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On the safety of suborbitalrocket launches from the Polish coast

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Abstract

This paper presents a rocket flight safety analysis using methods from the internationally recognized standard RCC 321-20 with an emphasis on a suborbital launch from the Polish coast. Currently, several entities are launching (or planning to launch) suborbital rockets and land them in the Baltic sea – and such flights are expected to be performed using more and more capable rockets with increasing launch frequency. While the present approach in Poland is to close a predefined air space, monitor or close the maritime zone to any traffic and ensure that the impact point dispersion of all rocket elements will fit within that restricted area, established and proven methods often take advantage of advanced calculations of flight risk to the public, aircraft and vessels. This paper demonstrates this approach and compares relative rocket or missile flight safety from Poland to other locations frequently used for such exercises. The results of this work may also be beneficial when planning safety measures for military exercises involving missiles.

Keywords: Military exercise safety, suborbital launch vehicles, safety & defense, IAMD/BMD targets

1. Introduction

Suborbital rockets are relatively small rockets used for scientific research, technology development, education, and, in recent years, for space tourism. They follow a suborbital trajectory, meaning that the landing point does not go beyond the Earth's surface. This trajectory is similar in shape to a parabola. Suborbital flights enable payloads to reach high altitudes, even higher than the orbit of satellites, but the rocket returns to the surface after reaching its apogee (Noga T., 2021). They also have significant potential applications for the military sector, of which the most important ones include simulating missile attacks, testing military rocket technologies, calibrating or comparing military radar readings, and disposing of military rocket engines. For over ten years

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(Okninski, et al., 2015), (Marciniak, B.; Okninski, A., 2014), numerous Polish entities have been developing rocket technologies (Cieśliński et al., 2021), (Magiera, R., et. al., 2019), but the lack of test range infrastructure that allows for high-altitude flights is a barrier inhibiting their development. Moreover, the introduction of missiles with relatively more extensive range than before (such as CAMM-ER or GLMRS) is planned in the Polish military, so the capability to increase Polish abilities to conduct safe flight tests over the Baltic Sea is also required from the defense sector's perspective. This could be beneficial for the entire eastern flank of NATO. In this paper, we discuss the feasibility of conducting rocket flights from the Polish coast to altitudes higher than ever before, and we show that it is possible to perform the launch safely as long as well-established safety procedures are followed.

2. Rocket flights safety analysis and procedures – state-of-the-art

2.1 Test ranges

Within the context of suborbital rockets, test ranges allow the launch to be performed safely. The basic requirements are to be legally and practically able to close off certain land/sea and air areas in predefined danger zones. Additionally, infrastructure is often built on test ranges to facilitate rocket launches. This includes, but is not limited to, rocket launchers, integration facilities, propellant storage, meteorological infrastructure, warehouses and control rooms, sometimes located in shelters. Examples of active test ranges in Europe are the Andøya Space Center, ESRANGE (Figure 1) and the El Arenosillo. There are not many test ranges around the world that conduct suborbital launches, and few have up-to-date legal codes regulating them. An example of such a code is The Space Industry Act and The Space Industry Regulations in the United Kingdom (UK Civil Aviation Authority, 2023).

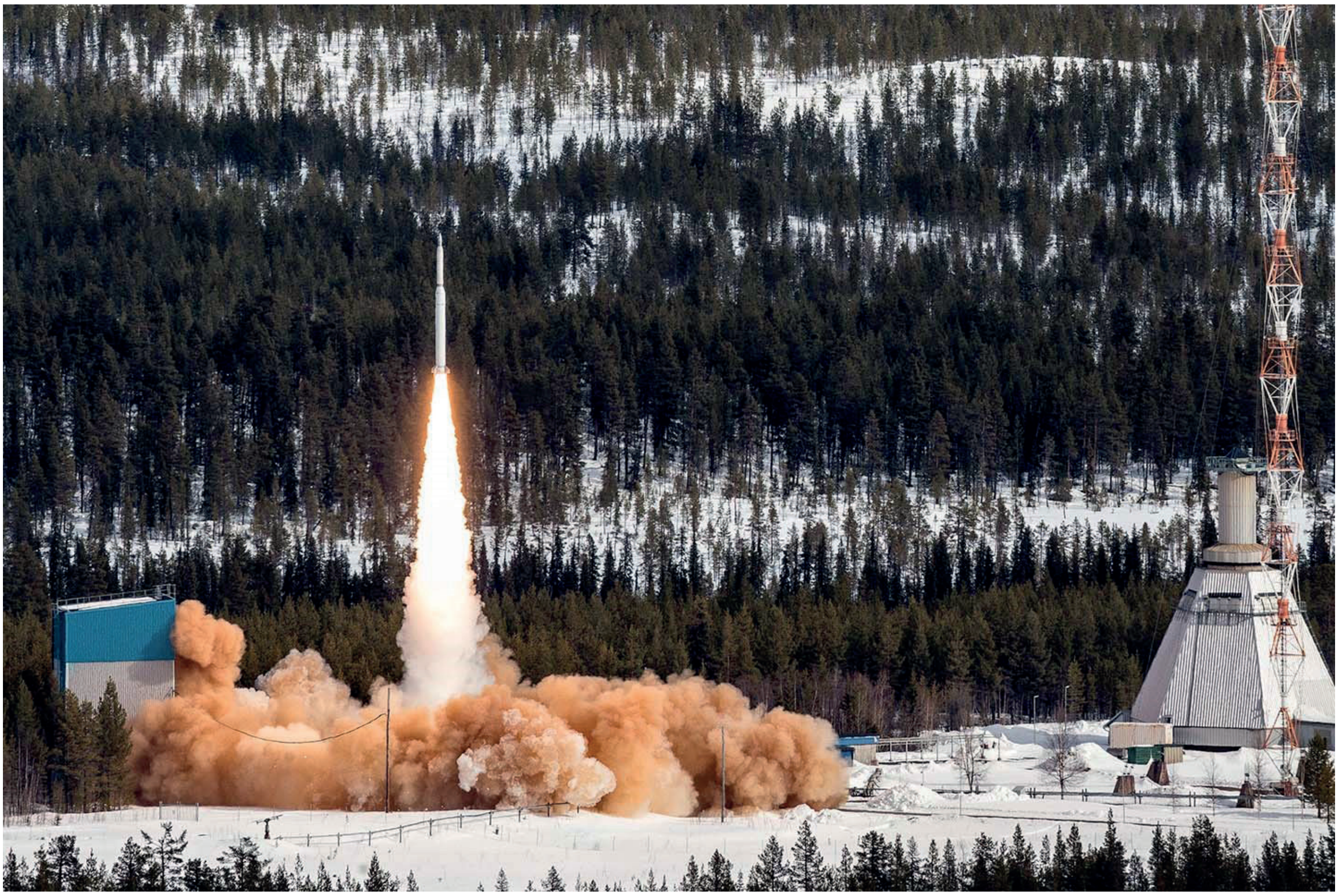

Figure 1. Maxus 9 rocket launch from ESRANGE
Source: Swedish Space Corporation.

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2.2 Safety procedures

As a means of ensuring the safety of everyone in the near vicinity of a rocket launch, numerous rocket launch procedures have been created by both government agencies and private entities. These include the Range Commanders Council and the Federal Aviation Administration, published several procedures and regulations, i.e., (Range Commanders Council, 2020), which detail what risks may be involved when conducting a rocket launch and how to mitigate them. Occasionally, rocket or missile launch failures occur (e.g., South Korean ballistic missile Hyunmoo 2-C crashed near its test firing site in October 2022 (Ji Da-gyum, 2022). Such malfunctions may cause damage or casualties to third parties. Hence, the importance of conducting flight safety analysis is clearly visible.

A sample checklist that summarizes the flight safety process is presented below. It is based on literature analysis, as well as Ł-ILOT experience in organizing rocket flight tests in Poland (4 successful launches of ILR-33 AMBER rocket, over a dozen launches of cold launch demonstrator) and abroad. Specifics may vary between countries and test range policies.

1. Define requirements
   Testing a rocket vehicle – whenever it's a missile, a civil suborbital rocket or a launch vehicle – inherently generates substantial risk and may lead to catastrophic consequences. However, the said risk can be controlled and quantified, and it is common practice to define the acceptable risk level. This needs to be defined by the regulator, who often elects to set numerous requirements for individual and collective risks for individuals, ships, aircraft and spacecraft. For example, RCC-321-20 (Range Commanders Council, 2020) and (CAA, 2021) presents a comprehensive requirement discussion and definition. Sample tolerable risk values are shown in Figure 2.

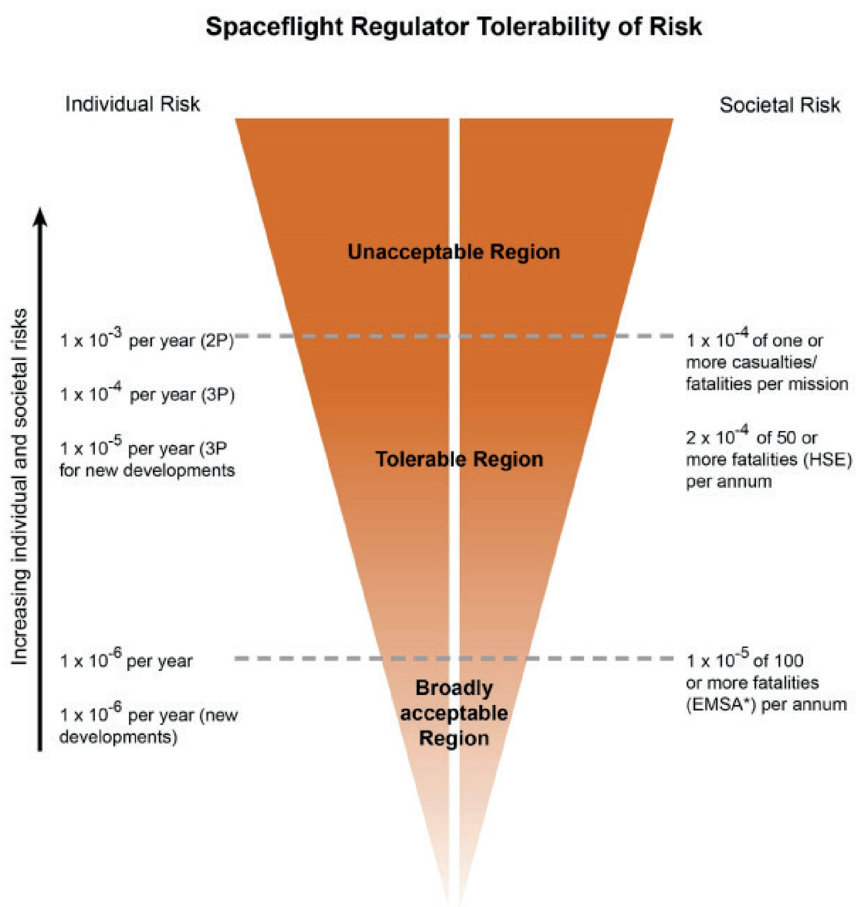

Figure 2. Indicative tolerability of risk. 2P and 3P refer to second and third parties, respectively, i.e., people directly involved with the activity (excluding spaceflight participants) compared with people who are not involved; EMSA is the European Maritime Safety Agency
Source: (CAA, 2021).

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2. Define a vehicle and its mission
Each vehicle (i.e., air defense missile, cruise missile, sounding rocket, launch vehicle, hypersonic rocket prototype, etc.) will have different characteristics that will play a crucial role in the safety analysis. An identical vehicle may generate different risks depending on what type of mission it is to perform. Therefore, it is necessary to perform a flight safety analysis for each vehicle type and mission type of the vehicle. It is recommended to allow some margin on both the vehicle design and mission parameters to allow planning flexibility.

3. Consider failure modes and their effects
Failures can include an engine failing to ignite/reignite, loss of control, loss of vehicle attitude reference, motor explosion, attitude error, staging failure, and software error (Australian Space Agency, 2019). For each failure, it is necessary to determine its probability and model its effects, including a release of fragments or a non-nominal trajectory. In the worst-case scenario, the vehicle may have an impact on a densely populated area or critical infrastructure, which is why a Flight Termination System is often employed (Haber, Bonnal, Leveau, Vila, & Toussaint, 2013).

4. Consider the environment
Another aspect to be taken into account is the environment. A rocket launched in the middle of a desert may generate no risk at all. Conversely, a rocket launched near a densely populated area can inflict severe damage if a malfunction occurs. It is, therefore, imperative for any flight safety analyst to be well aware of the environment. This includes population density, marine and air traffic patterns, location of critical infrastructure and even orbital traffic in case of space flights.

5. Calculate trajectories and fragments (include failure scenarios)
To calculate the risk of a mission, calculating the trajectory of the vehicle is necessary. Two types of simulations are performed – a nominal flight and a flight with failure modes on. Even when no failure occurs, the trajectory cannot be predicted perfectly. A Monte-Carlo or another statistical analysis is performed to assess the probability of impact in a given area (Figure 3). One can refer to (Noga, Michalow, & Ptasinski, 2021) for further discussion on such approaches. Trajectories with failure scenarios are then computed, and the way they are modelled depends on the failure modes analysis in Point 3. When explosive failures or utilization of the Flight Termination System are expected, which is often the case, one can expect hundreds of thousands of trajectories to be computed (Figure 4). Of course, this approach requires a reliable model of fragment generation, including mass and velocity distribution (Gee & Lawrence, 2013).

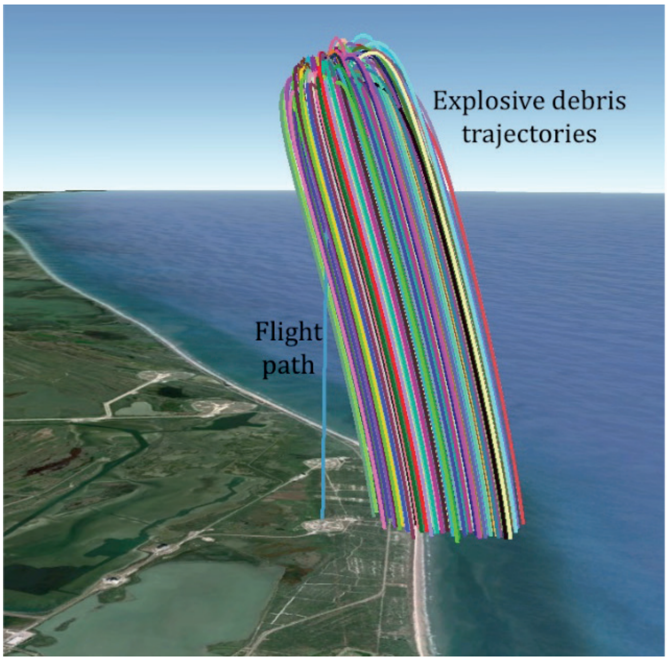

Figure 4. A set of explosive trajectories. A launch vehicle ascents and experiences a failure, activating a Flight Termination System. This generates thousands of adequately modelled fragments, and each fragment is propagated until it impacts
Source: (Manuel Capristan, Francisco, 2016).

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6. <u>Calculate risk of a mission</u>
The last step is to combine all impact points, considering each set's probability. The result of such an analysis can be a set of isopleths with a given probability of an accident. This data can be used to actually calculate the risk of inflicting damage or to obtain the casualty estimation by integrating the impact probability over areas, taking into account population density and the area over which the impacting rocket inflicts damage. Alternatively, an impact probability distribution can be plotted on the map in the form of isolines.

7. <u>Verify if an area needs to be monitored or closed altogether</u>
Based on work found in Point 6, it can be decided that the flight is too risky and cannot be proceeded unless certain safety precautions are taken. This can be, for instance, the use of a Flight Termination System that will not allow the rocket to continue its flight in the case its trajectory is not nominal or to define a hazard zone and forbid the public from entering it and monitoring this area prior to and during the flight – or both.

8. <u>Define the final hazard zone</u>
If the analysis indicates that a hazard zone should be defined, it needs to be officially defined and announced to the public. Parts of the air space and maritime zones may be closed. At times, the test range does not have the authority to forbid a third party from entering the hazard area (i.e., to forbid a ship from entering an area on international waters). However, it is not uncommon to define a hazard zone in international waters and even over the territory of another country. For instance, ESRANGE allows for safety cases with a non-zero probability that the rocket will land within the territory of Norway or Finland (Storbacka, 2022).

9. <u>Monitor the hazard zone and environmental conditions</u>
In many cases, it is necessary to close the hazard area specified in Point 8 from any traffic or at least to monitor the area to ensure that no ship, plane or person enters it (see Section 2.3 for an example of how it's done in the EGLIN test range). It is also necessary to monitor the environment. A rocket vehicle might be safe to fly with limited wind speed, or it might be the case that the dispersion was calculated with a certain bandwidth of allowed wind, and it has to be ensured that the wind stays within said bandwidth before authorizing the flight (Spiralski, M. et. al., 2020).

10. <u>Launch</u>
The vehicle is authorized to launch if monitoring the hazard area and environmental conditions shows the launch is safe. After the launch, the vehicle's trajectory is often monitored. If a Flight Termination System is used and the trajectory is not nominal, flight safety operators may decide to terminate the flight by cutting off the thrust or by destroying the rocket. After the rocket's impact or a soft landing, it is sometimes necessary to collect it afterwards, as it may pose further danger. This is mostly the case for land test ranges.

2.3 Case study – Eastern Gulf of Mexico Test and Training Area (Eglin)

The USA has multiple test ranges for rocket and missile tests, ranging from small complexes, to medium ranges (NTTR, Eglin) and the largest one in the world (KMR). In this section, we focus on the Eastern Gulf of Mexico Test and Training Area –shown on the map in Figure 5. The range consists of a relatively small land area with accompanying restricted airspace. However, most of the test and training missions occur over international waters, with a total of 101,000 square miles of surface and airspace (Office of the Secretary of Defense, 2018). This allows for testing new, advanced, high-range munitions, i.e., SDB II gliding bomb, Tomahawk and JASSM cruise missiles, and AIM-120 AMRAAM anti-aircraft missile. The other planned test activities include drone swarms, hypersonic weapons, and interceptors (Patriot PAC-2 and PAC-3). Civilian activities are also planned with NASA JPL Mars ascent vehicle flight tests (Figure 6). Access to the maritime part of the test range is for the most part not restricted, neither for aircraft nor ships. Moreover, the vast majority of its area lies in international waters. Despite this, over 10 thousand missions per year are conducted in the area – shown in more detail in Figure 8.

The procedure is as follows: the contractor provides the range with a test and vehicle description. Based on this, a safety analysis is conducted, the hazards are identified and evaluated, and safety criteria for conducting the test are developed (Range Safety Group, 1994). For rocket tests, it is determined (1) whether the test fits the safety limits of EGTTR, (2) and which test zones need to be cleared of people, aircraft and sea vessels. An example of the size and shape of closed areas is shown in Figure 8 (Tucker, Theater Missile Defense Extended Test Range Supplemental Environmental Impact Statement – Eglin Gulf Test Range. Volume 2, 1998).

The Range Safety Office is to communicate the extent of the clearance area, time, and date of the flight test, once they are defined, to the FAA, the Coast Guard, the Florida Marine Patrol (FMP), the Department's Division of Emergency Management, and

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local police jurisdictions for assistance in the clearance of designated land and sea-surface areas (Tucker, Theater Missile Defense Extended Test Range Supplemental Environmental Impact Statement – Eglin Gulf Test Range. Volume 1, 1998). The size and location of each zone are determined using computer models. If any of the hazard zones include a place of living of the general population, critical infrastructure, or a public building, e.g., a school or hospital, the test shall be redesigned or cancelled.

The maritime area of the test range is monitored primarily using the Automatic Identification System and shore-based radars. In some cases, aircraft, including maritime patrol aircraft with on-board radars are used. The test proceeds if the risk of damaging or sinking a ship within the hazard area is acceptable. Otherwise, the test is postponed until the number of ships falls below the calculated threshold (Range Commanders Council, 2020).

The area outside the hazard zones, but under the flight path, is to be monitored prior to the test event to determine the location of the general population or traffic. If the Range Safety Office concludes that the population or ship traffic is in a safe position, the test proceeds. Regarding the airspace, the Warning Areas that EGTTR is composed of (Figure 5) may be closed to private and commercial aircraft. This is done only for the areas affected by dangerous activity and only for the duration of said activity (EGLIN Air Force Base Florida, 2015).

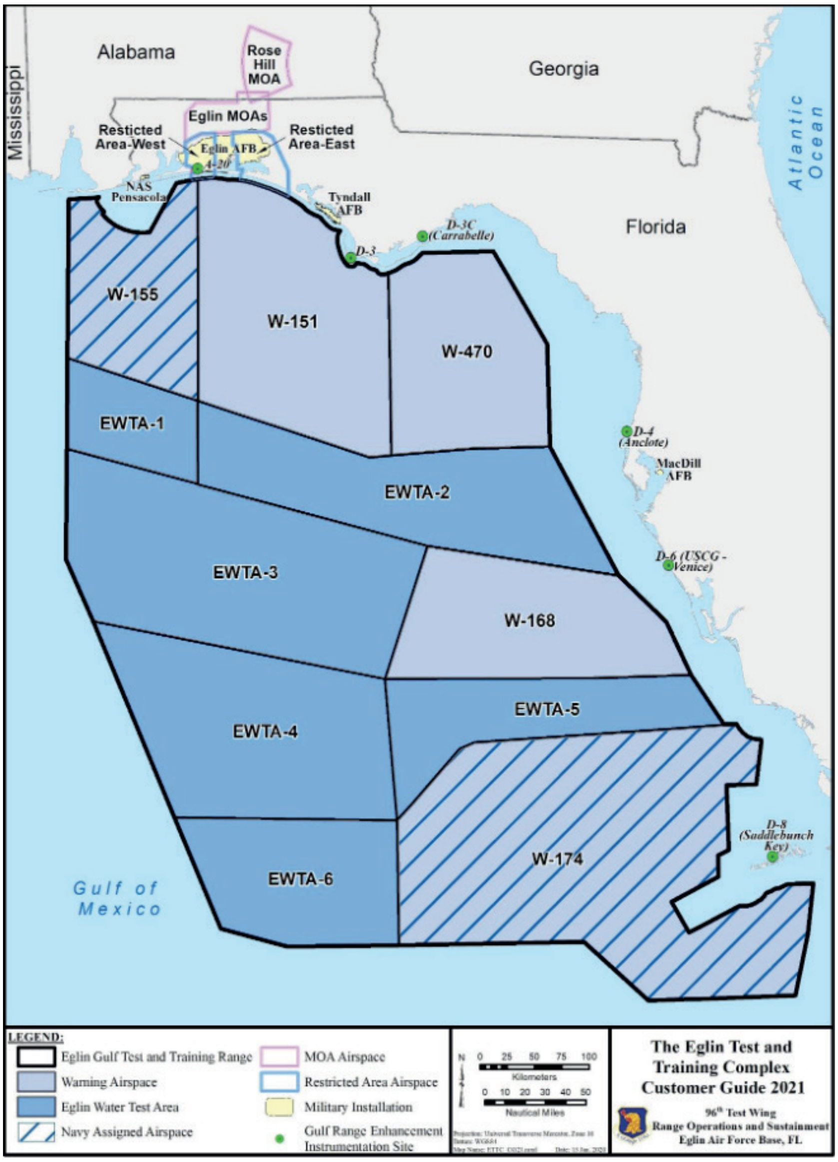

Figure 5. Eglin Test and Training Complex map
Source: Office of the Secretary of Defense, 2018.

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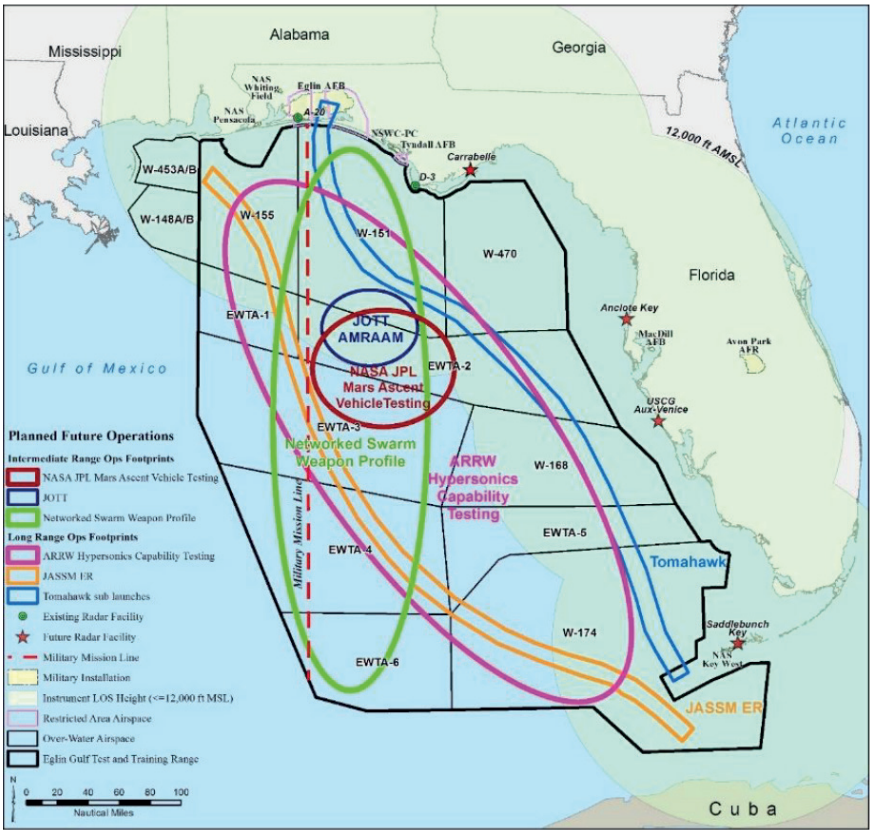

Figure 6. Long-Range Operations in the EGOMEX
Source: Office of the Secretary of Defense, 2018.

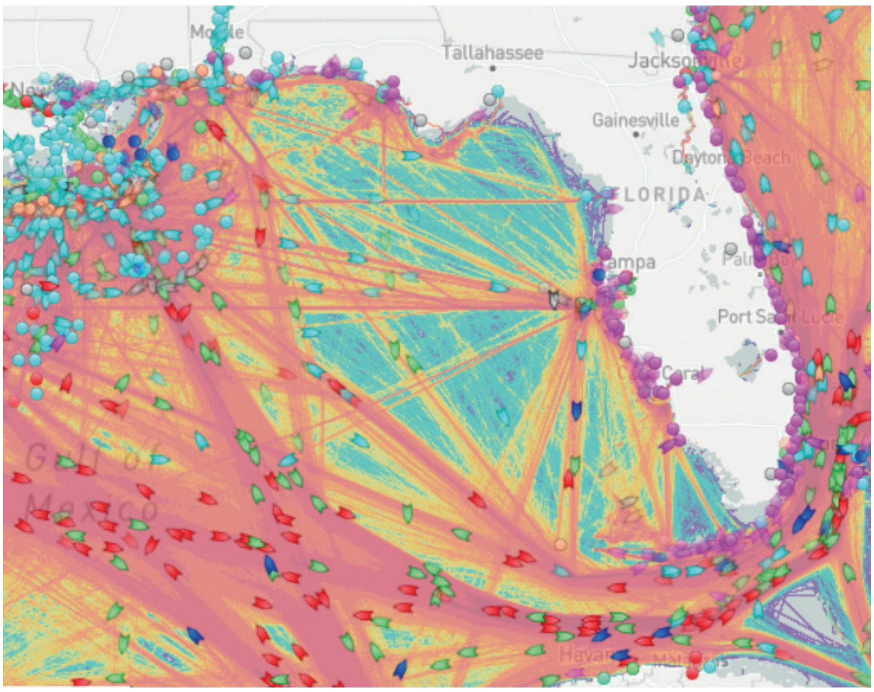

Figure 7. Mean marine traffic density in the area of EGTTR, for 2022
Source: MarineTraffic: Global Ship Tracking Intelligence, 2023.

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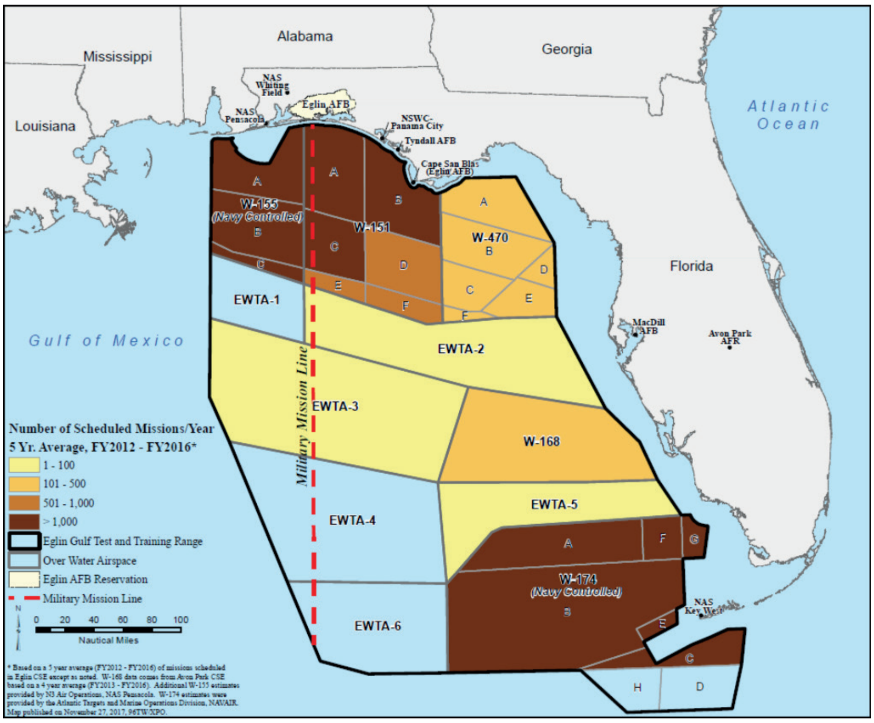

Figure 8. Five Year Average of Scheduled Missions for FY 2012-FY 2016
Source: Office of the Secretary of Defense, 2018.

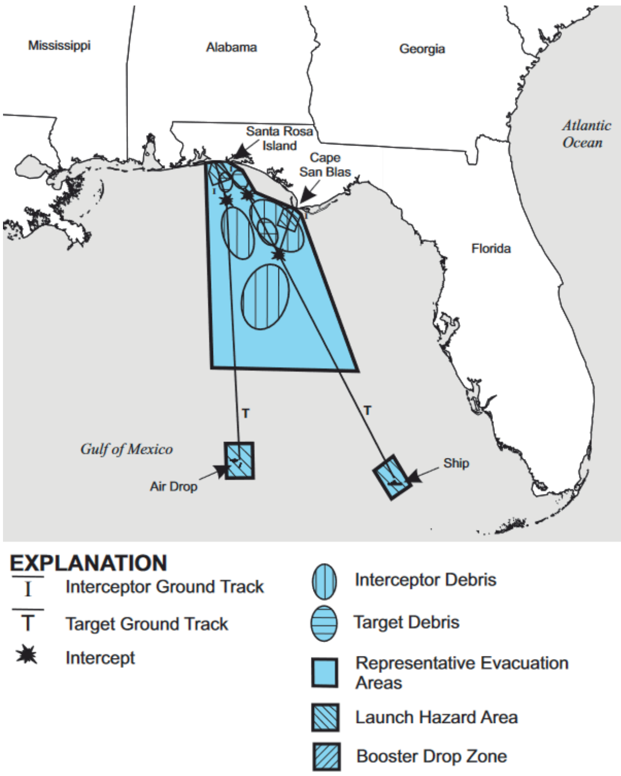

Figure 9. An example of hazard areas for ballistic missile intercept test
Source: Tucker, Theater Missile Defense Extended Test Range Supplemental Environmental Impact Statement – Eglin Gulf Test Range. Volume 2, 1998.

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3. Air Force Training Centre Ustka

One of the most prospective test ranges in Poland is the Central Air Force Training Ground (in Polish: CPSP) near Ustka located on the Baltic Sea coast, which began operating in the organizational structures of the Air Force and Air Defense in 1996. The first experimental combat shooting was performed in 1988. Interest in conducting exercises in this area was also shown by representatives of NATO countries, including Great Britain, the Netherlands, Germany, Italy, Czech Republic, Hungary and Slovakia. In recent years, it has become an advanced, well-equipped training ground, one of the selected specialized NATO training grounds for ground vehicles, radars, UAV, missiles or manned aerial systems (Centralny Poligon Sil Powietrznych, 2023) – see Figure 10.

For civil launchers, the formal path for the organization of a launch campaign is as follows:

1) The launch provider sends a request to the Armed Forces General Command (Poland) in order to receive approval for entrance to CPSP with flight object
2) The launch provider visits the CPSP for technical discussion with the representatives on test and logistics details – the airspace reservation, etc., are decided then.
3) The launch provider countersigns an agreement with the administrator on land use of the specified firing stand.
4) The launch provider receives and agrees with the test campaign program and test methodology document, that presents the mission profile, limitations (weather conditions, etc.), apogee, downrange and other parameters of the tests.

Figure 10. A photo shot from exercises with the use of missiles at CPSP. Credits: General Staff of the Polish Armed Forces
Source: Ustka, 2023.

The firing stands for rockets are located up to ~200 m from the shoreline (both sands or paved areas). For rocket and missile testing, the allowed flight zone is a combination of sea area and airspace. Within the CPSP, there are DANGER-type airspace elements (EP D53), whose subspace EP D53A allows for operations from sea level to UNLIMITED altitude (since 2019). The first such possibility appeared during the ILR-33 AMBER rocket flight attempt (already flown at CPSP twice for low altitudes – 23 & 8 km, the letter in 2K version, see Figure 11). The second subspace, EP D53B, allows operations up to 20 km above sea level. The maximum width of the EP D53 A zone is 40 km, the length (diagonal) is 45 km (EPD53A) or 60 km (EPD53A +EPD53B) – see Figure 12. It is possible to close the airspace for the purposes of rocket flights, the Command of the Test Site is responsible for reserving the airspace (Polska Agencja Zeglugi Powietrznej, 2021).

Figure 11. ILR-33 AMBER and AMBER 2K rockets’ launches from CPSP. 2019 booster separation moment (left), 2022 lift-off moment (right). Credits: Ł-ILOT.

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What is significant is that this area exceeds beyond the Polish territorial waters, entering a contiguous zone. This is a key factor limiting the capability of sea area restriction. The sea zone may be announced as dangerous for navigation, but this is not tantamount to a prohibition on entry (a vessel enters at its own risk). If the warning is ignored by the entering unit, it is necessary to suspend operations until all units have left the area. Due to the heavy traffic on the Baltic Sea, during the exercises, the security for the area of operation is organized with the use of Navy ships – OSORS (Ship Forces for the Protection of the Shooting Area). The ships are positioned at the ends of the defined outline of the basin, controlling surface traffic and preventing an unwanted object from entering the shooting area. In the case of shooting at a distance of approximately 15 km from the coastline, additional protection in the form of ships is not required, and the basin itself is directly closed to shipping.

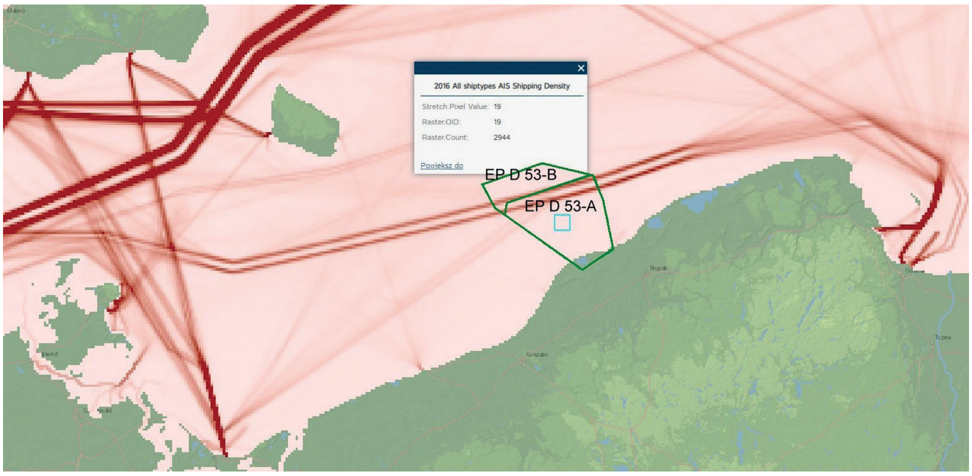

Figure 12. Intensity of sea traffic within the AIS system accompanying vessels in 2016. The largest traffic in the Baltic Sea area is 36,292 units. The sea corridor crossing the CPSP accommodates approximately 2,651 units, which is a daily average of just over seven units
Photo. https://maps.helcom.fi/. The significant cost of securing the basin by OSORS means that launches of suborbital rockets can only take place during military exercises (with the use of OSORS) within the launch window granted by the Command of the Training Range when the costs of the OSORS are assured by the Ministry of Defence for their operations. This situation is very unfavourable when planning commercial flights for customers. It should be noted that this requirement is conditioned primarily by the training ground's internal regulations, not by Polish law directly.

4. Analysis of Ustka and its comparison to other test ranges

The thesis of this paper is that CPSP is at no significant disadvantage when it comes to flight safety compared to other existing and active test ranges. The lack of suitable regulations is the main stopping point that prevents Polish entities from flying to space on a suborbital trajectory from Poland. To support this argument, the CPSP is compared to two other European test ranges: Andøya Space Center in Norway and CEDEA in Spain. Three aspects are compared:

1. A quantitative comparison of the expected casualty risk due to a suborbital rocket flight, expressed in the form of isolines showing the maximum safe apogee above the given location.
2. Qualitative comparison of air traffic
3. Qualitative comparison of marine traffic.

4.1. Population density

As mentioned in Section 2, test ranges tend to be located in low-populated areas. Knowing the statistical distribution of impact points of falling and dangerous fragments and the population density, it is possible to calculate an Estimated Casualty value. As explained in Section 2, the computation of the statistical distribution is a significant task in an actual mission. In the case of this study, however, the purpose of the exercise is to quantitatively compare different test ranges using the same generic scenario. Therefore, a simple distribution model has been defined: a bivariate normal and circular impact distribution. The radius of the distribution is modelled based on the VSB-30 sounding rocket (Garcia, A. et. al., 2011), and it is assumed that the standard deviation of the statistical distribution of impact is equal to 20% of rocket's apogee (maximum altitude).

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For any given distribution defined by a nominal impact point and standard deviation, the following procedure is performed:

1. The population density model is loaded into the computational space. For this study, a JCR-GEOSAT 2018 published by Eurostat is used (Batista e Silve, Filipe et. al., 2021). It is a regular grid map of 1 x 1 km cells reporting the number of residents for the year 2018 in Europe. Its reliability is reported as very high for Norway and southern Spain, and medium in the case of Poland, which yields an accuracy of approximately 84%, which is deemed sufficient for this high-level analysis.
2. A lethal area of the rocket is calculated. It represents the area on the ground around the impact point, where it would be lethal for any person hit. It can be approximated as (Federal Aviation Administration, 2001):

$$A_C = 10(l + 0.61)(d_{max} + 0.61) \tag{1}$$

   Where A_c is the lethal area [m²], l is the rocket's length [m] and d_{max} is the rocket's maximum diameter [m].
3. Which grid elements from the population density model lie within the energetic range of the rocket are then checked. Then, for each grid element within the energetic range, the probability of fragments impacting the grid element is calculated (equation A-10 in (Federal Aviation Administration, 2011)):

$$P_i = \frac{A_i}{\pi\sigma_a\sigma_b\left(c_{2,\mathrm{i}}^2 - c_{1,\mathrm{i}}^2\right)}\left(e^{\frac{c_{1,\mathrm{i}}^2}{2}} - e^{\frac{c_{2,\mathrm{i}}^2}{2}}\right) \tag{2}$$

   Where P_i is the probability of impacting i-th grid element, A_i is the area of the i-th element, σ_a and σ_b are standard deviations of dispersion ellipse and $C_{1,i}$ and $C_{2,i}$ are normalized measures of dispersion ellipses' that touch corners of the i-th grid elements and that are closest and furthest from the ellipse centre, respectively.
4. The Estimated Casualty from a given mission is calculated using the following equation:

$$E_c = \sum_{\substack{Areas\ withing \\ the\ energetic\ range}} P_i A_c P_d \tag{3}$$

Where P_d is the population density of the i-th area.

The procedure above was performed across each node of the meshed data set. The result is a set of geographical locations with assigned maximum safe unguided suborbital flight altitude. To visualize this result, points with the same altitude are connected, thus creating isolines. A sample interpretation of the resulting map is shown in Figure 13.

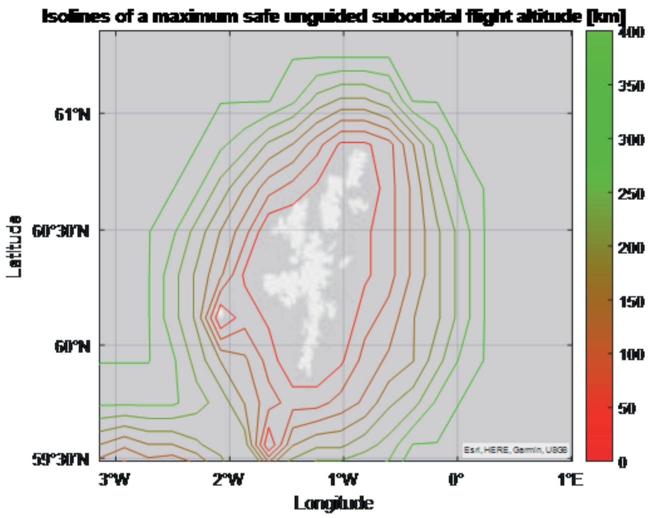

Figure 13. The result for an island on the North Sea. Flights directly above land are not safe at all. Flights near the coast can be executed at a low altitude (in red), and the further away from the coast, the higher flights are possible (green). The highest altitude considered in this study is 400 km.

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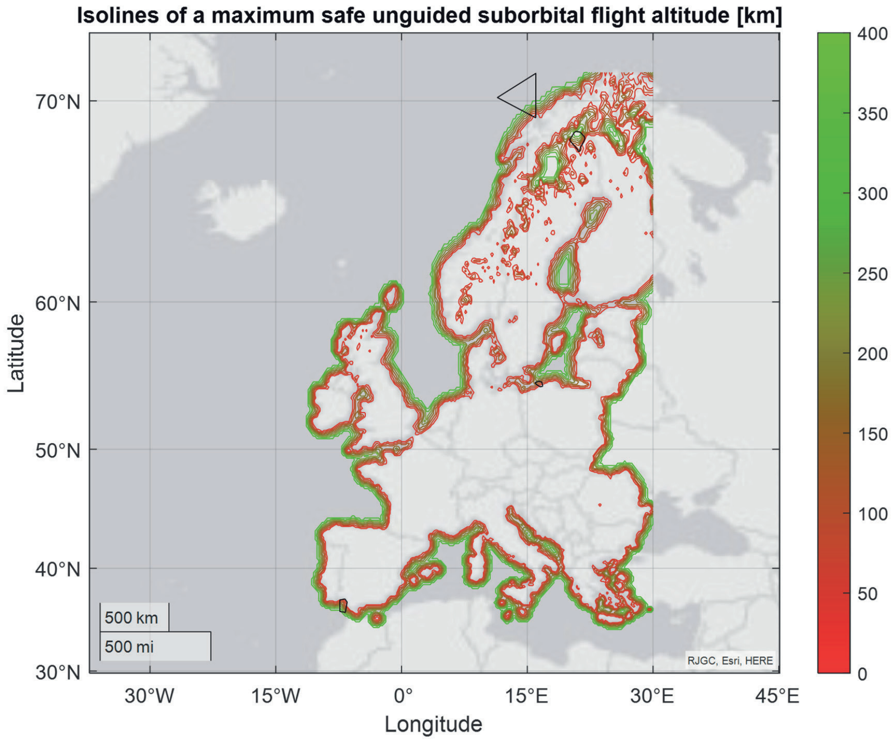
The overall result is shown in Figure 14. As Europe is densely populated, only flights above the sea are safe. Exceptions include small areas of Scotland, Romania and – most importantly – vast areas in Scandinavia. It comes with no surprise that the only large European range which allows suborbital spaceflight – ESRANGE – is located there, near the city of Kiruna. The figure also shows borders (black lines) of test ranges: CEDEA (near Gibraltar strait), Andøya (Norway), Esrange (Sweden) and Ustka (Poland). The map shows that flights are allowed above Greenland, Africa, Asia and East Europe because no population density data was included in the database used.



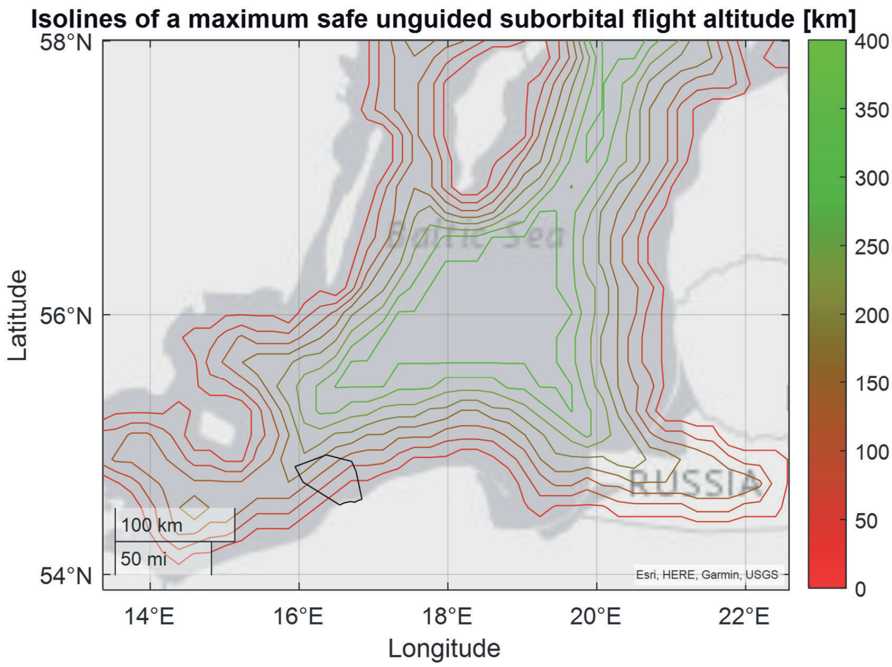


Figure 14. The overall result of the quantitative analysis of flight safety (top) and a close-up to the Baltic Sea (bottom). Contour of CPSP in black

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4.2. Air and Marine traffic

The CPSP is located in the south-central part of the Baltic, vis-à-vis the Bornholm deep. Assuming the rocket launches towards the North, the map showing the density of marine traffic shows two popular navigable routes that the ground track of a trajectory must cross that are relatively close to the test range. When comparing Ustka qualitatively to Andøya Space Center and CEDEA, it is clear that the other two test ranges also need to cope with marine traffic. CEDEA, located near the Gibraltar Strait, must particularly deal with substantial marine traffic, as shown in Figure 17. Also, see Figure 7 which shows marine traffic on Eglin. A quantitative analysis has been performed for CPSP based on the traffic data recorded in the years 2018–2023 by Polish receivers of the AIS system. The analysis assumed a rocket's flight with the dispersion-to-apogee ratio modelled exactly like in the analysis from Section 4.1, for a flight to an apogee of 100 km. The proposed Danger Zone for maritime traffic is shown in Figure 15. The Danger Zone is an area where no ship can enter without violating rocket flight safety requirements. The analysis performed with AIS data aimed to establish how much the maritime traffic would impede a flight or how much the marine traffic would suffer should the test range have the power to close this area for a rocket launch. To do that, it was established, based on AIS data, whether any ship was within the area at a given moment of time during last year, which was divided into 15-minute long instances. The results are shown in Figure 16 and indicate that for most of the time during the year, there was at least one sea vessel in the danger zone, but that there were also intervals without any vessels in the proposed area. The histogram shows that for most of the time, there were between 0 and 6 ships in the danger zone, which can be considered low-to-moderate marine traffic.

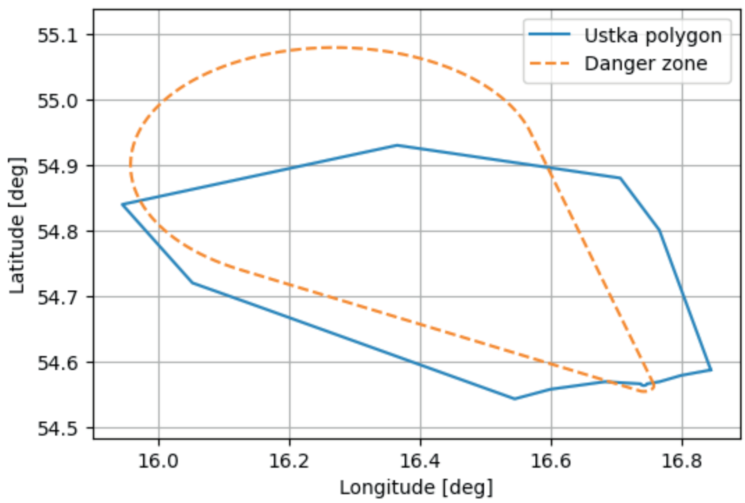

Figure 15. The proposed Danger Zone for maritime traffic in the vicinity of the training ground in Ustka for a 100km altitude flight

The analysis indicates that on average, 11.8% of 2022, no vessel was in the danger zone, and approximately 50% of that time, only two ships needed to be restricted to perform a flight. Nighttime is less busy and would allow more flexibility when marine traffic is concerned.

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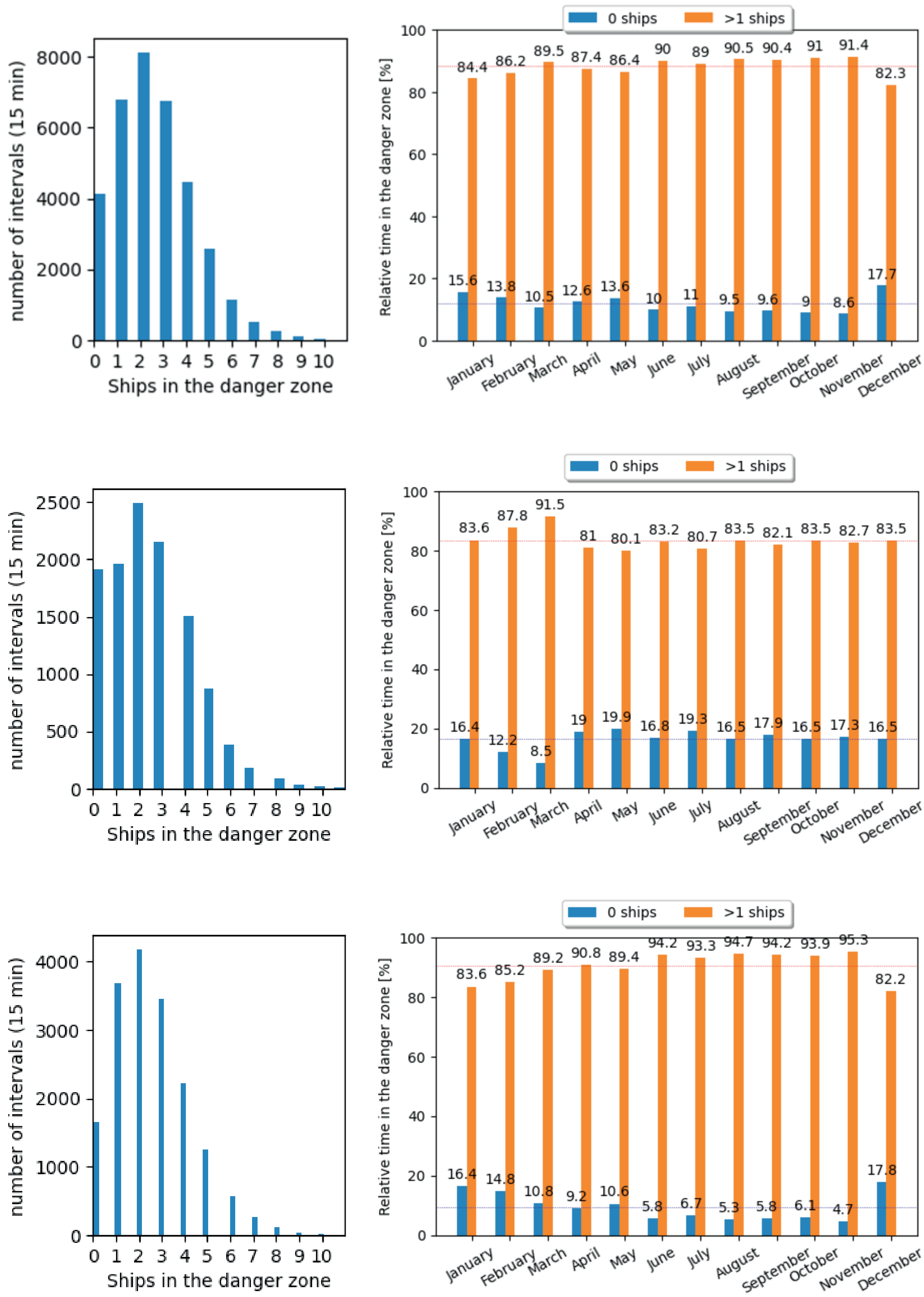

Figure 16. The result of the AIS data analysis of ship safety – Danger Zone as specified in Figure 15. Any time (top), nighttime (middle) and the daytime (bottom). It was assumed the daytime starts at 8am and finishes at 8pm

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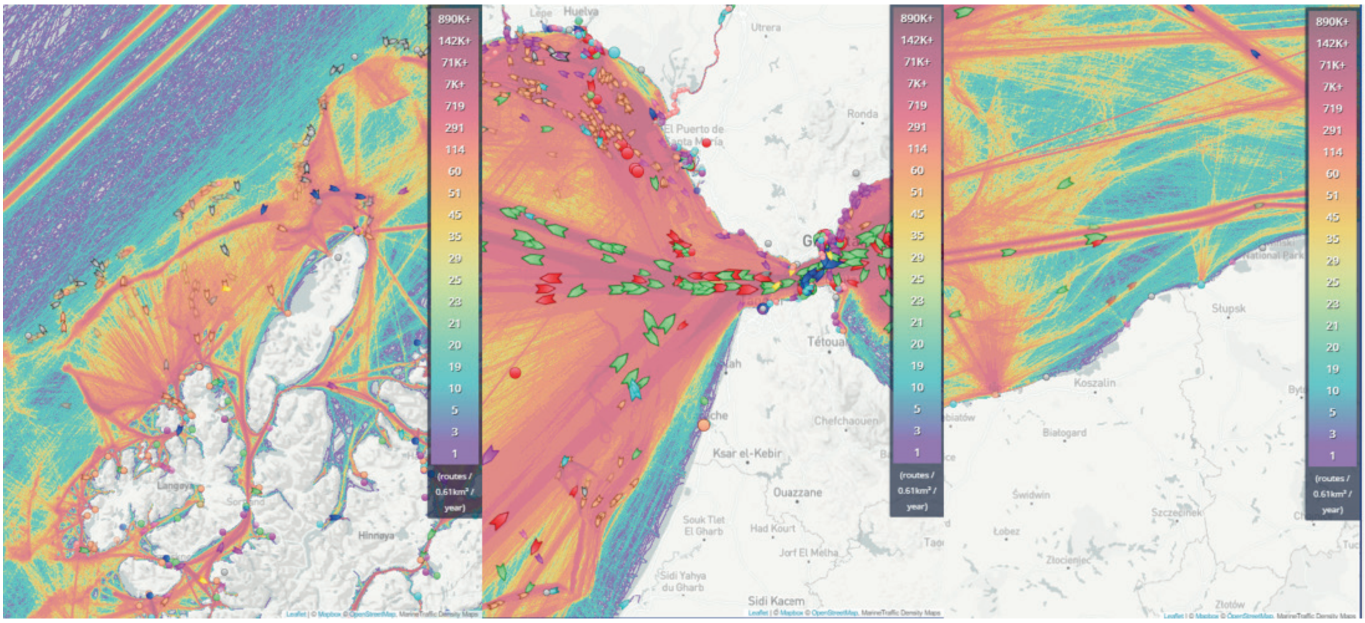

Figure 17. Marine traffic density for year 2022 near the Andoya Space Center (left), El Arenosillo (center) and CPSP (right) MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic Retrieved 7 August 2023, from https://www.marinetraffic.com.

4.3. Comparison between test ranges

Table 1 presents an overall comparison of the considered test ranges. It shows that Ustka is suitable for performing high-altitude rocket flights and is at no disadvantage compared to the existing test ranges.

Table 1. Risk-wise comparison of test ranges

Risk	Comparison type	Andøya Space Center (Norway)	CEDEA/El Arenosillo (Spain)	CPSP (Poland)
Injuring a third party	Quantitative	Unlimited apogee	Unlimited apogee (however, the dispersion still might be beyond the current impact zone)	Unlimited apogee, provided that the central area of the Baltic sea is provided for landing. 160 km for a nominal impact point within a current impact area (however, the dispersion would still be beyond the current impact zone)
Hitting a ship / need to stop marine traffic	Qualitative/ Quantitative	Low marine traffic	Very large marine traffic	Low-to-moderate marine traffic
Hitting a plane / need to stop air traffic	Qualitative	Very low traffic	Moderate air traffic	Moderate air traffic

5. Conclusions

This paper discussed the feasibility of high-altitude rocket flights from the CPSP and has shown that the Baltic sea coast can be an attractive location for military and civil flight tests. OSORS might not be needed at all for conducting such tests. Specifically, high-altitude flights and those above the Kármán line are possible on the Baltic Sea, as long as adequate safety measures are met – i.e., the analysis proposed in Section 2.2. is performed. Please note that the altitude of 160 km and other figures and maps are for comparison only, as the purpose of the exercise was to quantitatively compare different test ranges using the same generic scenario. As explained in Section 2.2, in an actual mission, the computation of the statistical distribution is a significant task requiring computation and procedures dedicated to a given mission and vehicle. Especially, rockets with low flight heritage require careful treatment and may need to have stricter constraints imposed.

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Air and marine traffic near CPSP, while remaining an issue to be accounted for, is lower or comparable to traffic existing near other test ranges. Having said that, it is important to ensure that the CPSP can monitor or close larger marine and air areas than is currently possible. A quantitative analysis was performed using simplified procedures, which is deemed adequate for this high-level analysis. Currently, the lack of proper legislation and regulations is a blocker of further development of Polish suborbital rockets. Securing this would allow further development of rocket technologies in Poland while allowing the military to perform military exercises with newly acquired missile systems.

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Declaration of interest
The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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