Orbital launches from Esrange Space Center:

Risks, costs and other consequences for Norway

Report 25th February 2025

CAA Norway

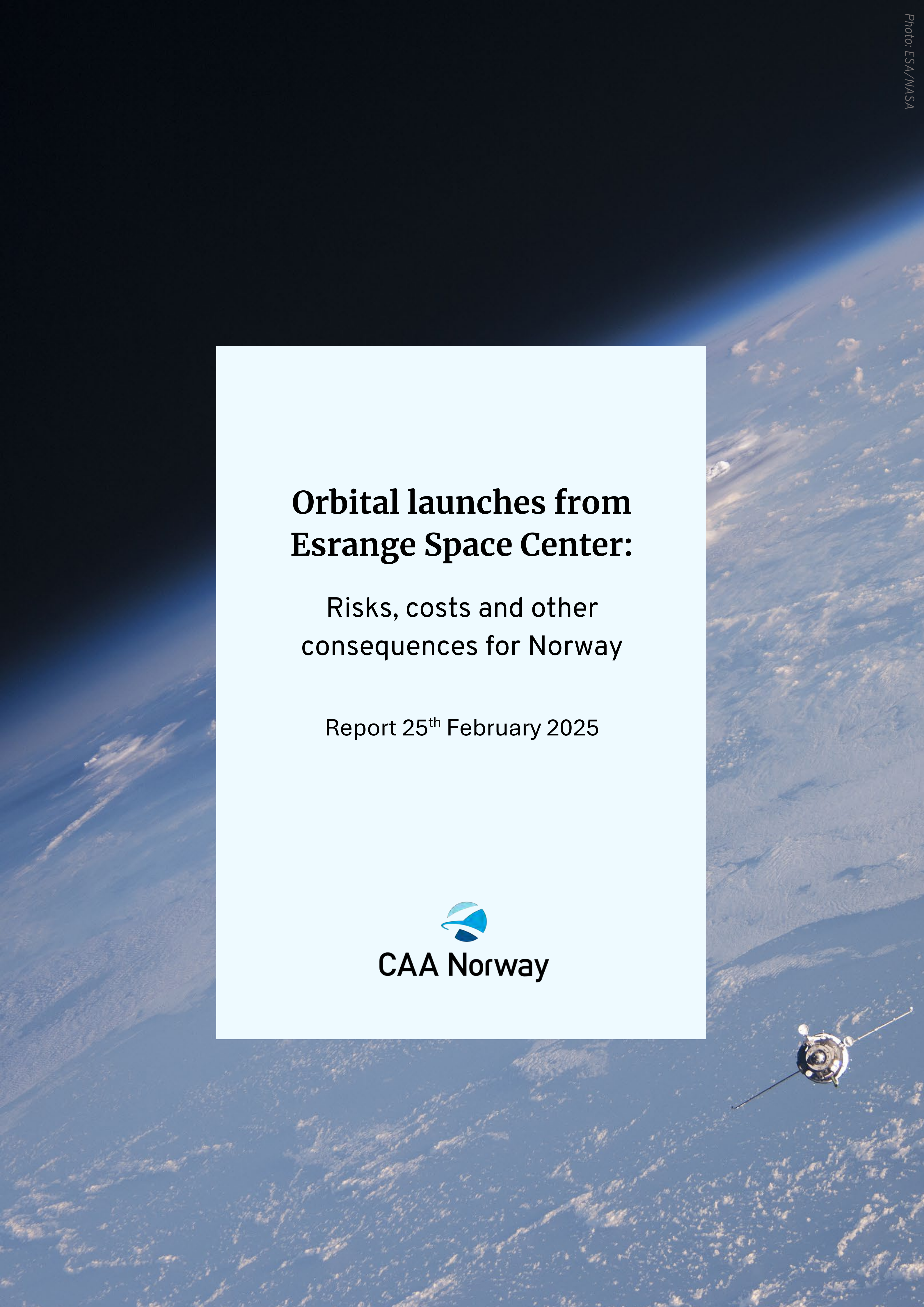

Photo: ESA/NASA

Content

1. Background and aim of report

1.1 Report

The Civil Aviation Authority (CAA) has been tasked by the Ministry of Trade, Industry and Fisheries (NFD) to assess, and write a report on, the risks, socio-economic costs, and other consequences for Norwegian security and societal interests as a result of potential rocket launches from Sweden that pass over Norway. NFD has also asked the CAA to determine the safety requirements that must be imposed on the potential launch of orbital vehicles passing over Norway ('the Report').

The Report aims to give the Norwegian government a clearer picture of the aforementioned risks and consequences of the rocket launches from Sweden over Norway.

1.2 Background

Esrange Space Center is a rocket launch site and spaceport established outside Kiruna in Sweden and is owned and operated by the Swedish Space Corporation (SSC). Sounding rockets (sub-orbital rockets) have been launched from Esrange Space Center since 1966. When launching sounding rockets, rocket parts are supposed to land within defined safety areas in Sweden and therefore not affect Norway.

The new spaceport – Spaceport Esrange – opened on 13th January 2023. Spaceport Esrange aims to provide launch services/capabilities for small satellites into orbit. Launching satellites into orbit requires orbital launch vehicles, which in general are larger and more powerful than sounding rockets, to be launched from Esrange along a path/trajectory crossing over Norway into orbit.

Last year there were media announcements that rocket launches are planned from Spaceport Esrange, with the first launch scheduled for 2025[1]. SSC announced in two media releases on 5th June 2024[2], and 27th June 2024[3] respectively that it has entered into agreements with two rocket producers regarding the launch of orbital rockets from Spaceport Esrange.

[1] SSC has since said in several international forums that the first launch will not be until 2026, possibly 2027.
[2] Swedish-South Korean partnership take satellites to Space from Europe - SSC - Swedish Space Corporation
[3] SSC and Firefly to launch satellites from Esrange - SSC - Swedish Space Corporation

Glossary

CAA	Norway Civil Aviation Authority (Luftfartstilsynet)
CE_C	Conditional Expected Casualties
Esrange Space Center	Esrange space facility, including the spaceport, sometimes in the report referred to as Esrange
E_C	Expected casualties
FAA 450	The United States' Code of Federal Regulation, Title 14, Chapter III, Subpart C, Part 450. Launch and reentry requirements
FSA	Flight Safety Analysis
FSH FAA	Flight Safety Handbook
FTS	Flight Termination System
FSS	Flight Safety System
NFD	The Norwegian Ministry of Trade, Industry and Fisheries
PoF	Probability of Failure
SNSA	Swedish National Space Agency (Rymdstyrelsen)
SSC	Swedish Space Corporation

2. Executive summary

2.1 Executive summary

In this report, CAA Norway has assessed the risks, socio-economic costs, and other consequences for Norwegian security and societal interests that would result from potential rocket launches from Esrange Space Center that pass over Norway as well as the necessary safety requirements that must be imposed.

The report highlights the impact such launches could have on Norwegian people, the Sami way of life, the environment, and conservation efforts. Imposing measures such as road closures and suspension of local air and marine traffic will have implications for all transport of goods and people in the affected area, including travel for health services, and furthermore will have implications for the fishing industry. The Armed Forces points at the risk that launches may impact on the Armed Forces' ability to maintain situational awareness and operations, as well as impact their ability to transit to/from operational areas.

Evacuations and traffic restrictions due to rocket launches from Esrange Space Center could lead to substantial economic impacts on industries and businesses in Norway. Any stop of production in the oil and gas installations could result in estimated costs of at least 1.7 billion NOK (153.01 million USD[4]) per launch. Municipalities would need to update emergency plans, incurring additional costs, while Norwegian authorities would face extra expenses in assessing and managing risks associated with the launches from Esrange.

The information provided by SNSA and SSC to date is insufficient to evaluate the actual risk of a launch over Norway from Esrange Space Center. One key element a Flight Safety Analysis (FSA) must take into account is recent and representative population numbers, including fluctuations due to seasonal variations.

It is noted that, for launch vehicles passing over Norway, the use of flight abort does not protect the populated areas within the flight safety limits. The report questions whether it may be necessary to apply some alternative or additional requirements to U.S. Code of Federal Regulations Part 450, noting the lack of established practices for evacuation or notification when a launch occurs over land, especially when the land in question is located in another country.

CAA Norway recommends that relevant Norwegian authorities conduct an assessment of the risks a launch will pose to the people in Norway and Norwegian interests, determining whether these risks are acceptable.

2.2 Sammendrag

Luftfartstilsynet har i denne rapporten vurdert risiko, samfunnsøkonomiske kostnader og andre konsekvenser for norsk sikkerhets- og samfunnsinteresser som vil kunne oppstå fra eventuelle rakettoppskytninger fra Esrange Space Center som passerer over Norge. Det er også vurdert hvilke sikkerhetskrav dette stiller til eventuelle oppskytinger.

[4] NOK 11,11 per USD, 21st February 2024

Rapporten redegjør for hvilken innvirkning slike oppskytninger kan ha på befolkningen i Norge, samiske interesser, miljøet og verneområder. Innføring av tiltak som veistenginger og innstilling av flyginger og skipstrafikk, vil ha konsekvenser for all transport av varer og mennesker i det berørte området, inkludert pasientreiser til/fra helsetjenester. Tiltak vil også ha konsekvenser for fiskerinæringen. Forsvaret har pekt på risikoen for at oppskytinger kan påvirke Forsvarets evne til situasjonsforståelse og operasjoner, og i tillegg påvirke transport til og fra operasjonsområdene.

Evakueringer og trafikkrestriksjoner på grunn av rakettoppskytninger fra Esrange Space Center kan medføre betydelige økonomiske konsekvenser for industrien og bedrifter i Norge. Stopp i produksjonen på olje- og gassinstallasjoner kan resultere i anslåtte kostnader på minst 1,7 milliarder NOK (om lag 153,01 millioner USD) per oppskytning. Kommuner må oppdatere beredskapsplaner, noe som medfører ekstra kostnader, mens norske myndigheter vil ha ekstra utgifter til vurdering og håndtering av risiko knyttet til oppskytninger fra Esrange.

Den informasjonen som per i dag er gitt av SNSA og SSC er ikke tilstrekkelig for å vurdere den faktiske risikoen ved en oppskytning fra Esrange Space Center over Norge. Et sentralt element en sikkerhetsanalyse (Flight Safety Analysis, FSA) må ta hensyn til er nylige og representative befolkningstall, inkludert svingninger på grunn av sesongvariasjoner.

Det bemerkes at for oppskyting som passerer over Norge, beskytter ikke bruk av *flight abort* de befolkede områdene innenfor flysikkerhetsgrensene (flight safety limits). Rapporten stiller spørsmål ved om det kan være nødvendig å anvende alternative krav eller tilleggskrav til det amerikanske regelverket Part 450, og påpeker mangel på etablerte praksis for evakuering eller varsling når en oppskytning skjer over landområder, spesielt når landområdet det er tale om er i et annet land.

Luftfartstilsynet anbefaler at relevante norske myndigheter skal gjennomføre vurdering av hvilken risiko en oppskytning vil utgjøre for befolkningen i Norge og norske interesser, og avgjøre om risikoen er akseptabel.

3. The operator and the planned activity

3.1 Purpose and scope

In this chapter we give an overview of what is known of the planned operations and the operator as well as an overview of Esrange Space Center. The descriptions are based on material received from SNSA, SSC and information in the public domain; in particular, information published on the websites of SSC, Firefly and Perigee.

3.2 Esrange Space Center

3.2.1 Location and ownership

Esrange Space Center is a space facility located in northern Sweden, above the Arctic Circle. Spaceport Esrange is located at 67.876°N, 21.175° E[5]. The main Esrange Base Area is approximately 4 km^2 in size and is located about 45 km east of the city, Kiruna, in Norrbotten County. Esrange is surrounded by a large unpopulated area.

Established in 1966 by the European Space Research Organisation (ESRO), Esrange Space Center has been operational for nearly six decades. Esrange was transferred to the Swedish Space Corporation (SSC) in 1972 and is still owned and operated by SSC. Esrange Space Center is designated as a vital installation by the Swedish Government[6].

3.2.2 Swedish Space Corporation (SSC)

SSC, in Swedish 'Svenska rymdaktiebolaget', with company number 556166-5836, is a Swedish private company, wholly owned by the Swedish Government. SSC states in their company presentation that they are "a renowned, full-service supplier of state-of-the-art space engineering, satellite and launch services to commercial and institutional customers worldwide."[7] SSC comprises around 700 employees in 21 locations and nine countries around the world.

The SSC Group is organized into three business divisions[8]:

- Science Services provides scientific ground instrument hosting, UAV flight test services, and sounding rocket and stratospheric balloon launch services at Esrange Space Center and develops payload experiments and flight systems for sounding rockets and stratospheric balloons. Several new "Testbed" services and related infrastructure are also currently being developed at Esrange, including launch vehicle developmental testing and orbital launch capabilities for small satellites. Infrastructural services at Esrange are also provided by this division.
- Satellite Management Services is the operator of one of the world's largest civilian networks of ground stations for satellite communication. Numerous types of on-orbit

[5] The stated location differs somewhat in different sources: (67° 53N, 21° 04 ; *Esrange User's Handbook,* Volume I page 8)
[6] *Esrange Users' Handbook,* Volume I, page 24.
[7] AboutSSC_SSC_CompanyPresentation.pdf
[8] *Esrange User's Handbook,* Volume I, page 7.

services are within its responsibility, including: launch and early operations support, antenna hosting, data processing, satellite telemetry, tracking and control. Esrange constitutes one of the major hubs in the Satellite Managements Services network.

- Engineering Services provides engineering, operations and consultancy services to the international space market and support all projects by bringing consulting expertise to all phases, from designing and testing to launch and operations.[9]

3.2.3 The facilities and infrastructure

Esrange is equipped with facilities for launching sounding rockets, high-altitude balloons, and, more recently, small satellites. It also includes satellite ground stations. Esrange offers testing facilities for reusable rocket technology, engine and fuel tests, and other space-related technologies, including test firing of solid and liquid rocket motors.

On 13th January 2023, SSC inaugurated the orbital launch site, Spaceport Esrange, intended to establish the capability to launch small satellites into orbit. Spaceport Esrange, also called Launch Complex 3 or LC-3 in short, is located approximately 4 km east of Esrange Main Building comprising Operations Center, Safety Center, Telemetry Station, as well as offices, hotel and restaurant. LC-3 will include three planned launch pads: LC-3A, LC-3B and LC-3C[10]:

- LC-3A - intended for smaller orbital and suborbital launch vehicles with potential blast profiles up to 1.5 metric tons TNT equivalent.
- LC-3B – intended for small-to-medium orbital and suborbital launch vehicles with potential blast profiles up to 3 metric tons TNT equivalent, primarily for testing of reusable launch vehicles and planetary landers etc.
- LC-3C – intended for medium orbital launch vehicles with potential blast profiles up to 15 metric tons TNT equivalent.

Spaceport Esrange plans to contain generic infrastructure to support multiple launch service providers. Activity on its different launch pads will be limited to one launch vehicle/campaign at a time. Blue Whale 1 is planned to occupy the smaller launch pad (LC-3A)[11] while Firefly will, as far as we understand, be based on LC-3C. The establishment of additional orbital launch sites is not ruled out as a possibility [12].

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[9] Esrange User's Handbook, Vol I page 7.
[10] Esrange User's Handbook, Volume IX, page 20-21.
[11] Swedish-South Korean partnership take satellites to Space from Europe - SSC - Swedish Space Corporation ('While Blue Whale 1 will occupy the smaller launch pad (LC-3A) at the orbital launch complex, the preparations continue for the facility's two other launch pads. Europe's program for reusable rocketry, called Themis, is set to conduct hop-tests at pad LC-3B.)
[12] Esrange User's Handbook, Volume IX, page 7.

Figure 3.1: Map of Esrange base area from Esrange User's Handbook Volume IX Spaceport, page 11, LC-3 circled in red.

For the launch of sounding rockets, an Esrange impact area has been established: a large area where only space-related activities, reindeer herding and recreational activities are allowed. The area is divided into three zones (A, B and C), access to each of which can be 'closed' by SSC in conjunction with launch activities. Zone C ends by the border of Norway. According to the Esrange Safety Manual, Zone C may only be used for impacts during the period from 1st October to 30th April, ref. page. 52. The manual also states that Zones B and C contain 21 shelters that are built in order to offer the local population protection during rocket launches.

Figure 3-2: Map of Esrange Impact Areas published as part of Esrange Safety Information.

The Esrange User's Handbook (the Handbook), Volume I touches on the use of the Esrange Impact Area for orbital launches: "Although any/all the downrange zones can also be used for LV stage impact(s) during orbital launches, there is no requirement to do so from a trajectory design perspective."

It is furthermore stated at point 3.3.4 on propulsive landing of the Esrange User's Handbook Volume IX: "Esrange Space Center will have the capability to host test flights of reusable launch vehicles from LC-3 beginning in 2022. Pad LC-3B is specifically intended for the launch and landing of vehicles that will perform propulsive landings. The large impact area (5,200 km2) downrange from LC-3 could also be used as a landing area."

Restricted airspace is established from ground to unlimited altitude (GND/UNL) above Esrange ground impact area and activated when needed.[13]

3.2.4 Restrictions on operations

We have not been able to identify any limit in the total permitted orbital launches per year from Spaceport Esrange, or any restrictions related to time of day. There is however a local

13 AIP Sweden ENR 5.1-5, ref. ES R01 and ES R01A.

agreement in which SSC *tries* to refrain from launching in September due to public safety reasons, but nothing formally prevents a launch taking place in the month of September.[14]

3.3 Operations and planned launches at Spaceport Esrange

3.3.1 Information provided from SNSA and SSC

In the information provided to CAA Norway in October 2024 SSC has stated the following:

- FAA Part 450 will be used.
- No flight safety analyses in accordance with FAA Part 450 have been done.
- Two possible launch azimuths are depicted, respectively on 346° and 350°, in the model safety analyses.
- Different trajectories are suggested: lofted and direct, without any specificities to the impact on risk.
- What will be deemed a nominal flight.
- All trajectories from Esrange will include a dogleg manoeuvre.
- No trajectory will pass over the city of Tromsø.
- When a launch vehicle crosses into Norwegian territory, it will have an altitude of approximately 80 km.
- Spent stage 1 boosters will fall into Greenland/Norwegian Sea southwest of Svalbard. Payload fairing halves will fall in the same region.

The information provided includes a model safety analysis done in 2018/2020 for two possible launch vehicles, called launch vehicle 1 (LV1) and launch vehicle 2 (LV2). No details of the launch vehicles are given other than: LV1 "is a small sized, two stage, liquid fueled, with 603 kN thrust at liftoff and ~500 kg payload (commercial satellite)"; and LV2 "is a small sized, two stage, liquid fueled, with 189 kN thrust at liftoff and ~150 kg payload (commercial satellite)". The analyses are made according to FAA Part 417.

We will not go into detail on all aspects of the information received in connection to the model safety analyses, only elements that are of particular importance in relation to the issues reviewed in this report.

3.3.2 Safety Policies for Spaceport Esrange

According to Esrange User's Handbook Volume II Safety, SSC has – in accordance with Swedish law – ultimate responsibility for the safety of all activities at Esrange Space Center. Any activity to be performed at Esrange must be approved by Esrange Safety Board.

Specific requirements that must be met when implementing SSC' safety policy are described in the Esrange Safety Manual[15]. SSC has, according to the Handbook, defined processes and requirements for safe operations of all types of operations at Esrange, including orbital launch. Furthermore, it is stated on page 8 of the Handbook: "All range users must supply SSC with information regarding trajectories, dispersions, failure modes and debris catalogs in sufficient detail for SSC to perform a pre-requisite Flight Safety analysis. After sufficient documentation

[14] *Esrange User's Handbook,* Volume IX, page 9-10, see also page 30 re. launch cadence.
[15] https://sscspace.com/uploads/Esrange-Safety-Manual.pdf

has been provided, the Esrange Flight Safety Officer (FSO) will prepare a Flight Safety Plan for presentation to and approval by the Esrange Safety Board."

Quantitative safety requirements for flight safety are presented on page 9 of the Handbook: "SSC employs quantitative safety limits to determine acceptable risk levels for mission. These levels are typically in line with internationally recognized standards for safety."

Safety policies specific to orbital launches are described at pages 16-18 of the Handbook. Of the safety policies mentioned here, we have noted the following:

- "For each orbital mission to be conducted at Esrange, SSC will perform a full safety analysis (including both Ground Safety and Flight Safety) which will require significant input from the Launch Service Provider."
- "All orbital launches from Sweden will require authorization by Swedish Authorities. In order to obtain approval for an orbital launch, SSC (as the launch site operator) will need to apply for a launch license, together with the Launch Service Provider. As part of the license application, a safety analysis will need to be included."
- "The range user must submit all required safety review documentation to the SSC Range Safety Office no later than 6 months before the anticipated launch date."
- "Flight Termination System report, according to the Esrange FTS approval process (final version 4 months prior to launch). Any independent safety analysis can also be shared with SSC as part of the review documentation."
- "Both Ground Safety and Flight Safety analyses must be performed by SSC to ensure that the mission fulfills the requirements in the Esrange Safety Manual and other applicable regulations."
- "SSC will perform a Flight Safety analysis based on the range user's input. This analysis will be based on Swedish Flight Safety Authority methodology. The result of the Flight Safety analysis will then be compared to the risk limits defined in the Esrange Safety Manual. A Flight Safety Plan (...) will be written for each orbital launch, based on the Flight Safety analysis. The Flight Safety Plan must be approved by the Esrange Safety Board."
- "The on-board Flight Termination System must be compatible with the Esrange ground systems and meet the requirements stated in RCC 319-14 for design, performance, testing, analysis and documentation of the FTS."
- "The range user shall coordinate with the ESC Range Safety Office to determine the flight termination criteria during flight. The flight termination criteria shall address the following:

    1 Valid data shows the vehicle violating a defined Flight Safety limit

    2 Vehicle performance or location is unknown, the vehicle is capable of violating a defined Flight Safety limit, and

    terminating flight would mitigate the risk

    3 Orbital launch vehicles not capable of achieving a minimum acceptable orbit

    4 Gross trajectory deviation or obvious erratic flight rendering the vehicle uncontrollable

5 Other mission-specific conditions, as defined by the ESC Range Safety Office"

- "The ESC Range Safety Office will be responsible for Ground Safety during countdown operations and Flight Safety from lift-off until all vehicle components have either impacted the surface of the Earth or been injected into orbit."
- "Orbital launches from Esrange Space Center will result in restricted access to certain areas, both for personnel working inside the (fenced) Base Area as well as the general public in various areas around the base."
- "SSC is responsible for range clearance prior to a launch. This involves restricting public air, land and sea traffic."

The Esrange Safety Manual (ESM) was last updated 9th November 2023, as far as we can understand based on the change record, in order to take into account orbital launches from Spaceport Esrange. It is stated in point 2.5: "SSC recognizes that not all requirements are applicable to every operation, and therefore the requirements can be tailored to match the actual requirements of the particular project or campaign." A process for waivers is described in the ESM.

The risk criteria to be met are established in the ESM, and the relevant criteria is shown below:

C1-Public
Page 49
SCIENCE-60-4208 ver 10.0
Esrange Safety Manual

6.2.1 Public Risk

Probability of Casualty (Pc) for individuals shall be below 1×10^{-6}.

The Expectation of Casualty (E_C) shall be less than or equal to 1.49×10^{-4}.

> For example, if the assessed risk falls between 100×10^{-6} and 149×10^{-6}, it would be rounded down to 1×10^{-4} and thereby satisfy the FAA criterion.

The probability of hitting an aircraft (Pi) with debris capable of causing a casualty shall be below 1×10^{-6}.

6.2.2 Mission Essential and Critical Operations Personnel Risk

Probability of Casualty (Pc) for individuals shall be below 10×10^{-6}.

The Expectation of Casualty (E_C) shall be below 300×10^{-6}.

6.2.3 Impact Risk

The probability of spent stages, experiment bodies or other vehicle debris impacting on protected property areas shall be below 1×10^{-3}.

During activities utilizing the Esrange Impact Zone, the probability of spent stages, experiment bodies or other vehicle debris impacting outside Esrange Impact Zone shall be below 1×10^{-1}.

Figure 3.3: Esrange Safety Manual, ver. 10.0, 16th November 2023.

Furthermore, it is stated that there may be additional mission specific requirements obtained in the flight permission.

In a presentation CAA Norway received from the Swedish Government 20th February 2023, SSC has stated "The Esrange risk criteria are based on Federal Aviation Administration (FAA) part 450 Launch and Reentry Licence Requirements, which are used in all US launch ranges and for US launch service providers launching from outside the US. Several US launch ranges are surrounded by areas that are densely populated, so the risk criteria are considered to be very conservative when used by Esrange Space Center."

3.3.3 Information in Esrange User's Handbook Volume IX Spaceport

Other information in Esrange User's Handbook Volume IX Spaceport relevant for the planned operations:

- "A launch vehicle cannot operate in a shared airspace with aircraft and other flying vehicles. The airspace north of Esrange Space Center will be closed (all the way to the borders with Norway and Finland) for every launch attempt. Before exiting Esrange-controlled airspace, launch vehicles must attain an altitude sufficiently above air traffic flight levels."
- "There cannot be any planned impacts on foreign nations without agreements in place. Impacts near populated areas (including oil rigs) shall also be avoided."
- "Fig. 5 shows the allowable impact locations as a function of downrange distance and azimuth. Green areas indicate where a planned impact can be allowed, whereas red areas indicate where planned impacts are anticipated to be forbidden."

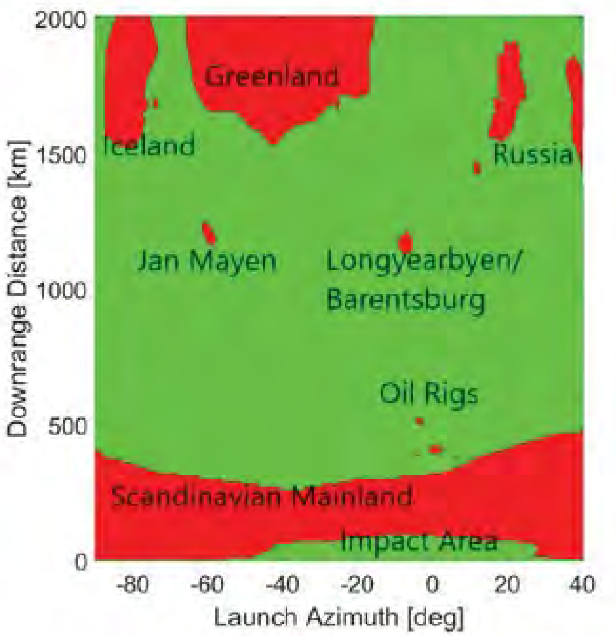

Fig. 5 - Figure showing the allowed locations for a planned impact (in green)

Figure 3.4: From Esrange User's Handbook Volume IX Spaceport, page 9.

- "Orbital launches from Esrange must follow the risk criteria specified in the Esrange Safety Manual (ESM). (...) What this means for a specific launch vehicle must be evaluated in a Flight Safety Analysis. Possible additional constraints may also need to be applied to the trajectory to satisfy the risk criteria. Since the risk numbers are based on probability of failure, the restrictions imposed on an individual type of launch vehicle may become less stringent after two successful missions."

During a launch campaign "SSC will also offer Launch Team support, meteorological support and make Range Operations personnel available to support the Launch Service Provider (LSP) during each campaign. SSC is responsible for range clearance prior to a launch. This involves restricting public air, land and sea traffic. This includes Esrange Space Center, the downrange impact areas, NOTAMs (Notice to Airmen), NOTMARs (Notice to Mariners), public radio announcements etc."

Furthermore: "SSC will perform launch vehicle tracking and receive flight telemetry data via antennas based at Esrange Space Center and downrange stations (e.g, Svalbard). This also includes initiation of the Flight Termination System in the event of anomalies outside of the required flight safety requirements."[16]

3.3.4 Launch azimuths

In the material CAA Norway received from SNSA in October 2024, two possible launch azimuths are depicted, respectively at 346° and 350°. The model safety analysis done in 2018/2020 are based on these azimuths. See chapter 5.2 for illustrations of these launch azimuths.

As far as we understand, all azimuths between 346° and 350° are not ruled out as possible launch azimuths. SSC has clarified in writing, in material received from the Swedish Government on 28 February 2023, that "The chosen flight path gives the minimum time over populated areas. The population density is very low below the flight path."

The information given to CAA Norway as part of this process differs somewhat from the information published in *Esrange User's Handbook*, Volume IX, Spaceport:

"The primary constraint for the initial flight azimuth is the Esrange downrange impact area. This would mean an initial azimuth of between 320° and 020°. However, a reliable launch vehicle without any planned impacts on land can apply for other azimuths. Each proposed trajectory will be assessed according to the defined risk constraints."

Figure 3-5: From Esrange User's Handbook Volume IX Spaceport, page 8, showing azimuths between 320° and 020°.

Furthermore, the Handbook states: "Large parts of most trajectories will be over sparsely populated areas, including inhabited areas within the Esrange downrange impact zone. The

[16] *Esrange User's Handbook*, Volume IX Spaceport, page 28.

largest settlement that lies within the range of possible trajectory azimuths is the Norwegian town of Tromsø, situated at a distance of 220 kilometer and 337° direction from LC-3. Depending on the launch vehicle, doglegs to avoid Tromsø might be necessary in order to meet the required risk criteria."

In a presentation given by SSC at ICAO NAT workshop on 13th and 14th May 2024 about the integration of new entrants into North Atlantic airspace, SSC presented as a possibility two different launches, a more direct trajectory with two upper stage burns and a lofted trajectory. The so-called direct trajectory is given an azimuth of 337° while the more lofted trajectory seems to be at an azimuth of 346°.[17]

3.3.5 Nominal flight/ termination

The material received depicts what would be considered a nominal flight, i.e. the sector that a nominal flight could traverse as part of a nominal launch, for example launch vehicle LV1. Due to the importance of clarity on what the impacted areas are, the information received from SSC is included in this report. The following illustration shows an orbital launch at an azimuth of 346°:

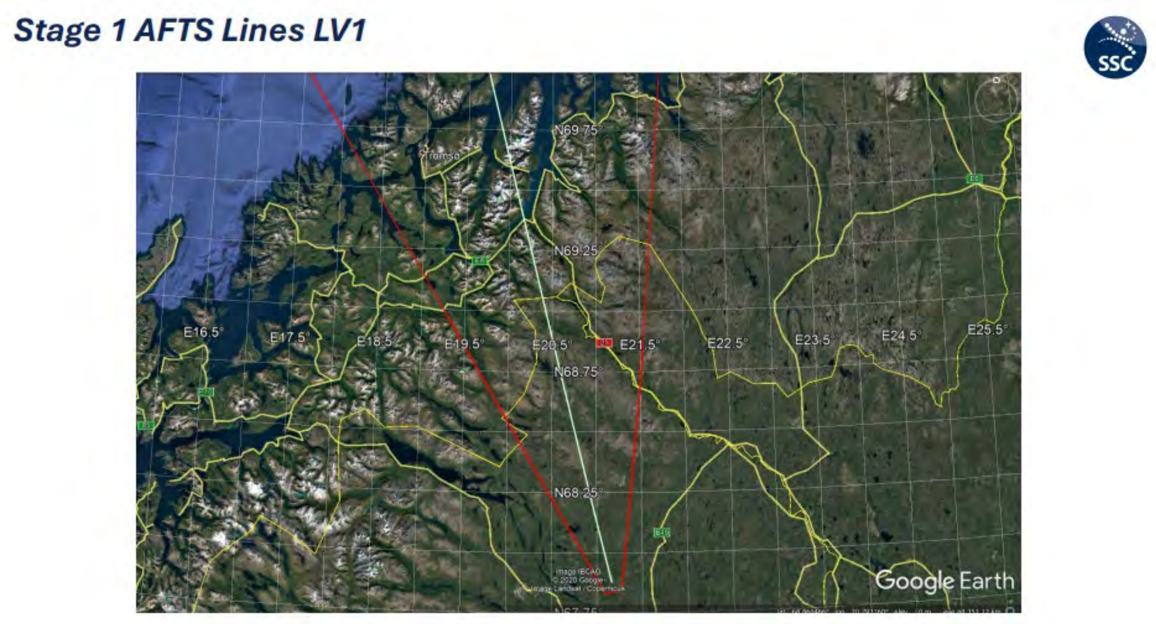

Figure 3-6: Figure part of PowerPoint presentation received from SNSA 25th October 2024.

Esrange Safety Manual point 6.5.7.5 states the following flight Termination Criteria:

1. Flight termination is required when valid data shows that the launch vehicle has or will violate a flight termination boundary.
2. Flight may be terminated as a result of gross trajectory deviation or obvious erratic flight. This action may be taken if, in the judgement of the FCO, further flight is likely to increase the hazard potential.

17 https://www.icao.int/EURNAT/Other%20Meetings%20Seminars%20and%20Workshops/NAT%20Workshop%20on%20New%20Entrants%20Integration%20(2024)/NATWKSCSO%20PR05%20SWE%20Swedish%20Space%20Corpn.pdf

3. Actions to be taken when having loss of data, such that the Flight Control Officer (FCO) cannot certify vehicle performance within Flight Safety limits, are specified in the Flight Safety Operation Plan for each particular mission.
4. An orbital launch vehicle not capable of reaching a minimally acceptable orbit.
5. Other flight termination criteria may be enforced due to the uniqueness of a particular mission. These criteria shall be documented in the Flight Safety Operation Plan.

3.3.6 Altitude

In information CAA Norway received from the Swedish Government on 28th February 2023, the launch vehicle is described to be at a height of 70-120 km when passing into Norway. The material received in October 2024 states that when a launch vehicle crosses into Norwegian territory, it will have an altitude of approximately 80 km. The altitude will depend on launch vehicle, trajectory and payload mass.

In the Esrange User's Handbook Volume IX Spaceport page 8 it is stated: "A launch vehicle cannot operate in a shared airspace with aircraft and other flying vehicles. The airspace north of Esrange Space Center will be closed (all the way to the borders with Norway and Finland) for every launch attempt. Before exiting Esrange-controlled airspace, launch vehicles must attain an altitude sufficiently above air traffic flight levels."

3.3.7 The launch vehicles

Thus far SSC has announced two partnerships with space transportation companies to launch from Spaceport Esrange. Firefly Aerospace, a U.S. Company and its Alpha rocket[18], and Perigee Aerospace, a South Korean company and its Blue Whale 1 rocket[19].

As part of its consultation process for the Report, CAA Norway sent letters to Perigee Aerospace and Firefly Aerospace requesting information about inter alia the orbital launch vehicles, testing, licensing, trajectories, reentry, mishap plan and payload. Due to regulatory restrictions, Firefly Aerospace is only permitted to share publicly available information about the Alpha launch vehicle and referred us to their website. Perigee Aerospace did not furnish us with any information about Blue Whale 1.

The following information is therefore taken from publicly available information on the space transportation companies' own websites.

Table 3.1: Publicly available information on the rockets Blue Whale 1 and Alpha.

Company	Perigee Aerospace	Firefly Aerospace
Country	South Korea	USA
Rocket name	Blue Whale 1 (BW1) [20]	Alpha
Total weight	19.8 tons	54.1 tons
Weight of payload	150-170 kg into a 500km Sun-Synchronous orbit	630 kg into a 500 km SSO 1030 kg into a 300 km LEO
Overall length/Fairing diameter	21 m / 1,6 m	29,48 m / 2,2 m
Propellant	Methane and liquid oxygen	RP-1 and liquid oxygen

[18] https://sscspace.com/ssc-and-firefly-to-launch-satellites-from-esrange/
[19] https://sscspace.com/swedish-south-korean-partnership-take-satellites-to-space/
[20] https://perigee.space/mission/

Engines and structure	Engines: Powered by nine "Blue 1S" main engines and a single "Skyblue" upper-stage engine. Structure: Constructed mainly from high-strength and lightweight carbon composites.	Engines: The first stage is powered by four Reaver engines, while the second stage uses a single Lightning engine1. Both engines utilize a tap-off cycle. Structure: Constructed from lightweight carbon fiber composites
	Two stage	Two stage
Previous launches	None	5: • 3rd July 2024 (success) • 22nd December 2023 (Partial success, with the second stage failing to perform its circularization burn) • 14th September 2023 (success) • 1st October 2022 (partial failure because satellites deployed into a lower than intended orbit) • 2nd September 2021 (terminated)
First planned launch from Esrange Space Center	2026/2027	2026/2027

SSC has stated publicly that the first orbital launch from Spaceport Esrange will not be until 2026/2027.

More information on the Alpha rocket can be found in the Payload User's Guide:
https://fireflyspace.com/wp-content/uploads/2024/10/Alpha-PUG-5.0.pdf

3.3.8 Payload and orbit details

The launch service is intended for satellites weighing up to 1000 kg, with a primary focus on micro and mini satellites. SSC aims to offer rideshare opportunities for CubeSats and smaller payloads. This service will enable orbits suitable for sun-synchronous, polar low Earth orbit (LEO) satellites.[21]

[21] https://sscspace.com/services/science-launch-services/satellite-launches/

4. Swedish System for Approvals and Oversight

4.1 Consultation with Rymdstyrelsen

As part of preparing the report for this investigation, CAA Norway asked The Swedish National Space Agency (SNSA) on 21st June 2024 for the following information:

- Approvals which Esrange Space Center has been granted, in accordance with Lag (1982:963) om rymdverksamhet § 3, including any new approvals for the planned orbital launches.
- Which regulations and standards will be used for regulating the orbital launches from Esrange Space Center, and a description of the approval process.
- The risk criteria to be used for the assessment of orbital launches from Esrange Space Center.

In a meeting between Rymdstyrelsen and CAA Norway on 2nd October 2024, SNSA gave a presentation which included information on the licencing process for orbital launches. The information provided looked similar to information CAA Norway received from the Swedish Government 28th February 2023, and consisted of:

- A paper from SSC dated 20th February 2023 (ref. SSCDOC-4-44) with the title Flight Safety and Licensing Process – one page
- Appendix 1: PowerPoint with the title Esrange Flight Safety Analysis and Licensing Process
- Appendix 2: Explanation to slides from appendix 1

On the day following the meeting on 2nd October 2024, CAA Norway sent an email to SNSA, that included copies of the information received the previous year and asked that updated versions of the documents to be sent to CAA Norway. Updated information regarding the flight safety information was received on 28th October 2024, but none in relation to the approval process. (Flight safety information is handled in chapter 7.)

The report is therefore, as far as approvals and supervision are concerned, based on the information received on 28th February 2023.

4.2 Licensing process

According to the information received, under current legislation, SSC is obliged to apply for a permit for conducting orbital launches from Esrange. In Esrange User's Handbook Volume II Safety, it is stated, "SSC (as the launch site operator) will need to apply for a launch licence together with the Launch Service Provider", ref. page 16.

Esrange User's Handbook Volume IX Spaceport, states under point 4 Licensing:

"All space activities to be performed in Sweden by non-governmental entities (including commercial companies) require a permit from the Swedish government. Approved permits will identify the scope of the authorized activity, and any associated limitations. The Swedish government retains the right to withdraw previously approved permits if a licensee deviates from any stipulated obligations.

The Swedish National Space Agency (SNSA) is the responsible government entity for reviewing applications to conduct space activities, for coordinating with other agencies and authorities affected by the applications, as well as presenting the applications to the Swedish government. SNSA also acts as the control agency for organizations granted permits and is obliged to notify the government on any violation of the law."

SSC and SNSA have developed a concept for a licensing process that is, as far as we understand, adapted to a new future space act. The licencing process is described by this illustration:

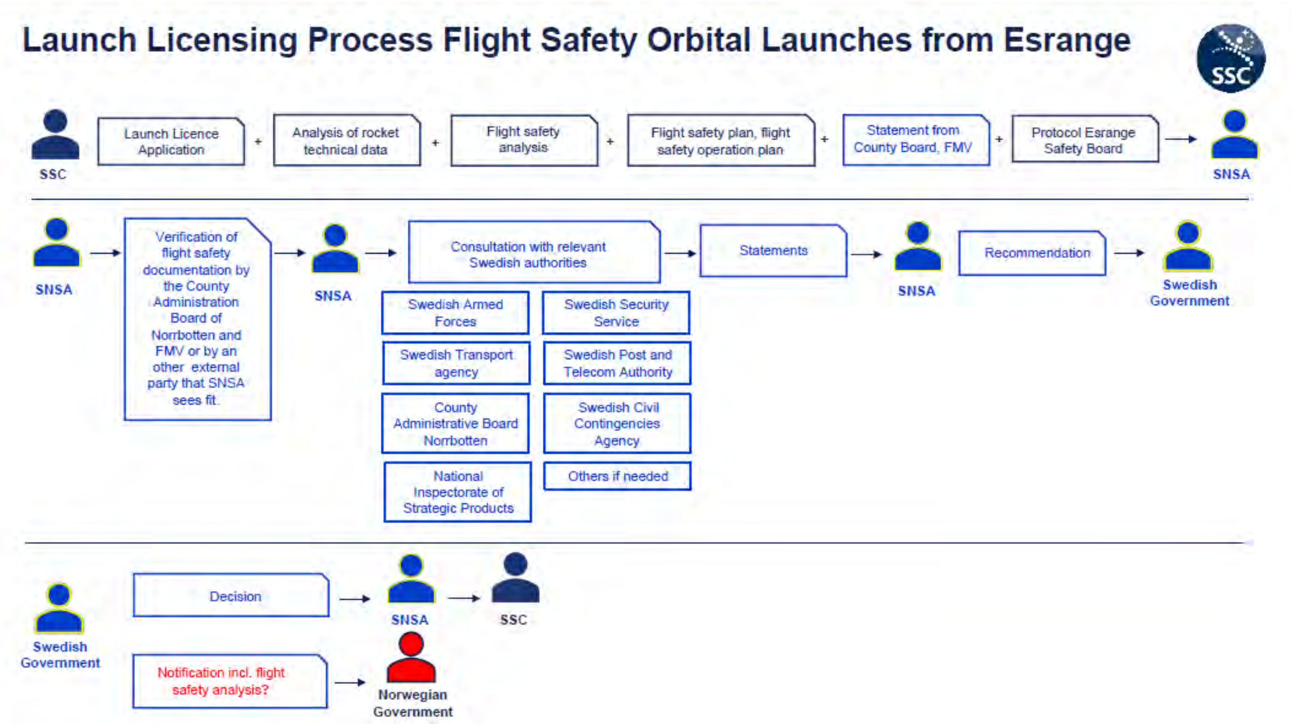

Figure 4.1: Illustration part of PowerPoint presentation received from the Swedish Government 28 February 2023.

Regarding verification of flight safety documentation, the process shows that this is to be done by the County Administration Board of Norrbotten and FMV (the Swedish Defence Materiel Administration) *or* by a third party of SNSA's choice. Following this, there will be a consultation with relevant Swedish authorities, before SNSA issues a statement. It is the Swedish Government that, after scrutiny and upon the recommendation from SNSA, validates and grants the launch to take place.

The document received also states that the "outlined licensing process includes parts requiring bi- and multilateral dialogues, mainly with neighboring countries. The document should be seen as a starting point for such a dialogue between experts and involved agencies."

4.3 Regarding the application and documentation

Esrange User's Handbook, Volume IX, Spaceport includes information on the application process:

“Commercial Launch Service Providers will simply need to provide SSC with the information required for the SNSA launch license application. As a baseline, the following information will be required:

- Technical description of the launch vehicle
- Flight safety analysis
- Description of payload (i.e., satellite/s, owner/s, country/countries of origin, mission descriptions, related launch licenses, etc.) if known at the time of admission of the launch license application, otherwise to be provided when known
- Reliability (i.e., that the applicant has the necessary technical expertise and financial conditions to carry out the identified
- space activity)
- Concept of operations and accountability between the parties involved (i.e., who is responsible for what)
- Description of the liability insurance or other similar means of financial responsibility that are planned (in accordance with the requirements of the UNOOSA Liability Convention), to protect from claims by third parties for death, bodily injury, or property damage or loss
- Compliance with ITU regulations regarding frequency allocations and orbital positions
- Description of environmental assessment and risk mitigation during flight
- Description and mitigation of any resulting space debris”

4.3.1 Timeline

According to *Esrange User’s Handbook*, Volume II, Safety, the range user must submit all required safety documentation to the SSC Range Safety Office “no later than 6 months before the anticipated launch date”, ref. 10.2. This is not fully in line with the Esrange Safety Manual Data Requirement Schedule where it is stated that for orbital vehicles, trajectory, payload and vehicle data must be submitted to SSC no later than T-9 months prior to the campaign. According to the schedule a full Flight Termination System Report shall be submitted to SSC no later than T-6 months.

According to the Handbook Volume II Safety, both “ground safety and flight safety analyses must be performed by SSC to ensure that the mission fulfils the requirements in the Esrange Safety Manual and other applicable regulations.”

Whichever timeline is correct, it gives an indication of the time planned to use on independent review of the flight safety analysis and flight safety data, taking into account that SSC will receive data from the range user most likely six or nine months before planned launch.

4.4 Regarding the flight safety operational process

The flight safety operational process is illustrated as this:

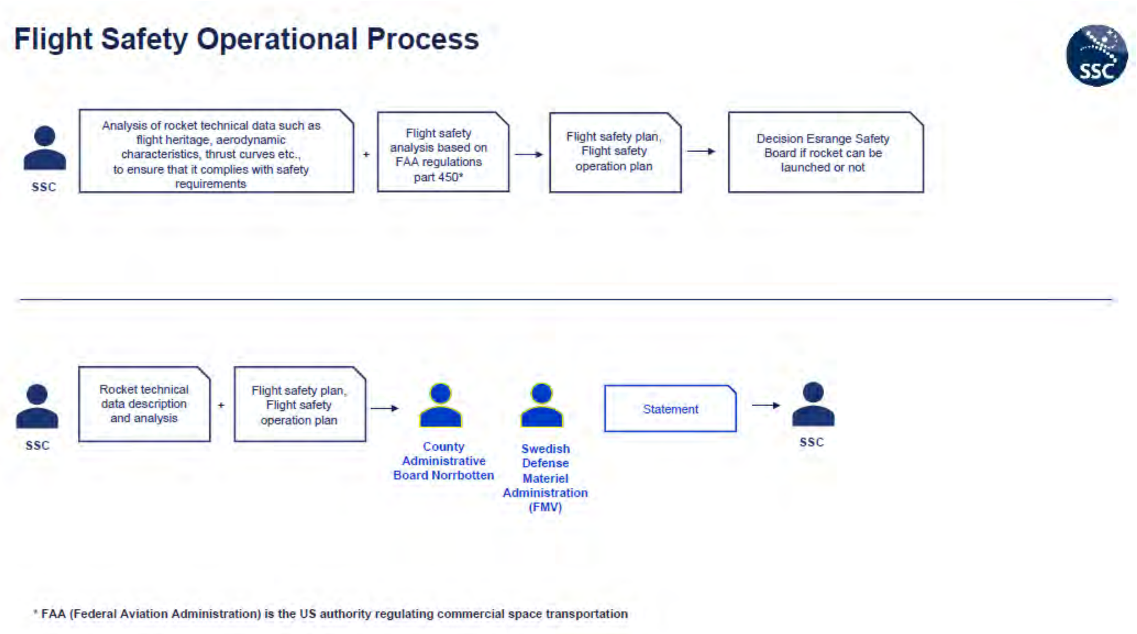

Figure 4.2: Illustration part of PowerPoint presentation received from the Swedish Government 28 February 2023.

As far as CAA Norway understand, safety-related work and review occur while the case is handled by SSC, while SNSA and the government will make other types of assessments (typically economic, insurance, considerations for Swedish defence and security policy).

The process depicted above shows that the Flight Safety Plan and the Flight Safety Operation Plan will be sent to the County Administration Board of Norrbotten and FMV (the Swedish Defence Materiel Administration), and the outcome of the review is to be sent to SSC in the form of statements. According to the first process depicted above, the case will be handled by the Esrange Safety Board and if they come to a positive decision, an application will be sent to SNSA.

In the Swedish policy paper “SOU 2021:91 En ny rymdlag” on page 326, the process is described as following: “It can be mentioned in this context that each planned rocket launch, as well as new rockets and combinations of engines and rockets, are reported by the Swedish Space Corporation to the County Administrative Board of Norrbotten County. The planned launches are described in a Flight Safety Plan that the Swedish Space Corporation submits to the County Administrative Board for review. The Swedish Defence Materiel Administration conducts a summary review of the Swedish Space Corporation’s documentation on behalf of the County Administrative Board and informs the County Administrative Board if it is deemed reasonable. The Swedish Space Corporation has developed internal safety regulations, the Esrange Safety Manual, which all actors at Esrange must follow. The final decision on whether each individual launch can be carried out is made by the Swedish Space Corporation’s internal body, the Esrange Safety Board, and is based on the County Administrative Board's opinion and its own analyses."

Based on the illustrations and information received, it seems that no independent verification or review of the flight safety analysis will take place after the application has been sent to SNSA. However, there may be a fault in the process presented, and that SNSA has meant to include a possibility to ask for third party review undertaken by outside consultants.

4.4.1 Esrange Safety Board

SSC safety policy and Esrange Safety Manual must be followed by all participants at Esrange. Any activity to be performed at Esrange must be approved by Esrange Safety Board. The Flight Safety Plan, as well as the final decision regarding whether each individual deployment can be carried out, is made by the Esrange Safety Board. The Esrange Safety Board is of vital importance to the internal review system for all activities at Esrange.

The Esrange Safety Board is presented in the Esrange Safety Manual (ESM) page 17:

"The Esrange Safety Board consists at least of the following permanent members:

1. Head of Esrange Space Center (chairperson)
2. Rockets and Balloons Department Manager (alternative chairperson)
3. Orbital Launch and Rocket Test Department Manager (alternative chairperson)
4. Safety and Launch Team Manager for R&B
5. Safety and Operations Team Manager for OLRT
6. Security Manager
7. Range Safety Officers
8. Ground Safety Engineer (senior)
9. Flight Safety Engineer (senior)

To form a quorum, at least four of the permanent members must be present.

Waivers may be granted by Esrange Safety Board provided that, by SSC, acceptable risk levels can be maintained."

Re. 4, R&B is the Rockets and Balloons department, and re. 5, OLRT is the Orbital Launch and Rocket Test department. It follows from ESM that "senior" roles are to be selected by the managers.

We have not found any information on specific requirements for how the Esrange Safety Board should be formed when reviewing safety matters relating to orbital launches.

4.5. General

In preparing the report, we have read the Swedish policy paper SOU 2021:91 *En ny rymdlag*[22], because it gives an explanation of the current permit / licensing process for orbital launches. We have noted that the paper includes extensive discussions on the question of which entity or authority should grant permits and exercise supervision over space activities under a new Swedish space act. As far as we understand, there may therefore be some changes in relation to the current system for permits and supervision under the new space act. SNSA has informed

[22] https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2021/11/sou-202191/

us that the work on the new space act is ongoing, and a new act is not foreseen to be in place until 2026.

We have not found any reference in the SSC procedures or Handbooks to the requirement according to the Norwegian Act on Civil Aviation, that in order to operate in Norwegian airspace, a permit from Norwegian authorities is required. This also applies for orbital and sub-orbital launch vehicles.

5. Consequences from Consultation with Norwegian authorities and affected parties

5.1 Purpose and scope

As part of its report into the risks and consequences of launching orbital launch vehicles from Spaceport Esrange over Norway, CAA Norway consulted affected municipalities, Norwegian authorities and other affected interest groups.

The purpose of the consultation was to gain information about the possible costs and consequences within the impacted areas in Norway of launching orbital launch vehicles from Spaceport Esrange.

CAA Norway asked the following parties for input on the socio-economic costs and other consequences for Norwegian security and societal interests as a result of any orbital launches from Sweden that pass over Norway:

- The Norwegian Directorate for Civil Protection (Direktoratet for samfunnssikkerhet og beredskap (DSB))
- Directorate of Fisheries (Fiskeridirektoratet)
- The Norwegian Ocean Industry Authority (Havindustritilsynet)
- The Norwegian Offshore Directorate (Sokkeldirektoratet)
- The Norwegian Environment Agency (Miljødirektoratet)
- The Norwegian Water Resources and Energy Directorate (Norges vassdrags- og energidirektorat (NVE))
- The Norwegian Public Roads Administration (Statens vegvesen)
- Sámi Parliament (Sametinget)
- The County Governor in Nordland (Statsforvalteren i Nordland)
- The County Governor in Troms and Finnmark (Statsforvalteren i Troms og Finnmark)
- The Governor of Svalbard (Sysselmesteren på Svalbard)
- Norwegian National Human Rights Institution (Norges institusjon for menneskerettigheter)
- Nordland County Council (Nordland fylkeskommune)
- Troms County Council (Troms fylkeskommune)
- Finnmark County Council (Finnmark fylkeskommune)
- The Norwegian Fishermen’s Association (Norges Fiskarlag)
- Norway's Coastal Fishermen's Association (Norges Kystfiskarlag

CAA Norway asked for input from the following potentially affected municipalities to map costs and consequences of the proposed activity:

- Alta Municipality
- Balsfjord Municipality
- Bardu Municipality

- Gáivuotna - Kåfjord - Kaivuono Municipality
- Hasvik Municipality
- Karlsøy Municipality
- Kvænangen Municipality
- Loppa Municipality
- Lyngen Municipality
- Målselv Municipality
- Nordreisa - Ráisa - Raisi Municipality
- Senja Municipality
- Skjervøy Municipality
- Storfjord - Omasvuotna - Omasvuono Municipality
- Tromsø Municipality

5.2 Impacts and areas affected

SSC has suggested two possible trajectories (azimuths) for launches from Spaceport Esrange, see Chapter 3.3.4. The following illustrations were prepared by the Norwegian Mapping Authority (Kartverket) for CAA Norway, based on the coordinates received from SSC, and show the two suggested trajectories (the blue line) for the two launch vehicles' trajectories over Norway.

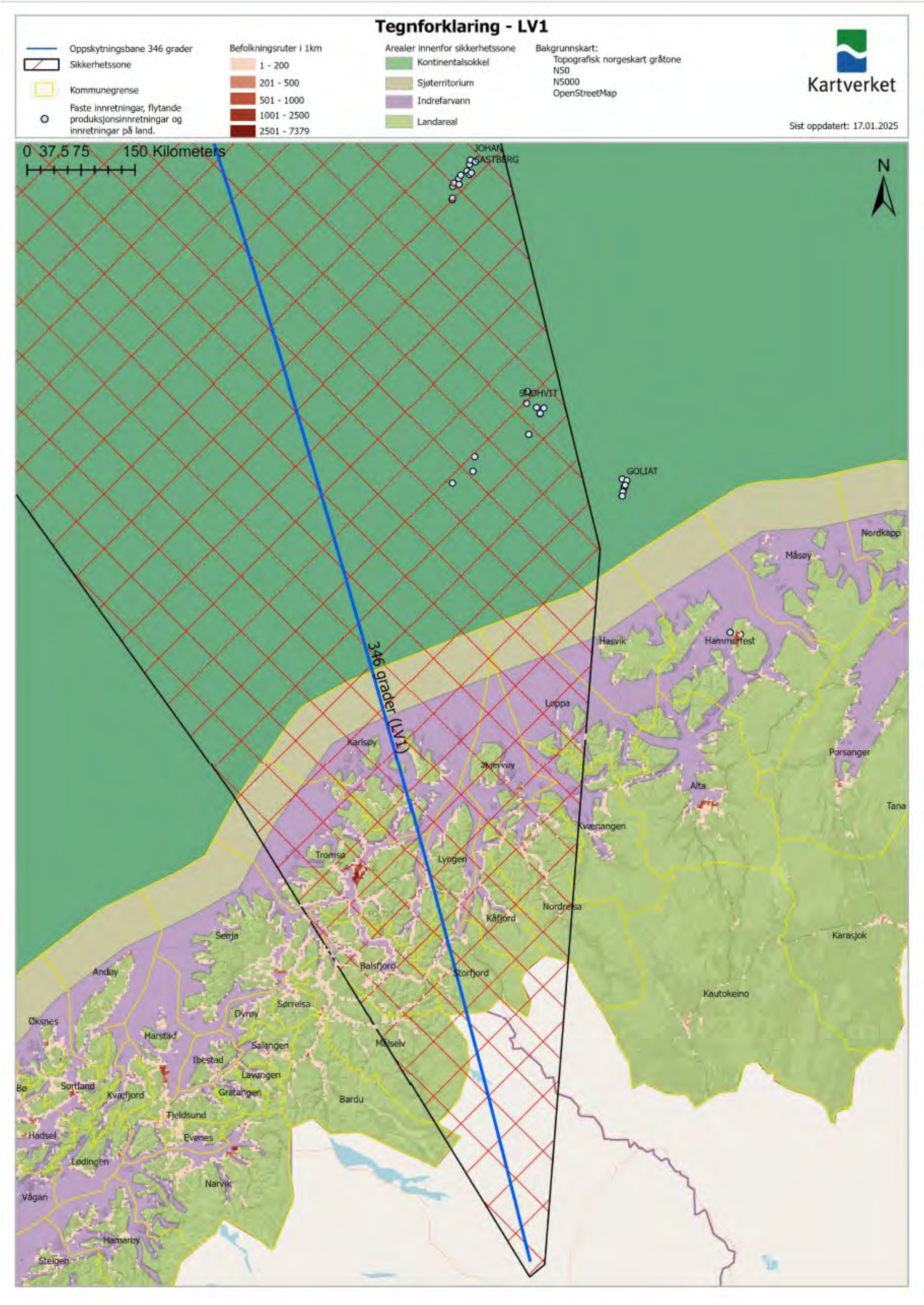

Figure 5.1: Illustration of trajectory for Launch Vehicle 1 (LV1) depicting affected municipalities.

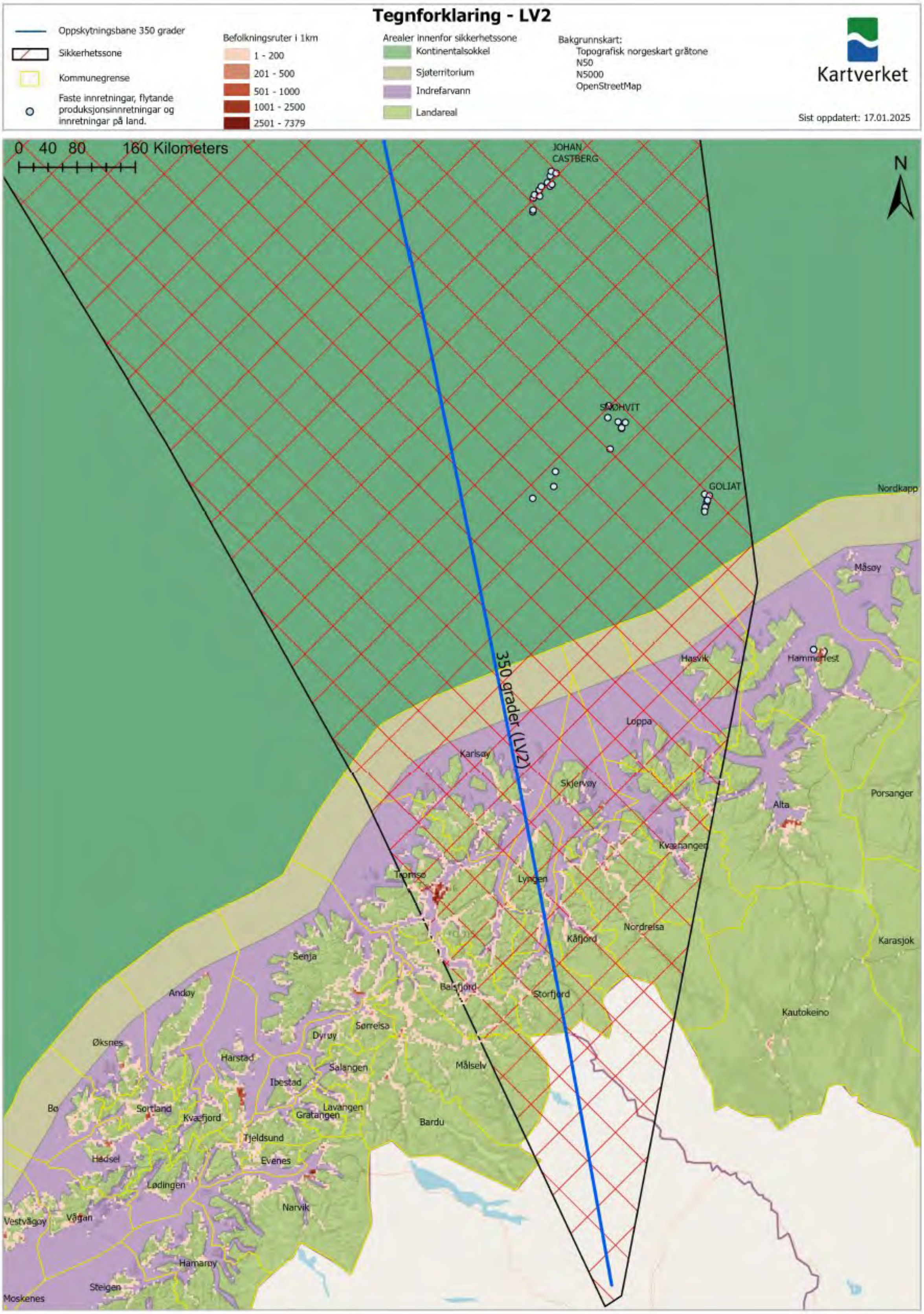

Figure 5.2: Illustration of trajectory for Launch Vehicle 2 (LV2) depicting affected municipalities.

5.3 Affected municipalities and their populations

The municipalities in the affected area have a widespread population, but the area also contains several built-up areas with relatively dense population, for example Storslett, Sørkjosen, Lyngseidet, Skibotn, Olderdalen, Nordkjosbotn, Storsteinnes, Hansnes and Skjervøy[23]. Northern Norway's largest city, Tromsø, lies in the affected area. The below illustration shows density of population in affected municipalities. The darker 'orange' depicts a more heavily populated area, while the lighter yellow depicts a sparser population.

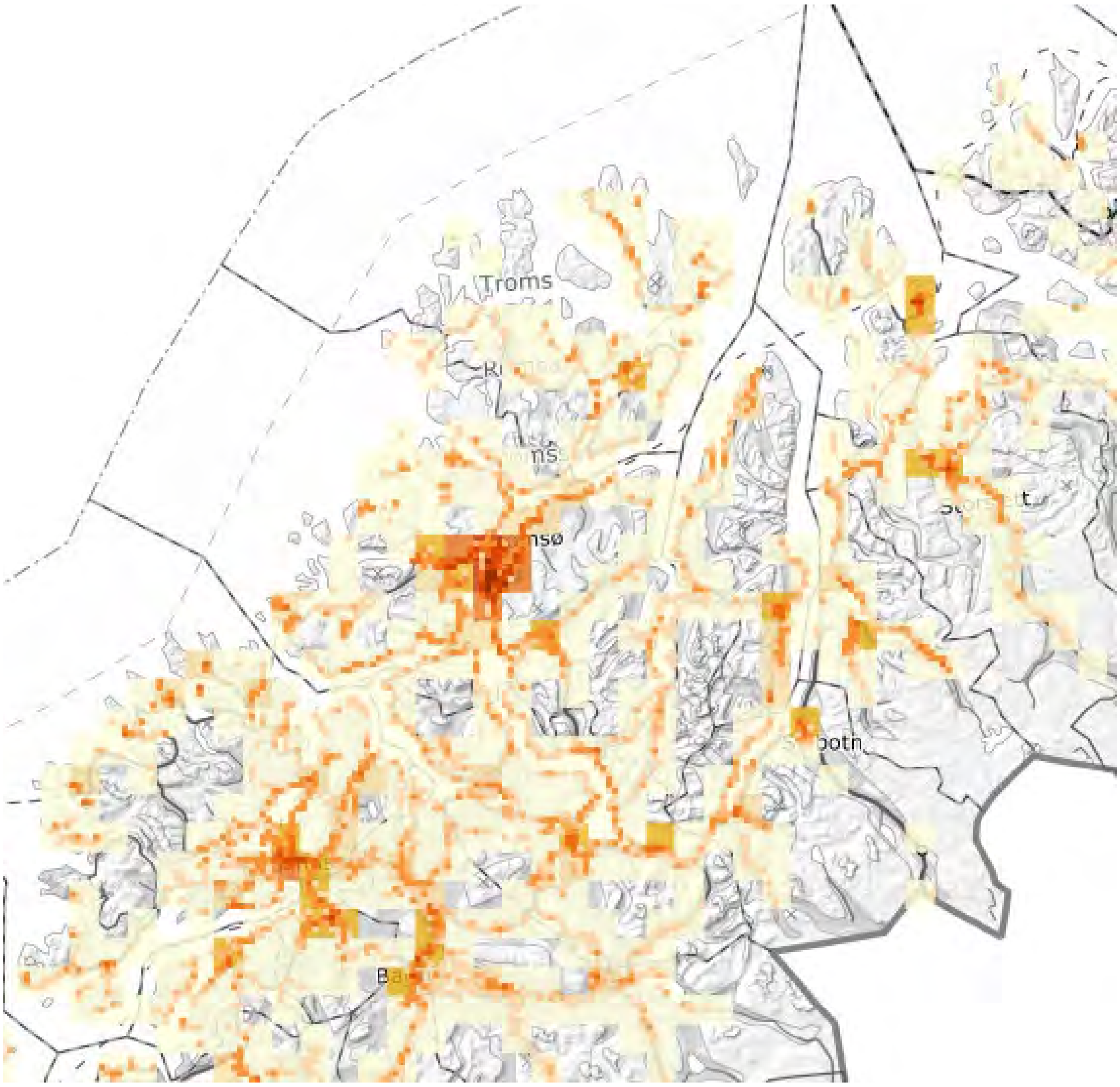

Figure 5-3: Illustration from Statistics Norway showing density of population.

The following table shows municipalities within the lines as shown in figures 5-1 and 5-2, as well as their respective population. The purpose is to illustrate the population numbers most affected by the launches from Esrange.

[23] https://kart.ssb.no/befolkning/

Table 5.1: Population as of 1st October 2024.

Municipality	Population, 31st December 2024
Tromsø	79 421
Bardu	3 961
Målselv	6 794
Senja	14 948
Balsfjord	5 595
Karlsøy	2 223
Lyngen	2 734
Storfjord - Omasvuotna - Omasvuono	1 829
Gáivuotna - Kåfjord - Kaivuono	1 955
Skjervøy	2 784
Nordreisa - Ráisa - Raisi	4 810
Kvænangen	1 131
Alta	21 877
Loppa	864
Hasvik	977
Total	**151 903**

Source: Statistics Norway (SSB)
Regional population
Updated: 25th February 2025
https://www.ssb.no/en/befolkning/folketall/statistikk/befolkning

If either planned or unplanned debris from any rockets were to fall, some of the impacted areas are categorised and summarised below in chapters 5.3.1 – 5.3.12. This information was gathered by CAA Norway as a result of its consultation for this report.

5.3.1 Tourists and the affected area

As well as permanent residents in the affected area, there are also a large number of tourists who visit in the affected area, especially in the city of Tromsø and the surrounding area. By way of example, a survey conducted by PWC regarding greenhouse gas emissions in Tromsø municipality, estimated that in 2023 there were 700,000 tourists in Tromsø from 120 different countries. Unofficially it is estimated that Tromsø municipality was visited by 900,000 foreign tourists in 2024; this number is set to increase in 2025.

The assessment of the number of tourists in Tromsø is supported by official statistics from Statistics Norway (SSB) on overnight stays. The statistics for 2024 show that the total number of hotel overnight stays in Tromsø in 2024 was 1,012,100. In December, there were 116,625 hotel overnight stays, while May was the month with the fewest hotel overnight stays, with 44,128. In addition to hotel overnight stays, according to statistics in 2024, there were 172,771 overnight stays at campsites in Tromsø. as well as overnight stays in AirBnb and other privately-owned accommodation, for which we have not found reliable statistics regarding 2024.

Although the largest tally of tourists is most evident in the Tromsø-region, there are also tourists in other parts of the affected area. For example, Storfjord recorded 60,955 overnight stays at campsites in 2024, while the number for Skjervøy was 18,994, Lyngen 18,449, Kvænangen 12,189, Nordreisa 10,439, Kåfjord 3,841, and Karlsøy recorded 14,714 overnight stays at campsites in 2024.

One of the challenges in estimating the number of people in the area is due to the fact that it is a large area with overnight stays outside hotels and campsites, where people use their own motorhomes for overnight stays, or camp in tents or private cabins.

Cruise traffic in Norway has been increasing in recent years, and the number of cruise passengers has risen. Another trend is that the season has become longer than before. According to statistics from the Norwegian Coastal Administration (Kystdatahuset), cruise traffic has doubled from 2016 to 2023. Troms county had 307 cruise ship calls in 2024, most of which were in Tromsø. In total, there were approximately 205,000 passengers on board cruise ships that called at Tromsø. It is estimated that about 198,000 of these passengers were on land in Tromsø (day visits).

In addition to cruise passengers, many of the travellers on the Hurtigruten/Coastal Route also make day visits to Tromsø, and it is estimated that this amounted to about 180,000 in 2024.

The nature of tourism in the affected area is on an all-year round basis, i.e. the tourist numbers are not constrained to a particular season. Phenomena such as the Northern Lights in winter, and the Midnight Sun in summer, attract tourists.

5.4 Impact on daily life in the affected area

Some other significant consequences to consider include the following: the impact that proposed launches from Spaceport Esrange could have on business and community life in the region. I.e. if there has to be a pause on commercial activity, and if sheltering inside is necessary, or if evacuation of a particular area is necessary.

Additionally, if an accident were to occur, infrastructure such as telecommunications and power supply can be vulnerable, depending on the location. Debris can lead to polluted drinking water if it were to land in water sources or catchment areas.

Uncertainty related to the safety risks of rocket launches can result in stress and concern within the affected areas. Fear of potential accidents can negatively impact quality of life. In Vanderberg, California, the local community reports a diminished quality of life due to the rising frequency of SpaceX rocket launches. They describe these events as "loud and disruptive," with booming noises that feel like earthquakes and, in some cases, cause property damage and panic attacks.

5.4.1 Access and emergency access to healthcare

Outside of the area located around Tromsø, most of the affected municipalities can be considered remote, some are located on an island, thus making their residents particularly vulnerable when it comes to specialist health services.

In conjunction with the launches, the airspace over a larger part of Northern Norway will be closed. Such closure will impair the local population’s capaability to receive necessary medical help in a timely manner. For example, this affects the capability of the air ambulance service to transport critically-ill patients to specialised treatment, in or outside the region, in time.

Emergency preparedness and training of personnel for municipalities need to be considered if a mishap were to occur; the economic cost related to emergency preparedness and training for affected municipalities must also be considered.

5.5 Sami interests: way of life, reindeer husbandry, fishing

The Ministry of Local Government and Regional Development (KDD) emphasised the very migratory nature of reindeer husbandry: noting that reindeer move according to the eight seasons in Sami culture. The wide scope of reindeer husbandry is of particular note, including calving areas, slaughter areas and grazing areas. Any debris may affect the reindeer food chain, because lichen, the primary food source consumed by reindeer are particularly susceptible to toxins. Lichens, due to their exceptional biology, accumulate contaminants, which can subsequently be ingested by herbivores like reindeer. Thus, there can also be economic implications if reindeer husbandry becomes unviable due to lack of unpolluted food sources.

The Sami Parliament stated that the flight paths in the event of an accident could affect parts of the reindeer grazing districts in Northern Troms and Western Finnmark. The below map from Norwegian Institute of Bioeconomy Research (NIBIO)'s mapping solution, Kilden, shows an overview of the affected reindeer grazing districts.

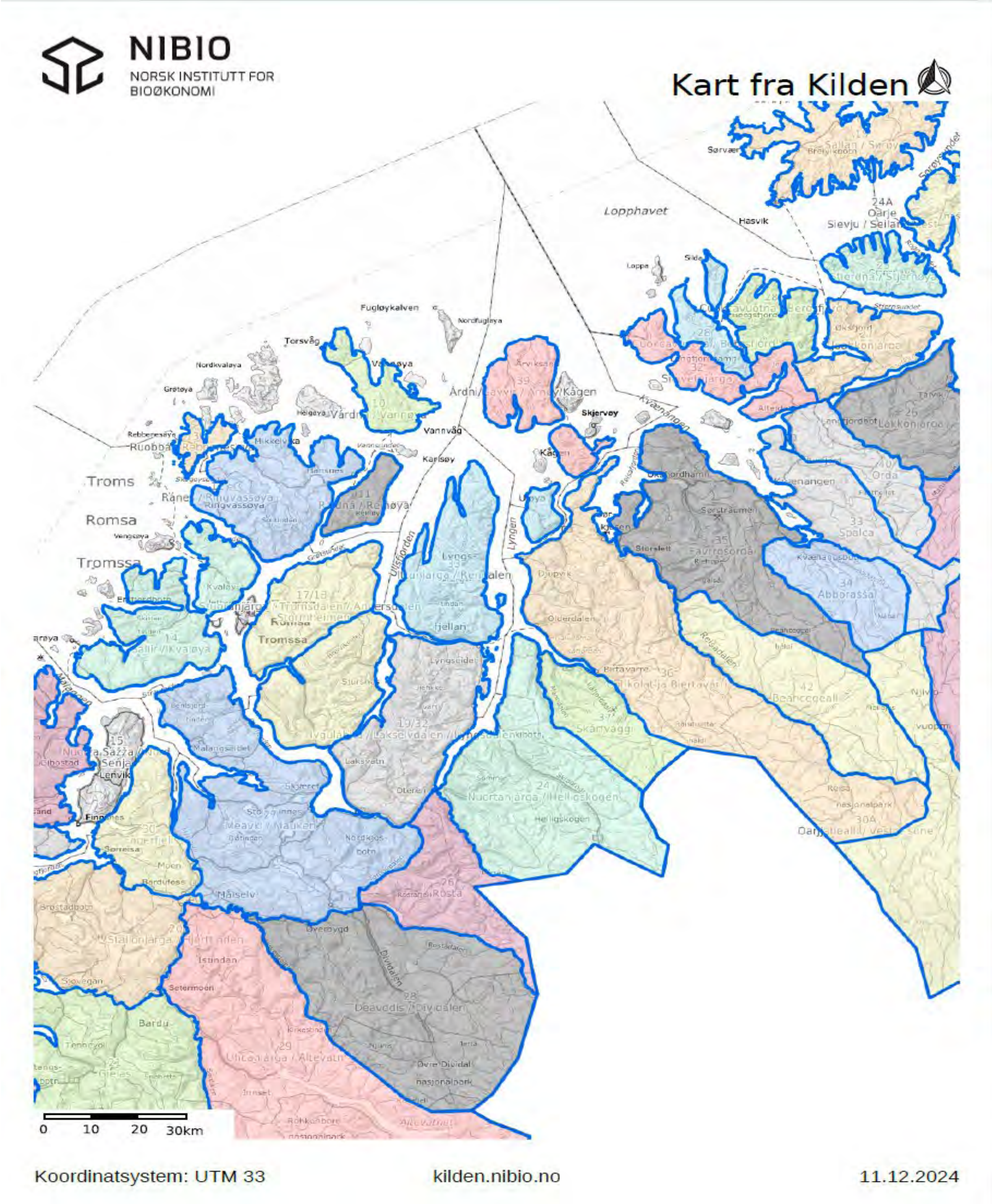

Figure 5.4: Map from Norwegian Institute of Bioeconomy Research (NIBIO)'s mapping solution, Kilden, of reindeer grazing districts.

Launches would also affect Sami fishermen in coastal fishing areas in Northern Troms and Western Finnmark. Attached is an excerpt from the Directorate of Fisheries' map service, which shows Sami fishing interests in Northern Troms and Western Finnmark. The areas with Sami fishing interests are marked in purple in the illustration below:

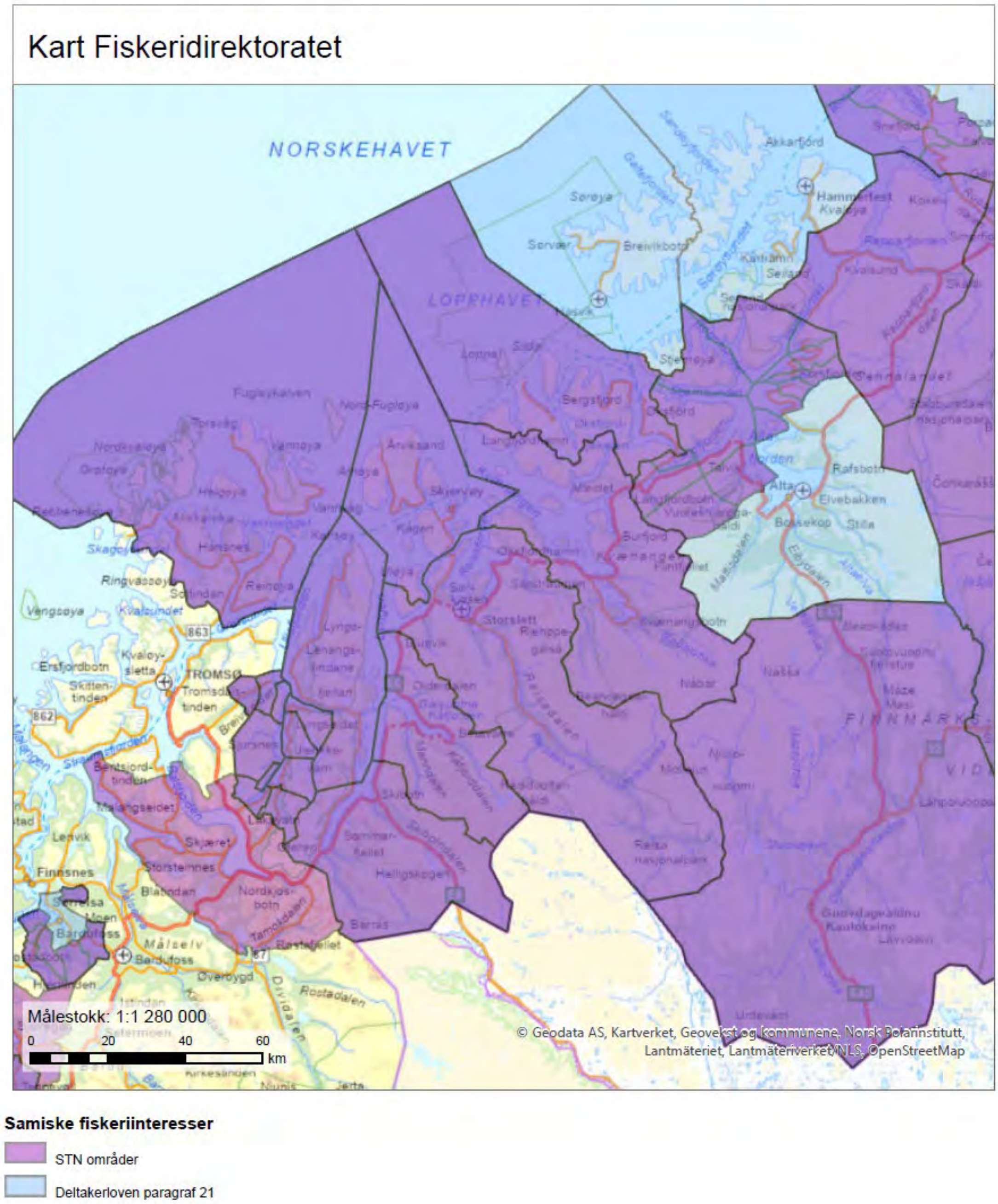

Figure 5.5: Directorate of Fisheries' map service, purple areas marks Sami fishing interests.

In addition, falling rocket debris could also pose a danger to Sami communities in Northern Troms and Finnmark more generally, as well as other Sami cultural practices such as land use: more specifically, fishing, reindeer husbandry, and the Sami way of life.

Due to the wide-spread and migratory nature of Sami land use (including reindeer husbandry), the key geographical areas related to Sami cultural practice are extremely large. As such, the impact and scope of affected cultural practice could be much wider than that which is mentioned above. It is difficult to be more exact with regard to the precise cost and consequences for Sami culture until more definite information is known, such as dates and precise flight path of any launches. Norway's obligations under the ILO Convention no. 169 on indigenous peoples and tribal peoples could also be in breach.

5.6 Environmental concerns

The extent of any environmental consequences and damage will depend on, for example, the size and content of any debris, whether it spreads over a larger area, whether there are releases of hazardous substances to the surroundings, and accessibility to the area. Rocket bodies are typically constructed from light-weight materials that can withstand extreme conditions, such as vibrations and significant temperature variations. Materials used are often aluminium, titanium, carbon composites, such as for instance, carbon fibre or stainless steel. Consequently, any resulting debris will degrade very slowly, leading to long-term persistence in nature. In addition, engines, electronic devices, adhesives, magnets and bonding agents are made of resistant materials that might be toxic or release micro-plastics into nature if released.

The affected area covers a large portion of the Norwegian alpine and northern boreal region. The vegetation in this area is characterised by scrubs, grasses, birch, herbs and lichens. The ecosystems in these environments are especially fragile and susceptible to biotic as well abiotic disturbances. This is attributed to the short growing season, low productivity, slow chemical reactions and nutrient turnover, and isolated areas. There is a high degree of endemism (a species exists only in one location), as well as a number of critically-endangered species, such as *Vannelus vannelus* (vipe/lapwing), *Distichium hagenii* (polarplanmose/Hagens Distinctive moss) and *Limosa limosa* (svarthalespove/ black tailed godwit)[24] . The cold climate slows the degradation rates of contaminants, extending persistence in the environment.

The Norwegian Environmental Agency (NEA) highlighted that factors such as the number of planned launches, expected fallout, material and chemical usage, are important factors to take into account as environmental consequences. The NEA also emphasised that the cumulative impact of increased rocket activity can have negative environmental consequences including in the form of pollutants, waste, and seabed coverage. Rocket debris hitting areas without settlements will have environmental consequences. One hazardous chemical common in certain payloads, such as satellites, is a hydrazine-based propellant, which is highly toxic and carcinogenic. [25]

5.7 Impacts on conservation interests

Some examples of environmentally significant areas affected include the protected river (Målselva), which includes anadromous fish species, and Øvre Dividal National Park and Reisa National Part, both protected by regulations. The proposed trajectories span parts of **Øvre Dividal National Park**. The national park includes the upper parts of Dividalen and borders the Swedish border and has a varied landscape with pine and birch forests, high mountains, lakes, and marshes. It has rich mountain vegetation, rare fungi and lichen species, and special insect species. Dividalen is a habitat for several of our large predators; for example the Arctic fox breeds here. The purpose of the park is to preserve a large area of inland nature with few technical interventions within its geographical area, to ensure a great variety of ecosystems, high biological diversity, sustenance of many rare species, and preservation of cultural monuments.

Reisa National Park is situated within the affected area. The national park consists of the Reisaelva river's upstream areas, and borders to the west the Käsivarsi wilderness area in Finland. Reisaelva is one of Norway's most important salmon rivers. Reindeer herding has for

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[24] Artsdatabanken (Norwegian Biodiversity Information Centre)
[25] https://echa.europa.eu/substance-information/-/substanceinfo/100.005.560 4th February 2025

many successive generations been undertaken in the areas that currently comprise the national park. There is abundant evidence of ancient Sami habitation within and near the national park. Many thousand reindeer graze in the national park each year, and even more pass through it.

In addition to the national parks, the affected area includes several protected areas:

Dividalen Landscape Protection Area is an area that has been used by Sami for generations; Sami reindeer husbandry is still practiced there to this day. Lainiovuoma Sami village has its summer settlement at Cievccasjavre. It has been proposed to expand the Øvre Dividal Pational park with this protected area.

Lyngsalpan Protected Landscape (also called Ittugáissáid) covers an area of 961 km^2 and include more than 100 peaks higher than 1,000 metres and approximately 140 glaciers. The landscape protection area constitutes an important reference for the natural sciences of glaciology and Quaternary geology.

Nordkvaløya-Rebbnesøya Protected Landscape was designated as such in order to preserve a large expanse of continuous coastline; it extends over a vast area of sea with numerous islands and islets. Its area comprises 286 km^2. The protection area is representative of coastal culture in Troms and has evidence of rich cultural traditions dating as far back as the Stone Age. In terms of the natural environment, there are significant sea-bird colonies as well as other fauna, flora and Quaternary geology deposits.

Kvænangsbotn Protected Landscape is an area of 104 km^2, characterized by Sami and Kven land use and settlement throughout history. The area is protected to preserve the integrity of the landscape, including the visible natural landscape, plant and animal life, and traces that testify to Sami and Kven use of the areas.

Navitdalen Protected Landscape is located on the west side of the Kvænangsfjord, covering 188 km^2, and is a mountain valley protected to preserve the integrity of the landscape. This includes the visible natural landscape, plant and animal life, and traces that show Sami and Kven use of the area.

5.8 Impact on Svalbard

Svalbard is remote and reliant on connectivity to the mainland, main centres and support in emergencies, such as access to hospitals and emergency services.

According to the consultation response from the Governor of Svalbard, the preparedness on Svalbard is vulnerable to major unwanted incidents and unwanted events due to its remoteness. Health emergency preparedness and emergency services are particularly vulnerable, as mainland assistance can be quickly required, and access to Svalbard is vulnerable due to weather conditions.

The marked area in LV2 extends over large parts of the land area on Svalbard. Svalbard consists of several national parks and nature reserves. Based on the legend for LV2, rocket parts could fall over several communities and inhabited areas on the archipelago. The population of Svalbard (Longyearbyen and Ny-Ålesund) as of 1st July 2024, was listed as 2,595 people. In addition, the population of Barentsburg, 340 persons.

Cruise ship traffic in Norway has been increasing in recent years, and the number of cruise passengers has risen, also in Svalbard. According to data from Kystdatahuset, Svalbard had 303 cruise ship calls in 2024. In total 67,126 cruise passengers passed through the port of Longyearbyen. In 2024, there were a total of 67,656 tourists in Svalbard, with a total of 167,714 overnight stays, according to Statistics from Visit Svalbard. When considering the total number of people in Svalbard, the number of tourists must be taken into account.

There is one regular cargo service between Tromsø and Svalbard, operated by MS Norbjørn, a combined container and general cargo ship. The ship departs twice a month from Tromsø in the winter, and three times a month between April to November. Approximately once a month the ship also calls at Ny-Ålesund.

The Governor of Svalbard recommends that local conditions and limitations in preparedness on Svalbard shall be taken into account,

5.9 Local traffic and connectivity

Many residents in the affected areas rely on local flight and marine traffic as central to their daily lives. Several island communities rely on ferries, express boats, or aircraft to travel to and from the island. Such travel includes travel for the purpose of access to healthcare.

5.9.1 Roads and road traffic

An extensive road network secures connectivity in the affected area. Any damage by debris to a road may result in long detours; in the case of some roads, there are no alternative routes.

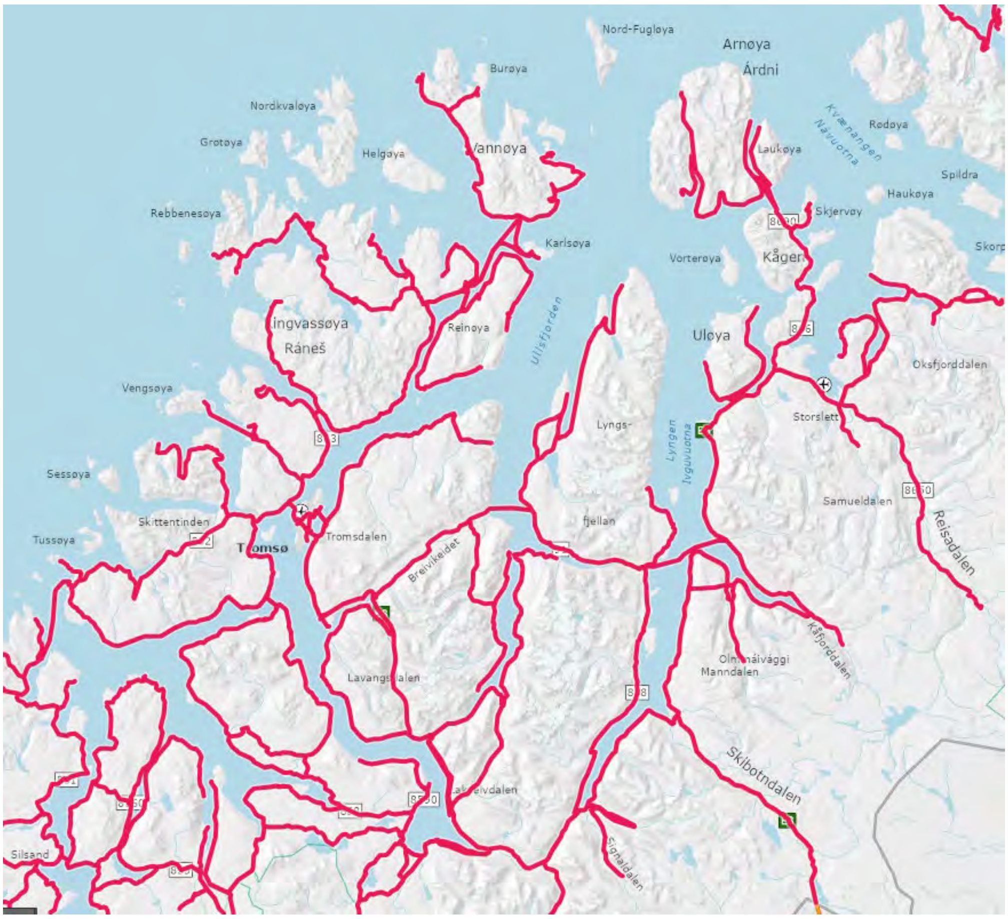

Figure 5.6: Map showing roads in the area; Norwegian Public Roads Administration

The Norwegian Public Roads Administration has traffic data for most of the roads, and these show that traffic varies greatly between different roads. On some of the smaller roads on islands, certain road sections can have traffic of 100 - 200 cars per day (annual average based on total traffic per year). Other road sections host traffic of 3000 - 5000 cars per day, and some up to 10 000 or more per day.

5.9.2 Ferries

There are a total of thirteen ferry connections in Troms and Finnmark which may be affected; all operate on a year-round basis. For some of the ferry connections, there are detour options; this however does not apply to the ferry connections that operate between islands, or between islands, and the mainland. Most of the routes have relatively short travel times (between twenty and forty minutes), and in terms of frequency, between one and twelve departures per day. Some of the routes are somewhat longer: up to two hours with one-two departures per day. The ferries in operation have varying capacities.

Table 5.2: Ferry connections, including information on passengers and cars in 2024.

Road	Ferry crossing	Passengers 2024	Cars 2024
FV7700	Bellvik - Vengsøy	11694	15415
FV7910	Mikkelvik - Bromnes	10285	11582
FV7908	Hansnes - Reinøy	37999	47897
FV7938/FV7695	Rotsund - Havnnes - Uløybukt	16375	19589
FV7944/FV8690	Storstein - Nikkeby-Lauksundskaret	37671	61919
FV862	Botnham - Brensholmen	39431	49743
FV863/FV7908	Hansnes – Karlsøy – Vannøy	56981	86931
FV882	Øksfjord - Hasvik	20232	44626
FV8012	Øksfjord - Bergsfjord – Sør-Tverrfjord	4809	10374
FV8023	Strømsnes - Kjerringholmen	14774	15656
FV8830	Korsfjord - Nyvoll	19762	21981
FV91	Breivikeidet - Svensby	167528	249883
FV91	Lyngseidet – Olderdalen	76668	141000

5.9.3 Express boats

There are seven express boat routes in Troms which may be affected. These are:

Tromsø – Skjervøy has a daily departure six days a week.

Tromsø - Lysnes (Senja) has one-two departures four days a week.

Tromsø - Finnsnes - Harstad has two-four daily departures.

Sommarøy – Tussøy – Sandneshamn has a total of eight departures over four days of the week.

Harstad – Bjarkøystedene – Skrolsvik has one-two daily departures.

Skjervøy – Kvænangen – Vorterøy has one-three daily departures five days a week.

Skjervøy – Arnøyhamn – Lauksundskaret has two daily departures.

The express boats operating between Tromsø and Harstad have a capacity of 296 passengers: these are the boats with the largest capacity. The boat operating from Tromsø to Skjervøy has a capacity of 147 passengers while the boat operating from Skjervøy to Vorterøy has a capacity of 46 passengers.

5.9.4 Local flight traffic

A launch as proposed would extend from the border in the east and outwards across the sea in the west, thus practically dividing Norway in two. There are several airports that could be affected by launches from Esrange. This particularly applies to Tromsø Airport and Hasvik

Airport, which are located within the affected area, but some surrounding airports may also be impacted. Flights from Southern Norway to/from airports in Finnmark would also be affected by restrictions. Hasvik Airport is important for connecting the island of Sørøya and the communities there to Tromsø and Hammerfest.

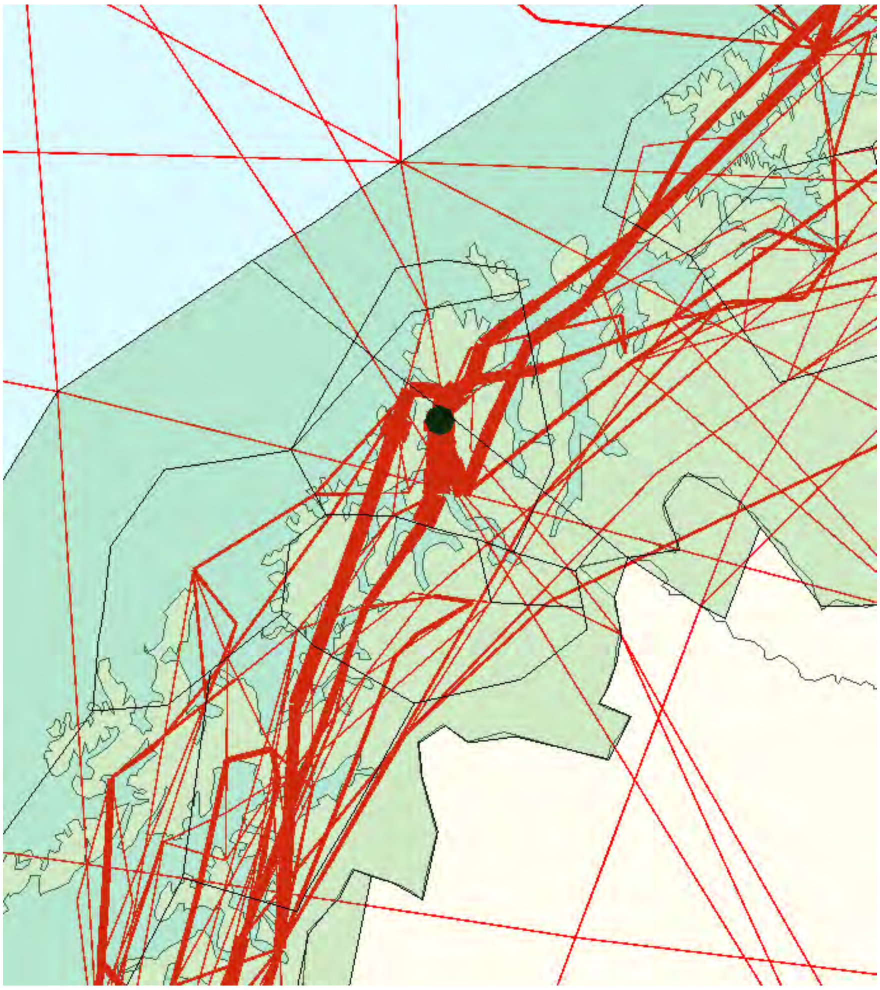

Figure 5.7: The above illustration is from Avinor Flysikring AS from 17th January 2025, and shows flights on that day to and from Tromsø Airport (marked by a black dot), and also other flights in the affected area this day. The purpose of the illustration is an example of the volume of flight traffic that would be affected by any restrictions over the course of one day.

Tromsø Airport is a central hub in the short-haul network for flights to and from Finnmark and southwards to Nordland. Cancellations and delays will therefore affect a large part of the flight schedule in Northern Norway but may also have consequential effects on other parts of national traffic. There is also a significant amount of international passenger traffic to/from Tromsø Airport. Consequently, both passenger and cargo flights, as well as the tourism industry in the entire region, is impacted if flights to and from Tromsø airport are affected. As an example, on 11th February 2025 a total of 85 scheduled flights departed from Tromsø Airport, while 88 flights were scheduled to arrive. In 2024 1,632,782 passengers travelled on domestic (scheduled) flights to/from Tromsø Airport, while 547,155 passengers travelled on international (scheduled) flights to/from the airport.

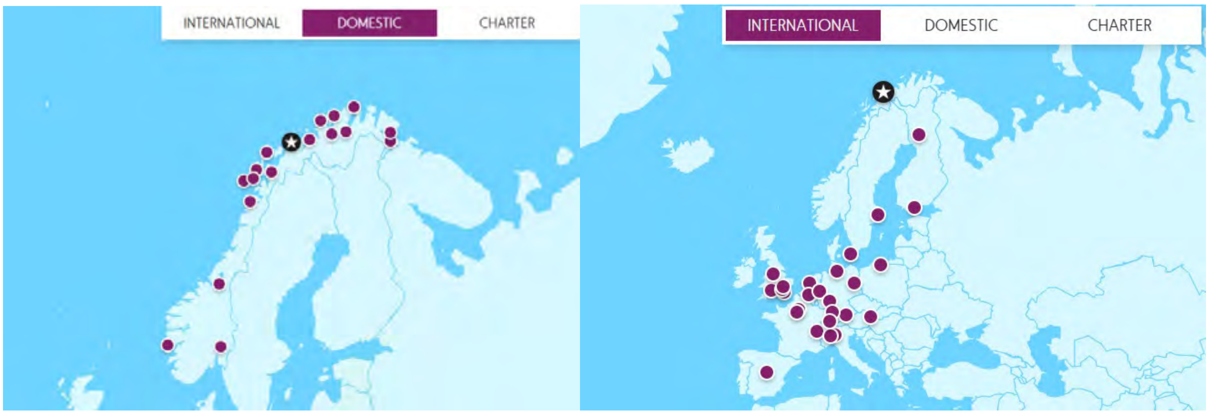

Figure 5.8: Map illustrations from *https://avinor.no/en/airport/tromso-airport/* of destinations for flights to/from Tromsø Airport.

5.9.5 Hurtigruten/Kystruten

Hurtigruten (The Coastal Express) and Havila Kystruten operates combined passenger, cargo and ferry services along the coast from Bergen in the southern part of Norway to Kirkenes in the northeastermost part of Norway. Every day a ship departs from Bergen and starts the journey to Kirkenes, and likewise a ship departs from Kirkenes and starts the journey to Bergen.

Hurtigruten has nine ships in operation that are certified for between 622 to 1000 passengers, in addition to about 75 crew members per ship. The number of passengers are normally lower than the certification, between 500 and 600.

Havila Kystruten has four ships in operation that are certified for 640 passengers, in addition to 76 crew members per ship.

In addition to its daily coastal routes, Hurtigruten operates other cruises along the Norwegian coast, typically to/from Tromsø, Finnmark or Svalbard from Oslo or Bergen.

5.10 Fisheries

Fishing and seafood constitute Norway's most important food production and are now Norway's second-largest export industry. According to the Directorate of Fisheries there are currently a total of 1,200 professional fishermen in Troms County. There are also many visiting fishermen, both in the ocean and coastal fleet, who operate in the sea areas off Troms. The outlined safety zone includes large parts of their fishing areas, which are among the most important in the North Atlantic.

In winter, there is rich cod fishing on the banks off Troms coastline, and a high density of fishing vessels. The rest of the year, fishing for cod, saithe, haddock, and Greenland halibut takes place. In recent years, herring has overwintered in the fjords of North Troms, resulting in the presence of a higher number of fishing vessels operating in the fjords. The extent of fisheries in the area is indicated in the map illustrations below. An abundance of further fisheries commerce takes place, in addition to the brief examples previously mentioned.

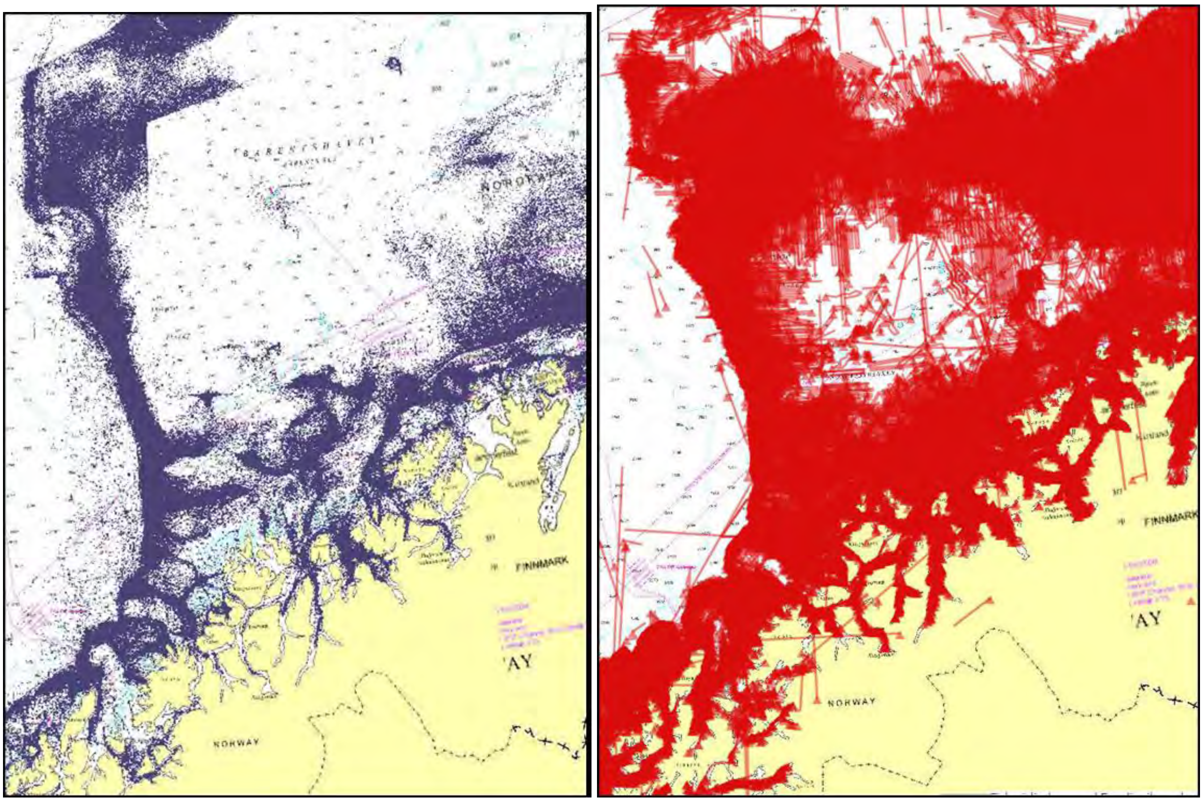

Figure 5.9: Illustrations from the Directorate of Fisheries that shows examples of fishing activity in the area.

The map illustrations above show examples of fisheries that take place within / in the vicinity of the affected area. The map sketch on the left with blue markings shows fishing activity based on position signals (AIS) from Norwegian fishing vessels over the past ten years. The map sketch on the right with red markings shows fishing gear (in this case, lines) that has been set in the area over the past ten years. The map sketches are taken from the Directorate of Fisheries' map database.

The Directorate of Fisheries provided feedback, that the affected area includes several important fishing grounds, from Malangsgrunnen in the southwest to Nordvestbanken and Tromsøflaket in the northeast, of which Tromsøflaket is by far the largest.

Fish valued at a net-worth between five and six billion NOK is landed annually in the area. The fisheries and fishing ports form the basis for a large and important fishing industry, which in turn provides many jobs locally, nationally, and in other countries. Today, there are nearly 1,000 employees in the fishing industry in Troms, as well as 1,300 indirectly employed in the county. A new impact analysis of the fishing industry was recently published by Nofima[26].

The Norwegian Fisherman's Association note that it will not be possible, from a practical perspective, to evacuate the entire outlined safety zone when satellite launches are to take place. Other parties have furthermore emphasised their concerns regarding the uncertainty of suggested launch windows.

[26] https://nofima.brage.unit.no/nofima-xmlui/handle/11250/3171659 (Only in Norwegian)

5.11 Impacts on offshore assets: Fixed oil installations

The illustrations following on the next pages show the proposed flight path for the two launch vehicles, LV1 and LV2. The affected area includes the following oil installations in the Barents Sea: Johan Castberg, Goliat and Snøhvit.

Snøhvit is a field in the central part of the Hammerfest Basin in the southern part of the Barents Sea. Snøhvit was the first field development in the Barents Sea and production started in 2007. The well stream, with natural gas, CO2, natural gas liquids and condensate, is transported in a 160-kilometre pipeline to the liquid natural gas (LNG) processing facility at Melkøya near Hammerfest.

Goliat is a field in the Barents Sea, 50 kilometres southeast of the Snøhvit field. The field is developed with a cylindrical floating production, storage and offloading facility. Eight subsea templates with a total of 32 well slots are tied-back to the offloading facility. Production started in 2016. The oil is offloaded to shuttle tankers for transport. Future gas export is planned via the Snøhvit pipeline to the liquid natural gas (LNG) processing facility at Melkøya near Hammerfest.

Johan Castberg is a field in the Barents Sea, 100 kilometres northwest of the Snøhvit field. The development concept is a production, storage and offloading vessel with additional subsea solutions which include 18 horizontal production wells and 12 injection wells. Oil will be offloaded to shuttle tankers for transport. Production is planned to start in early 2025. Investments for this oilfield, not including 2024, are in nominal values 61426 million NOK.

Figure 5.10: The illustration above shows the same illustrated trajectory for Launch Vehicle 1 (LV1) as in figure 5.1, but here shown in its entirety.

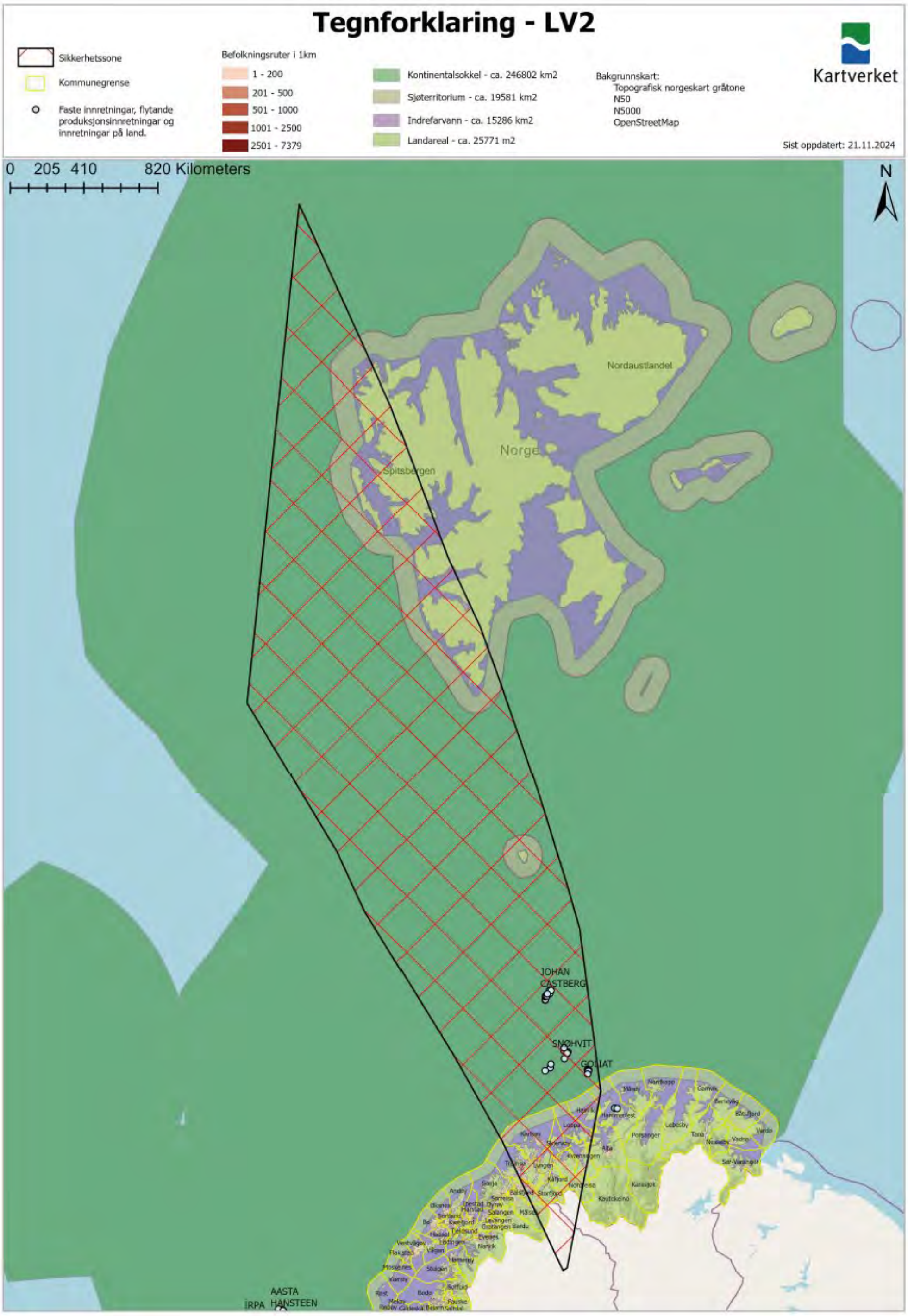

Figure 5.11: The illustration above shows the same illustrated trajectory for Launch Vehicle 2 (LV2) as in figure 5.2, but here shown in its entirety.

The Ocean Industry Authority listed the following within its areas of responsibility that could potentially be affected by the rocket launches from Spaceport Esrange in northern Sweden:

- Fixed offshore facilities
- Mobile offshore drilling unit (MODU)
- Subsea installations and pipelines
- Onshore process facilities
- Activities related to future offshore wind exploration

Both the Norwegian Offshore Directorate and the Ocean Industry Authority have expressed serious concerns about the potential for major accidents caused by falling objects or debris from rocket launches impacting offshore installations, onshore facilities, and MODUs. They stress that preventing major accidents is their top priority and find such scenarios unacceptable and emphasise the need to avoid them with high certainty.

NOD stressed that if any fixed installations offshore are at risk of being hit by parts of rockets or debris from rockets, the consequences can range from very large to extremely large, resulting in the need to shut down production and stop the export of oil/gas as well as to evacuate personnel.

The cost consequences of such a shutdown are then directly related to daily production and will be very high on a daily basis. NOD stipulate that this scenario is unwanted and should be avoided, i.e. with a high degree of certainty *not* to happen.

If impacted, the costs are directly related to daily production; costs on a per-diem basis will therefore be very high. The shutdown of oil and gas production from the fixed installations within the safety zone is estimated to result in lost revenues of approximately NOK 1520 million per rocket launch for five days. (The amount will be higher if the shutdown period in total is more than five days.) In addition, there are direct expenses of approximately NOK 184 million per rocket launch. Extra costs for the shutdown/demobilisation and startup/mobilisation (which both normally require additional resources with vessels and other equipment) are not estimated. Swedish authorities will therefore impose a total burden on oil and gas production on the Norwegian continental shelf in the order of NOK 1704 million per rocket launch (1.7 billion Norwegian kroner; 153.01 million USD[27]) if the shutdown period is five days or fewer.

5.12 Defence

The defence sector has emphasised that a launch may, depending on frequency, planned trajectory, timing, and known risks, necessitate the halting or redirecting of military activity. The paper Prop. 87 S (2023-2024), *The Norwegian Defense ledge; Long-term Defence Plan 2025-2036*[28], emphasises that the Armed Forces must have the ability to be present to establish and maintain situational awareness throughout the Norwegian vicinity. The need to maintain situational awareness in the northern areas increases up the conflict spectrum. Furthermore, task two under the Armed Forces' tasks[29] states the following: monitoring Norwegian areas of interest and the timely notifying of relevant authorities with regard to matters of significance for national and allied security. The Armed Forces, based on the information currently available, points out that there is a risk that launches may impact on the Armed Forces' ability to maintain situational awareness and operations, as well as impact their ability to transit to/from operational areas.

[27] NOK 11,11 per USD, 21st February 2024.
[28] https://www.regjeringen.no/en/dokumenter/prop.-87-s-20232024/id3032217/
[29] https://www.forsvaret.no/en/about-us/missions-and-values/missions

6. Introduction to orbital rocket launches and the associated risks

6.1 Purpose and scope

SNSA and SSC have informed CAA Norway that they plan to use FAA 450 to assess launches from Esrange Space Center. The purpose of this chapter is to give a brief introduction to orbital rocket launches and the associated risks. It explains how risk is assessed and managed according to the Code of Federal Regulations Part 450 subpart C[30]. The chapter aims to give an overview of the structure and content of FAA 450 for readers without any subject matter background, in order to understand how the various sections and analyses contribute to the complex risk calculations required for safe and compliant orbital launch operations. A more condensed overview of the requirements in FAA 450 is given in chapter 7.

6.2 Orbital rocket launch

Orbital launch vehicles launch vertically in order to reduce the time spent in the dense lower atmosphere, where air resistance is highest. As the rocket ascends and reaches thinner atmospheric layers, it begins a gradual pitch maneuver known as a gravity turn which helps the rocket shift from a vertical to a more horizontal trajectory, crucial for building the horizontal velocity needed to achieve orbit.

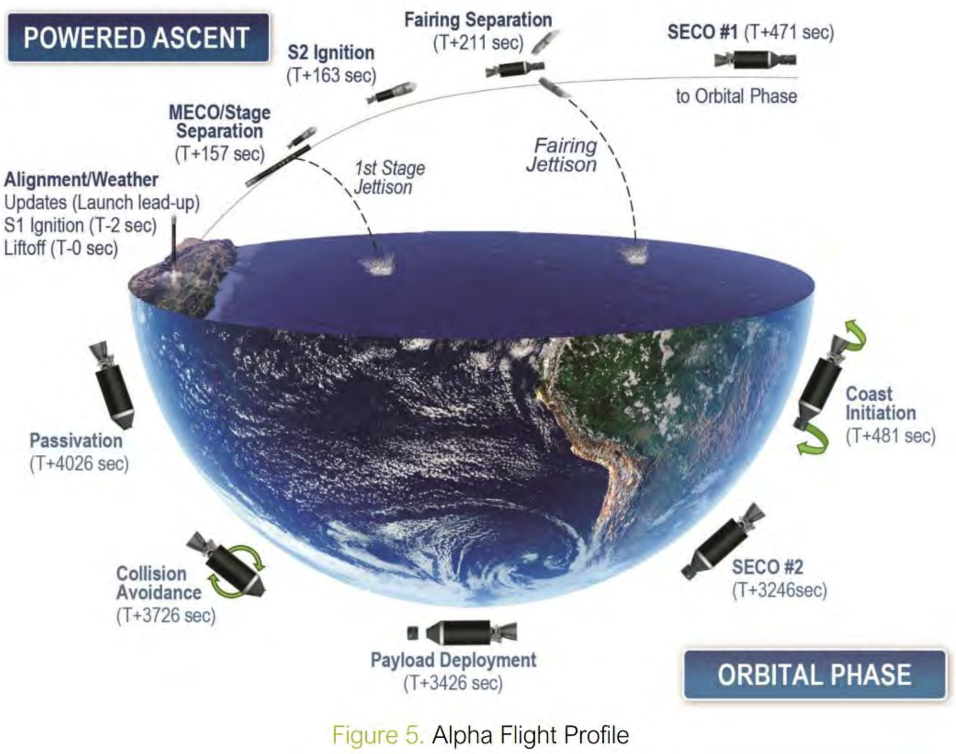

Figure 6.1: Firefly Alpha illustration, taken from Alpha-PUG-4.0.pdf, received 25th October 2024.

[30] eCFR :: 14 CFR Part 450 Subpart C -- Safety Requirements (FAR Part 450 Subpart C), retrieved 20.02.2025

Orbital launch vehicles consist of multiple stages, each of which is equipped with its own set of engines and propellant. Two-stage rockets are the most common solution today for sending satellites and other payloads into orbit around Earth. The first stage provides the necessary thrust to lift the rocket off the ground and through the densest part of Earth's atmosphere. Once the fuel in the first stage is depleted, it separates from the rest of the rocket and falls back to Earth, called first stage jettison. After the first stage separates, the second stage ignites. This stage has its own engine(s) and fuel, continuing to accelerate the rocket and adjusting its trajectory to reach the desired altitude and speed. This stage can also make adjustments to place the payload into a precise orbit.

6.3 Risk associated with orbital rocket launch

6.3.1 Definition of risk

Risk is a measure of an adverse outcome, such as for example, loss of life, together with its likelihood of occurrence. It is defined as the product of the probability of an adverse event occurring and the severity of its consequences. Risk requires the combination of three distinct elements: hazard, exposure and vulnerability, and occurs when all three elements are present. Eliminating any one of these elements eliminates the risk, and reducing any one subsequently reduces the risk[31]. For example, reducing the vulnerability of people in a boat to drowning by providing life jackets reduces the risk.

There are a number of hazards associated with the highly energetic nature of orbital space launch, posing a risk to the public: debris risk emerges where intact rockets, parts, fragments or explosives impact the earth with the potential to cause injury to the public in the form of blunt force trauma, explosive blast energy (fireball and overpressure), toxic release from a fragmented rocket and distant focusing of blast overpressure (DFO). The picture below schematically illustrates the possible failures and hazards, and links them to the respective paragraphs in the FAA 450 framework.

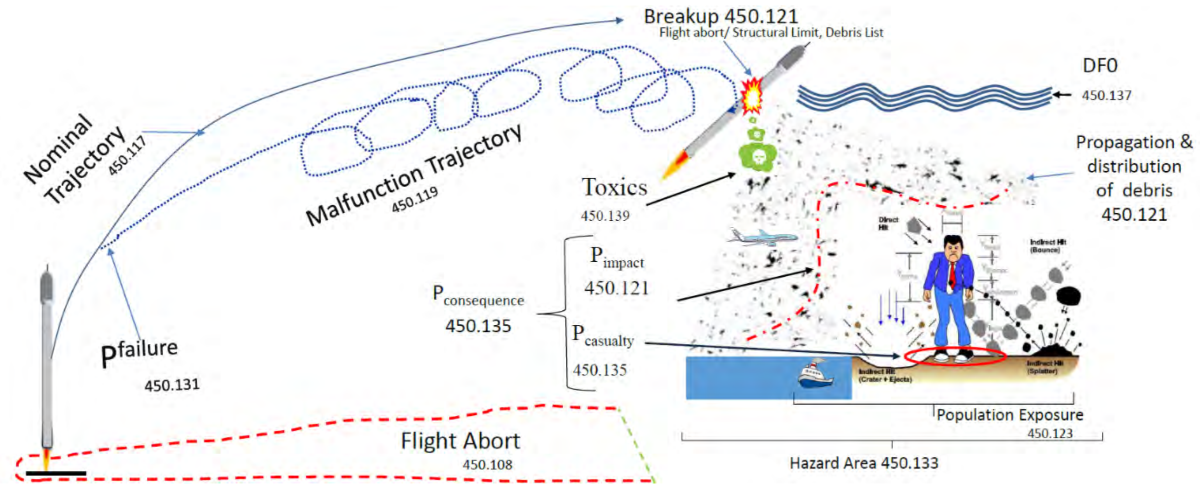

Figure 6.2: Components of the Flight Safety Analysis. From FSA Methodology Workshop 1 slides, 11 August 2023[32].

[31] Allahdadi, Firooz A., Isabelle Rongier, Tommaso Sgobba, and Paul D. Wilde, Safety Design for Space Operations, Sponsored by The International Association for the Advancement of Space Safety, Elsevier, Watham, MA, 2013. Chapter 4.

[32] https://www.faa.gov/media/84276

6.3.2 Risk tolerance

FAA defined that acceptable flight risk limits for "commercial launches should not expose the public to risk greater than normal background risk", defined as "those risks voluntarily accepted in the course of normal day-to-day activities"[33]. Ultimately, risks resulting from orbital launch operations are risks that the public, via the authority vested in the government, tolerates to secure certain benefits from an activity with the confidence that the risks remain within well-defined limits and are managed properly using established procedures[34].

This definition of acceptable risk for space operations is the main reason for spaceports to usually be located by the ocean. Launching over the ocean allows for a wider range of launch trajectories without flying over populated areas, which poses a significant risk to the public and property. In the event of a launch failure, debris will fall into the ocean rather than on land, significantly reducing the potential for casualties and damage.

Space operations risk management aims at finding the safest approach to attain mission objectives, minimizing hazardous conditions. Hence, launch operations safety requires the identification and quantification of hazards and risk drivers from normal and malfunctioning flight, the development and quantification of risk measures for mitigating risks and to ensure that any residual risks are maintained at an acceptable level, and the design and implementation of risk and hazard controls to assure public safety[35].

6.3.3 Aggregated and accumulated risk

Launch safety analyses attempt to quantify two important types of risk: Individual risk and collective risk, on a per mission basis. Both can be defined based on total (aggregated) risk or accumulated risk:

Accumulated risk is the risk from a single hazard, for example debris impact, throughout all phases of a mission.

Total (aggregated) risk is the accumulated risk due to all hazard sources associated with a mission (see above). Total risk can always be estimated conservatively as sum of accumulated risk from each hazard.

6.3.4 Probability of Casualty (Pc) or individual risk

Individual risk answers the question "What is my chance of being hurt?". For launch activities, individual risk is often defined as the probability that a single person will become a casualty as a result of the launch operation. Hence, Probability of Casualty (P_C) is a measure of individual risk. A casualty is defined as an individual who suffers injury or death as a result of a launch or reentry accident.

This probability ranges from 0 to 1, where 0 means no possibility and 1 means absolute certainty of an incident occurring.

FAA § 450.101(a)(2) states that "The individual risk, measured as probability of casualty (P_C), consists of risk posed by impacting inert and explosive debris, toxic release, and far field blast overpressure." Furthermore, FAA § 450.101(a)(2)(i) specifies "The risk to any individual member

[33] 99-9639.pdf, Retrieved: 18.02.2025
[34] Allahdadi, Firooz A., Isabelle Rongier, Tommaso Sgobba, and Paul D. Wilde, Safety Design for Space Operations, Sponsored by The International Association for the Advancement of Space Safety, Elsevier, Watham, MA, 2013.
[35] Allahdadi, Firooz A., Isabelle Rongier, Tommaso Sgobba, and Paul D. Wilde, Safety Design for Space Operations, Sponsored by The International Association for the Advancement of Space Safety, Elsevier, Watham, MA, 2013.

of the public, excluding neighbouring operations personnel, must not exceed a probability of casualty of 1 × 10^{-6} (one in a million) per launch." This implies that a launch is not authorized to proceed unless the probability of an individual member of the public being a casualty is no more than one in a million. The contour delimiting the area where the Probability of Casualty or Individual Risk exceeds one in a million determines the minimum size of the flight hazard areas, hence the areas from where people must be evacuated.

6.3.5 Expected casualty (E_C) or collective risk

Collective risk is the total risk to all individuals exposed to any hazard from a launch operation. It is often defined by the mean (or average) number of casualties predicted to result from the launch operation, also called Expected casualties (E_C). E_C is a measure of collective risk, not probability. It is the statistically expected number of casualties that would occur if the launch were repeated many times under virtually identical conditions. A casualty expectation of E_C = 1 × 10^{-6} (one in a million) casualties for a given mission means that if the launch were repeated under identical conditions a million times, not more than one casualty on average would occur.

Expected casualties (E_C) for the total mission, hence the sum of all E_C contributions from each failure mode and failure time is often referred to as mission risk. Expected casualties can also be calculated for a reduced set of events. An event may, for example, correspond to a particular response from a specific failure mode at a specific failure initiation, or be a planned circumstance such as stage separation or engine ignition. A reduced set of events tends to be for a period of flight, or type of occurrence.

6.3.6 Conditional Expected casualty (CE_C)

Conditional expected casualty answers the question to "how many casualties would occur if this particular type of failure happens in this period of flight at this point in time"?

A Conditional expected casualty value is calculated as Expected casualties (E_C) for a specified failure mode in a given time interval predicted to occur with absolute certainty. CE_C is calculated by dividing E_C by the failure probability, hence producing a conditional value for some event[36]. Removing the probability of each failure type at a given time from the collective risk (E_C) gives the possibility to evaluate potential consequences in specific accident scenarios if they were to occur despite low probability. This ensures that scenarios with low probability but high consequences, such as incidents that could involve multiple casualties, that can be hidden in the general expression of mission risk due to their low probability, are detected.

CE_C is used in high consequence event protection (§ 450.101(c)), flight safety limit determination (§ 450.108(c)(4)) and debris risk analysis (§ 450.135) shortly described below.

6.4 Risk and safety criteria

According to the FAA, the safety criteria in § 450.101 defines the safety criteria for the public and for assets that are fundamental flight safety requirements for all launch license applications. They ultimately define how safe is safe enough, and include collective risk, individual risk, aircraft risk, risk to critical assets, protection against high consequence events, disposal of orbiting stages, risk to people and property on-orbit, and notification of planned impacts. An operator must ensure that no member of the public on land, sea or air is exposed

[36] AC 450.101-1 High Consequence Event Protection, retrieved 18.02.2025

to launch risks that exceed the safety criteria thresholds, by responsibly implementing hazard mitigation strategies such as flight hazard areas.

6.4.1 § 450.101(a) and (b): Launch risk criteria

The flight of a launch vehicle may only be initiated if all risks to the public satisfy the criteria of § 450.101(a), which apply from liftoff through orbital insertion.

The collective risk to all members of the public, excluding persons in aircraft and neighboring operations personnel, must not exceed an expected number of 1×10^{-4} (one in ten thousand) casualties.

The risk to any individual member of the public, excluding neighboring operations personnel, must not exceed a probability of casualty of 1×10^{-6} (one in a million) per launch.

Any aircraft hazard areas necessary to ensure the probability of impact with debris capable of causing a casualty for aircraft does not exceed 1×10^{-6} must be established.

Both the collective and individual risk as well as aircraft risk consist of risk posed by impacting inert and explosive debris, toxic release, and far field blast overpressure.

6.4.2 § 450.101(c): High consequence event protection

FAA 450 does not formally define high consequence events, but the preamble states that: “high consequence events include incidents that could involve multiple casualties, massive toxic exposures, extensive property or environmental damage, or events that jeopardize the national security or foreign policy interests of the United States.”[37]

§ 450.101(c) requires that an operator must protect against a high consequence event in uncontrolled areas for each phase of flight.

The FAA defines uncontrolled and controlled areas in the following way:

6.4.3 Uncontrolled areas

In accordance with the definition in § 401.7, an uncontrolled area is an area not controlled by a launch or reentry operator, a launch or reentry site operator, an adjacent site operator, or other entity by agreement. Typically, uncontrolled areas include all regions outside of the launch or reentry operators’ property, and outside of the site operator’s property. An operator must satisfy the requirement to evaluate the potential for high consequence events in uncontrolled areas by evaluating the potential for high consequence events in all areas of land where there is no ability to prevent unauthorized access or otherwise by ensuring that no unauthorized persons are present during a launch or reentry operation.[38]

6.4.4 Controlled areas

An area may be considered controlled only if there is an ability: (1) to prevent unauthorized access or otherwise ensure that no unauthorized persons are present, and (2) to manage the location of any persons that are present during a launch or reentry operation.

Hence, Norwegian territory must be considered as an uncontrolled area for launches from Swedish territory.

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[37] Rule 450 Final, retrieved 18.02.2025
[38] AC-450 101-1B, https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_450.101-1B.pdf section 6.3, retrieved 18.02.2025

Protection against a high consequence event in uncontrolled areas per § 450.101(c) can be demonstrated by using any of the three following methods:

- using flight abort as a hazard control strategy in accordance with the requirements of § 450.108,
- ensuring the consequence of any reasonably foreseeable failure mode, in any significant period of flight, is no greater than 1 × 10^{-3} conditional expected casualties (CE_C), or
- establishing the launch or reentry vehicle has sufficient demonstrated reliability as agreed to by 'the Administrator' based on conditional expected casualties criteria during that phase of flight.

6.5 Flight safety and hazard control strategies

Flight Safety is achieved through a combination of prescribed hazard controls and hazard controls derived from the Flight safety analysis and Hazard control strategy determination and implementation. Figure 6-2 above shows how the different elements of the launch vehicle flight including failure and hazards are linked to FAA 450 Subpart C' paragraphs.

6.5.1 Hazard control strategies

In order to meet the safety criteria of § 450.101 for any phase of flight, one or more hazard control strategies must be applied. Different phases of flight may need different hazard control strategies. Also, multiple hazard control strategies may be needed during any one phase of flight to protect different sets of people and property.

Hazard control strategies are flight abort (§ 450.108), flight hazard analysis (§ 450.109), physical containment (§ 450.110) and wind-weighting (§ 450.111). Physical containment and wind - weighting hazard mitigation strategies for low energy test flights or for unguided suborbital launch vehicles. These two methods will hence not be further explored in this context since the focus is on orbital launch vehicles.

A flight hazard analysis (§ 450.109) is characterized as a hazard control strategy as it lays out a process by which appropriate hazard controls can be derived, although it is different from the other three hazard control strategies in that it does not specify specific hazard controls.

The hazard controls derived from the flight hazard analysis as well as those defined in the other three hazard control strategies, are then used as part of the input to the FSA that is used to show compliance with the safety criteria of § 450.101.

6.5.2 § 450.108 Flight abort

Flight abort is the process of controlled ending of vehicle flight to limit or restrict the hazards to public safety via activation of a Flight Safety System (FSS), also known as a Flight Termination System. In addition to the functional requirements for flight abort described here, there are a number of technical requirements covered in § 450.143 or § 450.145. The FAA has identified Range Commanders Council, Range Safety Group, Flight Termination System Commonality

Standard, RCC 319 (Range Commanders Council[39], the RCC324-11[40] and the SSCI91-701[41] as a suitable means of compliance to demonstrate high-reliability of an FSS.

When flight abort is used as a hazard control strategy (for example to comply with § 450.101(c) as stated above), flight safety limits must be determined and used to initiate flight abort to ensure compliance with the safety criteria of § 450.101, and to prevent continued flight from increasing risk in uncontrolled areas if the launch vehicle is unable to achieve a useful mission (§ 450.108(c)(1) and (2)). A useful mission means a mission that can attain one or more objectives, however, the collection of data related to a failure is not considered to be a useful mission (§ 450.119(a)(3)).

§ 450.108 (c)(4) states that an operator must determine and use flight safety limits that define when an operator must initiate flight abort to prevent conditional expected casualties (CE_C) greater than 1×10^{-2} in uncontrolled areas due to flight abort or due to flight outside the limits of a useful mission from any reasonably foreseeable off-trajectory failure mode in any significant period of flight.

When it is not possible to develop flight safety limits that prevent hazards from affecting uncontrolled areas, the purpose of § 450.108(c)(4) is to ensure that the failure modes that result in deviations from the planned trajectory, if the vehicle is unable to achieve a useful mission, will not result in a high consequence event. This is particularly important when public exposure is inevitable to allow vehicles able to achieve a useful mission to continue during a phase of flight when flight abort is still used as a hazard control strategy. If the vehicle fails after the overflight has begun and reaches flight safety limits protecting other portions of the uncontrolled areas from flight outside the limits of a useful mission, the consequence from flight abort must meet the criteria in § 450.108(c)(4).

Northeasterly missions launched from the Eastern Range are permitted to overfly some portions of Nova Scotia and Newfoundland on trajectories within the limits of a useful mission, a situation that frequently occurs according to the FAA[42]. It is important to recall that the risk from normal trajectories and malfunctioning trajectories within the lines of a useful mission/established flight limits is included in the calculation of risk to meet § 450.101 (a) and (c), and hence that protection against a high consequence event is achieved by ensuring the consequence of any reasonably foreseeable failure mode, in any significant period of flight, is no greater than 1×10^{-3} conditional expected casualties.

[39] RCC-319-19 Flight Termination System Tailorable Commonality https://www.trmc.osd.mil/wiki/display/publicRCC/319+Flight+Termination+Commonality+Standard, retrieved 18.02.2025

[40] RCC-324 Global Positioning and Intertial Measurements Range Safety Tracking Systems Commonality Standard 324 Global Positioning and Intertial Measurements Range Safety Tracking Systems Commonality Standard - Public RCC - TRMC Website (Confluence), retrieved 18.02.2025

[41] Space systems command instruction SSCI91-701, retrieved 18.02.2025

[42] From FAA presentation on Part 450, Part 450: Workshop Day 2, retrieved 18.02.2025

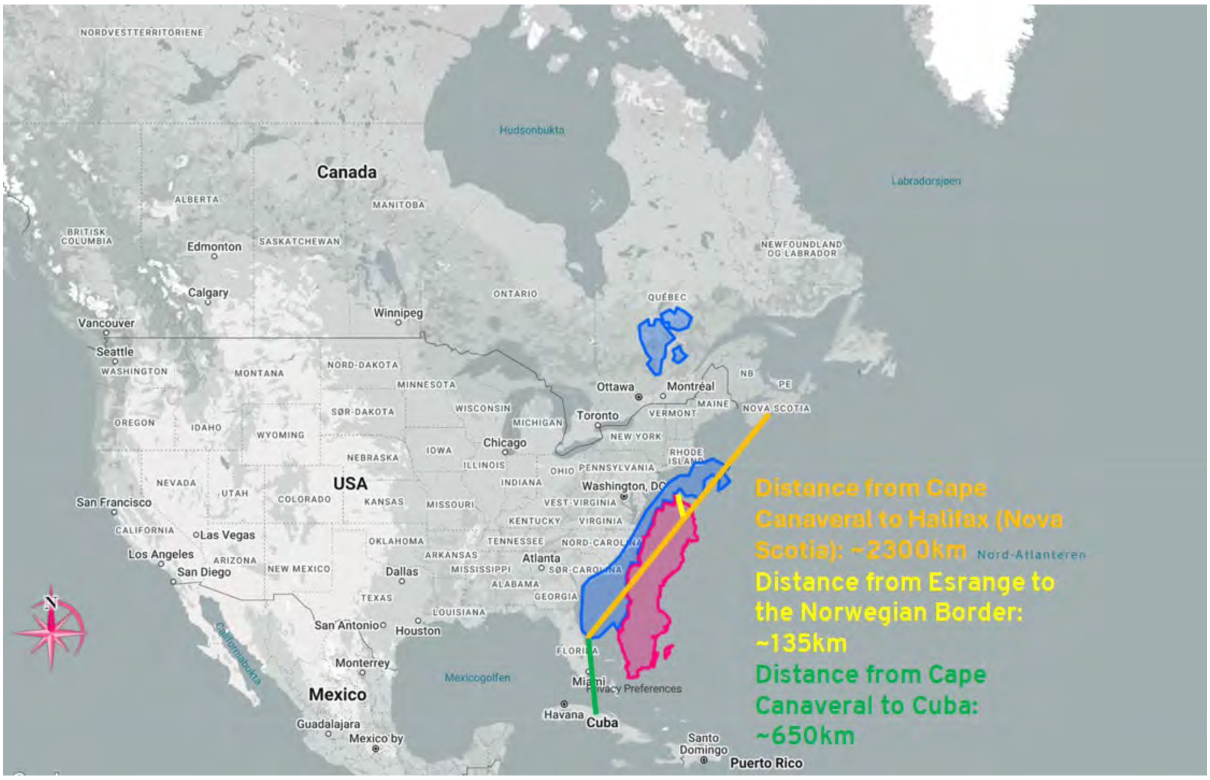

Figure 6.3: Illustration showing northeasterly missions launched from the Eastern Range permitted to overfly some portions of Nova Scotia and Newfoundland on trajectories within the limits of a useful mission, as compared to the longest possible distance from Esrange to the border of Norway.

Figure 6.3 showing distances on a map: The southernmost tip of Norway (blue shaded) is placed at the Eastern Range in Cape Canaveral The distance from there to Halifax on Nova Scotia is approximately 2300 km (orange line). In comparison, the distance from Kiruna to the Norwegian border is approximately between 75 km and 135 km. The yellow line here pictures the 135 km distance.

6.5.3 Flight safety analysis

In order to identify and control the risks from orbital launch activities, a systematic risk management process is needed, in which the Flight safety analysis (FSA) is a key part. An FSA is a set of analyses that quantifies public risk and establishes mitigation measures.

It includes trajectory analyses for normal (§ 450.117) and malfunction flight (§ 450.119), a debris analysis (§ 450.121), a population exposure analysis (§ 450.123), and a probability of failure analysis (§ 450.131). These analyses provide input to a debris risk analysis (§ 450.135), a far-field overpressure blast effects analysis (§ 450.137), and a toxic hazard analysis (§ 450.139). Together the set of quantitative analysis demonstrate compliance with the safety criteria of § 450.101, and provide input to a flight hazard area analysis (§ 450.133). The outputs are quantitative risk measures, risk maps, hazard areas and other mitigation measures.

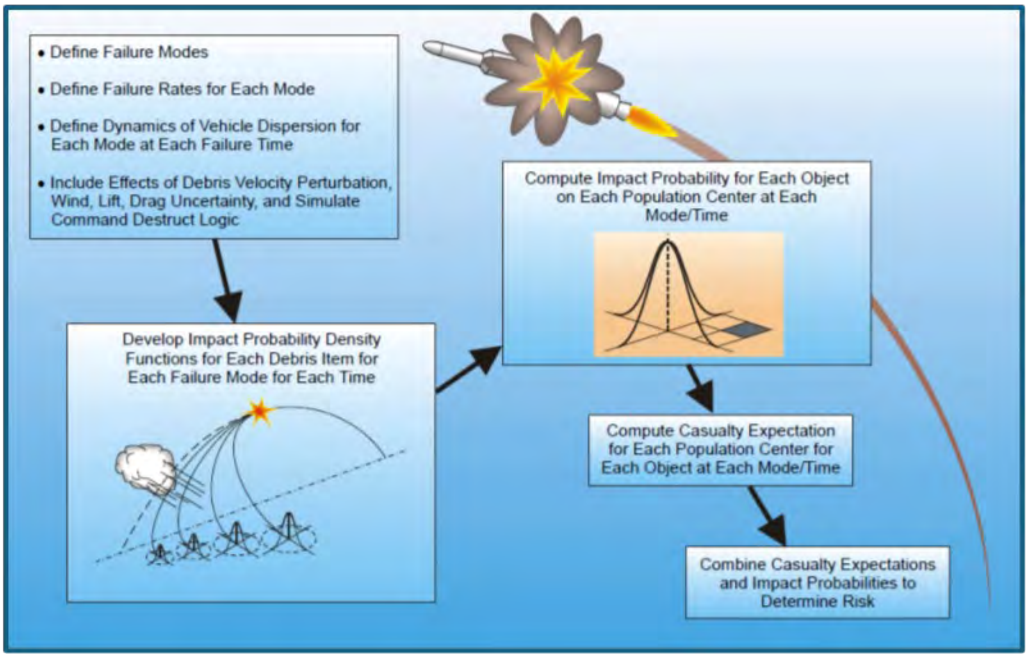

Figure 6.4: Overview of the General Cumulative Debris Risk Analysis Procedure. From Flight Safety Handbook, figure 4-2[43]

§ 450.115 contains the FSA method requirements, which are a key part. It states that the flight safety analysis method must account for all reasonably foreseeable events and failures of safety-critical systems during nominal and non-nominal launch or reentry that could jeopardize public safety.

§ 450.117 through to § 450.139 can be divided into two categories of analysis:

Analyses to develop key inputs to Quantitative Risk Analyses (QRAs):

- § 450.121 Debris analysis
- § 450.123 Population exposure analysis
- § 450.131 Probability of failure analysis
- § 450.117 Trajectory analysis for malfunction flight
- § 450.119 Trajectory analysis for normal flight

QRAs to demonstrate compliance with 450.101:

- § 450.133 Flight hazard area analysis
- § 450.135 Debris risk analysis
- § 450.137 Far-field overpressure blast effects analysis
- § 450.139 Toxic hazards for flight

It is not the scope of this document to go into detail of all the analyses forming the input into the flight safety analysis. However, certain key aspects important to the overland flight risk assessment will be discussed in detail.

6.5.4 § 450.117 and § 450.119 Trajectory analysis for normal and malfunctioning flight, and resulting risks

[43] Flight Safety Analysis Handbook: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Flight_Safety_Analysis_Handbook_final_9_2011v1.pdf

According to FAA, a nominal trajectory is developed from a simulation where each input parameter is set to the expected value.

Normal trajectories are developed by simulating flight where input parameters are sampled within the range of expected values. Thus, a trajectory analysis for normal flight is meant to analyze the variability in the intended trajectory and the uncertainties due to random sources of dispersion, such as winds and vehicle performance[44]. Accordingly, normal trajectory means a trajectory that describes normal flight.

A malfunction trajectory represents a vehicle's deviation capability in the event of a malfunction during flight. This deviation from normal flight is referred to as malfunction flight.

A malfunction trajectory analysis is necessary to determine how far a vehicle can deviate from normal flight. This analysis determines potential impact points in the case of malfunction and is therefore a vital input for the analyses needed to demonstrate compliance with risk criteria. Malfunction trajectory analysis must account for each cause of a malfunction flight, including software and hardware failures. For each cause of a malfunction trajectory, the analysis is required to characterize the foreseeable trajectories resulting from a malfunction.

Flight risk can, accordingly, be divided into normal risk and risk resulting from malfunctioning flight. Normal risk hence refers to failures on normal trajectories causing debris fallouts underneath the planned trajectory. Typical failure types include launch vehicle explosion, loss of thrust and structural failure. Risk from malfunctioning flight results from failure types causing the launch vehicle to deviate from the normal trajectory and can include guidance and navigation failures, thrust control failures.

6.5.5 § 450.121 Debris analysis and debris risk calculations (§ 450.135)

A flight safety analysis must include an analysis characterizing the hazardous debris generated from normal and malfunctioning vehicle flight as a function of vehicle flight sequence. Hazardous debris means any object or substance capable of causing a casualty or loss of functionality to a critical asset. Hazardous debris includes inert debris and explosive debris such as an intact vehicle, vehicle fragments, any detached vehicle component whether intact or in fragments, payload, and any planned jettison bodies (§ 401.7).

A debris analysis must derive plausible vehicle breakup scenarios and compute statistically valid debris impact probability distributions. These impact probability distributions are significantly driven by trajectory dispersion. The propagation of debris from each predicted breakup location to impact must account for all foreseeable forces that can influence any debris impact location and all foreseeable sources of impact dispersion.

[44] AC 450.117-1 Trajectory Analysis for Normal Flight, retrieved 18.02.2025

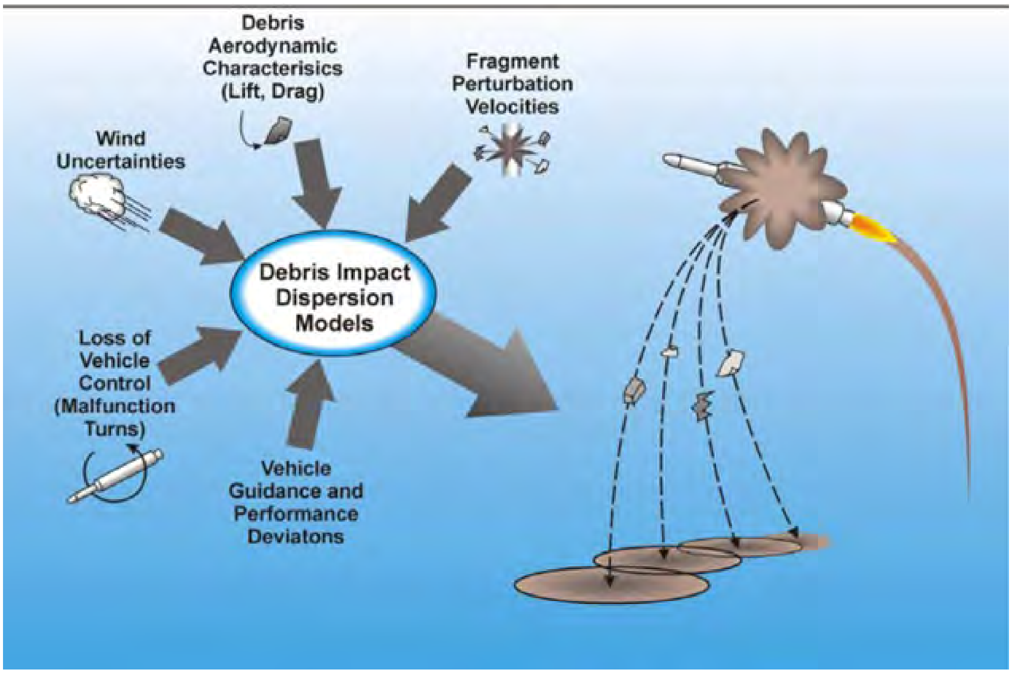

Figure 6.5 showing forces that can influence debris impact locations and dispersions. From Flight Safety Handbook, figure 4-7.[45]

A debris risk analysis must model the casualty area and compute the predicted consequences of each reasonably foreseeable failure mode in any significant period of flight in terms of conditional expected casualties. Key input to the debris risk analysis are the vulnerability models, statistically valid debris impact probability distributions and fragment characteristics of all hazardous debris resulting from the debris analysis (§ 450.121).

6.5.6 § 450.123 Population exposure analysis

Launch operations pose a risk to the public as debris usually cannot be contained to unpopulated areas, and hazardous debris is capable of causing casualties or injuries. To quantify risk, locations of people relative to potential debris impacts must be modelled. The degree of sheltering (meaning, for example, whether they are located outside, in a building or in a car) affects how vulnerable people are to certain types of debris. A flight safety analysis must account for the distribution of people for the entire region, including transient population, where there is a significant probability of impact of hazardous debris. The exposure analysis must characterize the distribution of people both geographically and temporally, and account for the distribution of people among structures and vehicle types.

Critical to the analysis performed for the launch from Sweden is the use of reliable, accurate, and timely sourced data as input for the population exposure analysis.

6.5.7 450.131 Probability of failure analysis

The purpose of a probability of failure (PoF) analysis is to characterize the likelihood of hazard generating events that could constitute a threat to people or property. The overall vehicle PoF must be distributed across flight phases and failure modes. For each hazard and phase of flight, a flight safety analysis for a launch or reentry must account for vehicle failure probability. The probability of failure must be consistent for all hazards and phases of flight. The method for

[45] Flight Safety Analysis Handbook: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Flight_Safety_Analysis_Handbook_final_9_2011v1.pdf

estimating the probability of failure strongly depends on the number of preceding flights of a launch vehicle.

6.5.8 § 450.133 Flight hazard area analysis as well as control of hazard areas (450.161)

The scope of § 450.133 is that a flight safety analysis must include a flight hazard area analysis that identifies any region of land, sea, or air that must be surveyed, publicized, controlled, or evacuated in order to control the risk to the public.

It is important to keep in mind that Norway, for launches from Sweden, is an uncontrolled area (see definition above) where these measures to control the risk to the public cannot be implemented. However, it is crucial to calculate and visualize flight hazard area contours over Norway to understand how the risk is distributed. These contours are based on containment regions for normal flight events, individual risk and/or probability of impacts. In addition, the collective risk for all persons on land and vessels that are affected by the launch in Norwegian territory should be calculated.

§ 450.133 is extremely important and is hence for the most-part written out here:

The analysis must account for the regions of land, sea, and air potentially exposed to hazardous debris generated during normal flight events and all reasonably foreseeable failure modes. It must also contain any hazard controls implemented to control risk from any hazard, the limits of a launch vehicles normal flight, all hazardous debris, sources of debris dispersion and a probability of one for any planned debris hazard or planned impacts.

The flight hazard area analysis for waterborne vessels must determine the areas and durations for regions of water that are necessary to contain, with 97 percent probability of containment, all debris resulting from normal flight events capable of causing a casualty to persons on waterborne vessels. Also, it must determine the areas and durations for regions of water where the probability of impact would exceed $1 \times 10{-}5$ or the individual probability of casualty for any person on board a vessel would exceed the individual risk criteria in § 450.101(a)(2) or (b)(2), and where reduced vessel traffic is necessary to meet the collective risk criteria in § 450.101(a)(1) or (b)(1). Hence, these are the areas where in controlled areas a NOTMAR would be issued.

The flight hazard area analysis for land must determine the durations and areas regions of land that are necessary to contain, with 97 percent probability of containment, all debris resulting from normal flight events capable of causing a casualty to any person on land. It must also determine the durations and areas of land where the individual probability of casualty for any person on land would exceed the individual risk criteria in § 450.101(a)(2) or (b)(2) and where reduced population is necessary to meet the collective risk criteria in § 450.101(a)(1) or (b)(1).

The flight hazard area analysis for airspace must determine the durations and volumes for regions of air to be submitted to the appropriate authority for approval necessary to contain, with 97 percent probability of containment, all debris resulting from normal flight events capable of causing a casualty to persons on an aircraft and where the probability of impact on an aircraft would exceed the aircraft risk criterion in § 450.101(a)(3) or (b)(3).

7. Flight Safety Analysis Requirements for Orbital Launches from Esrange over Norway

7.1 Purpose and scope

The purpose of this chapter is to provide an overview of a minimum set of requirements necessary to review the safety of the Norwegian public connected to an orbital launch from Esrange over Norway.

The description given in this chapter is limited in scope by subpart C in the Code of Federal Regulations Part 450[46], from here on referred to as 'FAA 450'. FAA 450 is currently being used by CAA Norway as a standard in assessing launch applications for launches from Andøya Spaceport. Norwegian authorities presuppose that an equivalent and complete FSA will be performed for launches from Esrange Space Center and that it is assessed by Swedish regulators[47]. Norwegian authorities will in the future adopt their own set of regulations which must be adhered to over Norwegian territories, with risk thresholds that may deviate from those of FAA 450.

The following sections include an introductory methodology essential for understanding what a Flight Safety Analysis (FSA) is, and how the regulatory framework utilises such analyses to quantify risk to the public in case of a launch vehicle failure. We provide an overview of the terminology of risk assessment for the case of orbital rocket launches alongside an overview of the flight safety methodology needed for the assessment of flight safety in the case of overflight over Norwegian territories. The methods and regulations described here should be understood as mandatory inclusions in a launch application to be reviewed by Swedish authorities, and any launch application that involves launches over Norwegian territories will be subject to a technical review by CAA Norway[48]. Chapter 7.2 provides an overview of the specific flight safety regulations intended to be used for the case of launches from Sweden over Norway.

7.2 Terminology and methodology

The regulatory framework for flight safety, subpart C of FAA 450, provides a set of rules for performance-based approval for rocket launches, based on quantifiable risk figures. The thresholds for the risk figures are set such that a normal launch operation should not disproportionately increase the risk of casualty (serious injury leading to hospitalisation) for a member of the public.

The term *risk* is defined here as the product of the probability of an event occurring and the consequence of the event. In the introduction below, of how *risk* is handled in the regulatory framework, we base our discussion on what is regarded by the FAA as acceptable means of compliance for FAA 450 – namely all current advisory circulars (AC) for subpart C of FAA[49] and

[46] FAA Part 450, https://www.ecfr.gov/current/title-14/chapter-III/subchapter-C/part-450/subpart-C, Retrieved: 19.12.2024
[47] Note to CAA Norway from the Swedish Space Corporation '*Responses to CAA questions on FSA*', doc. ref. SSCPROJ-1947775832-1977, dated 06.12.24
[48] Launch into Norwegian airspace requires a permit acc. to the Aviation Act of 11 June 1993 No 101 § 2-2.
[49] FAA Advisory Circular Repository. *An Advisory Circular is a methodological documentation of accepted means compliance for a requirement*. https://www.faa.gov/regulations_policies/advisory_circulars/

additional means of compliance officially stated by the FAA[50]. In addition, we rely on fundamental risk methodology presented in the FAA Flight Safety Handbook (FSH)[51]. For evaluation of toxic hazards and explosion far field blast overpressure (also known as distant focussed overpressure (DFO)), we have also used Sgobba et al. (2013)[52] as support.

7.2.1 Contents of a flight safety methodology

The requirements laid out for flight safety analysis in FAA 450 assume that the applicant for launch follows a general procedure for generating the necessary FSA results. The procedural generation of these results is instrumental for a performance-based assessment process for FSA to work. Such a process was designed to avoid ad hoc case-specific input parameter manipulation – in order to make an FSA fit certain requirements.

CAA Norway expects a general launch risk analysis procedure that, in line with FAA 450 must:

1. Identify all reasonably foreseeable hazards
2. Consider appropriate hazard control strategies
3. Develop a justified estimate of failure probability
4. Use accurate population exposure models
5. Develop a debris model based on representative vehicle data
6. Use the debris model to calculate impact probability and risk figures for the launch with vulnerability models with sufficient level of fidelity.
7. Provide adequate validation and verification of the methods used

A successful launch application has demonstrated that all of the points above are integrated in the implementation of the explicit FAA 450 requirements.

In the following we highlight how the primary steps in the procedure may be carried out in a rigorous way for launches with significant downrange populations.

7.2.2 Hazard identification

A *hazard* can be described as a source of potential harm[53] to a person. As described in the FAA Flight Safety Handbook (FSH) and the AC for FSA methodology, hazard identification entails identifying all functional failures associated with reasonably foreseeable hazardous events that have the capability to create a hazard to the public. In a qualitative assessment, the term *public* also includes infrastructure. For each threat, an event or series of events with justified probabilities that lead up to a hazard must be identified. A list of typical potential threats to near and downrange populations is presented in FSH, page 15, and presented below as an example.

For the case of overflight of Norwegian territories from Sweden, there is a significant population below the normal[54] flight path, which exposes the public to risks from failure on trajectory. This is the starting point for hazard identification.

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[50] Part 450 Subpart C Accepted Means of Compliance Table" https://www.faa.gov/media/85526
[51] Flight Safety Handbook 1.0, 2011, https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Flight_Safety_Analysis_Handbook_final_9_2011v1.pdf
[52] Sgobba, T. (2013). *Safety design for space operations*. Butterworth-Heinemann.
[53] Defined by level 3 on the Abbreviated Injury Scale (AIS*); An ext. energy threshold of 14.9 J for casualty*
[54] Trajectory type definitions are introduced in chapter 6.5.4.

7.2.3 Appropriate hazard control

In the case of significant conditional consequences for the Norwegian population from a failed rocket launch, a means of safe abort or termination of flight is the most probable mean strategy for hazard control. Flight termination lines and flight abort rules are key inputs to an FSA. For the overland flight risk this will be an iterative process that should be documented and available to the authority.

7.2.4 Probability of failure

The probability of failure (PoF) risk factor is one of the principal products of the hazard identification and should be based on historical data and other benchmarks. Moreover, since the launch vehicle design methodology have developed rapidly with the emergence of the '*new space*' commercial launch segment over the past couple of decades, some effort must be employed to ensure a recent, representative and unbiased PoF.

Table 7.1: Potential threats and example causes.

Potential threat	Example of failure mode
Structural failure	Joint failure, buckling, fracture, material fatigue, loss of primary structure
Inertial guidance system failure	On-board electrical failure, software error
Control failure	Nozzle failures, actuator jams, loss of flight controls, electrical power malfunction, hydraulic systems, actuation wiring
Propulsion failure	Partial or complete loss of thrust, failure of engine control systems, case burn-through, premature thrust termination
Flight Safety System failure	Inadvertent flight termination system action, failure of the flight termination system
Explosion	Explosive failure during normal trajectory flight
Failure to perform configuration change	Failure in stage, payload or fairing separation
Failure to ignite or shutoff	Start-up or shutdown of propulsion system is anomalous

Probability of failure is discussed in chapter 5 of the FAA Flight Safety Handbook. An advisory circular for PoF in FAA 450 § 131 is currently being written and is not published as of Jan. 25. The empirical evidence in the FSH, i.e. the flight history and test data for launch vehicle, is from year 2011 and earlier. Thus, it is uncertain that the data is representable for newer launch vehicles. Therefore, we also use a recent statistics paper by Wagenblast and Bettinger (2024)[55] that captures empirical failure statistics from new space developers from the period 2000-2022. Table 7.1 lists the most common threats and causes for vehicle failure that should be taken into account when developing a robust PoF estimate.

[55] Wagenblast and Bettinger (2024) Statistical reliability estimation of space launch vehicles, JSSE https://doi.org/10.1016/j.jsse.2024.10.001

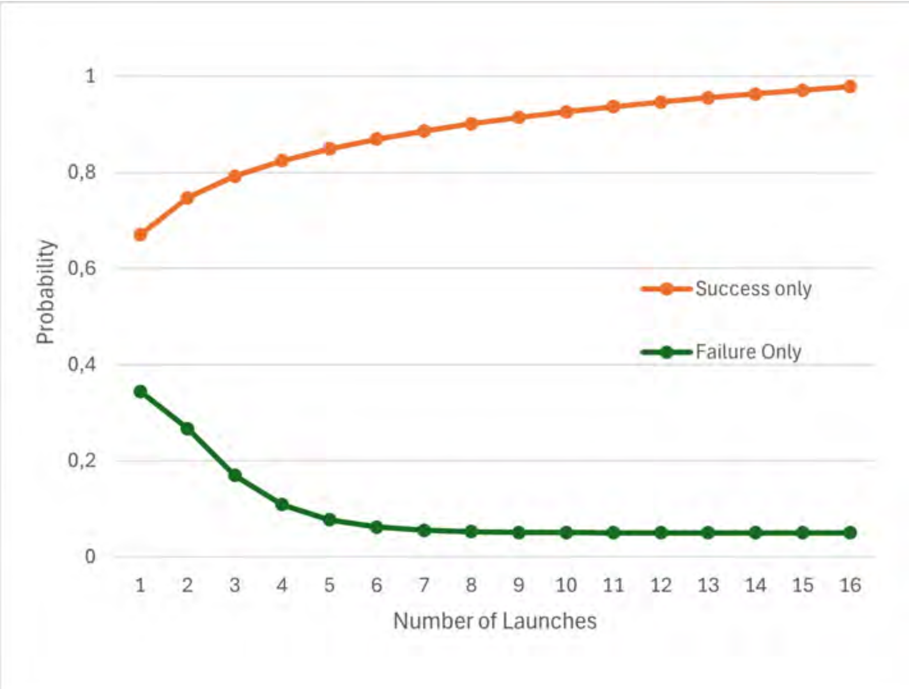

Figure 7.1: Illustration of how probability of success for a generic launch vehicle changes based on the number of consecutive successful (orange) or failed (green) launches.

In the FSH the FAA defines a *new developer* as a launch vehicle producer that *has not* achieved *at least one* successful orbital insertion *and* a probability of potentially hazardous failure below 33 %. They furthermore state that the PoF is as least twice as high compared to experienced developers. With this in mind, it can be extracted from table 5.3 in the FSH that the total probability of vehicle failure is centred at 79 % with 90 % confidence bounds at 58-92 %. For experienced developers, the historical failure probability presented in the FSH is 46% with confidence bounds ranging from 26-63 %. Moreover, as motivated by the list presented in Table 7.1, for new developers with too few data points to establish a statistically reliable and significant PoF, it may be necessary to use a bottom-up approach to develop a PoF from quantitative failure analysis. A possible balance between using historical data and failure probability analysis has been suggested by Wilde (2013)[56] – the 'Nearly Bottom-up Method'.

More recently than the FSH, Wagenblast and Bettinger (2024) used a statistical model to infer what the true success rate of a launch vehicle is, when only limited information on launch history is available. The paper underlines large differences in success rates for different vehicle providers, underlining the need for individual assessment. For six different US launch vehicles with 10 or less launches in the period 2000-2022, the overall PoF was 58%. The reliability of a launch vehicle is updated depending on the number of successful launches: the method estimates that the PoF of a launch vehicle with *one* successful flight may be as low as 30%, while the PoF of a launch vehicle that failed on the maiden flight is over 60%. Figure 7-1 illustrates how probability of *success* of a launch vehicle evolves depending on an increasing number of successes or failures. Roughly speaking, we would expect a launch vehicle with five *successive* successful launches to have a predicted success rate of over ~90%. These example graphs do not illustrate the self-correcting nature of the PoF very well, and a launch vehicle that starts off at the green slope illustrated in figure 7-1, can still tend towards the orange graph after

[56] Wilde, P. (2013), Probability of Failure Analysis Standards and Guidelines for Expendable Launch Vehicles, *Proceedings of the 6th IAASS Conference*. Vol. 715

a number of successful launches. The statistical methods illustrated here do provide an estimate for the true PoF, however, a conservatively set value can provide extra credibility in the safety analysis from the regulator's point of view. Based on the combined insight from the paper and Flight Safety Handbook above, available evidence points towards an a priori PoF of at least ~60% for launch vehicles with only a few launches or launch attempts. Since it is a driving factor of the risk to the public, the PoF should be set conservatively and only updated after several launches.

7.2.5 Accurate population exposure models

For launch scenarios with downrange populations within uncontrolled areas, a representative population exposure model is a highly important input to a Quantitative Risk Analysis (QRA). This entails that anyone overflying Norwegian territories should have a very accurate population model including transient and temporarily population distribution on a spatial and temporal scale – which includes seasonal variations and variations due to tourism and other sporadic increases in local population. Goods and person transport should be added to the analysis too, and sources for these input parameters must be accurate, recent and credible.

7.2.6 Representative debris model

A debris model for a launch over Norwegian territories must be based on launch vehicle data that is representable for the actual vehicle due to be launched. Break-up models should be based on stress analysis of the vehicle, and fragments should be individually characterized in terms of defining representable aerodynamic and material properties. Generic off-the-shelf models are not deemed adequate for this purpose by CAA Norway.

7.2.7 Expected casualties and Individual risk calculations

§ 450.115(c) stresses the necessity of rationalising the level of fidelity for FSA products. For the overflight scenario, especially the casualty area (CA) inside which people may be severely harmed, will be put under particular scrutiny by CAA Norway as it is a large driver of the risk to the public.

According to the Flight Safety Handbook, Expected Casualties (E_C) refers to the anticipated – according to analysis – number of people who may be severely injured or killed as a result of a spaceflight accident. This includes risks from inert and explosive debris, toxic releases, and pressure waves. The degree to which an individual must be injured to count as a casualty is based on the abbreviated injury scale (AIS) level 3. A piece of debris with an external energy of 14.9 Joules, is in AIS 3 expected to result in a significant chance of severe injury to an unsheltered person[57]. To be conservative, the 14.9 Joule threshold may be set as the limit for fatal injury in any unsheltered person. The FAA Part 450 uses E_C to assess the *collective mission risk*. This means that a large amount of context is needed to interpret the results, especially which population centres carry the largest portions of the risk.

The *individual risk*, as implemented in FAA 450, is the overall maximum risk to an individual resulting from a launch mission. This is the maximum risk for all individuals exposed to hazardous debris and connected hazards, and must be calculated for people located in all population centres. Accordingly, the individual risk is directly related to probability of impact of a piece of debris on a member of the public (or on a building sheltering a member of the public), the energy of impact, as well as the probability of failure. As with the E_C parameter, FAA 450 only

[57] See e.g. RCC-321-23 Supplement, Risk Criteria for Test Ranges.

defines a threshold for the mission maximum individual risk, so context in the form of casualty probability mapping is essential when assessing this risk parameter.

In addition, FAA 450 requires that a conditional risk assessment is included in the flight safety analysis to protect against high consequence events. The conditional expected casualty risk criterion was introduced to mitigate the severe consequences of vehicle failures, particularly for unproven vehicles with uncertain failure rates. By prohibiting population overflight when failure consequences are intolerable, FAA 450 aims to control the potential outcomes of such failures. This performance-based approach contrasts with prescriptive regulations and is exemplified by the Colombia accident, where a failure one orbit later could have led to a catastrophe over Houston – which would not have been quantified in a normal FSA.

The number of Conditional Expected Casualties (CE_C) may be stated as the expected number of casualties in uncontrolled areas (which all areas in Norway during overflight would be) that could occur from each foreseeable failure mode occurring at any point along the flight path given that the failure has already been realized. This is to say that it is the risk of casualty given that the launch vehicle has already malfunctioned at any given time.

In chapter 8.2, we also emphasize the need for a thorough mapping of DFO, which can also drive downrange risk. Furthermore, an assessment of toxic hazards must also be mapped, but may be difficult to include in the QRA.

7.2.8 Flight Safety Analysis results – verification and validation

If the launch operator follows the procedure outlined in Sec. 1 here, it is expected that the main deliverable to the licencing authority, i.e. Swedish authorities, is a thorough documentation of the method as well as the results of the FSA. Since the regulatory framework is performance based rather than prescriptive, *the methods producing the results are also a part of the assessment*. Details about software used to produce FSA results, and input parameters such as dispersion and statistical models for debris propagation, should be included and may be requested at any point in the assessment process.

Throughout the process of developing the methodology and producing FSA results, the launch operator should provide verification and validation of the methods and results. Such verification will be requested by Norwegian authorities when assessing the risk to the Norwegian public. This entails providing a benchmark for tools used in numerical simulations and documenting the validation process.

In the next section, we introduce the explicit requirements in FAA 450 that warrants deliverables for the assessment by Swedish authorities to ensure that a complete and representative FSA is used to estimate public risk.

7.3 Requirements applicable for overflight of Norway

Deliverables from a flight safety analysis that must be provided in order for CAA Norway to perform an assessment of the overflight risk to the Norwegian public are discussed in more depth in chapter 8. In this section we introduce how the flight safety analysis concepts introduced above are embedded in regulatory framework FAA 450.

The scope of flight safety requirements spans from § 450.113 through § 450.145, which all refer to the overarching safety criteria defined in §450.101.

7.3.1 General risk requirements and necessary description of methods

A flight safety analysis is guided by two main paragraphs in the FAA 450 framework – § 450.101 *Safety Criteria*, and § 450.115 *Flight Safety Analysis Methods*. This framework is based on experience from several thousand US launches and was revised with input from launch operators in 2016[58]. This report will not discuss the justification behind the threshold values.

Table 7.2: Summary of risk criteria as presented by § 450.101 Safety Criteria.

Risk Criterion	Threshold Value, per mission
Expected Casualties, E_C	$E_C \leq 10^{-4}$
Individual Risk, P_C	$P_C \leq 10^{-6}$
Conditional Expected Casualties, CE_C	$CE_C \leq 10^{-3}$

Table 7.2 presents the threshold values for allowable risk for a launch according to FAA 450. Following a procedure as outlined in chapter 7.2, these parameters are normally the results of a large number of simulations (Monte Carlo Simulations) of launch vehicle failure and prospective break up. In FAA 450, the validity of such analysis is regulated by § 450.115(c), which states that the following points must be included in an accepted FSA:

1. The scientific principles and statistical methods used;
2. All assumptions and their justifications;
3. The rationale for the level of fidelity;
4. The evidence for validation and verification required by § 450.101(g);
5. The extent to which the benchmark conditions are comparable to the foreseeable. conditions of the intended operations; and
6. The extent to which risk mitigations were accounted for in the analyses.

For each section regarding flight safety products (§ 450.117 - § 450.139), a justification of the points above must be provided. For the case of overflight over Norwegian territories, CAA Norway notes that point 3, on fidelity, may be of crucial importance in an assessment of safety. This is due to a possibility that the Norwegian public is exposed to the majority of the total mission risk from an orbital launch from Esrange Space Center. A decomposition of the risk is thus necessary and is discussed further in chapter 7.4.1.

A discussion of what documentation and which deliverables constitute a valid flight safety analysis for overflight over Norway is given in chapter 8.

7.4 Mission specific flight safety requirements

Regulations regarding flight safety are presented in §§ 450.113 through 450.145 in the licence requirements. The assessment process is dictated by how the applicant designs their safety system:

The design of the launch operation should involve an *a priori* assessment of high consequences to determine how a flight safety system (FSS) should be implemented. When flight abort as regulated in § 450.108 is used as a hazard control strategy, the licence applicant must justify the choice of rigor in flight hazard control. § 450.108(b)1 describes that the utilization of a *highly reliable flight safety system* is a valid control strategy, if the *a priori* evaluation of conditional risk warrants it. A highly reliable flight safety system, normally implemented as a flight termination

[58] *Changing the Collective Risk Limits for Launches [...]* Federal Register / Vol. 81, No. 139 / Wednesday, July 20, 2016

system (FTS), is regulated by § 450.145. If an FTS is implemented, a recognized means of compliance is the RCC-319[59], for which assessment is a very elaborate and time-consuming process. The RCC-319 is more prescriptive in nature compared to FAA 450 and thus contains a much higher number of control parameters that must be documented and reviewed.

Furthermore, the requirements for the description of flight safety require an applicant to very clearly carry out consequence modelling for failures that may happen on a normal trajectory and separate these from failures that happen on malfunction flight trajectories. Consequences for malfunction trajectories may be used as a qualitative argument by the Norwegian authorities for reduced feasibility of a launch – e.g. if the practical consequences (possible evacuation, economic consequences, etc.) are severe even with acceptable risk for the public.

7.4.1 Decomposition of risk for Norwegian population centres

The necessary depth and detail of population data in a launch application is described in AC-450.123 Population exposure[60] and chapter 9 and 10 in the FSH. Moreover, § 450.135 *Debris risk requirements* describes which collective and individual risk analysis outputs must be included in an application. Part (c) 5 of this latter requirement states that an applicant must submit "*a list of the collective risk contribution for at least the top ten population centres and all centres with collective risk exceeding 1 percent of the collective risk criteria*" and "*a list of the maximum individual probability of casualty for the top ten population centres and all centres that exceed 10 percent of the individual risk criteria*". These two requirements have particular value in an overflight scenario similar to launches over Norway from Esrange Space Center. This is due to the fact that it underlines the prospective need for – and practicality of – local safety measures carried out in downrange municipalities. Such safety measures, e.g. evacuation of areas with high concentrations of people, can only be implemented in close collaboration with local authorities, which may not be feasible for such a large area and population. Considering this, a dialogue is necessary between the operator of an overflight launch and CAA Norway on whether a list of E_C and I_C values for *all* population centres, transient and temporary population is needed.

The Flight Safety Handbook treats a possible risk decomposition in its example in Appendix A.4. A risk decomposition procedure must account for seasonal differences in the demographic composition as well as a sheltering model that is applicable for the different population centres. The population centre areas (or "grids") should be scaled so that the probability of impact is close to uniform across an area. The result of the analysis described above should be a list of contributions to E_C and I_C for the respective population centres, transient and temporary population, and all assumptions and justifications for sheltering types must be presented.

Furthermore, CAA Norway notes that since the affected areas in Norway will be uncontrolled, any evaluation of total mission E_C must be done without using hazard areas on Norwegian territories to reduce risk. Accordingly, no areas within Norway should be treated as controlled. It follows that risk taken on by the Norwegian public could not be reduced by introducing hazard areas (controlled areas) in Sweden or downrange outside the Norwegian territorial waters 12 NM border.

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[59] Range Commanders Council Flight termination systems commonality standard
[60] AC-450.123-1, https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_450.123-1_Population_Exposure_Assessment_2022.pdf

7.4.2 Other requirements

An evaluation of a flight safety analysis is normally an iterative process when utilizing FAA 450 for the purpose, as is intended by the regulatory framework. The authority may at any point during an assessment request supplementary information to assure that the correct justifications and prerequisites have been used in the analysis. Apart from the concrete analysis results, there are additional issues connected to flight safety and mishaps for which documentation is required for emergency response readiness, as discussed below.

7.4.3 Notification

Application for restricted areas (airspace) must be submitted to relevant airspace authorities. For Norwegian airspace, the application must be submitted to CAA Norway. Furthermore, notification of NOTMAR and NOTAM for the high seas and international airspace need to be issued.

Because launch into Norwegian airspace requires a permit according to the Aviation Act of 11 June 1993 No 101 § 2-2, notification of any launch to Norwegian authorities will be by application for such permit. The elements that are discussed in this report necessary to review the safety of the Norwegian public connected to an orbital launch from Esrange over Norway, will be part of the assessment of this application.

7.4.4 Distant Focussing Overpressure (DFO) risk

The DFO risk and how it is treated in FAA 450 is discussed in chapter 8.2. DFO is a mechanism by which an explosion can cause harmful overpressure at distances far beyond the immediate vicinity of the blast centre. The overflight over large population clusters will be happening with a launch vehicle that still has a significant amount of propellant onboard. Any intact impact will create a DFO risk and a thorough investigation into this, including a presentation of the methodology, is needed.

7.4.5 Toxic Hazards

CAA Norway requires to be notified about any use of toxics in a launch vehicle (or its payload) that is due for overflight over Norwegian territories.

There may be several different toxic substances in rocket propellants – for use in launch vehicles as well as payloads – of some examples being aluminium and perchlorate used as oxidizers in solid boosters and UDMH (Unsymmetrical dimethylhydrazine) also called heptyl, used in liquid fuel. The latter has caused severe environmental problems downrange from Baikonur Cosmodrome and in the Barents Sea, due to accidents or dropped Russian rocket stages[61,62]. The toxic hazard level of a released chemical is influenced by its physicochemical properties; such as its aggregate state (gas, liquid, or solid), particle size, acidity, alkalinity, and corrosiveness, the amount released, its biological effects (including irritancy, carcinogenicity, and toxicity), and how easily it can be removed from the environment[63]. Some toxic substances can persist in the environment for extended periods and accumulate in the food chain. Environmental concerns and impacts on conservation interests are discussed in chapter 5.6.

[61] Byers M, Byers C. (2017) Toxic splash: Russian rocket stages dropped in Arctic waters raise health, environmental and legal concerns. *Polar Record*. 2017; 53(6):580-591. doi:10.1017/S0032247417000547
[62] T.V. Koroleva, I.N. Semenkov, A.V. Sharapova, P.P. Krechetov, S.A. Lednev (2021) Ecological consequences of space rocket accidents in Kazakhstan between 1999 and 2018, Env. Poll., 268: 115711, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2020.115711
[63] Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials (2014), JSC 26895, NASA

7.4.6 Mishap plan

An accident directly affecting Norwegian land or sea areas could have catastrophic consequences. The affected municipalities initially hold the responsibility for preparedness in handling a situation, with the primary focus on securing lives and property. Health services and hospitals, as well as fire and police services, must also be ready if needed following an accident where a rocket or rocket debris impacts in Norway. The Norwegian Coastal Administration[64] is responsible for co-ordinating state and municipal preparedness for acute pollution, in order to protect lives, health, the natural environment, and commercial interests - both at sea and on land. The mishap plan must ensure rapid notification to Norwegian authorities, both civilian and military, as well as affected local authorities.

7.5 Conclusions

This chapter has introduced a procedure for generating flight safety analysis results necessary for assessing a launch application using the FAA 450 regulatory framework. The presented method corresponds to an accepted means of compliance for FSA for orbital launches from or over Norway. Specific documentation and deliverables from an FSA are discussed in chapter 8.

[64] https://www.kystverket.no/en/preparedness-and-emergency-response-against-acute-pollution/responsibilities-roles-and-resources/

8. Documentation necessary for risk assessment of orbital launches from Esrange Space Center over Norway

8.1 Purpose and scope

This chapter provides a summary of the documentation required by CAA Norway to review a flight safety analysis based on FAA 450 and related regulations for overflight of Norwegian territories, as laid out in chapter 7.

The overview given here should be interpreted as the minimum body of documentation that can be used by authorities to assess and prospectively accept the risk connected to an orbital launch. The main part of the documentation is corresponding to that needed to fulfil flight risk requirements § 450.101 and §§ 450.113 through 450.145. Requirements outside this scope, which affect assessment of a launch application are presented elsewhere in this report. A flight risk assessment as outlined by FAA 450 is usually an iterative process, and CAA Norway may need to request additional justification and documentation. Most generic documentation requirements can be produced by templates and methods suggested in the FAA Flight Safety Handbook and respective advisory circulars. However, a few requirements, especially those relating to notification and bilateral communication are unique for, and ad hoc to, the specific case of launches from Esrange over Norway.

8.2 Documentation pertaining to FAA 450

In the following, we present a list of documentation needed to demonstrate compliance with regulatory requirements for a typical launch operation application. The documents are preferably prepared in the form of reports with supplementary information such as test data, datasheets or analysis results. The review process is normally iterative between CAA and the launch operation applicant.

8.2.1 Flight Safety Analysis

The FSA documentation can largely be covered by two submissions: *a methodology* and a *report on FSA results*. CAA Norway does not issue official templates with formats for the documentation, so an applicant is free to tailor the format of deliverables provided that they contain the necessary evidence for compliance. The FAA 450 is designed such that the requirements regarding FSA invoke § 450.101 on risk criteria and § 450.115(c) on methodological rigor to ensure compliance. Table 8.1 summarizes the content of the main deliverables, and 450.115(c) should be followed for each of these. Where available, CAA Norway regard the advisory circulars for respective regulatory paragraphs to be valid means of compliance.

Table 8.1: Summary of documentation deliverables for FSA assessment by the CAA.

Regulation	Necessary Documentation
§ 450.117 Trajectory analysis for normal flight	**Methodology:** • Method used to describe the normal flight of a vehicle in accordance with 450.115 (c) • Input parameters with uncertainties and assumptions as used in the normal trajectory modelling in 6 DoF. • Description of worst atmospheric conditions, and how these are monitored and evaluated. Information about atmospheric model. **Analysis results:** • Nominal trajectory • Characterisation of trajectory variability • Characterisation of trajectory uncertainty
§ 450.119 Trajectory analysis for malfunction flight	**Methodology:** • Method used to describe malfunction flight of a vehicle in accordance with 450.115 (c) • Limits of useful mission methodology • Input parameters with uncertainties and assumptions as used in the malfunction modelling including: 1. List of causes and malfunction type 2. Quantitative description of parameters that influence malfunction **Analysis results:** • All sets of malfunction trajectories and their probability • Set of useful mission trajectories.
§ 450.121 Debris analysis	**Methodology:** • Description of all scenarios that may lead to hazardous debris • Impact and break-up methodology • Impact distribution methodology • Atmospheric data and model description • Quantitative description of physical and aerodynamic properties of harmful and hazardous debris • Uncertainties and assumptions in all parametric inputs
§ 450.123 Population exposure analysis	**Methodology:** • Description of the methods used to develop exposure input data in accordance with 450.115 (c) • Complete population exposure data
§ 450.131 Probability of failure analysis*	**Methodology:** • Probability of failure analysis methodology in accordance with 450.115 (c) **Analysis results:**

	• Representative set of data with graphs of predicted failure rate and cumulative PoF *for each foreseeable failure mode*
§ 450.133 Flight hazard area analysis	**Methodology:** • A methodology for flight hazard area analysis with waterborne and airborne vessel classes representative for the overflight region. Should include a notion of vulnerability criteria. **Analysis results:** • Coordinates of all hazard areas • Representative 97 percent containment contours for potentially harmful debris resulting from normal flight • Representative individual probability of casualty contours threshold at 10^{-6} or greater, given all foreseeable conditions within flight commit criteria • 10^{-5} and 10^{-6} impact probability contours for all debris capable of causing casualty on a waterborne vessel • 10^{-6} and 10^{-7} impact probability contours for all debris capable of causing casualty on an aircraft
§ 450.135 Debris risk analysis *	**Methodology:** • Methods for demonstration of compliance of § 450.101 risk criteria, including pre-flight analysis procedure • Atmospheric data description • Effective sheltered (including representative types of buildings, ground vehicles, waterborne vessels and aircraft) *and* unsheltered casualty areas for all fragment classes • Uncertainties and assumptions **Analysis results:** • Total casualty expectation for the entire proposed operation • A list of the collective risk contribution for at least the top ten population centres *and* all centres with collective risk exceeding 1 percent of the collective risk criteria • A list of the maximum individual probability of casualty for the top ten population centres *and* all centres that exceed 10 percent of the individual risk criteria • A list of the conditional collective casualty expectation for each failure mode for each significant period of flight under representative conditions and the worst foreseeable conditions
§ 450.137 Far-field overpressure blast effects analysis *	**Methodology:** • Methodology for determining the risk for downrange population from distant focussing overpressure effects, including that from intact impacts with remaining fuel

	• Justification of explosive yield used • Justification of shelter material strength and composition assumptions • Description of meteorological input • Description of methodology used for peak incident overpressure estimations, window breakage probabilities and the probability of casualty derivations **Analysis results:** • Graphs and data showing probability of casualty of 10^{-6} or greater, in Norwegian territories • Maximum expected casualties from far-field overpressure hazards
§ 450.139 Toxic hazards for flight	**Methodology:** • Means of obtaining toxicity information • Safety data sheets for toxic substances **Analysis results:** • Any analysis should be done on the basis of a dialogue with Norwegian authorities about necessary documentation – which is case specific depending on the particular substances used

* See *notes on these sections below.*

Notes on Table 8.1

Although all sections in FAA 450 shall describe a methodology that is representative for a specific mission, some are more general. For a few topics, launch statistics have improved significantly since the Flight Safety Handbook was published (2011), and more recent *a priori* knowledge should be utilised. Below we emphasize sections for which particular care should be taken when developing the methodology and subsequent FSA products.

§ 450.131 Probability of failure analysis

Probability of failure (PoF) analysis is discussed in more detail in chapter 7.2. A major challenge with new launch vehicles is to obtain a correct and unbiased estimate of PoF. The term "new launch vehicles" is not well defined but should be understood as a launch vehicle without a flight history, or where the launch vehicle design has been significantly altered and without a flight history based on such alteration. CAA Norway require that a rigorous statistical estimate is employed for the PoF, rather than the limited statistics of the Flight Safety Handbook. Especially two methods may be useful for new developers:

1. Time-dependent Bayesian update success rate analysis

Wagenblast and Bettinger[65] (2024) summarizes a method of using Bayesian statistics to obtain an unbiased estimate of PoF where only data from a limited number of launches are available.

[65] Wagenblast and Bettinger (2024) Statistical reliability estimation of space launch vehicles, JSSE https://doi.org/10.1016/j.jsse.2024.10.001

2. Beta distribution

This method requires work on the characterisation of flight phases and circumstances that are similar between the new vehicle and one with a certain flight history. SpaceX has developed a tool[66] for utilising Beta distributions on new launch vehicles, that is available through their webpage.

3. Nearly Bottom-Up (NBU) method

The NBU method[67] balances the commonly used top-down with the bottom-up PoF analysis by adjusting the historical failure frequencies to account for the unique features of the ELV under consideration. In doing so the method assesses flight experiences of launch vehicles that have been operated and developed under similar circumstances and combines them with the specific characteristics of the launch vehicle's subsystem and their weighted relative unreliability.

§ 450.135 Debris risk analysis
In cases where there are significant downrange populations, it is necessary to put special emphasis on the debris risk for communities and population centres where people reside, as opposed to just calculating the total risk according to the criteria in § 450.101. Such a decomposition of risk is discussed in more detail in chapter 7.4.1.

§ 450.137 Far field overpressure blast effect analysis
Far field overpressure from blasts produced by explosions of launch vehicles, also called distant focussing overpressure (DFO), is a mechanism by which an explosion can cause harmful overpressure at distances far beyond the immediate vicinity of the blast centre. Harmful pressures may even occur at distances on the order of some 10 km. A full solution for finding the risk of DFO is computationally demanding and technically difficult, as it requires thorough mapping of geography in a large area around the blast centre. FAA propose a *de minimis* approach to simplify the DFO screening, in AC-450.137-1[68]. Moreover, SpaceX have published a tool[69] intended to be used for initial screening for possible DFO risk, which is in line with the FAA recommendations and particularly takes risk decomposition for population centres into account. The tool can be downloaded from their website. The initial screenings for Norwegian territories should be done with such simplified methods on the day of launch, and if risks are found to be close to the thresholds, more accurate calculations using e.g. ray tracing of pressure waves may be employed.

8.3 Documentation outside the FAA 450 scope

The scope of the FAA 450 framework does not cover all hazards that are reasonably foreseeable for the case of overflight over Norwegian territories. CAA Norway requires that additional documentation connected to the topics below are submitted for review for any launch operation affecting Norway.

[66] https://www.spacex.com/media/New_Launch_Vehicle_Flight_History_International_Database.xlsx (*Probability of failure analysis for new launch vehicles*, Titulaer, S. IAASS 2024)
[67] Wilde et al. (2013), Probability of Failure Analysis Standards and Guidelines for Expandable Launch Vehicles, IAASS Conf Proc. ISBN 978-92-9221-279-7
[68] AC-450.137-1 *De Minimis Far-Field Overpressure Blast Effects Analysis*, dated Sept. 10, 2024
[69] Titulaer, S., SpaceX *Simplified far-field overpressure blast effects risk analysis*,13th IAASS Conference 2024

8.3.1 Special Considerations

Overflight of populated areas

The geographical situation for launches from Sweden differs from traditional launches performed under FAA 450 in that the launch site is located inland with the overflight crossing a national border, between approximately 75 km and 135 km downrange, proceeding to overfly uncontrolled populated areas of a foreign country (see chapter 5.2) before moving over the ocean. FAA 450 does to some extent describe launches over uncontrolled populated areas, however, the overflight scenarios are considerably further downrange compared to the situation described here, and CAA Norway recommends the following:

- For the period of flight possibly affecting Norway, it is necessary to demonstrate compliance with § 450.101(c) for all areas impacted by the phase of flight concerning Norway. In particular, if flight abort is used as hazard control strategy, it needs to be demonstrated that protection against a high consequence event is achieved for normal trajectories and malfunctioning trajectories within the lines of a useful mission/established flight limits by ensuring the consequence of any reasonably foreseeable failure mode, in any significant period of flight, is no greater than 1×10^{-3} conditional expected casualties.
- Norway is to be regarded as an uncontrolled area for launches from Esrange, and no flight hazard areas identified in § 450.133 located on Norwegian territory, including territorial waters, should be established, surveyed, controlled or evacuated as required in § 450.161 to meet the risk criteria in § 450.101(a) and (b) and reduce the total mission risk.
- Also, due to the accumulative nature of E_C it has to be shown that the collective risk for the part of the flight affecting Norway treated separately satisfies the risk criteria set forward in § 450.101.

Toxic hazards

Section § 450.139 on toxic hazards does not sufficiently cover all particular considerations needed for possible toxic debris (including fuel) in an overflight scenario within azimuths of 346 to 350 degrees. This topic is discussed in more detail in chapter 7.4.5 where it is concluded that CAA Norway will decide the correct course of action following a notification from a launch operator that possible toxics are present in a launch vehicle or its payload. Accordingly, any substance that conceivably can harm the Norwegian public, environment, flora or fauna, must be notified. In this context it is worth mentioning that SSC, according to the Esrange Safety Manual[70] does not consider kerosene-based fuels such as RP-1 (used in Firefly Alpha) as hazardous – and does not require a toxic hazard analysis for these. We note, however, that such fuels although not toxic may cause serious issues related to pollution in grazing, water, ocean and wetland areas which may require complicated clean-up operations.

Offshore Installations

Impacts on offshore assets are discussed in detail in chapter 5.11. Based on serious concerns from the Norwegian Offshore Directorate and the Ocean Industry Authority regarding possible major accidents affecting offshore installations, CAA Norway stress that particular attention is given to risks and consequences for these installations. Such installations are not treated as critical assets according to § 450.101(a)(4) nor are they strictly part of the public risk

[70] ESM v. 10.0, Chapter 8.3.2.7

assessment due to being outside the 12 nautical mile boundary. However, we stress that a public risk assessment according to AC-450.123 should be done nevertheless, in addition to estimating high consequence risks. Therefore, Norwegian authorities may require a dedicated assessment of risk to offshore assets, including conditional risks and far-field blast overpressure risk, if an installation is within or close to any hazard area or termination limit lines.

8.3.2 Documentation relating to the flight safety system

Under Part 450, rocket launch operators are required to demonstrate the reliability of their flight safety systems, as it is a crucial element to ensuring public safety. Specifically, § 450.145 mandates that a flight safety system must have a design reliability of 0.999 at a 95% confidence level.

To document compliance with § 450.145, launch operators typically must provide the following recognised means of compliance to the approval authority:

- Selection of adequate Means of Compliance including justification and demonstration of equivalent level of safety.
- Timeline of approval process and list of deliverables
- Compliance matrices in accordance with applicable requirements and standards (i.e. RCC 319, RCC 324, ISO standards)
- Detailed description of the flight safety systems, sub-systems and components (hardware (HW) and software (SW))
- HW and SW design documentation
- HW and SW analysis and reports
- Test procedures and test data

In order to demonstrate compliance an overview of specific requirements and assessment criteria, including the types of documentation and evidence considered (i.e. design documentation, analysis/test reports, test data, operational history, compliance matrices) is expected. Details regarding the standards applied (i.e. RCC 319/324 or others), any exemptions granted, list of non-compliances, what has been accepted or rejected, and the rationale behind these decisions will also be required as part of the documentation.

8.4 Conclusions

This chapter has introduced a minimum set of documentation, divided between methodology and analysis results, necessary to do a review of a flight safety analysis according to FAA 450. Also stated here are points that may be considered outside the scope of FSA requirements in FAA 450, which require a more specialised evaluation from both Swedish and Norwegian authorities. Note especially the need for a thorough assessment of risks to Norwegian Offshore assets, for which serious concerns have been raised by the Norwegian Offshore Directorate and the Ocean Industry Authority. Any assessment of use of toxics in a launch vehicle or its payload should be treated case specific and ad hoc in order to determine the level of analysis required to ensure safety for Norwegian public, fauna, flora and environment.

9. CAA Norway remarks on received and available documentation of planned operations

9.1 Purpose and scope

The purpose of this chapter is to provide comments on specific information on the planned orbital launches from Esrange Space Center provided by SSC. The remarks given here illustrate precarious issues for the overflight case, and must in any case be discussed in order to be prospectively resolved in an iterative process between all involved authorities and launch operators. Some of the reviewed information pertaining to details about the involved parties, launch vehicles, user handbooks and safety manual, is available through different sources online. Information and documentation concerning flight safety analysis for the case of launch over Norway has been provided to CAA Norway by the SSC.

This chapter covers some of the immediate safety concerns based on the available documentation about the first operations from Spaceport Esrange. Consequently, this chapter does *not* discuss considerations on socio-economic impacts, bilateral policies or practical issues on Norwegian territories connected to a launch operation.

9.2 Comments on planned operations

As far as CAA Norway understand, SNSA and SSC are of the opinion that the results from the model safety analyses are valid as proven facts of the feasibility of launches from Spaceport Esrange that pass through Norwegian airspace and over Norway. This is based on observations of SSC public communication, internationally in meetings on the matter, for instance in ICAO NAT workshop 13th and 14th May 2024 where they presented the following illustration shown in Figure 9-1 in their presentation on new entrants' integration in the NAT airspace region[71].

[71] https://www.icao.int/EURNAT/Other%20Meetings%20Seminars%20and%20Workshops/NAT%20Workshop%20on%20New%20Entrants%20Integration%20(2024)/NATWKSCSO%20PR05%20SWE%20Swedish%20Space%20Corpn.pdf

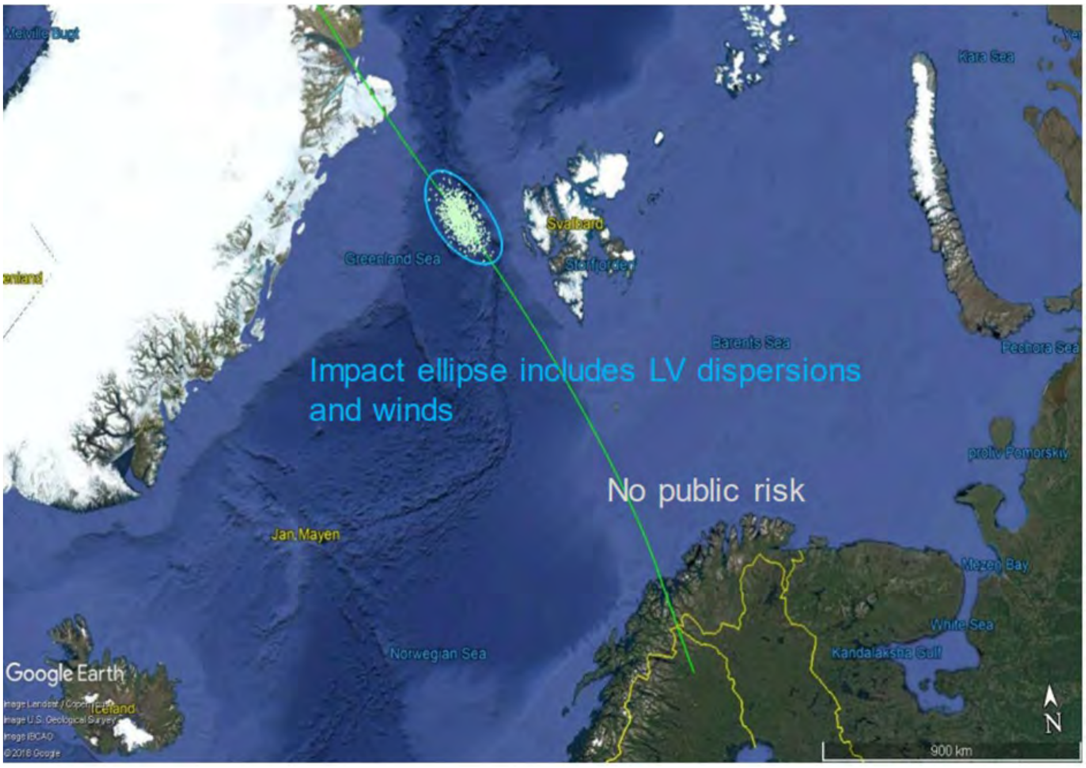


Figure 9-1: Illustration from SSC PowerPoint presentation, ICAO NAT workshop 13 and 14 May 2204.

In presentations it is generally stated "no public risk" on illustrations as the example shown above.

However, as discussed in previous chapters, a comprehensive safety analysis includes a range of elements, where both the methodology and premises are important to ensure an analysis of such quality that it can be used as a basis for risk assessment. Based on the information received from SNSA and SSC, CAA Norway would like to make remarks in relation to some important topics.

9.3 Area affected by flight safety limits

Flight abort for orbital launches is focused on protecting the public, including against high consequence events, in case of a failure. Flight safety limits must be established that define when a flight safety system must terminate a launch vehicle's flight. This in order to prevent the resulting debris from reaching any populated area outside the flight safety limits and ensure that the launch satisfies the public risk criteria. Hence, all areas within the flight safety limits will as such be affected by a launch since the launch vehicle is permitted to follow all trajectories within that sector. As elaborated in chapter 7, the safety criteria § 450.101(a) and (c) must be met to ensure public safety in the uncontrolled areas within flight termination lines.

In the documentation received[72] only Autonomous Flight Termination System (AFTS) lines are shown. It is however stated that "AFTS to be activated when the vehicle instantaneous impact point (IIP) crosses a limit line, and that "limit lines constructed to define an acceptable flight corridor". According to the documentation, no limit lines are shown for the IIP, but they would have to be located outside AFTS lines. Hence, the exact areas that may be affected for the

[72] SSC PowerPoint presentation *Flight Safety Analyses Results and Methodology Description*, slide 13, received 25th October 2024.

proposed azimuths are not known. We would also like to note that only nominal trajectories seem to be shown for both LV1 and LV2. No normal trajectories or malfunctioning trajectories are shown, and it is uncertain to which degree these have been included in the generic analysis.

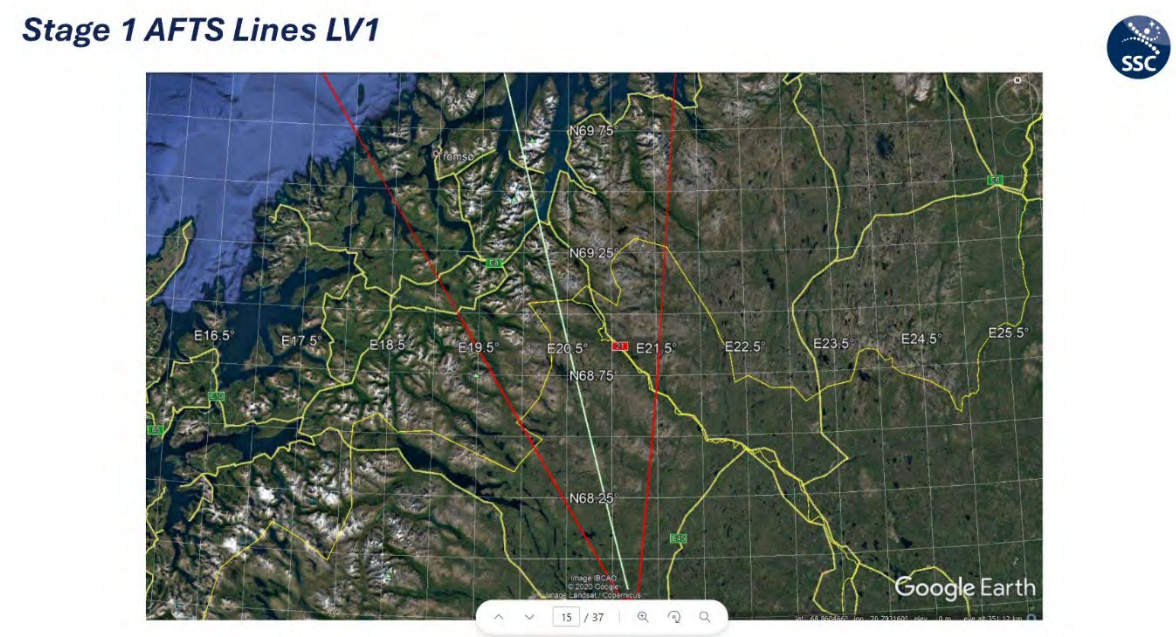


Figure 9-2: Part of PowerPoint presentation received from SNSA 25th October 2024, slide showing the AFTS lines for LV1.

SSC have provided no detailed justification on the placement of AFTS lines. As can be seen in figure 9-2, the city of Tromsø is located within the AFTS lines for LV1, and hence flight abort is no hazard control strategy for protecting the city of Tromsø in particular, but also other uncontrolled, populated areas in Norway located within the flight corridor in general. This is also the case for LV2. This does not seem to be according to § 450.108(c)(3) which states that "An operator must determine and use flight safety limits that define when an operator must initiate flight abort for each of the following:

> "*To prevent the vehicle from entering a period of materially increased public exposure in uncontrolled areas, including before orbital insertion, if a critical vehicle parameter is outside its pre-established expected range or indicates an inability to complete flight within the limits of a useful mission*"

It is stated that "*all trajectories from Esrange will include a dogleg manoeuvre*" and that "*no trajectory will pass over Tromsø*"[73]. However, it is unclear if this statement refers to nominal trajectories only, or also to all normal and malfunctioning trajectories which does not seem to be the case considering the shown AFTS lines.

Since no full flight safety analysis in accordance with Part 450 has been done, CAA Norway has not tried to determine the exact areas that may be affected for the proposed azimuths. See more on the affected area in chapter 5.2.

[73] SSC PowerPoint presentation Vehicle and Trajectory Description, slide 2, received 25th October 2024.

9.4 Accurate population exposure models

The number of people in the overflight region impacts the flight safety analysis and risk calculations which determine whether a launch meets the criteria for risk to the public in FAA 450 and hence is safe.

The population numbers on the Swedish side of the affected area and the Norwegian side of the affected area differ greatly. In Kiruna Municipality, there were 22 426 residents at the end of 2024, of which 86.6% lived in Kiruna town according to statistics[74] from Statistics Sweden. The affected area in Sweden is sparsely populated,[75] whereas on the Norwegian side of the border there is a population of at least 150 000, see table 5.1 in chapter 5.3.

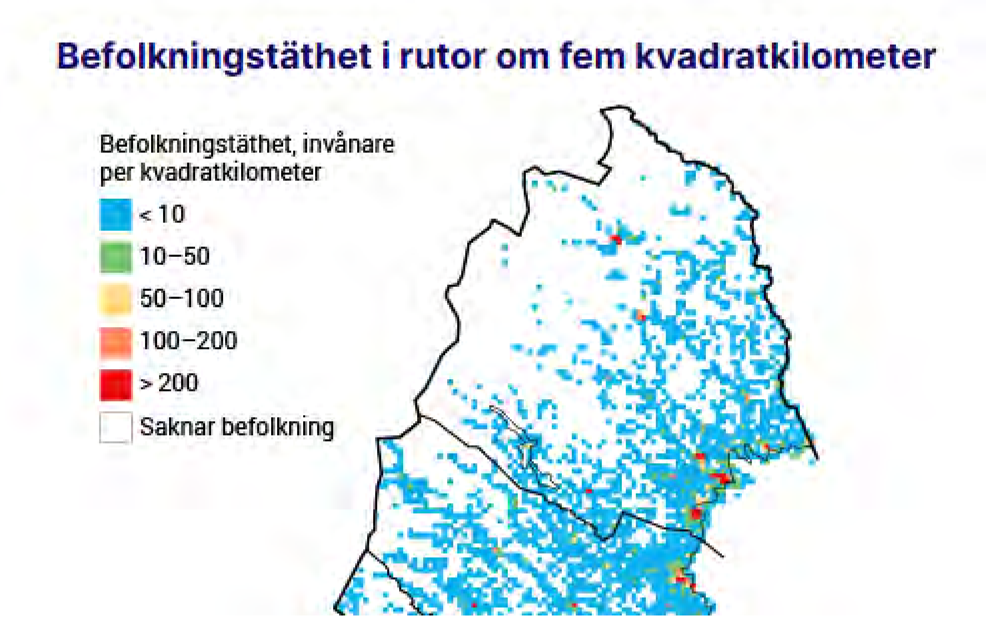


Figure 9-3: Illustration from Statistics Sweden that shows population density in 5 km grids. White indicates areas without population.

The information received from SSC indicates population in two areas within the affected area in Sweden. As far as CAA Norway understands shelters have been constructed in order to safeguard people in these areas during launch of sub-orbital launch vehicles.

[74] Kommuner i siffror (Only in Swedish). The percentage 86,6 relates to the population numbers from 2023.
[75] Statistics Sweden https://www.scb.se/hitta-statistik/sverige-i-siffror/manniskorna-i-sverige/befolkningstathet-i-sverige/ (Only in Swedish)

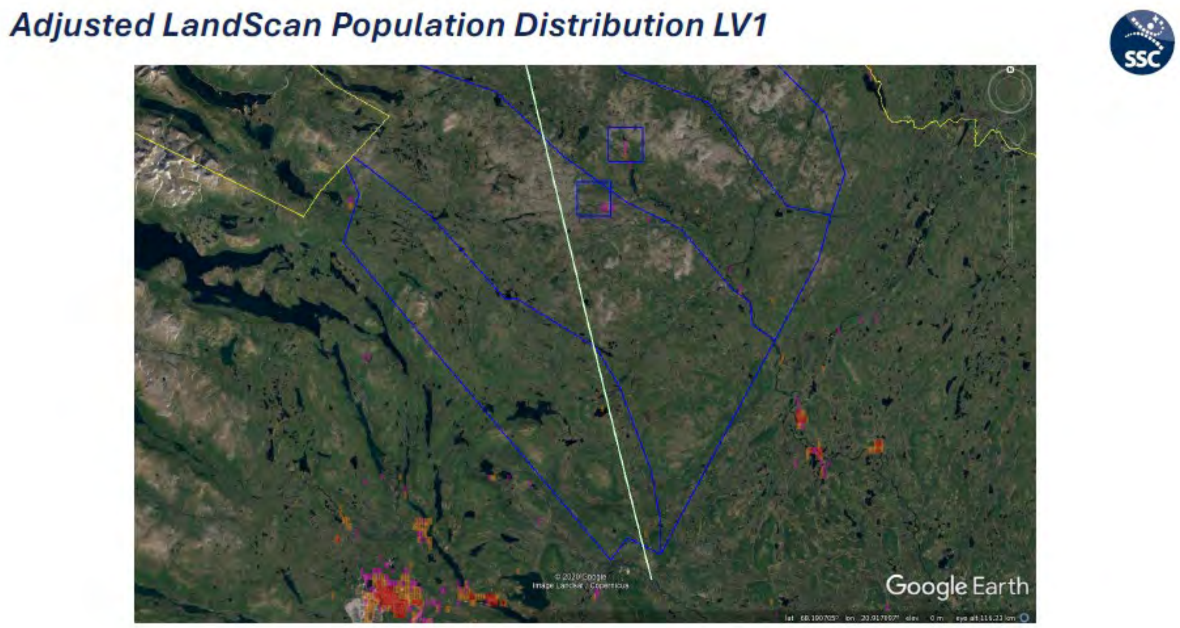


Figure 9-4: Part of PowerPoint presentation received from SNSA 25th October 2024, Illustration of population distribution.

The settlement pattern on the Norwegian side is different; there are settlements across large parts of the affected area. See the illustration in figure 5-3 in chapter 5.3 which shows the settlement in the area.

According to information received so far, outdated and non-specific population data from 2006 have been used in the generic flight safety analysis from 2018-2020[76]. The utilized grid size in the generic FSA analysis is not sufficient to resolve the population centres accurately, see also chapter 7.4.1.

In addition to the population in the municipalities in the affected area, a number of factors have to be included in the population analysis:

Traffic: All local flights, maritime traffic and road traffic must be taken into account. Air traffic comprises scheduled flights as well as non-scheduled flights and emergency medical services. For maritime traffic: shipping traffic, fishing vessels, ferries and high-speed traffic vessels, cruise ships and private boats have to be considered. Both transport of goods and people must be taken into account for road traffic. Fall type of traffic, emergency response traffic is also important to consider.

Seasonal variations must be included in the analyses: Activities such as cruise tourism, aurora watching, fishing, whale watching, outdoor sports, the midnight sun (and more) draw high numbers of tourists to the area all year round. They affect calculations both for land, sea and air. Accordingly, all aspects of traffic described above exhibit seasonal variations with large cruise ships, higher activity of smaller vessels, increased road and air traffic. Also, commercial fishing has a seasonal dependence with higher activities during certain periods of the year.

[76] PowerPoint presentation FSA results and methodology received from SNSA 25th October 2024, slide 4.

Events: Military exercises, sporting events, festivals/cultural events and other temporary activities increase the concentration of people in a delimited area and has to be taken into account.

For the most-part, tourists, as well as participants of events described above will be unsheltered.

9.5 Launch Vehicle Failure Probability

The SSC has stated to CAA Norway that no maiden flights (of orbital launches) will take place from Esrange Space Center. The Esrange Safety Manual provides a section on requirements for 'new vehicles', without defining the criteria for reliability. A detailed description of probability of failure is presented in chapter 7.2.4, from which we extract the following concluding remarks:

In the provided FSA results for launches over Norway, a PoF of 20% for each stage – yielding a total failure probability of 36% – has been used. SCC notes in communication with CAA Norway that "[...] *PoF used were considered reasonable*". The utilised value is much lower than expected for launch vehicles with similar flight history as Firefly Alpha, even with some added successful flights. For the case of Perigee BW-1, a separate and justified PoF is yet to be developed. Furthermore, a launch vehicle with on the order of ten successful launches cannot be considered flight proven, and the PoF is a key parameter in the FSA prerequisites that must be set conservatively. Accordingly, CAA Norway does not consider Firefly Alpha to be flight proven nor with a considerably low PoF compared to similar vehicles.

9.6 Expected Casualties Threshold

The operator and planned activities are described in detail in chapter 3. Therein, an excerpt from the updated Esrange Safety Manual is presented. The applicable requirement for expected casualties is stated as $E_C < 1.49 \times 10^{-4}$, however it is noted that a risk of 1.49×10^{-4} may be rounded down to 10^{-4}. This introduces a round-off "error" of 49% compared to the FAA 450 requirement, which SSC has stated will be applied on orbital launches over Norway. CAA Norway does not consider rounding off E_C in the proposed way as acceptable for complying with FAA 450.

9.7 Conditional Expected Casualties Threshold

In documentation provided by SNSA to CAA Norway in October 2024[77], it is stated that: "*No CE_C calculation has been performed so far for any other launch vehicle but will be performed for both Alpha and BW1 once SSC receives the required input data*". A calculation from a feasibility study was provided, for which the results are presented in Figure 9-5. The documentation from SSC additionally states for this figure that: "*The consequence of any reasonably foreseeable failure mode for when the IIP was in Norway* [...] *was no greater than 1×10^{-2} conditional expected casualties*". CAA Norway notes that the requirement for $<10^{-2}$ conditional casualties is for:

(1) *a priori* knowledge of the casualty expectation in uncontrolled areas, in any case invoking the CEc threshold in § 450.101 (c); and

(2) defining limit lines § 450.108 (c)(4) in an uncontrolled area due to flight abort.

[77] PDF document *CE_C Calculations* provided by SNSA to CAA Norway, dated Oct. 2024.

This is also discussed in chapter 6.3.6. It must furthermore be particularly stressed, that to find termination limits for the case of overflight over Norway, an operator *must* provide evidence that the CE_C is satisfied in uncontrolled areas due to flight abort or due to flight outside the limits of a useful mission from any reasonably foreseeable off-trajectory failure mode in any significant period of flight. This implies an analysis that reaches far beyond using a spatial and temporal stationary population distribution. In the feasibility study, a temporal resolution of 0.2 Hz has been used, which is much lower than recommended[78] and necessary to resolve CE_C risk for population centres in the overflight region. We furthermore emphasise that the CE_C-risk in the uncontrolled populated areas of Norway should remain below 10^{-3} for any significant period of flight.

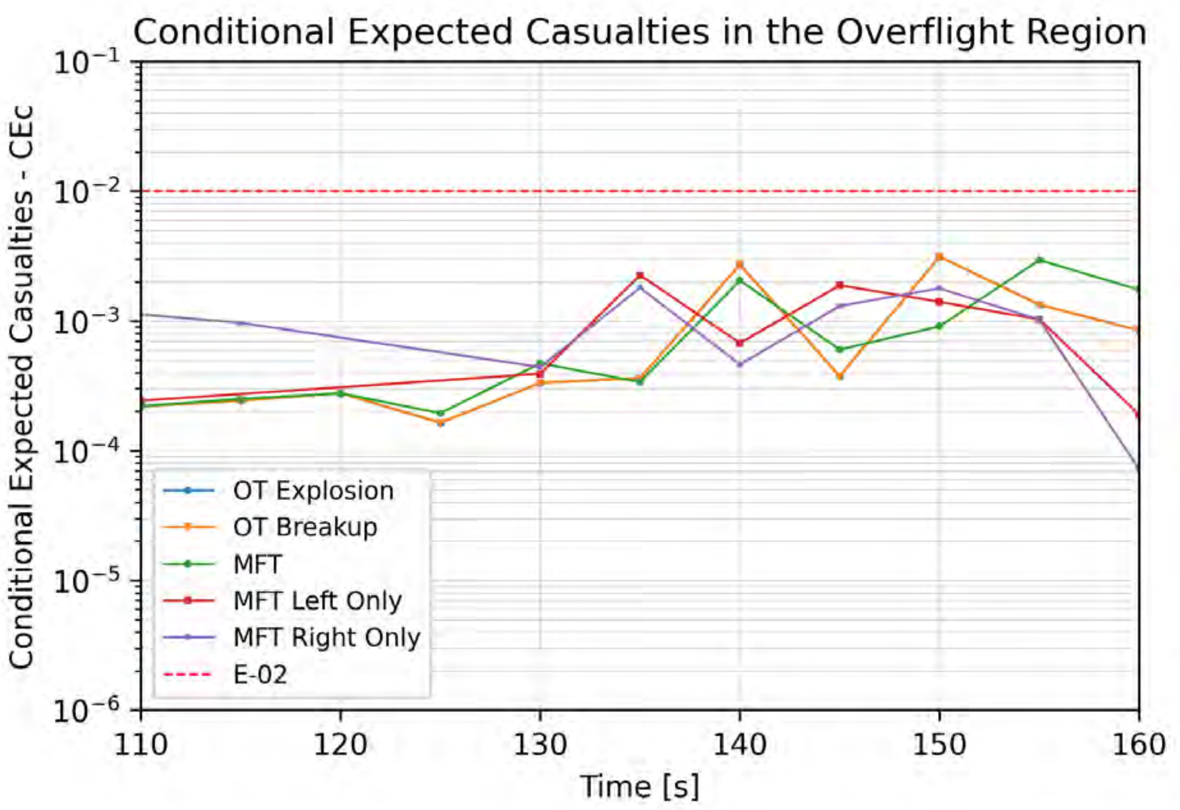


Figure 9-5: Conditional Expected Casualties from feasibility study provided by SNSA to CAA Norway, 25th October 2024.

9.8 Intact Explosions and TNT Equivalence

In the available FSA documentation from SSC, a 22% TNT equivalence has been used for intact impact explosions. Such an equivalence may be representable for idealised conditions for a mixture of liquid oxygen (LOx) and kerosene (RP-1) but offer no additional conservatism in the explosion yield. It is true that the operator licence regulation framework, FAA Part 420, lists 20% as a static explosion yield factor, and, for intact impacts, the FAA Handbook and advisory circulars present curves for intact impacts on hard targets that are close to 22% for LOx/RP1. However, for soft targets the yield is velocity dependent, and in general >20%. Moreover, for mixtures of LOx and natural gas such as methane (intended to be used on Perigee BW-1), a

[78] Chapter 9.2 in AC-450.101-1

much more conservative yield factor should be used[79,80], possibly with some variation due to mixing conditions and impact speed. CAA Norway note that a public risk estimate derived with 20% TNT equivalence for intact impacts will not be considered conservative.

9.9 Conclusions

In this chapter we have discussed some of the immediate safety concerns based on available documentation about the first orbital launch operations from Spaceport Esrange. The information on flight safety analyses has been provided directly to CAA Norway by SSC, and additional information has been retrieved from the user handbook, safety manuals and other publicly available data on facilities, launch vehicles, and area affected by launch operations.

The points raised here pose some precarious concerns raised from the documentation, which are in need of immediate attention and discussion between relevant authorities. Details regarding FSA and its fulfilment are discussed in chapters 7 and 8.

[79] Blackwood et al. (2023), An Interim Set of TNT Curves for LOX/LNG Explosions, NASA doc 20230003746
[80] Berkowitz, A., & Titulaer, S. (2024). Development of a Lox/Methane intact impact yield curve for a new launch vehicle. *Journal of Space Safety Engineering*, *11*(4), 590-604.

10. Main findings and recommendations

10.1 Purpose and scope

CAA Norway has been tasked with assessing the risks, socio-economic costs, and other consequences for Norwegian security and societal interests, and the security requirements for potential rocket launches from Sweden that pass over Norway, as well as the safety requirements that must be imposed.

In chapter 6, the general definitions and concepts relating to risk are discussed. The socio-economic costs and other consequences are outlined in Chapter 5 and are not repeated here. Furthermore, Chapters 7, 8, and 9 provide detailed information on the security requirements and the specific safety and risk issues launches from Esrange Space Center over Norway raises. In this chapter we summarize some key findings and at the end of the report give four recommendations.

10.2 Part I - Main Findings

10.2.1 Insufficient details in risk estimation

There is currently not enough detailed information in order for CAA Norway to evaluate what the actual risk of a launch over Norway from Esrange Space Center would be. The specific information needed in order to evaluate the risk is outlined in Chapter 8.

It is CAA Norway's understanding that, due to the way the risk assessment and application process is set up in Sweden, the risk for Norwegian areas will not be clarified until late in the process. It is crucial that the Swedish authorities plan to allow the relevant Norwegian authorities sufficient time to review and consider the risk for a launch over Norway.

The time needed for Norwegian authorities will depend on the quality of the information received, and that all necessary elements as discussed in this report are part of the analyses.

10.2.2 Assessment of risk

Chapter 7 of this report details the safety and security requirements that need to be fulfilled by the operator according to FAA 450. Usually, spaceports are located on the coast to avoid launching over uncontrolled or populated areas, particularly early in the flight. This reduces risks to the public significantly as discussed in previous chapters. The risk from orbital rocket launches is highest in the early phases of the flight, which can be visualized by looking at public NOTMAR areas for various orbital launches.

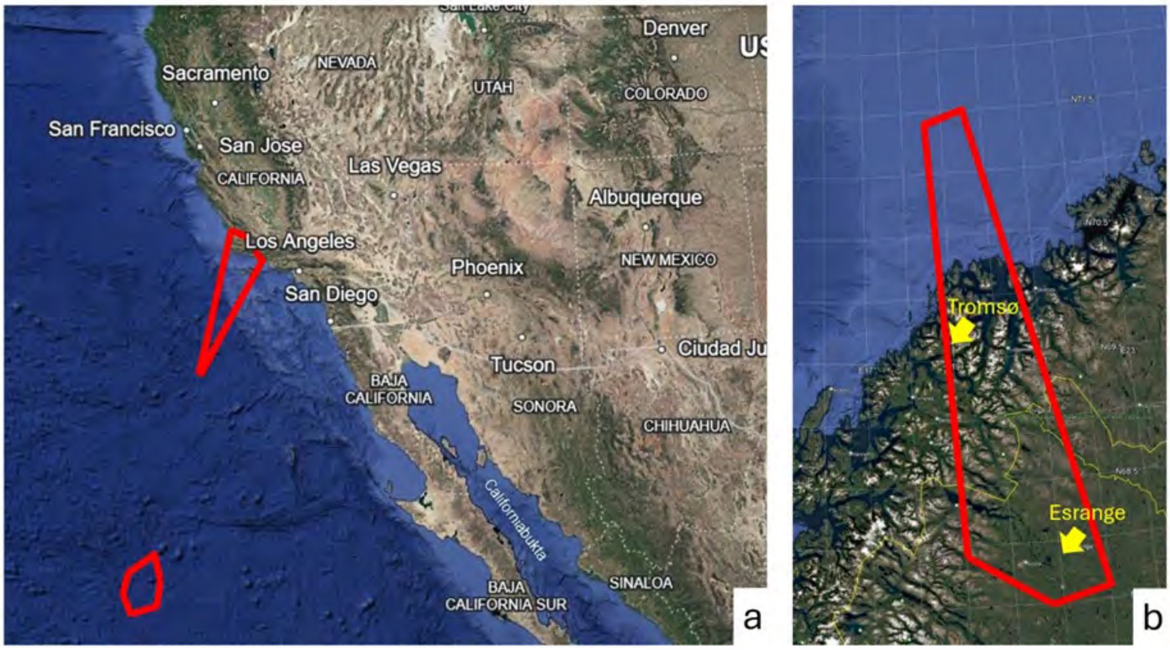


Figure 10-1 (a): NOTMAR area for Firefly FLTA005 launched from Vandenberg Space Force Base on 4th July 2024. (b): NOTMAR area for Firefly FLTA005 overlaid onto Esrange.

As an example, figure 10-1 (a) shows the NOTMAR area for Firefly FLTA005 launched from Vandenberg Space Force Base on 4th July 2024. The red lines delimit the NOTMAR areas. As can be seen, they typically extend from the spaceport outwards along the trajectory, and become narrower at the end. For planned jettison of the first stage booster and fairing, a new hazard area or areas are determined further out, also shown in figure 10-1 (a). Recalling that NOTMAR areas define areas of high risk, they are usually surveyed, publicized, controlled, or evacuated in order to control the risk to the public, composed of collective, individual and aircraft risk.

In figure 10-1 (b), the NOTMAR area for Firefly FLTA005 has been overlaid as if the launch vehicle was launched from Esrange. It is crucial to notice that the NOTMAR area for FLTA005 from Vandenberg is not directly representative for launches of Firefly Alpha from Esrange, as its final size and shape depend highly on the Flight Safety Analyses. The visualization does, however, serve to illustrate the typical shape and size of NOTMAR areas for comparable orbital rocket launches and how they would appear over Norway.

Norway will be an uncontrolled area based on the fact that all Norwegian territories lie outside the area that the spaceport and Sweden can control. Hence, no identified hazard areas on land, sea or air can be surveyed, publicized, controlled, or evacuated in order to control the risk to the public. The actual extent of any hazard areas cannot be determined exactly until the Swedish operator and Swedish authorities provide the precise information needed and perform detailed flight safety analyses for the specific launch vehicles.

Typically, overflight occurs in later phases of the flight when risks are lower and/or the launch vehicle has reached significantly higher altitudes. Examples of this include overflight over islands in later phases of the flight after NOTMAR areas are cleared, or the overflight of land masses, often of other continents, prior to orbital insertion. Figure 10-2 shows approximately distances for launches from Starbase, Texas to Cuba[81] and from Cape Canaveral, Florida to

[81] Note that launches from Starbase, Texas does not overfly Cuba.

locations often discussed in context with overflights. The distance from Kiruna to the Norwegian border ranges from approximately 75 km to 135 km. See also figure 6-3 in chapter 6.2.13, where the longest distance between Esrange and Norway is shown as illustrated.

Figure10-2: Illustration showing approximately distances from Starbase to Havana, Cuba, and from Cape Canaveral to Sagua La Grande, Cuba as well as to Exumas, Bahamas.

For launches from Sweden over Norway, populated areas are located both within and outside of the acceptable flight corridor. The use of flight abort can only protect against high consequence events outside the determined flight safety limits. Therefore, for the uncontrolled region within the flight safety limits the use of flight abort is not a sufficient hazard control strategy. Furthermore, the geographic context for launches from Esrange over Norway is significantly different from the one FAA 450 is typically applied to, because US commercial spaceports are usually located on the coast, and overflight over uncontrolled, populated land areas occurs during the later phases of flight. Therefore, it may be necessary to apply some alternative or additional requirements to FAA 450.

Consequently, it is of utmost importance for Norwegian Authorities to assure that the safety criteria are fulfilled for launches from Sweden over Norway for the entire duration for the overflight, in order to ensure public safety and protection against a high consequence event in the uncontrolled areas within flight safety limits.

According to Esrange User's Handbook Volume II, all safety documentation must be submitted to SSC "[...] no later than 6 months before the anticipated launch date". The Esrange Safety Manual Data Requirement Schedule states that for orbital vehicles, certain data (trajectory, payload and vehicle) must be submitted to SSC no later than nine months before anticipated launch date. These estimated timelines do not seem realistic based on the tiered approach usually used for FAA 450, and especially in a situation where Norwegian authorities need to independently assess the risk.

Conclusion – Recommendation 1

Chapter 7 of this report details the safety and security requirements that need to be fulfilled by the operator, while chapter 8 details information necessary to review the risk for Norway. CAA Norway has in chapter 9 given some remarks regarding the documentation and information which has been provided so far.

While the precise risk of launches from Esrange Space Center over Norway remains unknown until precise detailed information is provided by the Swedish operator or Swedish authorities, information from comparable launch operations suggests that there is a risk associated with allowing launches over Norway. Consequently, CAA Norway recommends that the relevant Norwegian authorities conduct an assessment of the risks a launch will pose to the people in Norway and Norwegian interests, and determine whether this risk is acceptable, taking into account the interests and safety of the Norwegian people and the severity of the risk.

10.2.3 Impacts on daily life

The consequences of a failed launch, resulting in debris fallout in Norway, could have very serious consequences, encompassing loss of life, damage to infrastructure and drinking water, as well as pollution and environmental harm. Statistically, any launch vehicle will experience a failure at some point, regardless of its flight history and the probability of failure. Even highly reliable launch vehicles, such as the SpaceX Falcon 9 with an unprecedented flight history, may experience failure; a Falcon 9 B5 had a failure in July 2024 (12th July 2024).

The analyses presented by SSC have not taken actual nor recent population data in the affected areas into account. Furthermore, neither the number of people living in the area nor the high number of tourists and other transient populations are represented. The affected areas in Norway are significantly more populated than the areas on the Swedish side, and it is not possible to find any trajectory from Esrange that does not overfly populated areas in Norway.

For launches from spaceports near the coast, large hazard areas for sea and air are surveyed, controlled or evacuated and hence vacant of ships, fishing vessels and aircraft in order to limit the risk to the public. However, for the situation of launching over populated areas shortly after liftoff - if people were required to evacuate - it would have an enormous impact on people's daily life, as evidenced by the potential number of launches, the duration of the launch period for each launch (often spanning several weeks), and the daily launch windows in the launch period (possibly between two and four hours in duration).

CAA Norway finds it difficult to reconcile how evacuation on land may be avoided, while we would evacuate people if the launch were to occur over water – i.e. leisure boats, fishing vessels, shipping vessels and air traffic. While in theory such evacuation of the affected area is possible, this would not be without significant cost that must be taken into account when deciding on what is deemed acceptable. Financial costs are discussed further in chapter 5.

Impact upon the daily life of indigenous people

It is additionally important to consider whether allowing launches with measures that that may undermine the cultural, economic, and environmental rights of the Sami people, may be a breach of Norway's obligations under the ILO Convention No. 169 on Indigenous Peoples and Tribal Peoples in Independent Countries (1989).

ILO Convention No. 169 upholds the protection of the cultural rights of indigenous peoples. Reindeer husbandry is not merely an economic activity for the Sami people; it is a central part of their cultural identity and traditional way of life. Any actions that disrupt this practice could be seen as a violation of their cultural rights. The Convention requires that indigenous people have the right to the lands that they traditionally occupy, and the resources therein. Reindeer husbandry relies on extensive grazing lands, and any encroachment or restriction on these lands could impact the Sami's ability to sustain their traditional practices. The Convention also emphasizes the importance of sustainable development that respects the needs and aspirations of indigenous peoples. Disrupting reindeer husbandry without providing sustainable alternatives or support could undermine the Sami people's economic and social well-being. Environmental changes have a significant impact on reindeer husbandry and the Convention obliges states to take measures to mitigate these impacts and support the resilience of indigenous practices. Failure to address these environmental challenges could be seen as neglecting these obligations.

General human rights aspects
CAA Norway finds it pertinent to question whether allowing launches over Norway, with measures that significantly impact daily life, would breach of Norway's obligations under Article 8 of the European Convention on Human Rights on the right to respect for private and family life. Almost all aspects of daily life would be affected, which would include all forms of transportation, the school day for students, access to healthcare and emergency healthcare, and the freedom to conduct one's daily life.

It must also be mentioned that, based on the information available about the potential risks associated with launches from Esrange, and the consequences events and fallout could have for the population in the affected areas, it is possible that Norwegian authorities have a more active duty to protect their own population to safeguard the right to life as defined in Article 2 of the European Convention on Human Rights. Such duty to act may imply that Norwegian authorities have an obligation to ensure that the risk to the population is managed within what can be considered acceptable.

Given the current lack of information, CAA Norway cannot conclude what implications the launches from Esrange over Norway will have on Norway's obligations under the ILO Convention No. 169 and under Article 8 of the European Convention on Human Rights. It is important that an analysis of these obligations is conducted once more information is known about the launches from Esrange over Norway.

Conclusion – Recommendation 2

Any risk-reducing measures implemented in Norway to reduce hazards from launches from Esrange Space Center, including within territorial waters, will have significant negative consequences for the population. Such measures could range from evacuation to requirements to stay indoors, limitation of tourism, suspension of local air, sea and road traffic, as well as suspension of activity for coastal fishermen. Such measures will result in economic losses and additional costs for businesses and all other affected parties. On this basis, CAA Norway recommends further consideration of whether it is advisable to have flight hazard areas located on Norwegian territory, including within territorial waters, i.e. whether such areas can in fact be established and surveyed, controlled or evacuated in order to meet the public risk criteria.

10.2.4 Economic costs

If measures such as evacuation, restrictions on gatherings of people, and restrictions on flights, road and marine traffic are imposed, this would directly affect industry and business interests. If coastal fishermen are required to stay ashore, it would have consequences both for fishermen and the fishing industry. The northern parts of Norway (Finnmark) would be isolated if the E6 were to be closed, affecting transportation of goods and people. The risk of fallout from rockets and the consequent evacuation of oil and gas installations, could result in significant economic consequences, estimated at 1.7 billion NOK (153.01 million USD) per launch in addition to startup costs (assuming the shutdown is no more than 5 days). The investment costs for a new oil and gas production field, with production starting early in 2025, have been substantial.

Affected municipalities must update their emergency-preparedness plans to handle a situation with fallout after an accident. Establishing municipal preparedness for this new crisis scenario will have an economic cost, which affected municipalities will likely insist be covered. The direct costs associated with any impact following an incident or accident (debris hitting Norwegian territory or Norwegian vessels) is expected to be covered by Sweden in accordance with the liability convention.

Although it has not been possible to fully assess what the potential economic consequences would be for the public, municipalities and industry, it is deemed that these consequences would be substantial.

Norwegian authorities will incur additional costs related to managing the risk to Norwegian areas during case processing. It must be considered whether these costs should be fully covered through processing fees or demanded to be covered by Swedish authorities in another way.

Conclusions – Recommendations 3 and 4

Due to the significant economic costs associated with the impact on oil and gas production in the Barents Sea, CAA Norway recommends that no launches be permitted in areas where there is any risk to Norwegian oil and gas installations.

If any direct or indirect measures were to be accepted for risk-containment, they will most likely incur economic costs or result in financial losses. Additionally, the handling of launches by Norwegian authorities will require follow-up and processing, which also entails economic costs. CAA Norway recommends that is considered whether Sweden cover any financial losses or additional costs, directly or indirectly related to launches from Sweden, including resultant processing by Norwegian authorities.

10.2 Part II – Recommendations

Recommendation 1

Chapter 7 of this report details the safety and security requirements that need to be fulfilled by the operator, while chapter 8 details information necessary to review the risk for Norway. CAA Norway has in chapter 9 given some remarks regarding the documentation and information which has been provided so far.

While the precise risk of launches from Esrange Space Center over Norway remains unknown until precise detailed information is provided by the Swedish operator or Swedish authorities, information from comparable launch operations suggests that there is a risk associated with allowing launches over Norway. Consequently, CAA Norway recommends that the relevant Norwegian authorities conduct an assessment of the risks a launch will pose to the people in Norway and Norwegian interests, and determine whether this risk is acceptable, taking into account the interests and safety of the Norwegian people and the severity of the risk.

Recommendation 2

Any risk-reducing measures implemented in Norway to reduce hazards from launches from Esrange Space Center, including within territorial waters, will have significant negative consequences for the population. Such measures could range from evacuation to requirements to stay indoors, limitation of tourism, suspension of local air, sea and road traffic, as well as suspension of activity for coastal fishermen. Such measures will result in economic losses and additional costs for businesses and all other affected parties. On this basis, CAA Norway recommends further consideration of whether it is advisable to have flight hazard areas located on Norwegian territory, including within territorial waters, i.e. whether such areas can in fact be established and surveyed, controlled or evacuated in order to meet the public risk criteria.

Recommendation 3

Due to the significant economic costs associated with the impact on oil and gas production in the Barents Sea, CAA Norway recommends that no launches be permitted in areas where there is any risk to Norwegian oil and gas installations.

Recommendation 4

If any direct or indirect measures were to be accepted for risk-containment, they will most likely incur economic costs or result in financial losses. Additionally, the handling of launches by Norwegian authorities will require follow-up and processing, which also entails economic costs. CAA Norway recommends that is considered whether Sweden cover any financial losses or additional costs, directly or indirectly related to launches from Sweden, including resultant processing by Norwegian authorities.

10.3 Closing remarks

This report is written based on the information known as of 25th February 2025, and, as stated in Chapter 3, only very little pertinent information is known about the rockets and the planned launches. Assessments may therefore change based on new information.

Furthermore, the report only provides an overview of the consequences a launch could have, and a more detailed review could also reveal other important consequences. The consequences for the Armed Forces are discussed in very general terms, in order to keep this as a public report. Factors such as changes in the population could alter the risk. Changes in rockets, rocket safety systems, etc., could also alter the risk.

SNSA and SSC have stated that they will base the flight safety analysis on FAA 450. This report mainly discusses what is related to Subpart C, as an investigation of the safety requirements for launches has been requested by NFD. There are also other requirements in FAA 450 that must be met, in addition to FAA 450 being based on the fulfillment of certain external requirements and standards outside of FAA 450.

This report is based on the current version of FAA 450. If there are changes to the requirements in FAA 450, a specific assessment must be made of what the change entails and whether the change means that FAA 450 can no longer be used as a basis for assessing the safety of the Norwegian public, with regard to launches made from Esrange Space Center, which travel over Norway.

Annex - Spaceports of the world

Spaceports for Orbital Launches

A spaceport is defined in the Oxford English Dictionary as “a base or facility from which spacecraft are launched”. There are various methods for launching spacecrafts (normally known as orbital launch vehicles or orbital rockets), including land-to-air, sea-to-air, and air-to-air, with vehicles following an orbital or a sub-orbital (ballistic) trajectory. “Land to air” means launching the rocket vertically from a dedicated pad on land, and “sea to air,” launching the rocket from a mobile platform at sea. Horizontal launches consist of specialized aircraft that can take off horizontally, and after the aircraft has reached the maximum altitude possible with the jet-engine, it either switches to a rocket engine or deploys a rocket carried onboard the aircraft.

It is difficult to say anything certain about the number of spaceports in the world. For example, there are some facilities with little activity, making it hard to assess whether they are still in use. When it comes to proposals for new spaceports, it can be challenging to evaluate the feasibility of some initiatives. Some proposals for new spaceports develop rapidly, and equally, new circumstances can lead to initiatives being abandoned[82].

Based on the available information at the time this report was prepared, there are approximately 30 spaceports around the world that launch orbital rockets vertically[83].Additionally, there are numerous sites globally that conduct sub-orbital rocket launches, along with a handful sites offering horizontal launch capabilities, such as Spaceport Cornwall in England, Spaceport America in New Mexico and Oita airport in Japan.

There are proposals worldwide for 20 new vertical launch sites for orbital rockets (along with some horizonal launch sites). The suggested locations include among others, Nova Scotia in Canada, Canary Islands in Spain, Morotai and Biak Islands in Indonesia and Western Australia Spaceport. Of the proposed 20 locations, 19 sites have coastal locations while only one site, Shaanxi in China, is inland.

[82] For example: Equatorial Launch Australia announced in December 2024 that they would cease operations at Arnhem Space Centre and relocate to a new site in Queensland and there develop Australia Space Centre Cape York: https://ela.space/news/ela-to-move-spaceport

[83] BryceTech, 31st December 2024 file:///C:/Users/irk/Downloads/Bryce%20Launch%20Sites%202024%20(6).pdf

Figure Annex-1: Active orbital spaceports (orange dot); proposed orbital launch sites (red dot); European orbital spaceports in progress (green dot). Criteria for inclusion: if proposed, regulatory recognition, launch contracts for orbital launches. Statistics taken from BryceTech 31st December 2024. Excluded from the map are locations for engine-testing; missile, suborbital and horizontal launches. (See final page of this report for a larger version of this map.)

Spaceport selection criteria

The process of finding a suitable spaceport location involves a complex evaluation of a variety of criteria, such as location, safety, security, operations, environmental, political and business. These criteria include determining the best available trajectories to reach the desired orbits, where inclination and latitude decides the location's degree of potential. For example, a polar or sun-synchronous orbit requires a north or southward trajectory, while a geo-stationary orbit is best reached when launching towards the east. Launching in an eastward direction is advantageous, as it leverages the Earth's rotation[84].

Furthermore, infrastructure and connectivity for transportation of personnel and equipment is often considered vital, as well as easy access to power and water. Meteorological conditions must also be taken into account. Noise coming from engine testing and launches can disturb bird and animal life on land and sea, as well as the general public. Failed launches can produce a shower of debris and unburned propellant over a wide area, and safety for the people and property downrange of the spaceport is therefore also one of the selection criteria for the location of a spaceport. Launching over sea reduces the risk of damage from falling debris to the public, property and terrestrial environment, in the event of a failure.

[84] Thomas G. Roberts, Spaceports of the world, 2019. A report of the CSIS Aerospace Security Project. CSIS, Center for Strategic and International Studies.

Spaceport locations

Most spaceports are situated along a coast, as this location typically fulfils a wide range of the criteria outlined above. Most launching states want to avoid creating drop zones that include populated areas and/or to launch over foreign territory.

The Michigan Spaceport Site Evaluation Study ('the Study') highlighted two concerns related to the proposed location in the State of Michigan, U.S., one of which was the rocket trajectory (flight path) over Canadian territory. The Study recommended involving Canadian authorities early in the planning and licencing process[85].

To solve the issue of congested spaceports in the U.S., there are proposals to develop systems for sea launches. Both China[86] and South Korea[87] have recently tested such systems, and from 1995 to 2014, the multinational (Norway, Russia, Ukraine and U.S.) company Sea Launch launched 32 orbital launch vehicles from its mobile maritime launch platform. The activity was suspended after the Russian invasion of Ukraine.

Downrange safety was the most important factor when the European Space Agency (ESA) chose Kourou on the east-coast of French Guiana as their preferred site for a spaceport. ESA initially evaluated 14 coastal locations around the world suitable for this purpose, with sites ranging from islands in the Pacific, to islands in the Atlantic Ocean[88].

Inland spaceports

As Figure Annex-1 shows, most spaceports have costal locations. However, some countries have placed their spaceports inland, such as in Russia, China and Iran. Currently, there are nine inland spaceports, as shown in the table below:

China:

- Jiuquan Satellite Launch Centre
- Taiyuan Satellite Launch Centre
- Xichang Satellite Launch Centre

Russia

- Kapustin Yar
- Plesetsk Cosmodrome
- Yasny Launch Base/Dombarovsky
- Vostochny Cosmodrome
- Baikonur Cosmodrome (Located in Kazakhstan, but operated by Russia)

Iran

- Imam Khomeini Space Launch Terminal (Semnan Space Center)

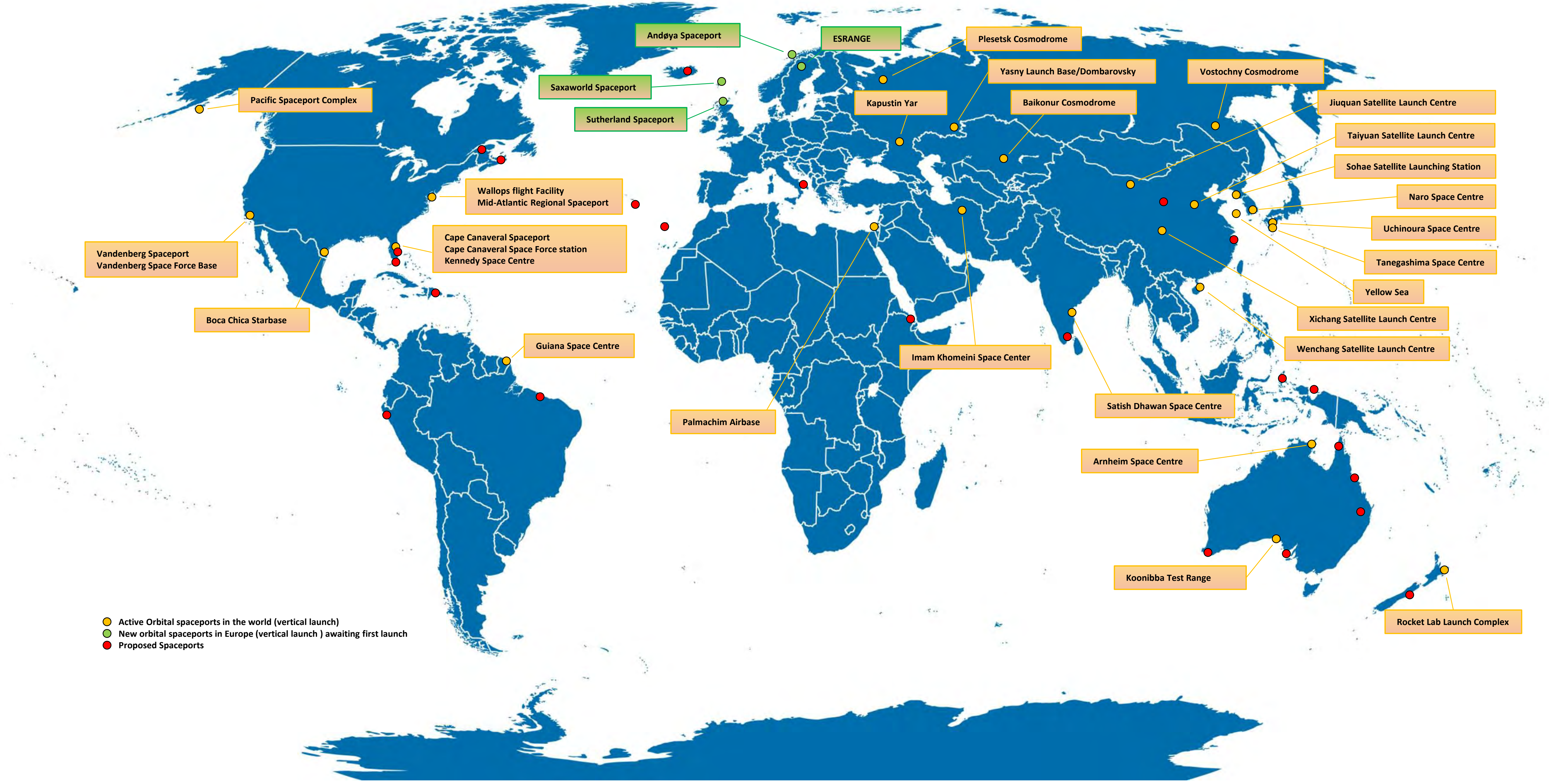
[85] Kimley Horn, 2020. Michigan Spaceport Site Selection and Feasibility study. Michigan Aerospace Manufactures Association.
[86] Zhengyu SONGa, Zhifeng XIE, Limin QIU, Dalin XIANG, Jinglin LI. 2021. Prospects of sea launches for Chinese cryogenic liquid-fuelled medium-lift launch vehicles. Chinese Journal of Aeronautics 34 (1): 424-437.
[87] https://www.astronomy.com/space-exploration/watch-south-korea-tests-solid-fuel-rocket-with-sea-launch/
[88] Tommaso Sgobba. 2013. Safety Designs for Space Operations. The International Association for the Advancement of Space Safety (IAASS).

Downrange from these spaceports, both controlled downfall in the form of ejected rocket stages, as well as mishaps, resulting in uncontrolled downfall made of rocket debris and fuel, have caused deaths, damage and pollution issues. One example is the accident at Xichang Satellite Launch Centre (China), in 1996 where a Long March 3B rocket deviated off the nominal course and crashed in a nearby village, killing at least 6 people and injuring a significant number of inhabitants[89]. The "proton" accident in Kazakhstan in 2013 resulted in what is believed to be the worst ecological accident in Russian space history, when a rocket carrying 620 tons of highly toxic and carcinogenic fuels exploded and spilled debris and fuel over an area of 1 km^2[90].

The primary reason these countries have selected inland locations for rocket launches seems to be mainly political and/or due to strategic defence considerations, where security interests have been the leading argument for the location choice, according to Brian Harvey who has written extensively on Russia's and China's space programmes[91]. Despite having an extensive coastline suitable for eastward launches, the Soviet Union built all its spaceports inland. The Soviet Union kept the location of Baikonur Cosmodrome a secret during the Cold War, sometimes referring to it as a 'hide-away' in the Kazakh Steppe.

China recently built their fourth coastal spaceport (Wenchang Satellite Launch Centre) to accommodate the latest version of Long March rockets, as they became too large to be transported by railway or road and instead had to be shipped to a launch site by boat[92]. China also has plans to build another coastal launch site in Ningbo, as well as a fourth inland launching site in the Shaanxi province. Of the proposed 20 new vertical launching sites for orbital rockets that are known in the world, the only proposal for a new spaceport with an inland location is the Shaanxi site.

[89] https://www.smithsonianmag.com/air-space-magazine/disaster-at-xichang-2873673/
[90] Koroleva T.V, Semenkov I.N, Sharapova A.V, Krechetov P.P, Lednev S.A. 2021. Ecological consequences of space rocket accidents in Kazakhstan between 1999 and 2018. Environmental Pollution, volume 268, Part A.
[91] See Brian Harvey 2004. "Chinas Space program. from conception to Manned Spaceflight". Springer, praxis publishing, Chichester, UK.
[92] https://spacenews.com/xichang-to-build-commercial-spaceport-to-boost-chinas-launch-capacity/



Andøya Spaceport
ESRANGE
Plesetsk Cosmodrome
Saxaworld Spaceport
Sutherland Spaceport
Yasny Launch Base/Dombarovsky
Vostochny Cosmodrome
Pacific Spaceport Complex
Kapustin Yar
Baikonur Cosmodrome
Jiuquan Satellite Launch Centre
Taiyuan Satellite Launch Centre
Sohae Satellite Launching Station
Wallops flight Facility
Mid-Atlantic Regional Spaceport
Naro Space Centre
Cape Canaveral Spaceport
Cape Canaveral Space Force station
Kennedy Space Centre
Uchinoura Space Centre
Vandenberg Spaceport
Vandenberg Space Force Base
Tanegashima Space Centre
Yellow Sea
Boca Chica Starbase
Xichang Satellite Launch Centre
Guiana Space Centre
Wenchang Satellite Launch Centre
Imam Khomeini Space Center
Satish Dhawan Space Centre
Palmachim Airbase
Arnheim Space Centre
Koonibba Test Range
Rocket Lab Launch Complex
Active Orbital spaceports in the world (vertical launch)
New orbital spaceports in Europe (vertical launch) awaiting first launch
Proposed Spaceports