HyImpulse

LAUNCH RISK ASSESSMENT

SR75 – FIRST FLIGHT

Version 5.0

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2 INTRODUCTION

HyImpulse Technologies GmbH is a start-up for hybrid rocket launch vehicles in Germany and represented by the 100% subsidiary HyImpulse UK Ltd in the United Kingdom. HyImpulse is developing a sounding rocket called SR75 with a hybrid rocket motor based on paraffin fuel and liquid oxygen.

The SR75 shall be launched in Q2 2024 for the first time from Lamba Ness, Unst, in cooperation by HyImpulse and SaxaVord Spaceport.

This document integrates the navigational risk assessment of SaxaVord Spaceport [Saxa-01] with the risks associated to a launch of SR75. The launch campaign is expected to last around 2 weeks and will involve one single launch of SR75 from the Lamba Ness range and the partial recovery of its debris from the sea.

3 APPLICABLE AND REFERENCE DOCUMENTS

[CAP-760]	Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases
[HIT-01]	HyImpulse Flight Safety Analysis – A.N.O. Licence
[HIT-02]	HyImpulse Ground Safety Analysis – SIA. Licence
[RD-01]	Risk management: Expert guidance, https://www.hse.gov.uk/managing/theory/index.htm
[Saxa-01]	SVS-NRA Navigational risks assessment
[Saxa-02]	SAXA-UK-OPS-PLN-001 Maritime Emergency Response Plan
[Saxa-03]	SAXA-UK-OPS-PLN-001 Maritime Communications Plan
[SIA-01]	Space Industry Regulations 2021

4 DEFINITIONS AND ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
ANO	Air Navigation Order
FSA	Flight Safety Analysis
GSA	Ground Safety Analysis
HIT	HyImpulse Technologies GmbH, HyImpulse UK Ltd.
NRA	Navigational Risk Assessment
RAMS	Risk Assessment Method Statement
SIA	Space Industry Act 2018
Saxa	Saxa Vord Spaceport
SR75	Sounding Rocket 75 (HyImpulse product)

5 Mission Profile and Drop Areas

SR75 is an unguided sounding rocket which is planned to be launched from SaxaVord Spaceport, UK. Engine cutoff will occur approximately 30s after liftoff and it is planned that the rocket will reach an apogee of about 30 km. At the apogee, the nose cone will separate from the booster. The mission profile is summarized in Figure 1.

The impact point of the booster will be inside the drop area in Figure 2. The rocket booster of the SR75 launch vehicle is expected to land 30nm (54km) north of the launch point. The nose cone will fly along a similar trajectory, landing 2 km before of the booster.

A 20km radius Exclusion Zone will be in place around the expected splashdown point (Figure 3), which will be communicated as part of the Notice to Mariners for this launch. A recovery vessel will remain outside of this Exclusion Zone and monitor activity in the vicinity. The recovery vessel will be fitted as per the Boundary Boat and will be able to communicate with Range Operations at the Spaceport. The Boundary Boat will operate outside of the 1.8km Launch Exclusion Zone that will exist around the launch point on Lamba Ness. See SAXA-UK-OPS-PLN-001 Maritime Communications Plan [Saxa-03] for more information.

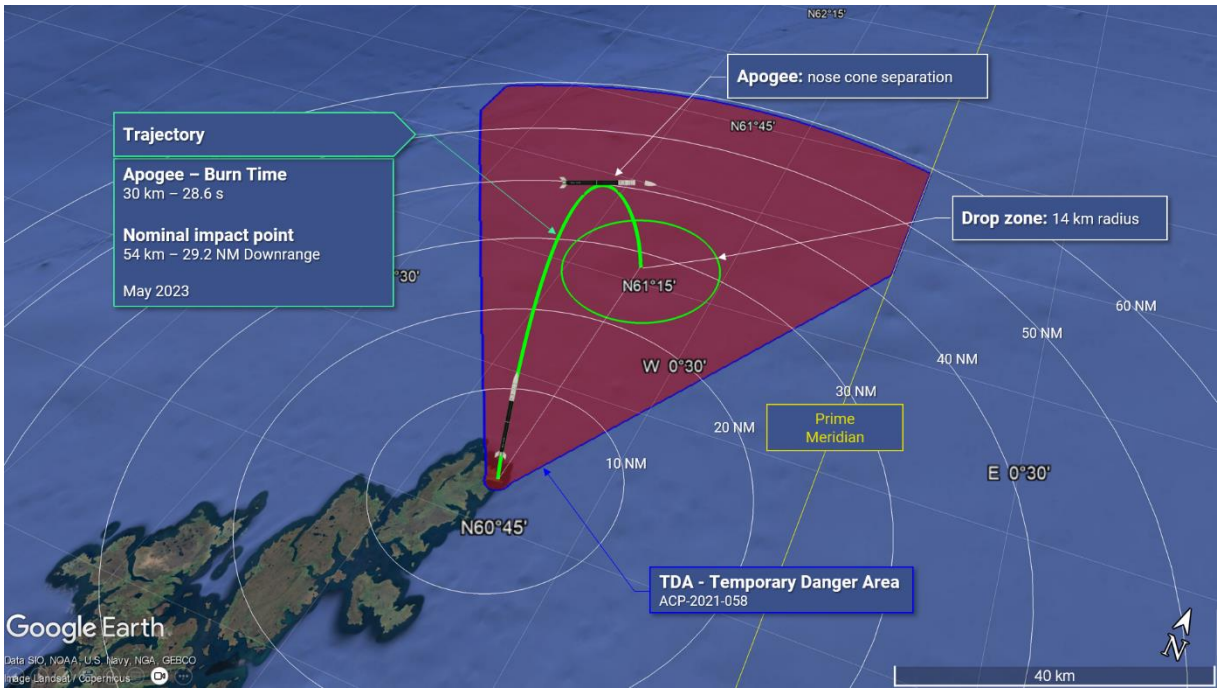


Figure 1: Flight trajectory

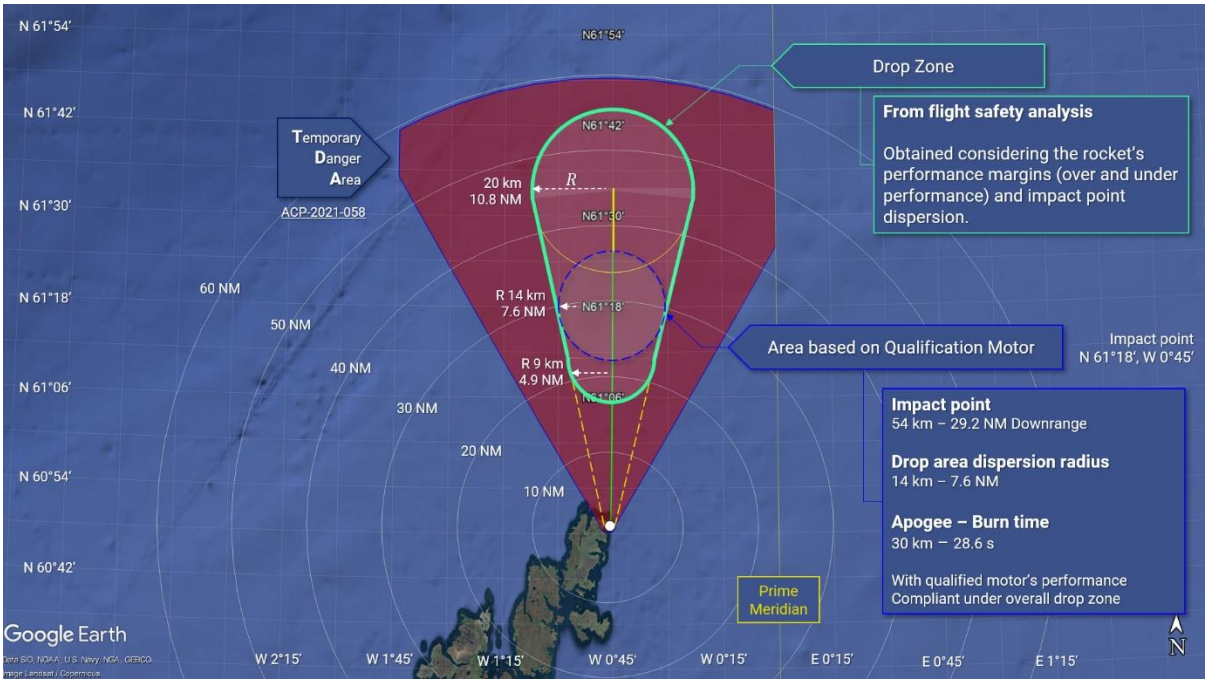


Figure 2: Planned drop area and dispersion.

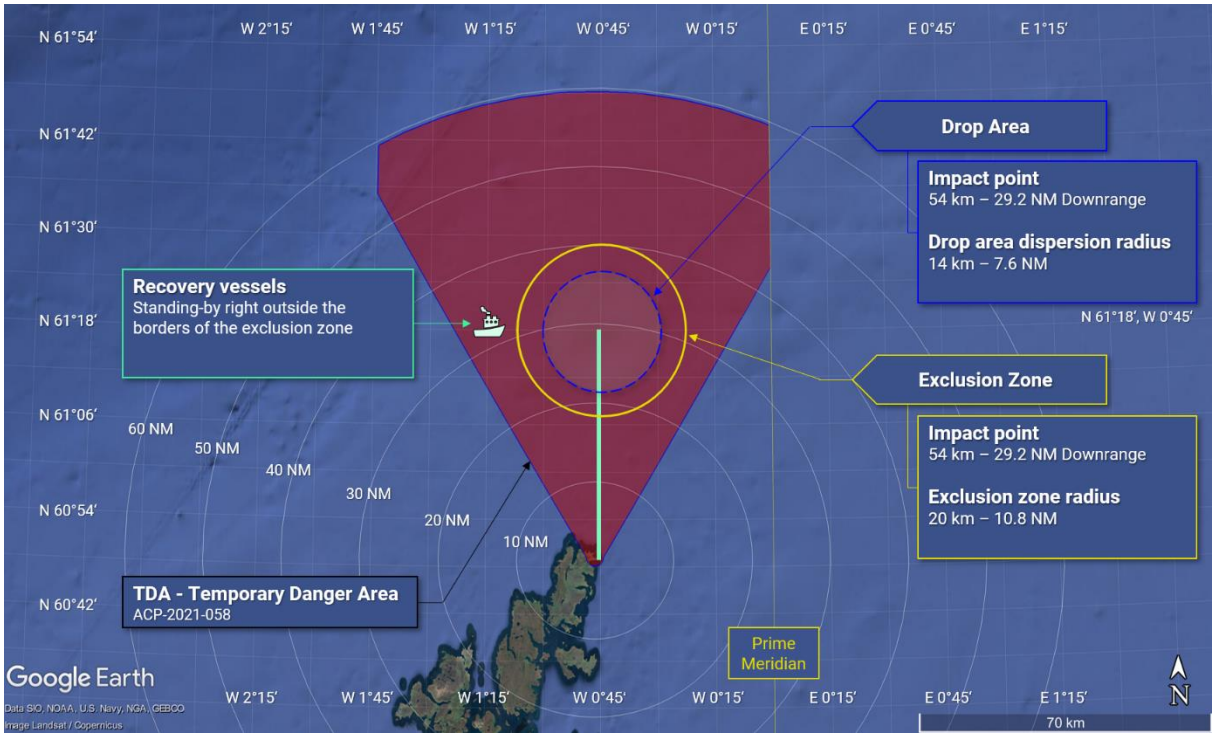


Figure 3: Exclusion Zone around the impact point – 20 km radius

5.1 EXCLUSION ZONE ON LAND

The Flight Safety Analysis (FSA) of HyImpulse [HIT-01] identified a hazard area on land, which is protected by roadblocks during loading operations and launch. The spaceport procedure includes the evacuation of the local population and domestic animals up to a 1.8 km radius from the launch pad. The hazard area will be monitored by Saxa. The Exclusion Zone is limited by the yellow dashed line in Figure 4 and its extension was assessed from the FSA. The alphabetical letters report the settlements in the area.

Only **A**, a farm, is included in the Exclusion Zone, but it will be unoccupied during launch operations. A vessel ("Boundary Boat") will be used to monitor marine activity around the launch site.

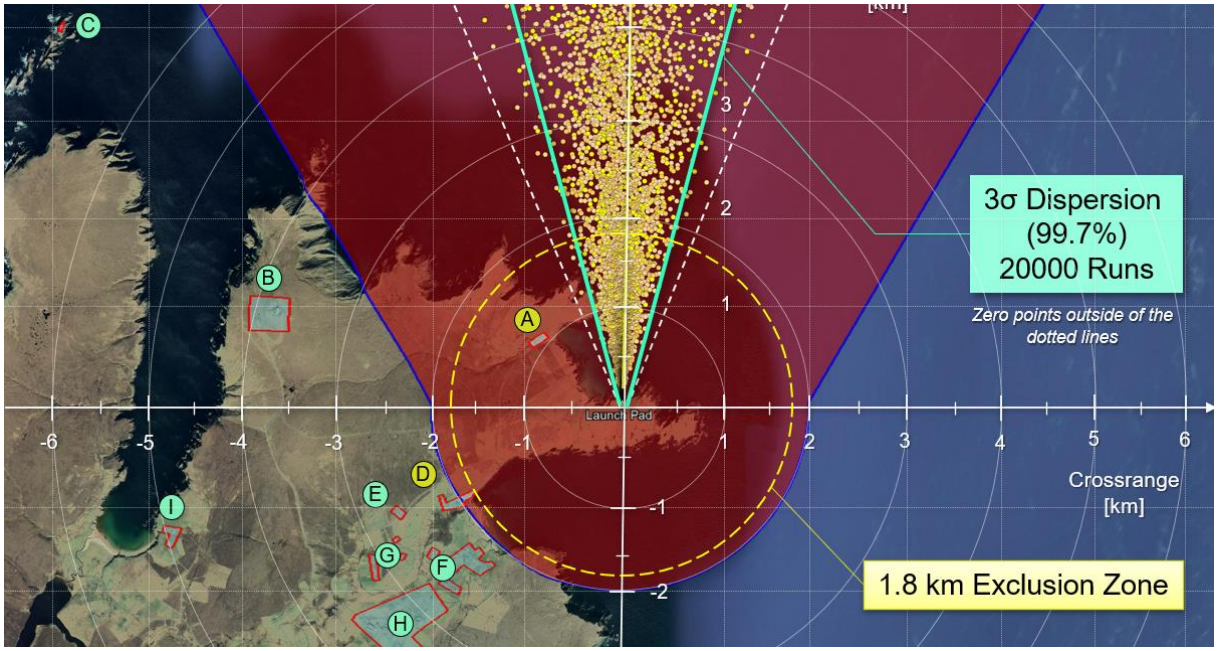


Figure 4: Exclusion Zone suggested by the FSA of HyImpulse

5.2 PLANNED DEBRIS

A recovery system based on parachutes is used to recover the launch vehicle. The number of planned debris falling into the sea is shown in Table 1. A total of 3 beacons are installed on SR75, 2 on the booster and 1 on the drogue parachute. Their signal can be captured within the radius of 2 km with a directional receiver antenna.

Table 1: Debris catalogue

Item	Specifications	Details
Nose Cone NOT recovered	Length 1.5 m Ø 0.64 m 140 kg	Hollow ogive (1.3 m) with a small cylindrical section at the base (0.2 m, 1.5 m total), composite materials. The body is hollow and contains a stainless-steel bar with ballast weights mounted on top. The total weight of the structures and ballast weight is around 140 kg. The body will tumble down and hit the water at around 220 m/s: water is expected to fill the body almost immediately after impact, and the nose cone is expected to sink directly.
Manacle Ring NOT Recovered	Ø 0.64 m 1.5 kg	Booster and nose cone are linked together using a manacle ring, that will be cut at nose cone separation (mechanical separation). The manacle ring is a thin steel band with several rectangular steel inserts along its length. The manacle is expected to sink directly.
Booster Recovered	Length 9.7 m Ø 0.64 m 800 kg	The booster (800 kg dry mass) will be slowed down with a drogue parachute first, then a main parachute, and it will impact the water together with the main chute. Water is expected to enter in the engine block from the nozzle section and fill it completely. The booster will likely assume a highly tilted/vertical position due to the higher mass of the engine section and relatively low center of gravity of the empty booster without the nose cone. The engine and the next component, the liquid oxygen (LOX) tank, are connected exclusively by the injectors

		and feed lines: the first interface is characterized by capillary holes and small pipes and water will hardly or very slowly be able to penetrate the LOX tank. If the LOX tank started to fill, the process would be very slow (hours): the recovery vessel will be located ca. 15 -20 km from the nominal impact area and the booster is provided with a locator beam. There should be sufficient time to successfully locate and recover the booster before a full filling of the LOX tank. In case the LOX tank is filled completely, the next component is the helium tank: the only interface between the two is, again, the feed line. In this case though, a pressure regulator (spring mechanism) is present and should be able to completely isolate the tank and stop the water. The Helium tank should thus always remain isolated and water-free. Located through on-board transmitter and 2 locator beacons.
Drogue Chute with structural attachments Recovered	Ø 2.8 m 4.8 kg Chute	The drogue will slow down the booster and kill the lateral component of the velocity. It will be cut when the main parachute opens. In a no-wind ideal condition, the drop area will be the same as the booster. The parachute hatch and the structural components are attached to the drogue via aramid rope. During the launch, the effect of the wind on drogue and main parachute (booster) will be simulated (with real wind data), in order to estimate, as closely as possible, the impact areas. The drogue will be located after the booster and recovered. Located through a locator beacon + hand tracker.

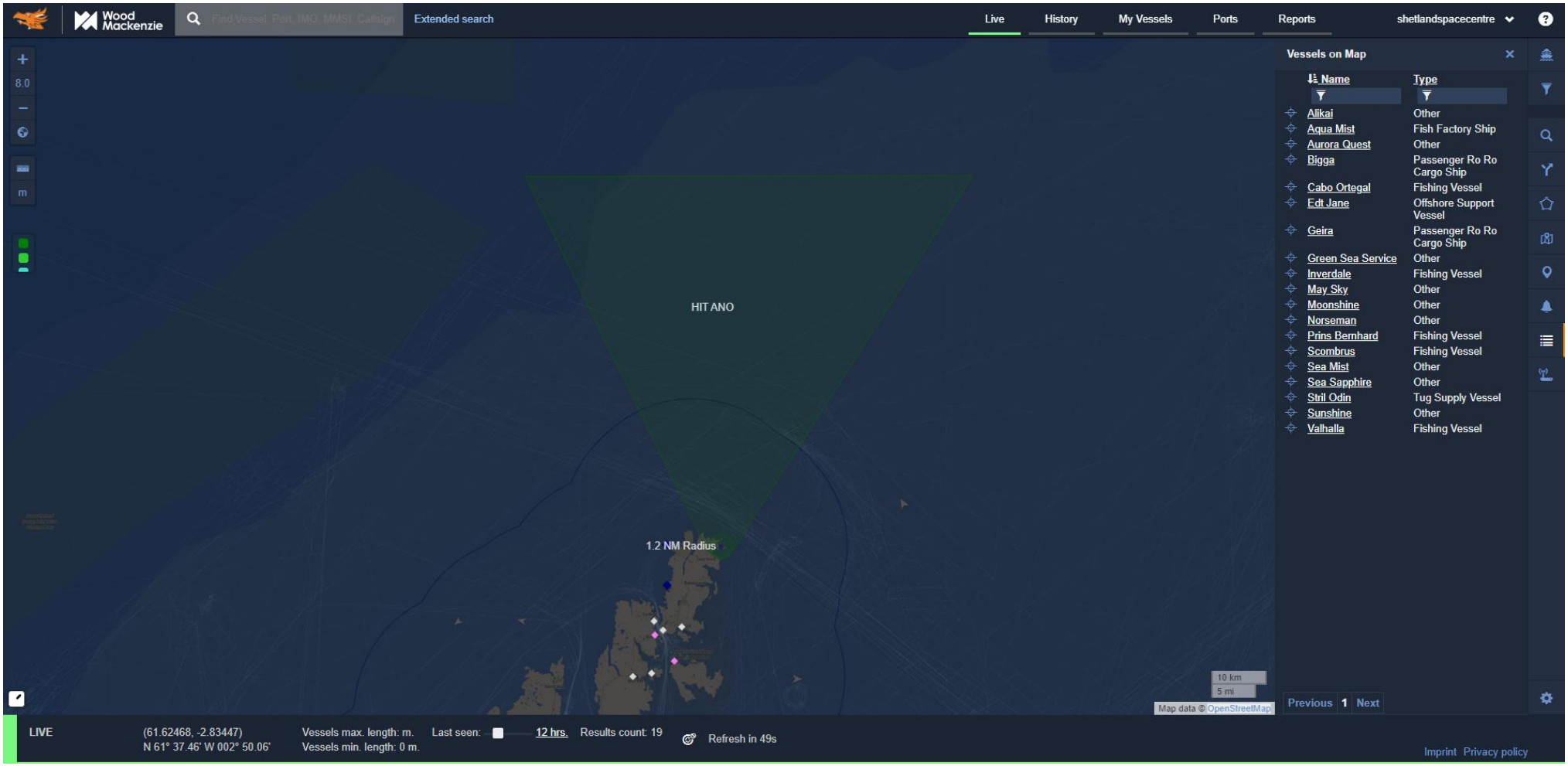
5.3 VESSEL TRAFFIC DENSITY

Figure 5 shows a heat map of maritime traffic for March 2019, which constitutes the same time of year for this launch. The area affected by the launch is circled in red. The majority of maritime activity is classed as “Fishing”, with “Other” making up the remainder. This “other” activity is likely connected with the operations at Sullom Voe oil and gas terminal, as tankers transit to and from the terminal on a regular basis.

Saxa also has access to AIS data on vesseltracker.com. Selecting the hazard area associated with this launch and undertaking a historical search for the month of March 2022 shows the following vessel types transiting the area:

- Fishing Vessels
- Cargo Vessels
    - Multi-purpose
    - Refrigerated
    - Palletized
    - General
- Oil and gas tankers

A screenshot from vesseltracker.com can be seen in Figure 5. This is from a live feed taken at 1225hrs on Friday 20th October 2023.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Find Vessel, Port, IMO, MMSI, Callsign
Extended search
Live
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My Vessels
Ports
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Vessels on Map
Name
Type
Alikai Other
Aqua Mist Fish Factory Ship
Aurora Quest Other
Bigga Passenger Ro Ro Cargo Ship
Cabo Ortegal Fishing Vessel
Edt Jane Offshore Support Vessel
Geira Passenger Ro Ro Cargo Ship
Green Sea Service Other
Inverdale Fishing Vessel
May Sky Other
Moonshine Other
Norseman Other
Prins Bernhard Fishing Vessel
Scombrus Fishing Vessel
Sea Mist Other
Sea Sapphire Other
Stril Odin Tug Supply Vessel
Sunshine Other
Valhalla Fishing Vessel
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1.2 NM Radius
10 km
5 mi
Map data © OpenStreetMap
Previous 1 Next
LIVE
(61.62468, -2.83447)
N 61° 37.46' W 002° 50.06'
Vessels max. length: m.
Vessels min. length: 0 m.
Last seen:
12 hrs.
Results count: 19
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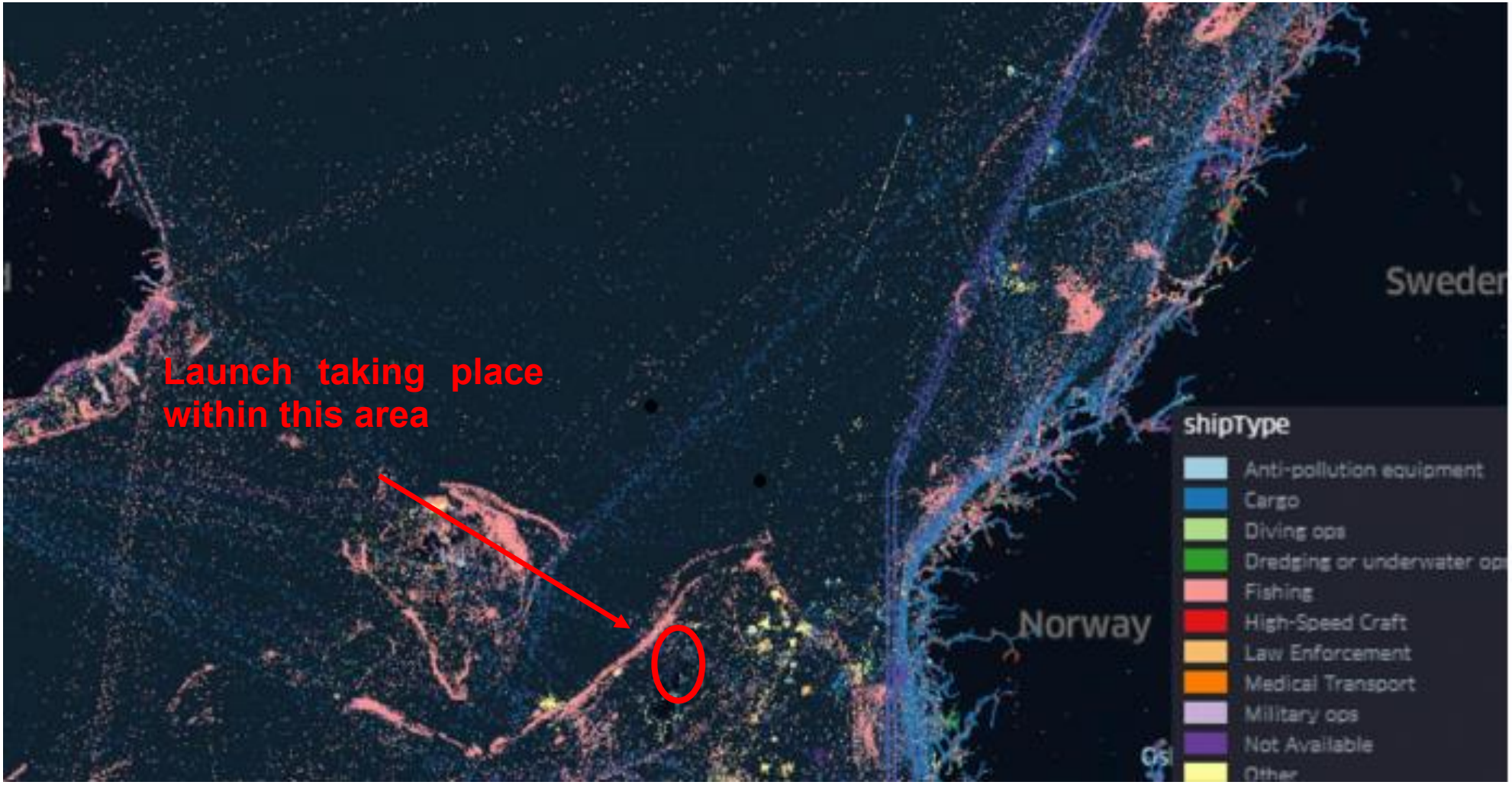

Figure 5: Historical maritime traffic heat map for March 2019

6 RISK ASSESSMENT

The Spaceport assessed the risks deriving from maritime navigation [Saxa-01]. The NRA of the Spaceport identified the risks presented in Table 16 of [Saxa-01], reproduced hereby. Only the scenarios related to the SR75 components are considered for this paragraph. **Error! Reference source not found.** summarizes the three risks applicable from the NRA.
The risk assessment relevant for this analysis is given in the last column (Future Risk) once the mitigations were applied by Saxa. A detailed discussion is presented in [Saxa-01], as well as their ALARP justification.

Table 2: NRA assessment adapted from [Saxa-01]

No.	Hazard Category	Hazard Scenario	Current Risk	Future Risk
9 [Saxa-01]	Machinery related accidents	Parachute lands on water and becomes entangled in a vessel's propulsion or steering gear	Moderate	Minor
1 [Saxa-01]	Other nautical safety	Parachute does not deploy, and rocket strikes a vessel	Moderate	Minor
6 [Saxa-01]	Other nautical safety	Spectator vessel: sightseeing, day boats and other recreational craft	Critical	Minor

Hazard categories from the NRA of Saxa can be applied to additional risks deriving from HyImpulse recovery operations, as shown in Table 3: Additional risks associated to HyImpulse operations.

Table 3: Additional risks associated to HyImpulse operations

No.	Hazard Category	Hazard Scenario	Current Risk	Future Risk
1	Accidents to personnel	Man overboard when collecting booster from the sea surface	Moderate	Minor
2	Loss of hull integrity/Flooding	Adverse weather disrupting boundary/recovery vessel operations	Moderate	Minor
3	Collision	Boundary/Recovery vessel collides with other traffic	Moderate	Minor

Accidents to personnel on board the vessel are minimized due to the pre-launch meetings held between maritime contractors and HyImpulse, where the recovery operations are agreed on both sides. However, depending on the weather conditions and the month of launch, and considering this to be the first attempt to recover the rocket debris from waters, an accident considering man overboard is considered as moderate. It can be mitigated by allocating a launch window with good visibility and sea conditions, if possible.
Adverse weather conditions (waves, wind) could cause the booster to collide with the hull, although severe damage to the hull is not expected due to the limited weight and dimensions of the booster. This risk can be mitigated by allocating a launch window with good visibility and sea conditions, if possible.
Collision between the boundary vessel or the recovery vessel with private vessels is considered as moderate. A press release to the public about this launch could attract tourists and vessels in the area. However, adverse weather conditions often expected between the months of January and March would cause less maritime traffic.

Emergency plan and communication plans of SaxaVord, as well as publication of Notice to Mariners would allow to regulate and contain the traffic downrange the spaceport.

ANNEX A shows the correlation between the risk levels used in [Saxa-01] and [HIT-02].

HyImpulse covered risk to personnel in the Ground Safety Analysis (GSA) [HIT-02]. The risks related to the recovery of SR75 are reported in Table 4: Identified major hazards – GSA [HIT-02]. The table reports only the risks which are assessed as moderate after the mitigations are applied.

Table 4: Identified major hazards – GSA [HIT-02]

Hazard	Assessment after mitigations
Hazard from damaged component storing high-pressure gas	Moderate
Hazards from non-empty tanks because of off-nominal trajectory	
Inaccessibility of shutdown point of RF transmitter causing longer exposure to high frequencies	
Powered avionics components due to incorrect touchdown detection	
Water entering the battery pack enclosure	
Floating unplanned debris damaging other vessels	

Note that in the risk scoring of HyImpulse, a moderate risk to personnel or public means that only minor injuries can occur [HIT-02] (see ANNEX A).

The FSA [HIT-01] also covered the risks occurring during flight and thus related to the dispersion of debris over the sea. Table 5 reports only the risks which are assessed as moderate after the mitigations are applied.

Table 5: Identified major hazards- FSA [HIT-01]

Event	Cause	Consequences	Assessment after mitigation
Nose cone separation failure	Software or mechanism failure	Hard impact upon landing	Moderate
	Failure in activating the recovery system	Hard impact upon landing	
	Parachute ejection failure	Off-nominal landing point; parachute partially functioning reducing the effects of hard impact	
	Failed structural support for parachute	Off-nominal landing point; parachute partially functioning reducing the effects of hard impact	
	Loss of power	Hard impact upon landing	
	Icing of pressure ports	Hard impact upon landing	
	Power outage	Hard impact upon landing	
Thrust termination after lift-off	Excessive wind gusts	Loss of vehicle	
	Structural failure due to excessive loads	Loss of vehicle	
	Fasteners loosening	Loss of vehicle	
	Burn-through motor casing	Loss of vehicle	
	Manufacturing defect	Loss of vehicle	
Thrust termination with nose cone separation	Nose cone separation premature activation	Hard impact upon landing	

The following mitigations measures have been considered by the spaceport:

- Prediction software for rocket trajectory
- Operation Areas communicated by the UKHO
- Local Notices to Mariners for local marinas and fishing organizations
- Nav Warnings provided to UKHO at least 5 days in advance
- Operational planning
- Precautionary area for rocket launches
- Recovery vessel
- VHF Sécurité Messages
- Lights and reflective tape on payload
- Notices to Mariners
- RAMS method for launch and recovery operations
- Emergency response plan to be made available to all marine personnel
- Regular weather forecasting
- Promulgation of launch information to local stakeholders
- Training of operational personnel
- Standard Operating Procedures for recovery from water

These points will be discussed in the next paragraph.

7 NRA MITIGATION MEASURES

The NRA under which this activity is taking place contains a summary of industry standard risk controls and mitigation measures. These measures are listed below with a summary of the measures Saxa has taken.

7.1 LOCAL NOTICE TO MARINERS

Information regarding the project, including coordinates, have been promulgated via email to the following organizations:

- Sullom Voe Harbour and VTS
- Shetland Islands Council (Ferries)
- Shetland Maritime Coastguard Agency
- Cooke Aquaculture
- Shetland Islands Fishermen
- Shetland Shellfish Management Organisation
- Scottish Fishermen’s Federation
- North Atlantic Fisheries College
- Seafood Shetland
- Unst Shellfish Ltd
- RYA Scotland
- Seafish
- Fisheries Rep, Defra
- UKHO
- MRCC Shetland
- HMCG Offshore Energy Branch
- NAVAREA XIX
- NLB
- Navigation Branch, MCA
- Lerwick Port Authority

7.2 RADIO NAVIGATION WARNINGS

Information regarding this project including coordinates will be provided to the UKHO at L - 7 days for issue at L - 5 days. Saxa began engaging with UKHO about this project in September 2021.

7.3 OPERATIONAL PLANNING

Planning for this launch began in September 2021 with stakeholder engagement beginning soon afterwards. Saxa has been able to clearly define the launch limits and arrange for the recovery of the rocket.

7.4 PRECAUTIONARY AREA (SPACE LAUNCH HAZARD AREAS)

The space launch hazard areas associated with this launch are shown in

Figure 6 below, and consist of the following:

Warning Zone bounded by the following coordinates, and shown in red in

1. Figure 6:

Latitude	Longitude
60°47.993'N	0°47.851'W
60°48.796'N	0°47.814'W
61°25.241'N	1°45.324'W
61°46.003'N	1°45.324'W
61°46.003'N	00°00.000'W
61°25.241'N	00°00.000'W
60°48.796'N	00°43.5405'W
60°47.993'N	00°43.5405'W

Launch Exclusion Zone: 1.8km radius around the point of launch, as shown in yellow in

2. Figure 6.

Exclusion Zone: a 20km radius around the intended splashdown point, 30nm north of the launch point, as shown in blue in

3. Figure 6.

The coordinates for the above Space Launch Hazard Areas will be promulgated via Notice to Mariners.

Figure 6 Space Launch Hazard Areas for HyImpulse launch

7.5 BOUNDARY BOAT AND RECOVERY VESSEL

Saxa has engaged the services of a local marine contractor for the provision of a Boundary Boat and a Recovery Vessel. The Boundary Boat will provide surveillance coverage and interdiction for the 1.8km radius Launch Exclusion Zone that will exist around the launch point. The Recovery Vessel will provide surveillance coverage and interdiction for the 20km radius Exclusion Zone that will exist around the intended splashdown area. Details of the vessels' capabilities are listed within document SAXA-UK-OPS-PLN-001 Maritime Emergency Response Plan [Saxa-02].

7.6 VHF SECURITÉ MESSAGES

The Boundary Boat will promulgate securité messages via VHF on Channel 16 if they are less than 1 minute long. A working channel for use on the day (likely Ch 67) of the launch will be determined and promulgated closer to the day of launch. [Saxa-03] contains more information on communications.

7.7 LIGHTS AND REFLECTIVE TAPE ON PAYLOAD

HyImpulse implemented several aids to make the rocket debris visible. The IALA recommendations are used as reference [RD-02]. Since rocket debris are not directly mentioned in the IALA catalogue, HIT is using the following aids.

7.7.1 Colour

- Nose cone and 50% of booster (the top part expected to float): white with yellow bands on the recovery module.
- Drogue parachute: white and yellow band at the top and bottom
- Main parachute: white and red

7.7.2 Lights

- The addition of lights is not foreseen, unless there is a clear request coming from MCA.
- HIT is planning for a launch during daylight hours, whenever possible.

7.8 NOTICES TO MARINERS

A Notice to Mariners has been sent to UKHO for onward promulgation.

7.9 RISK ASSESSMENT METHOD STATEMENT

This document constitutes the RAMS for this launch.

7.10 EMERGENCY RESPONSE PLAN

An emergency response plan is being submitted with the Marine Licence Application.

7.11 WEATHER FORECASTING

Weather forecasting is being provided under contract from the Met Office. This includes a Spaceport Weather Matrix at L – 14 and L – 7 days, and an Enhanced Spaceport Weather Matrix from L- 4 days. Saxa also envisage having on site meteorology equipment to provide up to the minute, local weather data.

7.12 PROMULGATION OF INFORMATION

Local stakeholders, including emergency services, have been informed of this launch activity using the Notifications process established under the Space Industry Regulations 2021 [SIA-01]. Stakeholders informed include:

- Police Scotland
- NHS Shetland
- Fire and Rescue
- Crofters, Landowners, and Lessees
- Unst Community Council
- Shetland Islands Council
- HMCG

7.13 TRAINING OF OPERATIONAL PERSONNEL

The necessary currency and competency for Saxa employees to undertake launches of much larger sub-orbital and orbital launch vehicles was gained with the project "Exercise Freya" (July 2022).

7.14 STANDARD OPERATING PROCEDURE

"Exercise Freya" (July 2022). helped test and adjust standard operating procedures for Saxa, as well as recovery operations for Ocean Kinetics and interactions with key stakeholders, such as MCA, UKHO, Marine Scotland, NLB etc.

7.15 COMMUNIATIONS PLAN

The comms plan is available in document SAXA-UK-OPS-PLN-001 Maritime Communications Plan [Saxa-03].

8 MARITIME BOUNDARY SURVEILLANCE

Exclusion and Restricted Zones will be monitored using a combination of land-based sensors, with a boundary boat in the waters off the coast of Lamba Ness: The land-based sensors will consist of 4 electro-optical cameras, with infra-red capability, situated at various points on the Lamba Ness Peninsula, and maritime radar to provide positive identification of craft within any Exclusion or Restricted Zones, plus wider area coverage.

In addition to this a bespoke software package is used to visualise the radar and camera imagery. The camera and radar systems are linked and can thus cross cue each other onto points of interest. The maritime radar will have a detection performance ranging from 6nm for small vessels to 40nm for larger vessels. The optical and thermal camera has a detection range from 10nm to 25nm depending on the size of the vessel. AIS data, out to a range of 50nm, will also be overlaid onto this visualisation.

Figure 7 below shows the arcs of the electro-optical camera system (green shading) and maritime radar (yellow shading). The boundary boat will be positioned outside of the 1.8km Exclusion Zone the will exist around the launch point and can plug any gaps that may exist in the surveillance system as well as interdict and communicate directly with approaching vessels. The boundary boat will also have direct communications with the Range Control Centre.

A separate vessel (the Recovery Vessel) will operate outside of the 20km exclusion zone that will exist around the intended splashdown point, 30nm north of the launch point. Information on the communication plan can be found at SAXA-UK-OPS-PLN-001 Maritime Communications Plan [Saxa-03].

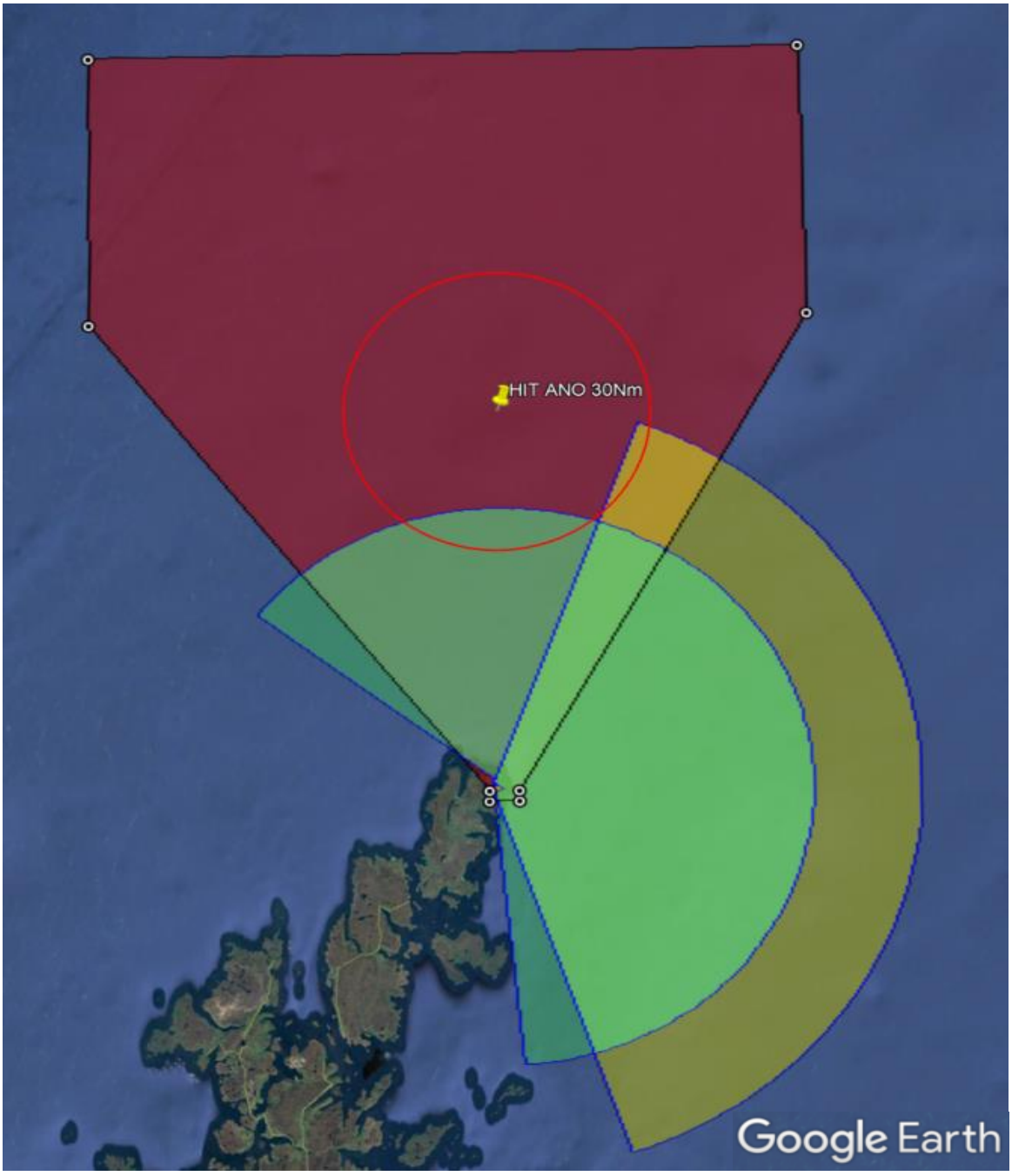

Figure 7 Maritime radar and camera system coverage

Error! Reference source not found. shows a list of the maritime surveillance assets with further detail on their capabilities.

Table 6 Surveillance assets

Asset	Capability
AIS Receiver	Provision of vessel data, such as identity, position, speed and course. Coverage out to 50nm
Maritime Radar	Provision of real-time picture of maritime traffic out to 40nm
Pan Tilt Zoom (PTZ), Electro-optical cameras	Provide day, night and all weather visual detection of vessels out to 10-25nm dependent on vessel size
Boundary Boat	Physical presence for maritime users and can provide overlap or plug any gaps in land based surveillance systems. Can assist with maritime emergencies and provide interdiction. It is also expected that any vessel undertaking these duties will, as a minimum, be equipped with the following: • VHF radio. Redundancy communications systems may also be required, such as satellite phone. VHF Channels monitored: 16, 67 and 70. • Standard life saving equipment, MOB recovery equipment and firefighting equipment such as a desk wash hose or fire extinguishers. • Medical Equipment – Cat C first aid kit plus standard workplace first aid kit and eyewash station • Maritime radar system • AIS transponder

9 CONCLUSIONS

The Launch Risk Assessment of HyImpulse considers the sounding rocket SR75 safe to launch and recover according to the operational procedures drafted by HyImpulse, SaxaVord Spaceport and the Marine Contractor.

ANNEX A. Risk Levels comparison

The risk levels used in the present document correlates to the risk levels used in the Navigational Risk Assessment (Pg. 53, Table 13) [Saxa-01] as follows:

[Saxa-01] - NRA	Outcome	[HIT-02] - LRA	Outcome
12-14: Very High Risk	VH	Catastrophic	
9-11: High Risk	Hig	Critical	
7-8: Significant Risk	Sig		
5-6: Moderate Risk	Mod	Moderate	
3-4: Low Risk	Low	Minor	
1-2: Negligible Risk	Neg		
0: No Risk	Non		

Note that for what concerns risks to the public or operating personnel, HyImpulse defined a risk as [HIT-02]

- Minor, if no injuries occur
- Moderate, if only minor injuries occur
- Critical, if one or more severe injuries occur
- Catastrophic, if fatal or permanently disabling injuries occur