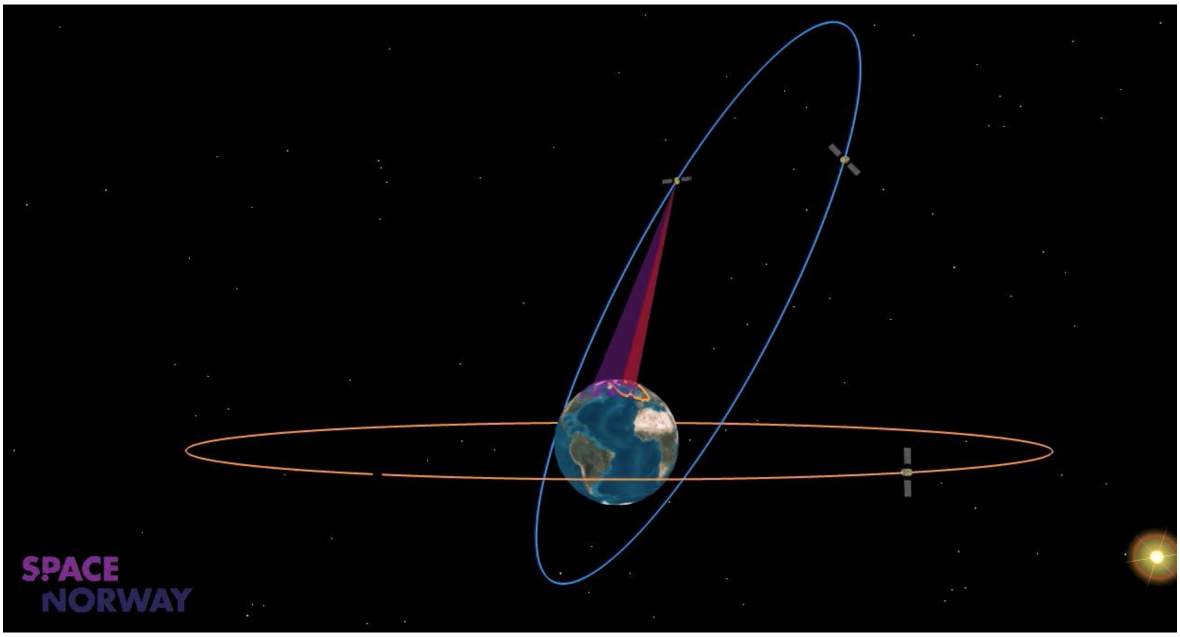

Figure 1. The TAP orbit (blue) and the geostationary orbit (orange)

Table 1: Orbital parameters for ASBM.

Parameters	Updated 2021	FCC application 2016
Orbit period	2/3 sidereal days (approx. 16 hours)	2/3 sidereal days (approx. 16 hours)
Epoch	01 Feb 2024 00:00:00	01 April 2019 00:00:00
Semi-major axis	32175.4 km	32177 km
Eccentricity	0.55	0.55
Apogee	43536 km	43509 km
Perigee	8076 km	8089 km
Inclination	62.6°	63.4°
RAAN	60.4°	280°
Longitude of apogee	69°E, 189°E and 309°E	19°E, 139°E and 259°E
Argument of perigee	268.9°	270°
Mean anomaly ASBM 1	257.5	117.25
Mean anomaly ASBM 2	77.5	297.25

The satellites will trace the ground track as seen in Figure 2 over a period of 48 hours (three orbital periods). The ground track repeats itself after 48 hours.

Each satellite will be active for up to 10 hours of the orbit, this active arc is centered +/-5 hours around each apogee. There will be a limited period where both satellites are operating at the same time (handover). This period is up to one hour long. The satellite payloads will not transmit outside the active arc.

The nominal minimum sub-satellite point latitude of the active arc is 35° N as shown by the blue part of the curve in Figure 2. The altitude at this point is 28 400 km and represent both the most southern point and the lowest altitude where the satellite payloads will be active, though not necessarily used. The minimum sub-satellite latitude of the active arc can, however, be down to 31° N some of the time during the satellite lifetime and the maximum sub-satellite latitude up to 64° N.

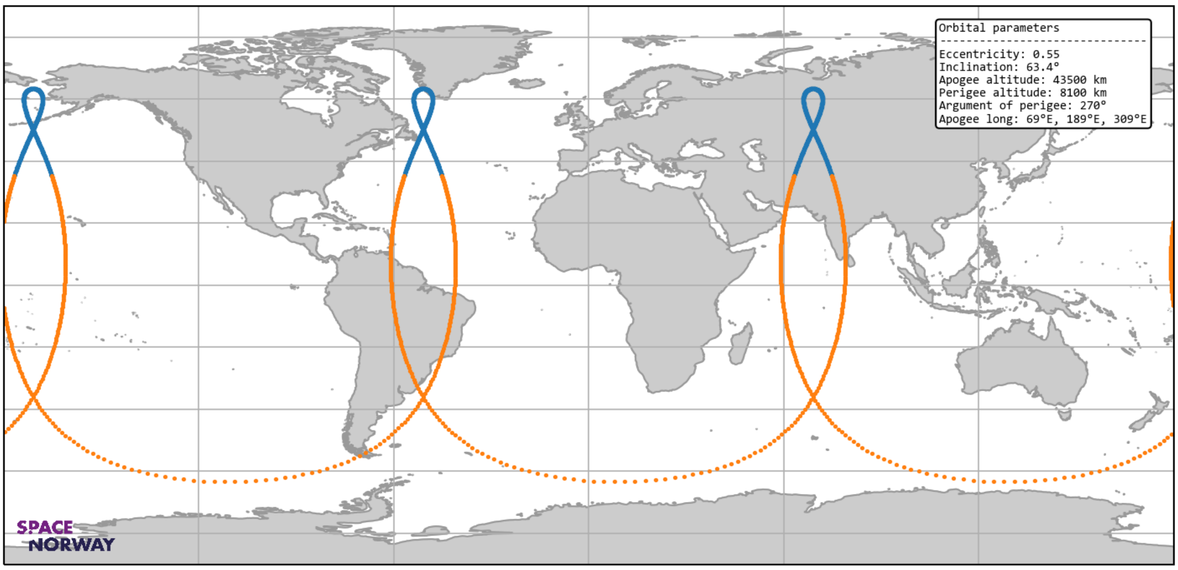

Figure 2. ASBM satellites ground track. Active part of the orbit is indicated by the blue curve. The satellite payloads will not transmit in the orange parts of the orbit.

3.2 Coverage

The coverage of ASBM is not affected by the slight changes in orbital parameters. The Ka-band payload will have a set of Pan-Arctic beams. These beams are organized in a cluster of seven beams as shown in Figure 3.

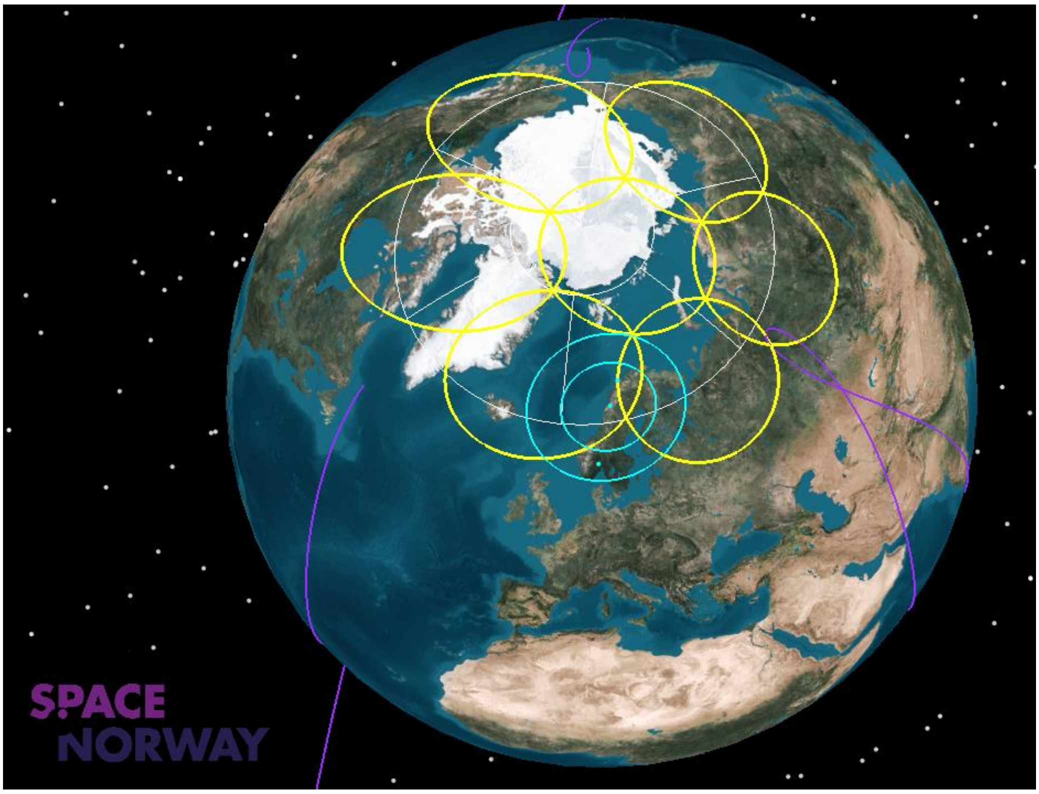

Figure 3. Ka-band seven-beam cluster at apogee (beam coverage for illustration only)

The Ka-band multi-beam antenna is a 1.5 m shaped reflector-antenna with a cluster-feed giving 3.1° beamwidth for each of the seven beams. A four-color frequency reuse scheme is used, as shown in Figure 4. The gain at Edge of Coverage is 33 dBi.

In addition, there will be a steerable feeder link beam pointing towards the gateway location in Norway, see Figure 3. The satellite feeder link antenna is a 0.8 m parabolic reflector antenna which will communicate with 9 m Ka-Band earth station antennas in Tromsø (19° E, 69.7° N) and Bardufoss (18.5° E, 69.1° N).

4 Ka-Band Frequency Plan

Table 2 sets out the Ka-band frequency plan as it will be used for different purposes. The feeder links and telemetry links will only be transmitted and received though the steerable feeder link beam covering Norway (the light blue coverage in Figure 3).

Table 2 Ka-band frequency plan (feeder links, TT&C and commercial user band)

Down-link	17.7-19.7 GHz Feeder-link (RHCP)	19.79-19.80 GHz Telemetry (RHCP)	19.96-20.2 GHz User-link, multi-beam (LHCP)
Up-link	27.5-29.0 GHz Feeder-link (LHCP)	29.0-29.1 GHz Telecommand (LHCP)	29.6-30.0 GHz User-link, multi-beam (RHCP)

4.1 User links

A Combined Broadband Processor (CBP) is used, enabling flexible bandwidth usage together with an 8x8 MPA (Multi-Port Amplifier) providing flexibility in power distribution among the beams. When power and bandwidth is equally distributed between the seven beams the EIRP Spectral Density per beam will be 32.9 dBW/MHz.

The frequency plan as given in Schedule S (and shown here) is an example of a possible plan using the four-color scheme in Figure 4

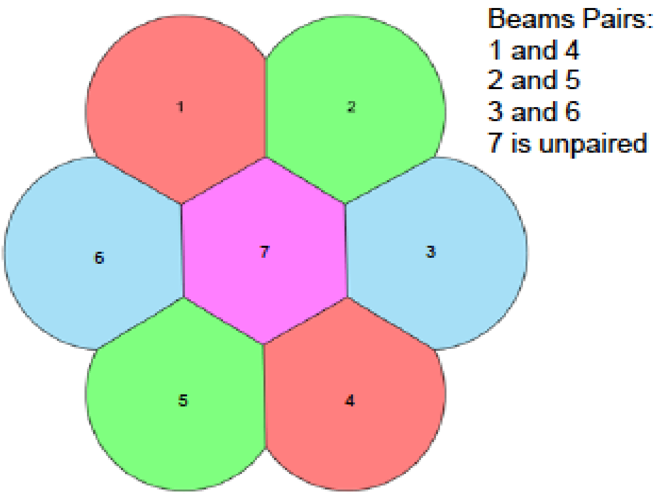

Figure 4 Ka-band seven-beam cluster using four-color scheme

4.1.1 Downlink

The downlink frequencies are limited to the band 19.96-20.20 GHz. The 240 MHz of bandwidth can be distributed as 60 MHz per beam using the four-color re-use scheme:

- 19,960-20,020 MHz (Beam 1 and 4)
- 20,020-20,080 MHz (Beam 2 and 5)
- 20,080-20,140 MHz (Beam 3 and 6)
- 20,140-20,200 MHz (Beam 7)

4.1.2 Uplink

The uplink frequencies are limited to the band 29.6-30.0 GHz. The 400 MHz of bandwidth can be distributed as 100 MHz per beam using the four-color reuse scheme:

- 29,600-29,700 MHz (Beam 1 and 4)
- 29,700-29,800 MHz (Beam 2 and 5)
- 29,800-29,900 MHz (Beam 3 and 6)
- 29,900-30,000 MHz (Beam 7)

5 ITU Filings and Power Levels

The relevant ITU-filings for the ASBM system, submitted through the Norwegian Administration, are NORSAT-H1 and SLEIPNER-1. SLEIPNER-1 is an updated filing replacing the original NORSAT-H1 filing which expired 2021-11-11.

5.1 Protection of geostationary satellite (GSO) services through EPFD limits

The ASBM satellite system complies with Article 22 of the ITU Radio Regulations. Consequently, the ASBM satellites and associated user terminals will meet all applicable EPFD limits.

EPFD evaluation of the SLEIPNER-1 filing was performed by ITU (CR/C/5051 MOD-2) and published in BR IFIC 2955 (21 September 2021). All findings were favorable. The Ka-Band EPFD masks submitted to FCC in the 2016 application are within the masks submitted to the ITU in the SLEIPNER-1 filing. ITU performed EFPD validation for Ka-Band using worst case masks. These masks are provided as separate xml-files.

- PFD Mask for Space Station (17.8-18.6 and 19.7-20.2 GHz): ka4d_pfd_40khz.xml
- EIRP Mask for Space Station (17.8-18.4GHz): ka1_eirp_mask_ss_40khz.xml
- EIRP Mask for Associated Earth Station (27.5-28.6 and 29.5-30 GHz): ka1u_eirp_mask_es_30cm_40khz.xml

This addresses 24.f., 24.g., 25.d., and 25.3.iii. of the authorization for U.S. market access.[1]

The input, result and summary of the ITU favorable finding can also be found here: https://www.itu.int/en/ITU-R/space/Pages/epfdData.aspx (SLEIPNER-1, 318520415, NOR).

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[1] Space Norway AS, Petition for a Declaratory Ruling Granting Access to the U.S. Market for the Arctic Satellite Broadband Mission, IBFS File No. SAT-PDR-20161115-00111, Order and Declaratory Ruling, 32 FCC Rcd 9649 (2017) ("Space Norway Order") (granting Space Norway U.S. market access to operate its Arctic Satellite Broadband Mission constellation (the "ASBM System") in the Ku- and Ka-bands to provide broadband Internet connectivity services to unserved and underserved communities in the Arctic region of the United States).

5.2 Protection of terrestrial services through PFD limits

Protection of terrestrial services will be maintained through compliance with PFD limits as defined in Article 21 of the ITU Radio Regulations for those frequency bands where such limits exist. As shown in Figure 5, the ASBM System is well below the FCC PFD limits defined in §25.208.

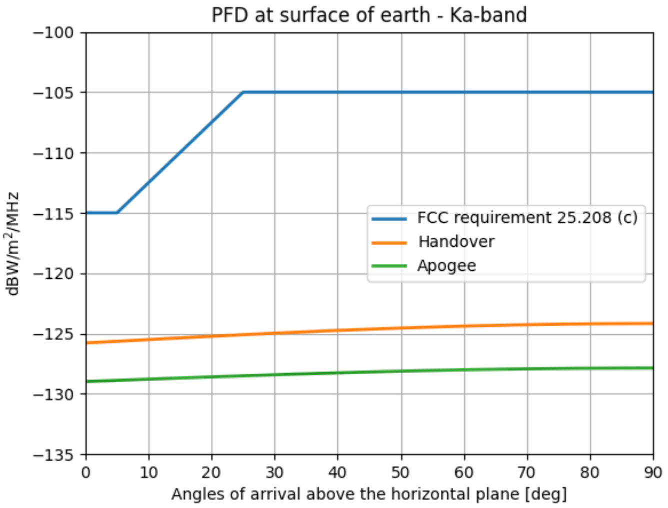

Figure 5 Comparing the Maximum Ka-Band PFD Levels of ASBM with FCC §25.208(c).

Apogee: 43,500 km
Hand-over: 28,454 km
Satellite EIRP: 35.9 dBW/MHz (51 dBW/32 MHz)

PFD at surface of earth is calculated for a worst-case scenario with one beam having 3 dB more power allocated to it. Remaining beams will have their power reduced correspondingly.

6 Operation, orbital debris mitigation, and disposal

6.1 Norwegian regulation and registration in UN space object registry

Since the Norwegian regulations regarding space objects is still under development, Space Norway is not subject to direct and effective regulatory oversight by national authorities with regards to orbital debris in Norway. Hence, in accordance with §25.114(d)(14)(v), we will provide details on collision risks, mitigation strategy and disposal of the satellites after end of life. Despite the lack of regulatory oversight, we have received confirmation from the relevant authority that the satellites in the ASBM system will be registered as Norwegian in the UN Space Object Registry (see Annex 1). Therefore, Norway will also assume the role and responsibility as the launching state.

6.2 Normal operations

Since the perigee of ASBM is more than 8000 km throughout its operational lifetime, it will not intersect with the LEO protected region. The high altitude of the apogee and the eccentricity of the orbit is such that there will be no intersection with the GEO protected region.

The spacecraft will however intersect with the MEO region and in particular the orbits used by radio-navigation satellites (circular orbits with altitudes around 21 000 km).

No proximity operations will be performed.

6.2.1 Orbital parameters and station keeping

The orbit control strategy is designed to optimize fuel efficiency while satisfying coverage requirements. The orbit will be maintained within these parameters:

- apogee longitudes within +/- 0.1 degrees
- eccentricity within 0.53 – 0.59
- argument of perigee 264-272 degrees
- inclination 62.30-63.63 degrees

Nominal station keeping maneuvers are planned to occur every fortnight and will be executed when the satellites are near perigee.

Eccentricity and argument of perigee will be maintained within requirements through two major maneuvers in December 2033 and December 2035 when assuming mission start in January 2023. These two maneuvers are reflected as major changes in argument of perigee in Figure 8 and eccentricity in Figure 9.

In total all maneuvers during the operational lifetime will require a delta-V of 180 m/s.

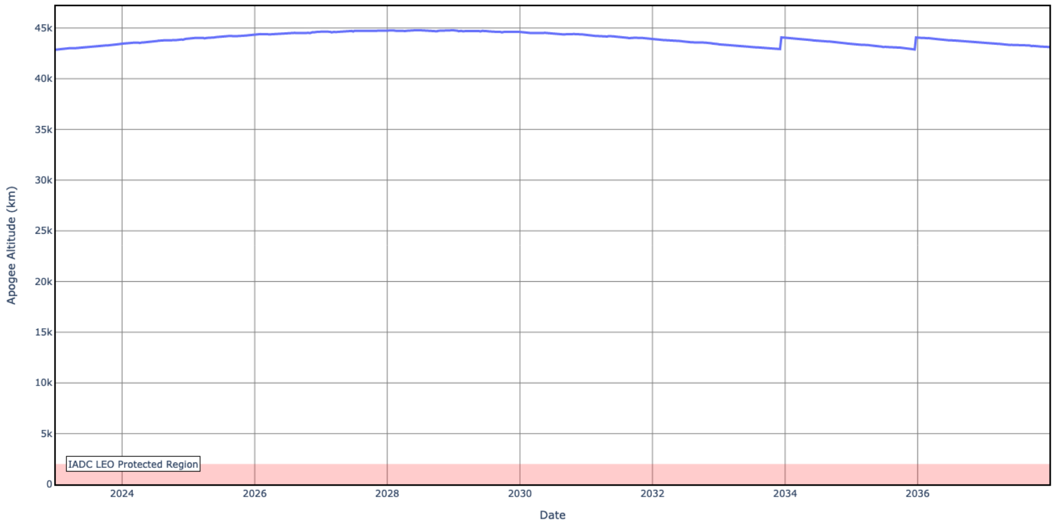

Figure 6 Apogee altitude variation during operational lifetime, 2023-2038

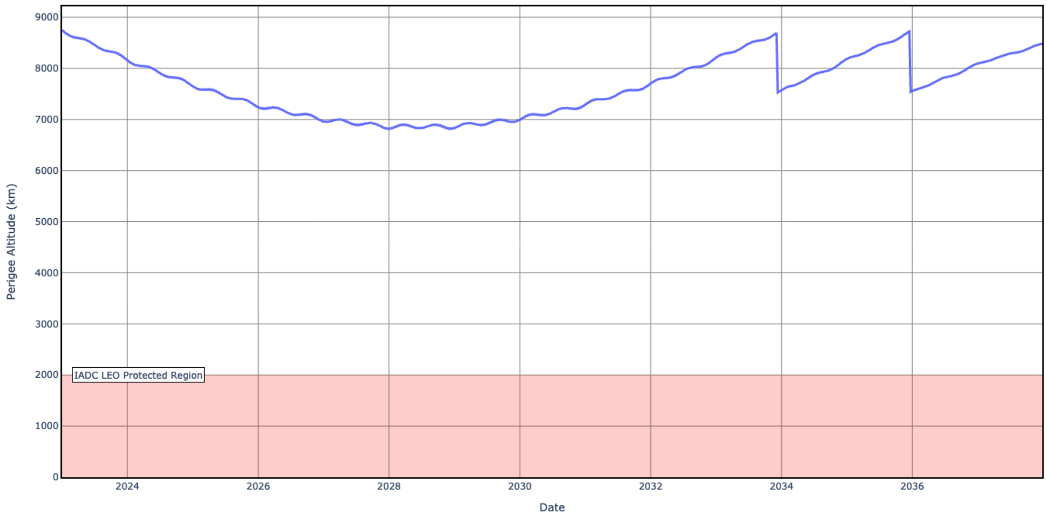

Figure 7 Perigee altitude variation during operational lifetime, 2023-2038

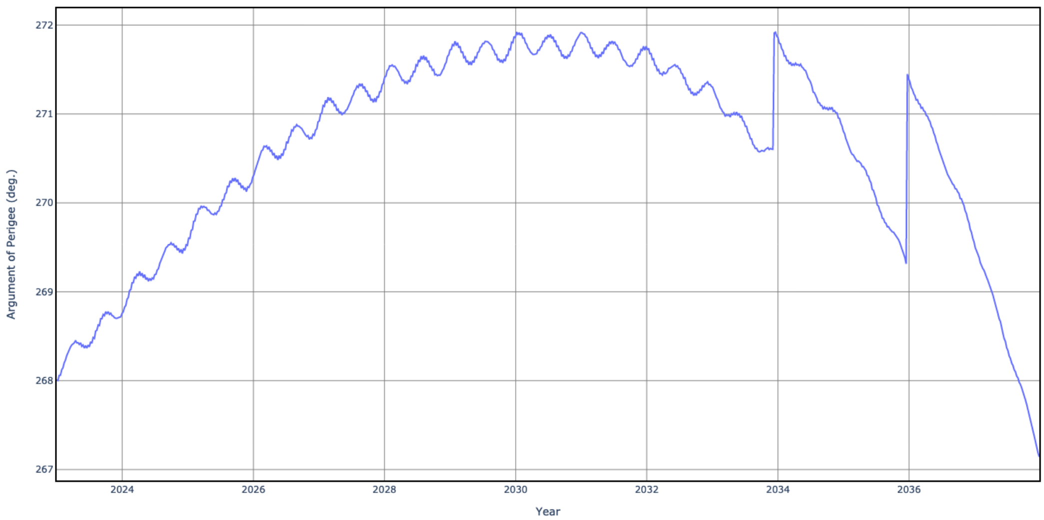

Figure 8 Argument of perigee variation during operational lifetime, 2023-2038

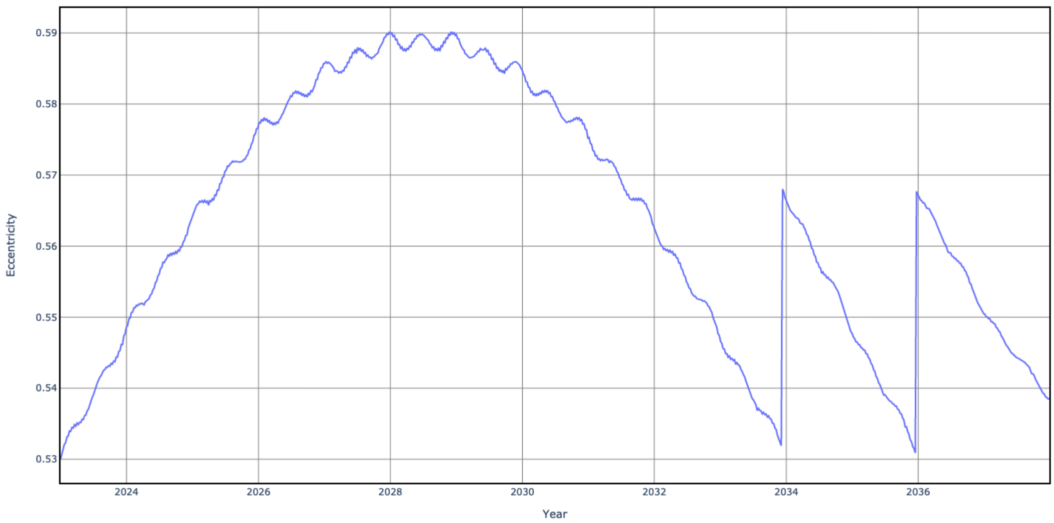

Figure 9 Eccentricity variation during operational lifetime, 2023-2038

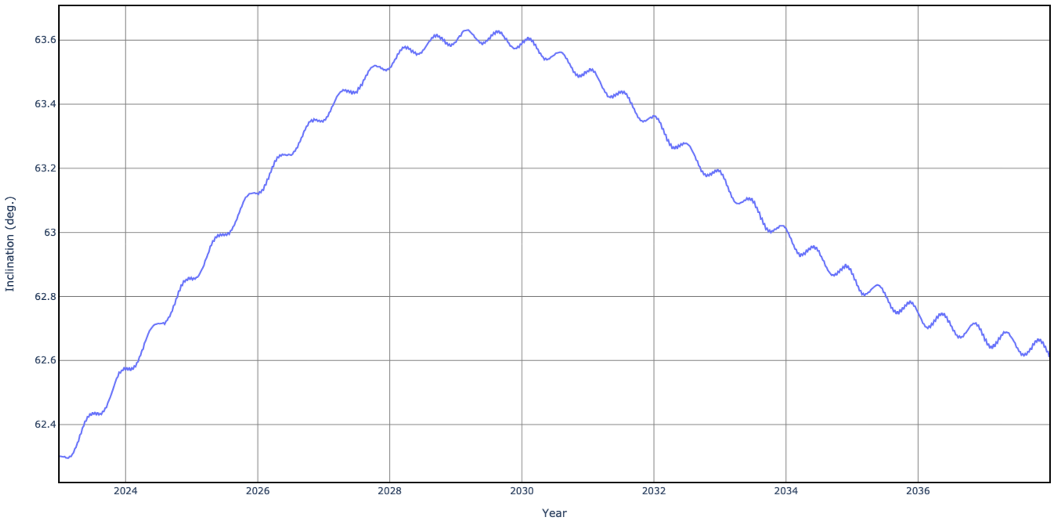

Figure 10 Inclination variation during operational lifetime, 2023-2038

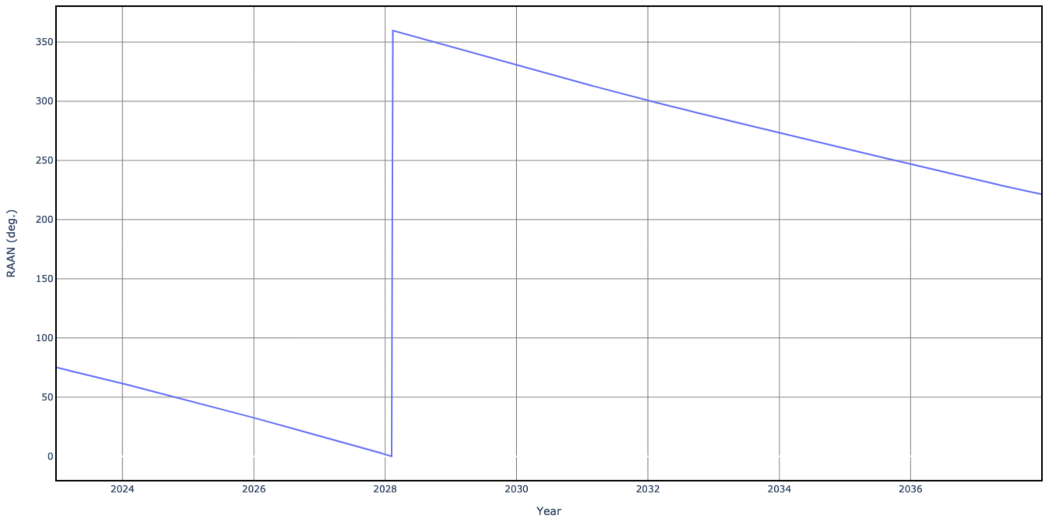

Figure 11 Right Ascension of the Ascending Node variation during operational lifetime, 2023-2038

6.3 Orbital debris mitigation

6.3.1 Release of orbital debris

No debris will be released during launch.

Propulsion for orbit raising and orbital maneuvers on the two spacecrafts are chemical and will therefore only release exhaust gases.

6.3.2 Collision risk with orbital debris larger than 10 cm

The NASA Debris Assessment Software was not possible to use for the ASBM system since the apogee altitude exceeds that of the geostationary orbit. This causes the software to crash. After consulting with NASA, it was decided to use the NASA ORDEM software version 3.1 to assess the collision probability with orbital debris larger than 10 cm in size.

The analysis was broken down into two separate parts, one for the assumed operational lifetime from 1 January 2023 to 31 December 2038 and a more refined analysis for the period from the de-orbit maneuver and re-entry (see section 6.4 for selection of disposal strategy). The orbital parameters used can be found in Table 3. For the operational lifetime, 2023-2037 we have assumed typical orbital values to simplify the simulations. For the re-entry phase, the orbital parameters on 1 June each year were assumed to apply for the respective year.

The area cross-section of the spacecraft was calculated using the Debris Risk Assessment and Mitigation Analysis (DRAMA) built-in tool CROC provided by the European Space Agency[2]. The satellite is modelled by the following input parameters and respective values of the basic structures:

Main Body: Width: 209.8 cm, Height: 384.8 cm, Depth: 230.7 cm
Solar Arrays: Width: 1.80 cm, Height: 206.0 cm, Depth: 972 cm

By computing this model, the average cross section is calculated to be 30.2 m^2. The area-to-mass of the satellite was then calculated by dividing the obtained average cross-sectional area by the final mass of the spacecraft: 30.2 m^2/2084 kg resulting in 0.015 m^2/kg.

The NASA ORDEM software yield these results for collision probability with orbital debris larger than 10 cm:

Operational phase, 2023-2038:	0.000031
Re-entry phase: 2039-2049:	0.000383
Total:	0.000413

ASMB system complies with the FCC requirement of 0.001 in §25.114(14)(iv)(1) for collision with orbital debris larger than 10 cm during the total orbital lifetime of the space station, including any de-orbit phases. This includes the operational lifetime where the spacecraft would normally be maneuvered to avoid collisions.

Table 3 Orbital parameters used in NASA ORDEM simulations

Year	Apogee [km]	Perigee [km]	Inclination [°]	Argument of Perigee [°]	RAAN [°]
2023-2037	43496	8101	63.4	270.0	75.0
2038	48164	8629	62.6	265.8	216.9
2039	49039	8761	62.6	262.4	206.9
2040	50193	8603	62.6	258.8	197.0
2041	48643	8151	62.6	255.5	187.0
2042	49350	7440	62.6	252.7	176.4
2043	50268	6513	62.6	250.5	164.8
2044	51360	5407	62.6	249.0	151.5
2045	52553	4191	62.6	248.6	135.7
2046	53772	2926	62.4	249.5	116.0
2047	54903	1709	62.1	252.1	90.4
2048	55786	686	61.6	257.4	56.5
2049	33503	100	61.0	265.9	12.9

[2] https://sdup.esoc.esa.int/

6.3.3 Collision risk with orbital debris smaller than 10 cm and micrometeoroids

Undergoing further study. Will be submitted as soon as it is completed.

6.3.4 Space situational awareness, collision avoidance and trackability

6.3.4.1 Determination of collision risk

Part of the regular schedule of the Flight Dynamics System (FDS) software (provided by GMV) is importing external products such as Two-Line Element (TLE) and Conjunction Data Messages (CDM) from other spacecraft operators. Space Norway has registered an account in Space-Track.org to retrieve such data. The setup has been tested and verified.

Our FDS software will be capable of the following:

- Assess the collision risk between a set of satellites and the TLE catalogue
- Analyze the conjunction data in a CDM file taking into account operational orbits
- Miss distance computation
- Collision Probability computation
- Maximum Collision Probability computation
- Dangerous conjunction detection

If a conjunction is predicted reports will be generated. These reports will allow Space Norway and the other operator to understand the criticality of this conjunction.

In case of a collision risk prediction a collision risk avoidance strategy will be implemented.

6.3.4.2 Strategy for reducing collision risk.

Space Norway will always attempt to contact the relevant operator in the case of a predicted collision risk.

The current strategy to avoid collision risks is to modify the epoch of the next station keeping (SK) maneuver instead of a specific collision avoidance maneuver. Therefore, this functionality is covered by the current design of the SK maneuvers module, where the user could modify the epoch of the next SK maneuver. Nominally, SK maneuvers are planned to be executed every 14 days. The system also supports maneuvers for the sole purpose of avoiding collision.

6.3.4.3 Sharing of ephemeris

TLEs and CDMs will be produced and shared after each new successful orbit determination as part of the regularly scheduled operations of the ASBM system.

The ASBM satellites has pre-registered with the 18th Space Control Squadron. Space

Norway has also made a commitment to share predicted ephemeris with the 18th Space Control Squadron.

6.3.5 Orbital precession in the event of loss of control or capability to deorbit

In case one of the satellites has a failure in their propulsion system or fails to execute a de-orbit maneuver the orbital precession will be as shown in Figure 12 - Figure 16. The orbit is relatively stable, but as can be seen in Figure 15, the perigee altitude will have periods where it intersects with the LEO protected region below 2000 km.

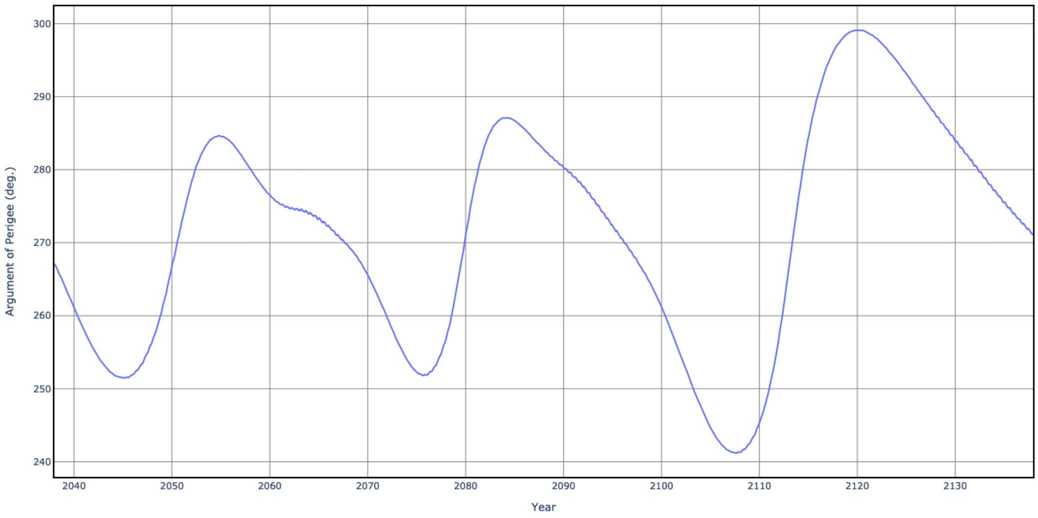

Figure 12 Argument of Perigee in case of loss of capability to perform de-orbit

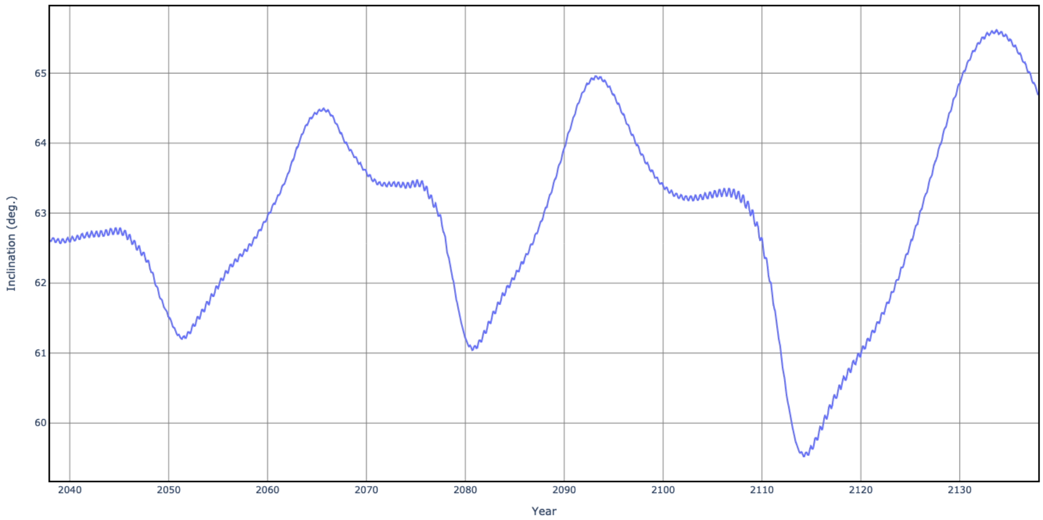

Figure 13 Inclination in case of loss of capability to perform de-orbit

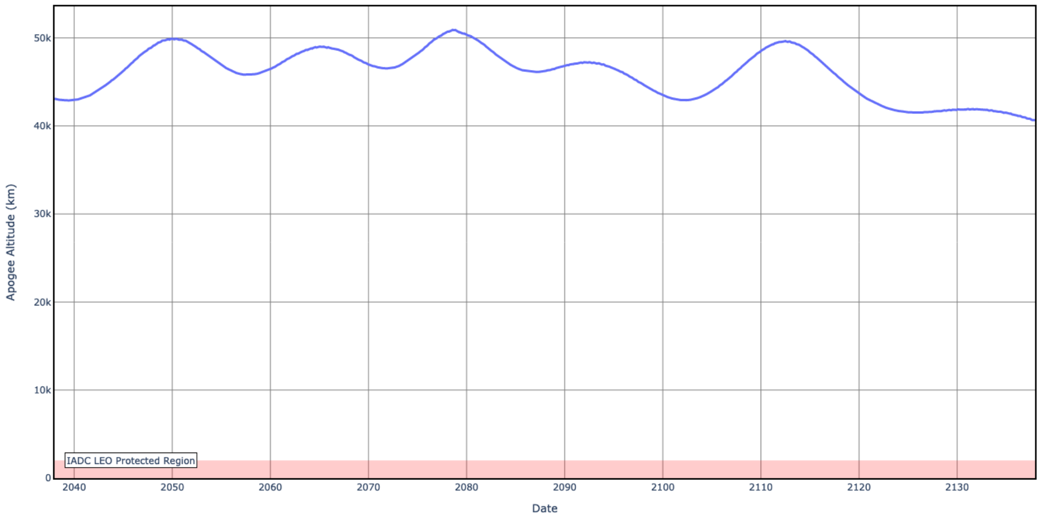

Figure 14 Apogee altitude in case of loss of capability to perform de-orbit

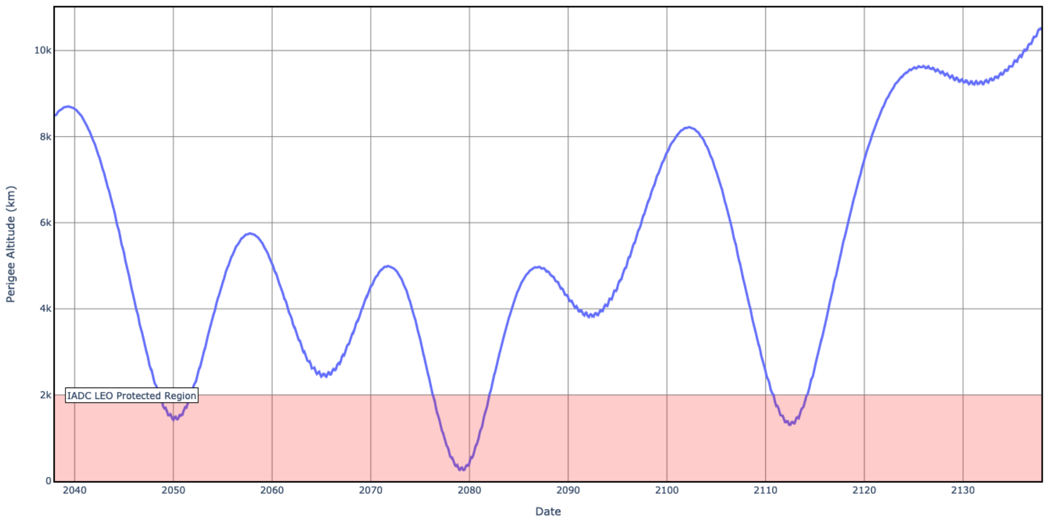

Figure 15 Perigee altitude in case of loss of capability to perform de-orbit

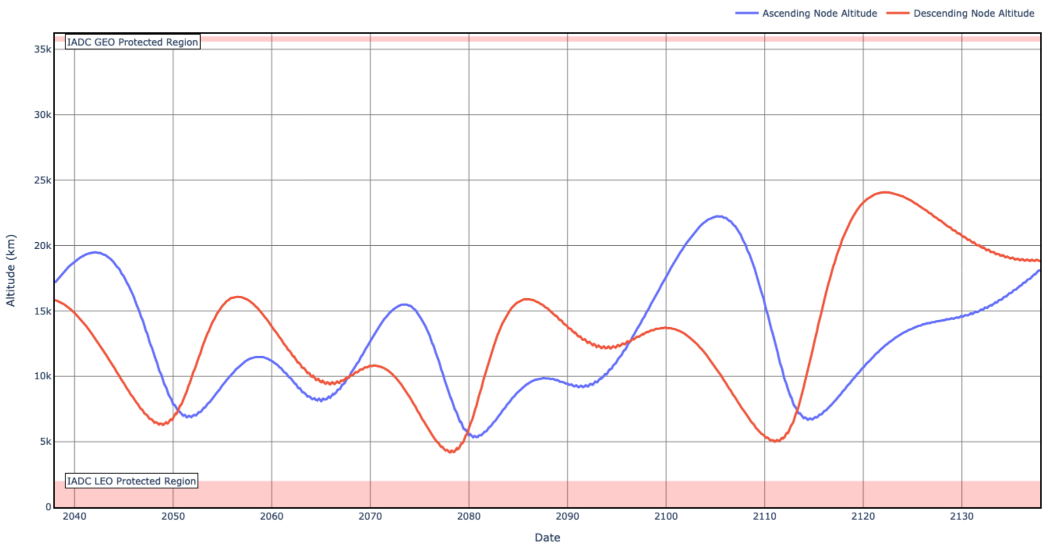

Figure 16 Altitude of ascending and descending nodes in case of loss of capability to perform de-orbit

Details on orbital precession simulations:

- Integrator
  - Type: RungeKutta89
  - Initial Step Size: 60 sec
  - Accuracy: 9.999999999999999e-12
  - Min Step Size: 0.001 sec
  - Max Step Size: 2700 Sec
  - Max Step Attempts: 50
- Force Model
  - Error Control: RSSStep
  - Central Body: Earth
- Primary Body
  - Earth
- Gravity
  - Model: JGM-2
  - Degree: 10 / 70, Order 10 / 70, STM Limit 100
- Drag
  - Atmosphere Model: JacchiaRoberts
  - Drag Model: Spherical
- Point Masses:
  - Luna
  - Sun
- Solar Radiation Pressure
  - Use Solar Radiation Pressure: Yes
  - SRP Model: Spherical

6.4 End of life and disposal strategy

As can be observed in section 6.3.5, there is a need for a disposal strategy to avoid intersecting the LEO protected region in the long term and to enable re-use of the ASBM HEO orbit.

There are three options available for disposal of the ASBM satellites:

- Eccentric graveyard orbit
- Near circular graveyard orbit
- Atmospheric re-entry.

These options are further explored below, and one of the strategies will ultimately be selected based on fuel budget, safety and sustainability.

6.4.1 Graveyard orbit

The U.S. Government Orbital Debris Mitigation Standard Practices, November 2019 Update (ODMSP) recommends two approaches for long term storage between LEO and GEO.

6.4.1.1 Eccentric disposal between LEO and GEO

The first method is an eccentric disposal orbit avoiding the LEO zone and the GEO zone. To achieve a long-term disposal orbit, a negative in-track delta-V executed at perigee must be applied. This will decrease the apogee altitude, reducing the magnitude of luni-solar perturbation that affect orbit eccentricity. The goal is to achieve a minimum perigee altitude above 2000 km. Long-term analysis (100-year) has been done to investigate the natural evolution of the uncontrolled orbit. High-fidelity orbital force models and no further application of propulsion. With a delta-V of 94 m/s the LEO stay-out-zone will be fully protected, and it will be possible to re-use the ASBM orbit as repeating ground track will also be interrupted. The GEO stay-out zone will remain protected with and without the de-orbit burn. Figure 18 shows that the maximum altitudes in the region around the ascending and descending nodes (+/- 15 degrees) never exceeds 30 000 km and will not intersect with the GEO protected region. A delta-V of 94 m/s can be accommodated in the fuel budget.

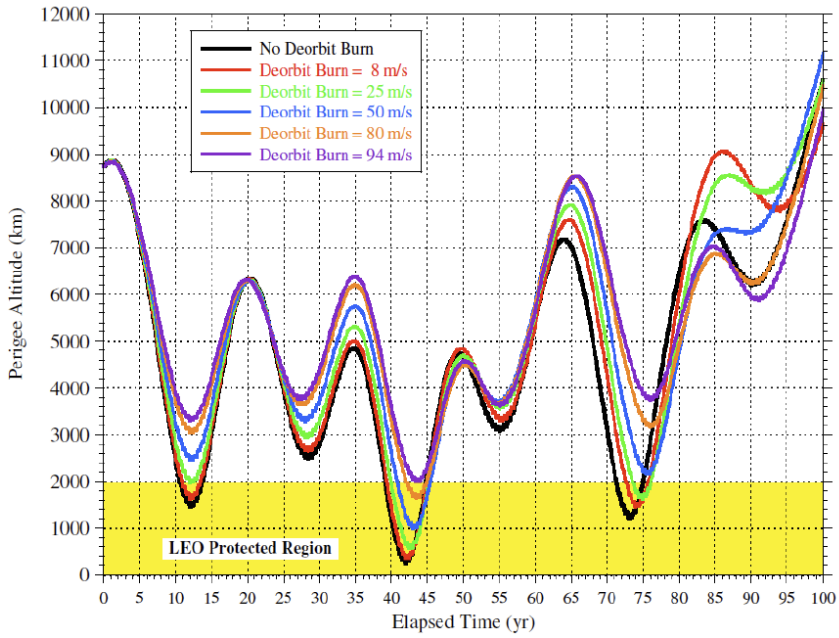

Figure 17 Perigee altitude, 100-year natural orbital evolution starting from post-deorbit initial conditions

6.4.1.2 Near-circular disposal between MEO and GEO

The second method is storage between MEO and GEO in near-circular orbit. For ASBM this would mean a circulation of the orbit. The apogee must be lowered below GEO altitude and perigee must be increased to above MEO altitude. Calculations on required delta-V to obtain a near circular orbit around 30 000 km altitude using an ideal Hohman transfer results in a delta-V of more than 1000 m/s. This is far beyond the fuel budget allowance for disposal and is therefore not a viable option.

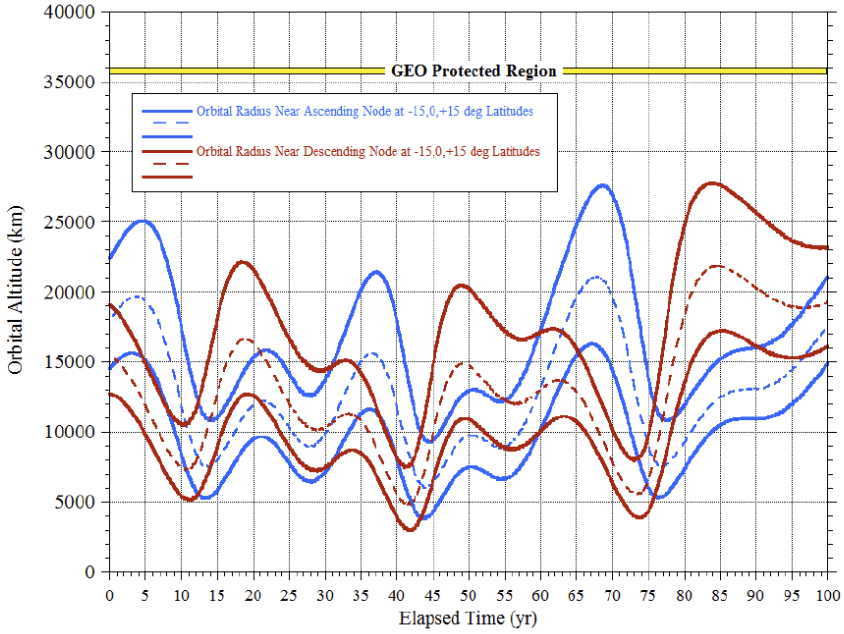

Figure 18 Ascending and descending nodes altitude, 100-year natural orbital evolution starting from post-deorbit initial conditions

6.4.2 Atmospheric re-entry

Undergoing further study. Will be submitted as soon as it is completed.

6.4.3 Selection of disposal method

Undergoing further study. Will be submitted as soon as it is completed.

6.4.4 End of life procedure

Undergoing further study. Will be submitted as soon as it is completed.

SPACE
NORWAY

Norsk Romsenter
Norwegian Space Agency

To whom it may concern

Deres ref./*Your ref.*: Vår ref./*Our ref.*: Dato/*Date:*
Oslo, 20.10.2021

Registration of satellites

This is to confirm that the satellites ASBMc1 and ASBM2, owned and operated by Space Norway, which are planned to be launched in Q4 2022/Q1 2023, will be registered in the Norwegian Space Object Register once the satellites are successfully placed into orbit.

Sincerely

Erik Uribarri
Senior Adviser,
External Relations and Strategy

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