DOI: 10.13009/EUCASS2025-056
11TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS)

SPACE TRAFFIC MANAGEMENT OF SUB-ORBITAL AND GROUND SUPPORT ACTIVITIES: POSSIBLE WAY FORWARD

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Abstract

The recent increase in space activity leads to a completely different perspective on space traffic management. In particular, the interactions between space and air traffic became a subject in itself for both orbital and suborbital missions, inducing potential traffic management problems. This depends on both the kind of objects and missions, such as orbital launch, re-entry, booster recovery, suborbital flight... Spacecraft transiting airspace involves different objects (satellites, launch vehicles, rocket bodies, space tourism vehicles, sounding rockets, aircraft…) and missions with various associated risks. These risks can generally be characterized by the amount of time in the airspace, the velocity of the spacecraft, and its altitude. The rise in the number of spaceports for orbital and suborbital missions contributes to increased space traffic in terms of location, launch sites, and widespread types of launch and re-entry missions. Despite the enhanced space activities, there are currently no specific and binding international standards for spacecraft crossing airspace. However, there are guidelines, national frameworks, and recommendations from organizations (e.g. UN-COPUOS, OSI) that cover part of the interaction between space activities and airspace transit.

In the frame of the IAF-IAA-IISL Working Group on Space Traffic Management (STM), sub-orbital activities and transit through airspace/ground support activities were addressed with the objectives of providing a status of the current situation, estimating likely developments, assessing collision risks due to the growth of the launcher and satellite markets, elaborating on potential air traffic coordination, providing an overview of legal aspects, providing possible recommendations for future operations, and proposing the possible implementation of these recommendations. This work was conducted by a group of experts in different domains, such as space and air traffic management, space surveillance tracking, legal framework, risk assessment, re-entry, and tracking improvement.

Based on previous publications [[1]][[2]][3][[4]][[5]][[6]][[7]], the authors propose a possible way forward in the management of suborbital/ground support activities in terms of operational guidelines and risk assessment.

Acronyms & Symbols

AOI	Areas of Interest
ATC	Air Traffic Control
ATM	Air Traffic Management
DoD	Department of Defense
EU	European Union
FIR	Flight Information Region
FSOA	French Space Operations Act
HOA	Higher Airspace Operations
HAPS	High Altitude Platform Systems
OSI	Outer Space Institute
RE	Re-Entry
SDS	Space Defense Squadron
SSA	Space Situational Awareness
SSN	Space Surveillance Network
SST	Space Surveillance and Tracking
STM	Space Traffic Management
UN-COPUOS	United Nations Committee on Peaceful Uses of Outer Space

Introduction

In the recent years, space traffic has rapidly grown mostly due to the large constellation market and increasing number of launch vehicles worldwide. The large number of services that space assets can offer and the extraordinary development of NewSpace opened a new space age, whose consequences are difficult to predict/master and need urgent shared regulation. This NewSpace context implies an increased transit through airspace and it impacts on the prediction of raising suborbital activity [1]. The risk linked to space vehicles going through airspace is currently limited, but it will increase mainly due to rocket body re-entry. The number of satellites is increasing much faster than rocket bodies, but the associated risk is usually more limited due to less probability of surviving debris during re-entry.

In this context, the Montreal Recommendations on Aviation Safety and Uncontrolled Space Object Re-entries by the Outer Space Institute (OSI) [8] provides recommendations mainly focused on satellites' re-entry due to the increased number of satellites in coming years (mainly due to satellite constellations). It is outlined that the risk of important damage to aircraft is high in case of collision due to the high speed of the aircraft. The main OSI recommendations consist in design rules (such as design to demise of controlled re-entry strategies), but also on the identification of liability of damage and improved predictions.

The space launches into orbit, re-entry from orbit, suborbital flights, hypersonic and supersonic flights, and high altitude platform systems (HAPS) are going to increase the number of interactions with airspace. The States are pushed to develop new regulatory models and approaches to allow safe and secure operations without disproportionately affecting the current aviation system [8][9]. At the same time the States are supporting the development of the necessary ground infrastructures such as different types of spaceports.

Tools are currently being developed and operational in order to improve prediction of uncontrolled re-entry trajectories. European Union is progressing in this direction with the EU-SST program.

The increased space activity induced an opportunity to develop spaceports providing commercial services mainly for small launchers and suborbital vehicles all over the world, thus increasing the potential interaction with airways. This reinforced interaction is mainly due to re-entry of launch vehicle stages and crossing of the airways. National regulations are being developed, but a coordination can be profitable to ease the interoperability and sharing of standards. European Union is promoting this approach for the European Countries having developed or developing space activities [11].

In June 2019, UN-COPUOS adopted a set of 21 voluntary non-binding Guidelines for the Long-term Sustainability of Outer Space Activities [12]. The Committee highlights the importance of considering transit through airspace across the different pillars [13]. From the policy point of view, the regulatory frameworks should address risks to people, public health and the environment associated with the launch and re-entry of space objects, as well as promoting policies to minimize the impacts of human activities on Earth. For the safety of the space operations, specific guidelines are established to take measures to address risks associated with the uncontrolled re-entry of space objects [14].

The main purpose of this paper is to outline the current progress to improve the management of space activities interacting with airspace and the corresponding ground infrastructures evolution. In the following of the paper, the boundary of space is assumed to be the Karman line, situated at 100 km from the see level.

1. Spaceports

In recent years the commercial exploitation of space in the context of the emerging new space economy has resulted in the outfitting of a number of different initiatives aimed at exploring opportunities to access and exploiting space for a variety of applications. A Spaceport is considered the operational base for commercial access to space and features dedicated ground based infrastructures and capabilities designed and outfitted to support sustainable commercial spaceflight pre-flight, launch, mission, re-entry and landing and post landing /turnaround operations of reusable vehicles. Specific initiatives are focusing on technologies aimed at developing innovative reusable space vehicles with the aim of reaching 100 km altitude on suborbital trajectories and possibly preparing for future generation transport between different points on Earth.

The number of spaceports has increased rapidly in last years in the frame of national programs, but the need for new spaceports is currently driven by private Companies developing new activities both for orbital and suborbital flight as a business (e.g. [15]).

The main drivers for Companies developing new launch systems with respect to spaceports are the limited launch cost, operational flexibility, access to a large number of orbits and ease of logistics. The "interference" with airways both for ascending and descending phases, may constraint the access to orbit and strongly depend on the envisaged missions and on the location of the launch site. New spaceports are currently under development all over the world, both in the frame of national programs and in the frame of private investment. The competition is strong and the offer is probably even too large with respect to the need. An overview of the current spaceport worldwide is provided in Fig. 1 from [16].

DOI: 10.13009/EUCASS2025-056

Different missions can be accomplished by spaceports and different objects can be launched, namely, rockets (orbital and suborbital) and balloons. In the fame of suborbital vehicles, we can distinguish experimental vehicles and demonstrators, suborbital unmanned / manned flights.

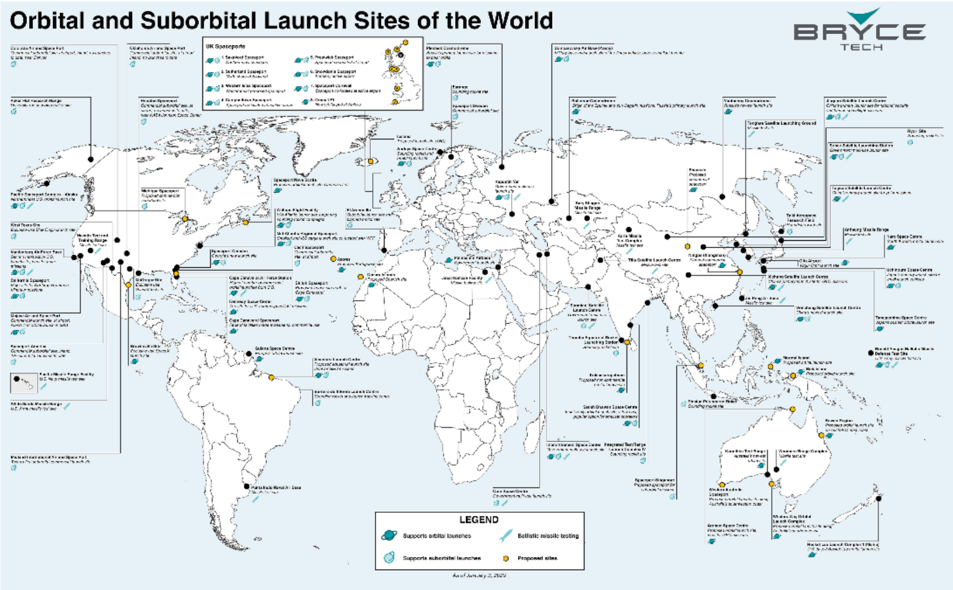
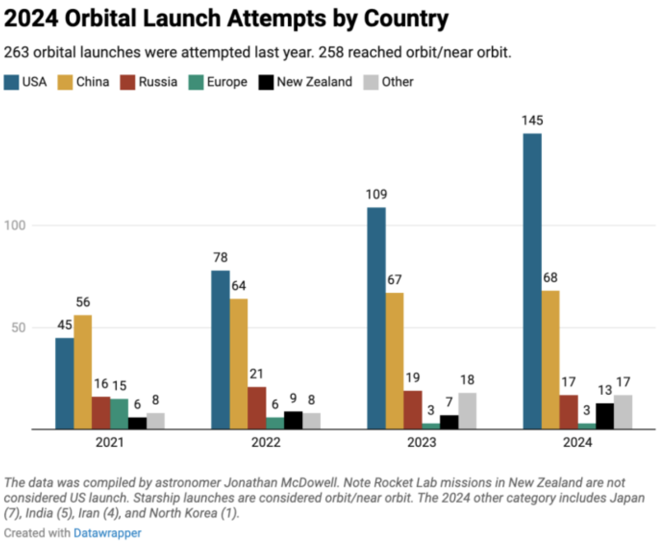


Fig. 1 –All of the World's Spaceports [16]

2. Space objects[1] considered in the group

Many kinds of space objects can interfere with the airspace in the different phases of their missions. The authors of this report screened different kinds of objects: balloons, ballistic vehicles, re-entry vehicles, rockets, point to point vehicles, high altitude platform systems (HAPS). The group decided to mainly focus on satellites, rocket bodies and suborbital vehicles after having analyzed the different types of interactions with airways.

This choice has been driven by physical and legal considerations. The chosen objects pass all the Karman line either going / getting back from an orbit with high mechanical energy (kinetic plus potential) or in ballistic flight with lower mechanical energy. The driving factors are the velocity (linked to kinetic energy) and the altitude (linked to the potential energy). The eventual impact of such objects on an aircraft can be detrimental due to the high energy involved. However, the probability of impact can be relatively low, as shown for example in [2], but increasing with the air and space traffic. The overall number of launches doubled in the last four years (period 2021-2024). This trend could be even increased in next years (Fig. 2).



[1] None of the five space law conventions define precisely what is a space object.

Fig. 2 – Orbital launch rates from 2021 to 2024 [17]

The number of new satellites launched in recent years (e.g. see [18] for a complete report) was dominated almost entirely by those establishing or expanding commercial satellite constellations in low-Earth orbits.

Currently, it is difficult to predict the risk of impact due to both the difficulty to predict the re-entry trajectory and the corresponding crossing of airways. This translated, for example, in the major breakdown of air traffic at the occasion of the tracking of a Chinese rocket upper stage re-entry in May 9th 2021.

From a legal standpoint, no specific international binding rules for re-entry bodies exist currently, however, liability conventions apply if an incident occurs, but no operation process is really in place. Some national legislation and regulation exist for assessing casualty risk for ascending trajectories and controlled re-entry (e.g. FSOA und US regulations). More precisely FSOA and US regulations state

- Casualty risk for satellite driven by risk criterion, but no rule for interference with air traffic management.
- Rocket stage: de-orbit of get rid of specific area.

Currently in the US there are several laws and regulations relating to controlled reentry. US commercial space launch operators are required to obtain licenses for launch and reentry. Under 14 CFR 450 (Part 450), the Federal Aviation Administration (Office of Commercial Space Transportation “AST”) requires commercial launch operators to provide information on its launch and reentry details as part of the process of applying for a launch and reentry license[2]. Another recent yet related regulation is the Federal Communication Commission’s newly adopted 5-year De-Orbit Rule[3]. This rule requires applicants for satellite communications licenses in Low Earth Orbit to comply with the 5-year de-orbit rule to meet “post-mission disposal guidelines.”[4] There are several exceptions.

The group has identified the following major topics linked to crossing of airspace and ground support activity:

- The uncontrolled re-entry of rocket bodies, whose probability of components surviving re-entry keeps on being relatively high.
- The procedure to follow up uncontrolled re-entry.

Prediction of re-entry is an essential tool to monitor potential interaction with airspace.

3. Re-entry of uncontrolled space objects

A recent analysis of uncontrolled re-entries involving spacecraft and orbital stages with a radar cross-section greater than 0.1 m^2, as well as debris with a radar cross-section exceeding 1 m^2, revealed that approximately 2300 objects re-entered the Earth's atmosphere without control between early 2010 and the end of 2024. Spacecraft accounted for 60% of the re-entries, while orbital stages made up 32% and large debris the remaining 8%. In the last 5 years (2020-2024), the number of uncontrolled re-entries exceeded 1600, with spacecraft accounting for 71% of the total, orbital stages for 22%, and large debris for 7% (Fig. 3).

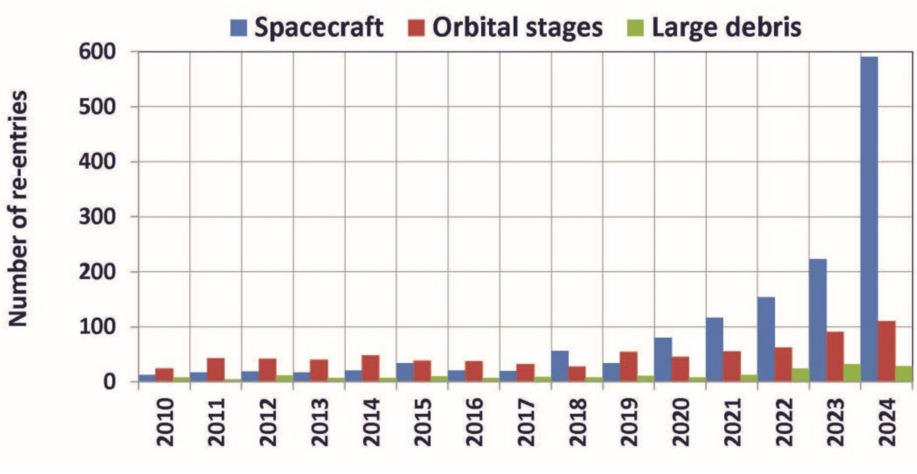


Fig. 3 – Annual number of uncontrolled re-entries of spacecraft, orbital stages, and large debris from 1 January 2010 to 31 December 2024

In terms of the returned mass, the cumulative mass of objects re-entering the atmosphere without control between 2010 and 2024 was estimated at approximately 2270 t, corresponding to an average annual re-entry of 152 t (around 3

[2] FAA, Vehicle Operator Licenses, https://www.faa.gov/space/licenses/operator_licenses_permits

[3] https://docs.fcc.gov/public/attachments/FCC-22-74A1_Rcd.pdf

[4] Id.

t per week). During the last 5 years, the total returned mass exceeded 1200 t, increasing the annual average to 240 t, or roughly 5 t per week (Fig. 4). Orbital stages represented 66% of the 1200 t of re-entered mass, followed by spacecraft with 27%, and large debris with 7%.

Even for objects not specifically designed to withstand the mechanical and thermal loads during re-entry, a mass fraction between 5% and 30% – or higher in exceptional cases (e.g., the tragic loss of the Space Shuttle *Columbia* on February 3, 2003, when the 84,000 fragments recovered corresponded to nearly 38% of the vehicle's mass at the time of re-entry) – can survive and reach the ground. With the exception of rare accidents such as the *Columbia* disaster or the re-entry of *Skylab* in 1979, most fragments recovered on the ground to date have originated from orbital stages.

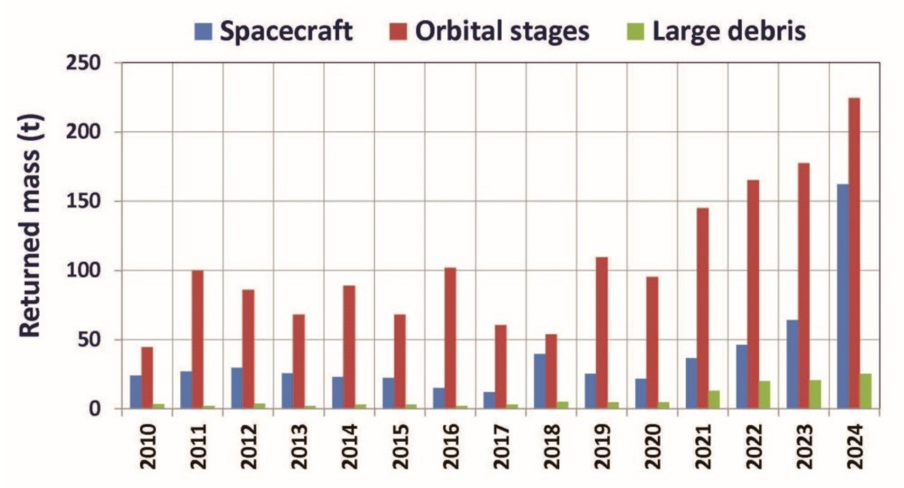


Fig. 4 – Annual returned mass associated with uncontrolled re-entries of spacecraft, orbital stages, and large debris between 1 January 2010 and 31 December 2024

For uncontrolled re-entries, the main factors to consider when assessing the expected risk of human casualties on the ground include: the number and area of debris likely to reach the earth's surface; the kinetic energy of each surviving fragment; and the proportion of the global population potentially at risk. This last factor depends on the orbital inclination of the re-entering object and the year in which reentry occurs. A kinetic energy of 15 J represents the minimum threshold for causing a potential injury – defined as an injury requiring immediate medical intervention – to an unprotected person on the ground. Below this threshold, the probability of injury is considered extremely low.

As in [2] and [19], the casualty risk to unsheltered individuals on the ground from uncontrolled re-entries was estimated in terms of the casualty expectancy, E_{CR}, associated with each re-entry event. E_{CR} was calculated as the product of the total debris casualty area (A_C) – i.e., the combined impact area of all fragments originating from the re-entering object – and the average global population density (P_D) within the latitude band overflown by the object at the time of re-entry:

$$E_{CR} = A_C \times P_D \tag{1}$$

The cumulative annual casualty expectancy (E_C) was then obtained by summing the individual casualty expectancies (E_{CR}) of all re-entry events occurring within a given year. The annual casualty probability (P) – representing the likelihood of at least one casualty in a given year – was thereafter computed as a function of the corresponding cumulative casualty expectancy, according to the following relationships:

$$P = 1 - e^{-E_C} \tag{2}$$

By evaluating the casualty expectancy associated with each of the 2300 uncontrolled re-entry events and assuming that none of them completely disintegrated in the atmosphere during re-entry, it was found that 14% of the spacecraft had a casualty expectancy greater than 10^{-4} (the global human casualty expectancy threshold above which an uncontrolled re-entry is considered potentially hazardous). Orbital stages exceeded this risk threshold in 77% of the cases, while large debris would have exceeded it in 31% of the cases.

The annual global probability – defined as the likelihood that, in a given year, someone anywhere in the world may be injured by fragments from uncontrolled re-entry events – is shown in Fig. 5 for the three objects categories (spacecraft, orbital stages, and large debris), as well as for the combined total of all these objects (intact objects plus debris).

Globally, the annual casualty probability remained below 2% until 2020, then increased significantly through 2024, especially for spacecraft and orbital stages. In 2023, 61% of the casualty probability was associated with orbital stages, 30% with spacecraft, and 9% with large debris. In 2024, the risk distribution changed, with 49% attributed to spacecraft, 44% to orbital stages, and 7% to large debris. Assuming that objects below a certain mass threshold, e.g., 300 kg, do not produce any fragments capable of surviving re-entry and reaching the ground, the casualty probability remains nearly identical to that shown in Fig. 5 up to 2019. However, beyond that year, the increase becomes less pronounced, reaching 4.7% in 2024 compared to 6.8% when all objects are considered, regardless of their mass. In 2024, the risk contribution from objects exceeding 300 kg was 61% from orbital stages, 32% from spacecraft, and 7% from large debris. This difference compared to the previous case – including all objects – is due to the exclusion of first-generation Starlink satellites with masses below 300 kg that re-entered after 2019.

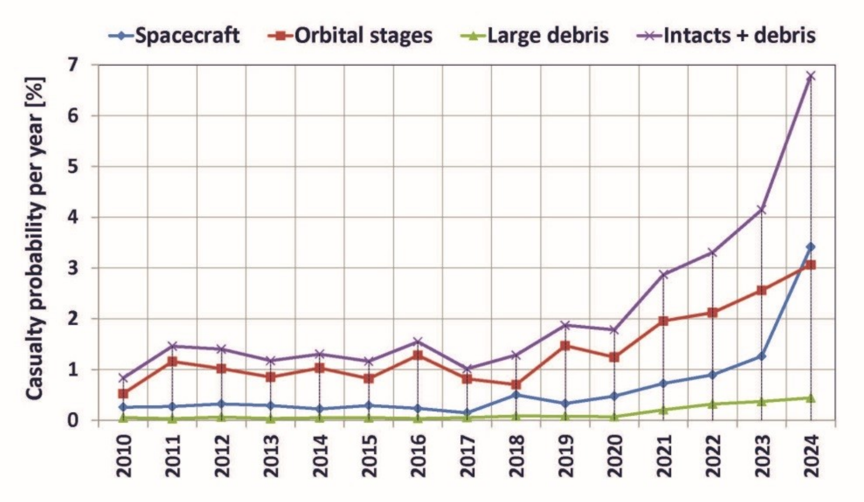


Fig. 5 – Annual casualty probability associated with uncontrolled re-entries of spacecraft, orbital stages, large debris, and all objects combined, from 1 January 2010 to 31 December 2024

The increasing trend in risk to unsheltered individuals on the ground due to uncontrolled re-entries (Fig. 5) could also be observed in relation to the risk posed to aircraft. Although the probability of a direct impact between re-entry debris and an aircraft remains low, the growing frequency of uncontrolled re-entries may result in a higher likelihood of close encounters.

In [20], the expectation of a collision with an aircraft was estimated for the period from 2019 – when the first Starlink constellation satellites were launched – through the end of 2024. Two distinct models were used to estimate the number of fragments, per re-entry, that could potentially cause a catastrophic failure to an aircraft. Additionally, different mass thresholds were applied to account for the potential complete disintegration of objects below a given value during atmospheric reentry. It was found that, although the hazard to commercial aircraft and passengers remains very low, the risk figures for 2024 were estimated to be 3 to 4 times higher than those for 2019, despite the number of flights and passengers being virtually the same in both years. In 2024, the collective casualty probability for commercial aircraft passengers ranged from 0.42% to 0.84%, which is approximately one order of magnitude lower than the corresponding values for individuals on the ground [20].

As with people on the ground, the risk to passengers on commercial flights from uncontrolled orbital re-entries, while not negligible, currently remains modest compared to the daily risks faced both individually and collectively. However, the significant increase observed from 2019, coupled with the projected growth of commercial air traffic and the accelerated expansion of orbital activities driven by the new space economy, presents a serious concern for the future. This highlights the urgency of adopting appropriate and effective mitigation measures in a timely manner, before the situation becomes critical. One possible solution is the application of the design-for-demise approach, particularly to satellites – such as the strategy announced by SpaceX for its latest generation of Starlink satellites – in order to minimize the risk posed by surviving debris. By contrast, implementing design-for-demise principles for orbital stages remains more complex, especially when these stages are designed for reusability. Consequently, an integrated risk mitigation strategy for both ground and airspace could include: controlled re-entries for orbital stages; and the implementation of design-for-demise principles for future satellite missions. In addition, the use of spacecraft re-entry prediction tools can enhance the forecasting of potential ground impacts and interactions with air traffic.

4. Space objects' re-entry prediction

From a global perspective, entities such as the U.S. Department of Defense (DoD), the European Space Agency, the EU SST Partnership, the Aerospace Corporation provide real-time decay and re-entry predictions for uncontrolled re-entry of man-made space objects into the Earth's atmosphere, between others. At the European level, the EU SST provides re-entry services to all EU Member States, EU institutions, spacecraft owners and operators, as well as other public and private entities. Access to these services is free of charge but requires prior registration. EU SST's re-entry service continuously assesses orbital objects decaying within the next 30 days, performs the tracking of the re-entering objects through the EU SST sensor network, and provides the refined re-entry prediction classifying the risk into

DOI: 10.13009/EUCASS2025-056

Minor/Medium/Major/Unknown risk levels. Only objects over 2.000 kg of mass or, if no mass information is available, radar cross-section larger than 1 m^2 (usually referred as *large debris*) are routinely analyzed.

To deliver this service, EU SST relies on three core capabilities: sensor tracking, processing, and service provision. Sensors from Member States collect tracking data, which is processed and stored in a shared database. From this data, products—such as those for the uncontrolled re-entry service—are generated by the Operations Centers (OCs) and delivered to end users via the SST Service Provision Portal (SST Portal).

Registered users of the EU SST service have access to two types of re-entry predictions through the EU SST Web Portal:

- **30 Days Re-entry List:** this list contains all space objects predicted to re-enter the Earth's atmosphere in an uncontrolled manner within the next 30 days. It is updated weekly or as needed. The long-term prediction includes the evolution of the re-entry window, with an accuracy of approximately one day.
- **Re-entry Report**: The Re-entry Report consists of a detailed analysis focusing on each object expected to re-enter approximately 3–4 days before the predicted re-entry epoch. This Re-entry Report complements the 30-Day Re-entry List by providing orbital information, 2D ground track maps for overflight prediction, and the expected ground swath, which is later used to confirm the re-entry in the final report. A final/decay Re-entry Report is issued to confirm the re-entry event and is released under one of the following circumstances: after Space-Track confirms the decay, three days have passed since the last estimated re-entry epoch, or the object is not detected in three consecutive sensor passes contributing to the EU SST.

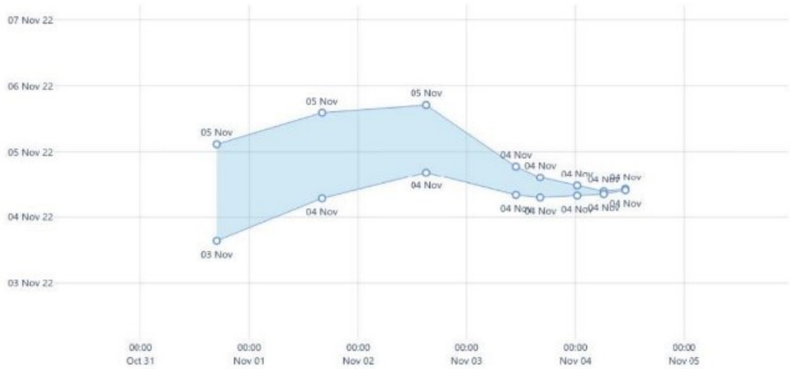


Fig. 6 – CZ-5B reentry window. Image credit: ©EUSST 2022

The use of the EU SST re-entry service and its products can be illustrated through real cases in which the entity has intervened. One such case involved the uncontrolled re-entry of a Chinese heavy-lift launch vehicle, Long March 5B (CZ-5B variant, 2022-143B on Space Track catalogue), which occurred in late October to early November 2022 (see Fig. 6). This vehicle injected into orbit the third module of the Chinese large modular space station on 31 October 2022. The EU SST sensor network closely monitored the re-entering object, and its radars narrowed down the re-entry window to 4 November. Based on EU SST analysis and external sources, EU SST confirmed that object CZ-5B decayed on 4 November 2022 at 10:01 UTC ±15 minutes (see [2] for more details).

Another noteworthy application of EU SST capabilities was the tracking and analysis of the semi-controlled re-entry of the AEOLUS satellite (2018-066A), which had completed its mission of measuring global wind profiles from Low Earth Orbit (LEO) at an altitude of approximately 320 km. On this occasion, EU SST provided support to ESA during the assisted re-entry phase. Following ESA's planning of the re-entry maneuver sequence and the confirmation that AEOLUS was expected to re-enter on 28 July (see Fig. 7), EU SST activated its sensor network to monitor the object during the terminal phase of re-entry—the most challenging segment to predict. EU SST acquired trajectory data, confirmed the re-entry path, and conducted detailed analyses to provide the most accurate possible estimates of the expected re-entry location and timing. Throughout the event, the European Commission, EUROCONTROL, and the European Aviation Crisis Coordination Cell (EACCC) were kept informed of EU SST's predictions and assessments. This exercise set a precedent for future assisted re-entries and contributed to the advancement of space safety and sustainability in an increasingly congested orbital environment (refer to [3] for further details).

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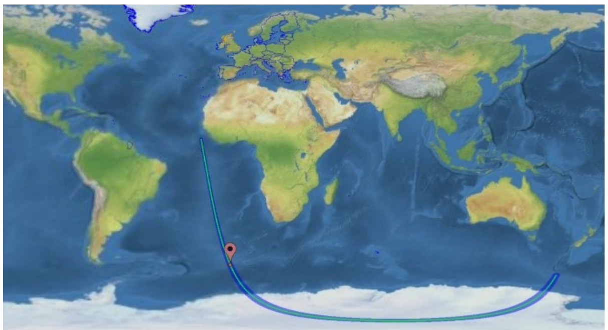

Fig. 7 – AEOLUS Reentry ground track. Credits: ©EUSST 2023

With the growth of space traffic and the resurgence of air traffic since the 2020 pandemic, the EU SST Partnership has recognized the importance of strengthening coordination with the air traffic community. This enhanced coordination aims to ensure that the information provided is tailored and ready-to-use for these users. In line with this objective, the EU SST launched a project in the third quarter of 2024, which included a consultation with European air traffic stakeholders to gather detailed information on their operational needs. The collected feedback was processed and analyzed during an online workshop held on April 8, 2025, which brought together over 60 representatives from the civil aviation sector. The results confirmed the need to further adapt the EU SST Re-entry Analysis service to better meet the requirements of aviation users. These needs include, among others:

- Dynamic reception of EU SST reports and information.
- Adaptation of risk metrics to aviation users, considering that safety risk assessment is of paramount importance for the aviation industry.
- Capability to address the impact of uncontrolled re-entries per selected Flight Information Regions (FIRs).
- Delimitation of areas along the objects' re-entry trajectories (Travelling Box) where the presence of debris would be more likely.

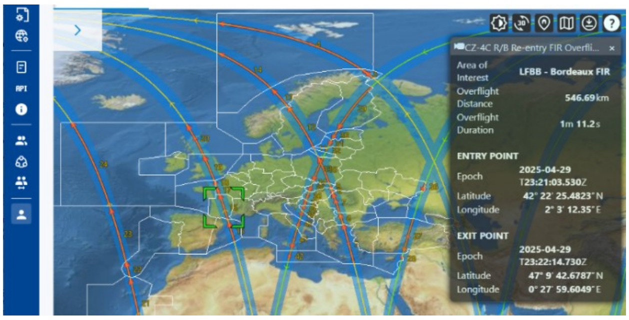

Fig. 8 – Re-entry visualization tailored to Air Traffic needs. Credits: ©EUSST 2025

5. Aircraft traffic density tracking

Aircraft traffic density tracking is a necessary input for prediction of potential impact of space traffic. In Europe these data are managed by Eurocontrol and DLR. Typical air traffic data worldwide are shown in Fig. 9. Aircraft are tracked using multiple different sources such as radar, multilateration, ADS-B and ADS-C, as well as position reports. Combining data from all these different sources is the best way to get an accurate picture of the air traffic. Obtaining aircraft positions over remote areas, such as the ocean, is often challenging. Space-based ADS-B data can fill this gap and contribute to global coverage.

Based on a historical data set of aircraft positions that combines data from various sources provided by Spire to the DLR Institute of Flight Guidance, a global air traffic density map was produced for the air traffic of 2023. The globe was divided into a 1° x 1° grid and the amount of time aircraft spent within a cell during a given time period was computed based on the historic aircraft positions. To calculate the annual air traffic density, the time that each aircraft spent within a grid cell in the year of 2023 was accumulated for all aircraft. Dividing that total time by the reference period and the cell area results in the average number of aircraft per km² at any given time. This number is comparable to the population density used for people on the ground. It provides a more accurate picture of the aircraft density within a cell than simply counting the number of aircraft flying through a cell within the same reference period. Fig. 9 illustrates the global air traffic density of 2023. The same procedure can be used to compute the air traffic density for different reference periods e.g. a month, a day, or a re-entry time window. Air traffic density can be used as an input to calculate the expected number of aircraft impacted by a hazardous fragment for a launch or re-entry event.

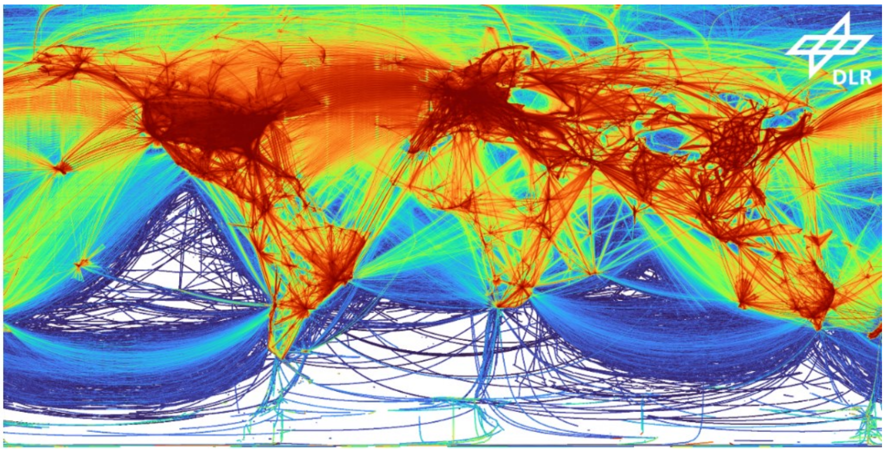

Fig. 9 – Air traffic density in 2023 (DLR)

Eurocontrol is the organism monitoring air traffic in the Europe FIR zones. An example of air traffic variation between the 1st quarter of year 2024 and 2025 is provided in Fig. 10. These data can be treated in order to provide air traffic density areas suitable for better identifying potential interaction between space and air traffic.

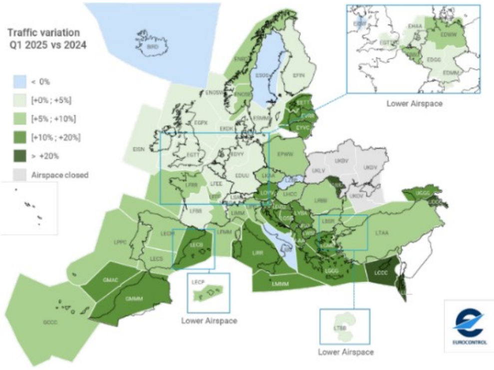

Fig. 10 – This data snapshot shows traffic variation between Q1 of 2025 and Q1 of 2024 (EUROCONTROL)

Uncontrolled re-entry of "rocket bodies" (to include any man-made matter returning into the atmosphere of Earth from Space without control) as opposed to the off-nominal events of launches or re-entries, presents risk to aviation. Air Traffic is Managed in airspace (below FL660) in Europe (Fig. 11) by EUROCONTROL Network Manager. Air Traffic Control is delivered by Member States of EUROCONTROL and Comprehensive Agreement States, also including Iceland. EUROCONTROL is closely connected to Air Traffic Management of USA, Canada, Middle East, and Near East countries operationally also [21].

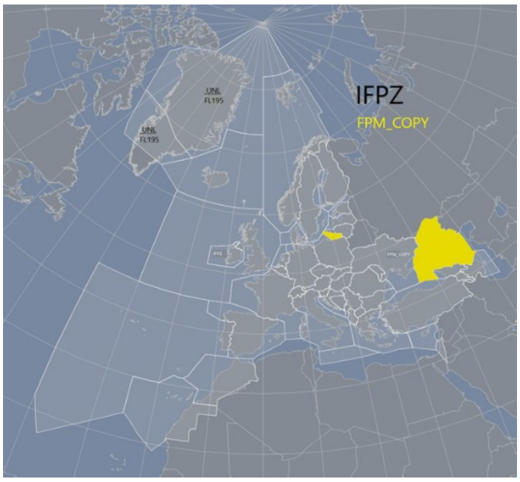

Fig. 11 – EUROCONTROL surveillance area

Risks to aviation associated with uncontrolled re-entry of "rocket bodies" can include, but are not limited to: Media Influence on Decision Making, uncoordinated approaches to risk, closure of Airspace (planned) Short Notice Closure of Airspace, and Unplanned Closure of Airspace, Impact damage to airframes, Engine(s) Ingestion, Structural failure, risk to life and lives.

It is clear that the risk overall to aviation being discharged in potential areas of re-entry is relatively low, but that it is a higher risk than operating in areas where there is no possible re-entry.

The commonly accepted casualty risk for a person on the ground (both in U.S. and Europe) is 10^{-4} per re-entry event. The Range Safety Group of the Range Commanders Council in the U.S. uses a threshold of 10^{-7} casualties per exposed flight for a launch event. This value is also taken by the ICAO SASP WG32 [2, 3]. An important difference between launch events and (uncontrolled) re-entry events is that the launches are predictable and, in general, have a much smaller risk area. Therefore, a discussion is necessary to see if launch risk thresholds should be applied to re-entry events.

From on EASA's Certification Specification 25 (Amendment27) for large aeroplanes, the probability thresholds shown in Fig. 12 can be derived.

Impact category	Event	Threshold
1	Depressurisation without injuries or minor puncture of fuel tank	10^{-3} pfh
2	Injuries or larger punctuation of fuel tank without fire (no critical fuel loss)	10^{-5} pfh
3	Limited number of severe or fatal injury or significant fuel loss	10^{-7} pfh
4	Hull loss	10^{-9} pfh

Fig. 12 – Acceptability thresholds per flight hour (pfh)

The need for efficient integration of spacecraft operations into controlled airspace has become increasingly urgent due to the growing frequency and geographical diversification of launch and re-entry activities across Europe. In response to these developments, the SESAR research project ECHO [22][23] introduced the European Concept for Higher Airspace Operations, which aims to enable the safe and efficient integration of high-altitude missions - such as orbital launches and re-entries - into existing Air Traffic Management (ATM). Building on this foundation, the follow-up project ECHO-2 [24] focuses on improving real-time situational awareness and coordination between space operators and air traffic stakeholders through the development of specialised monitoring and alerting capabilities.

At the centre of this initiative is the SpaceTracks Real-Time Mission Monitor (RMM), developed by the German Aerospace Center (DLR) [25]. The RMM, in particular its network-adapted version (N-RMM), has been tailored to the needs of the European Network Manager (NM) and is currently being evaluated for a future "Space Desk" within the Network Management Operations Centre (NMOC) at Eurocontrol in Brussels. Although still in the research phase, this system represents a pioneering prototype for real-time risk assessment and ATM response to nominal and non-nominal space events.

The RMM was developed to monitor space missions in relation to air traffic implications in real time. In the event of non-nominal behaviour, such as loss of control or structural failure, the system can dynamically assess debris trajectories and identify hazard areas. The RMM supports the automatic generation and dissemination of hazard data to the relevant air traffic control (ATC) centres to enable immediate and appropriate airspace mitigation measures such as temporary closures, coordinated evacuations and diversions.

By enabling rapid and targeted communication between space mission operators, the NM and ATC centres, the described ECHO 2 solution aims to move from conservative, wide-area and often static airspace closures to more dynamic, data-driven approaches. These would enable flexible, real-time airspace management that reduces the impact on civilian flight operations while ensuring a high level of flight safety.

While current development is focused on controlled launch and re-entry operations with cooperative information exchange on planned and actual flight path data, the system design can also be adapted to the challenges of uncontrolled re-entry operations. In particular, the ability to communicate and facilitate immediate updates to ATC enables the rapid implementation of mitigation measures and the timely reopening of previously closed airspace once the risk has passed. This capability is particularly important for managing risks posed by uncontrolled re-entries, where temporal and geographical accuracy is critical to minimising disruption.

Although SESAR ECHO-2 research and the RMM are still under development, they provide a promising conceptual and technical basis for a future operational framework. Such a framework would support both routine space operations and the mitigation of risks associated with uncontrolled re-entries, ensuring sustainable and scalable integration of space traffic into the global airspace system.

6. Impact of space debris over aircraft

A concrete example of impacts of space re-entry debris on aircraft is given by the Columbia accident well reported in the CAIB (ref) and in [26]. This sample case demonstrated the need of coordinated management between air traffic and space agencies. A number of high temperature tiles survived re-entry and widespread about the Columbia trajectory as other more consistent fragments. Following [27], the chance of an impact to general aviation was at least 1/100. However, most of the debris was small or low density to generate serious damage to aircraft.

The subject of fragmentation of orbital vehicles and the corresponding footprint on ground and on aircraft has recently become a question for FAA, the American regulator for aviation and space, which detected hot debris fall into Caribbean region for the SpaceShip missions IFT-7 and IFT-8.

Recent papers [28][29][30][31][32][33] analyze the casualty risk due to launch and re-entry activity. In particular, the cases of debris impact of re-entry vehicles such as Space Shuttle and Starship have been investigated in [34][35] in order to assess the hazard on aircraft on one side and the debris survival models on the other side. Following the recommendations by FAA, only objects having mass greater than 300 grams can cause catastrophic damage on civil aircraft. This is probably a conservative value, as shown by [35]. However, the time between a re-entry vehicle failure and when debris reaches typical aircraft altitudes is potentially long enough to mitigate the risks to aircraft. In the case of Columbia break down, 40 minutes occurred to most of the fragments to reach earth surface. In this time lapse several civil aircraft flew through the region where debris fell.

Examples already exist of either closure of air traffic due to uncontrolled re-entry objects endangering specific air traffic zones (the Chinese upper stage re-entry warning in November 2022 caused impacts on passengers and on aircraft company business) or space debris observed by aircrafts (wreckage from Russian Progress 23P cargo spotted by an Airbus A340 of LAN airlines in 2007) or suspected space debris impacting airplanes (unidentified object cracking the cockpit window of a Boeing 757-200 of a Chinese company at 9600 m in 1996 and forced to landing).

Paper [33] addresses the computation of casualty risk due to explosion of a rocket (or rocket elements) on aircraft focusing on the Atlantic area impacted by flights from the French Guyana spaceport by using Eurocontrol input data for air traffic. Two test cases are considered for computations, SSO and high inclination target orbits, providing consistent casualty risk differences.

The impact in airspace of fragments generated by the uncontrolled re-entry of human-made space objects should be addressed from two distinct perspectives. The first involves a statistical analysis aimed at calculating the probability of an aircraft being struck, using aircraft density as a key input parameter. The second concerns a real-time risk assessment, focused on identifying specific time windows during which in-flight aircraft may be at risk due to the re-entry without control of potentially hazardous space objects.

From the statistical standpoint, a possible methodological approach is described in [20], which examines uncontrolled re-entries of human-made space objects between 2019 and 2024. This study derives two simplified formulas to estimate the number of fragments capable of destroying an aircraft, specifically those with a mass greater than 300 g. To assess the impact expectancy on commercial aircraft per debris object during the 2019-2024 period, reference was made to values calculated in 2021 in [36]. These values were then adjusted using a correction factor to account for variations in commercial flight traffic over the years considered. Ultimately, the impact expectancy per re-entry event was obtained by multiplying the impact expectancy per debris object by the number of hazardous fragments generated during that event.

The second perspective addresses the identification of real-time risk windows during the uncontrolled re-entry of potentially hazardous space objects. Given that re-entry predictions are typically affected by large uncertainties that cannot be reduced below a certain threshold, the main challenge is to identify, with sufficient advance notice, the time windows during which specific geographic regions may be exposed to risk. Several studies by Pardini & Anselmo [30][31][32][33] describe methodologies for calculating these risk time windows.

7. Inputs for advanced warning system for ATC

Even if the risk to aircraft induced by satellite re-entries is extremely low, it could be mostly avoided. For helping future re-entry campaigns (assisted or natural or even controlled[5]), Airbus Defence and Space investigated how satellite operators or agencies might package the re-entry prediction data in a simple and compact format that could help air traffic management, airlines and airports for designing an advanced warning system and assessing the associated disruptions and costs.

Indeed, even though there are large uncertainties on the *location* and *timing* of the re-entry when considered separately, the re-entry *time* associated to each potential re-entry *location* is actually known in advance with surprising accuracy (less than 2 minutes when the prediction is 1 day before re-entry). This timing uncertainty corresponds to the cumulative uncertainty on semi-major axis and thus orbital period over the prediction horizon, Fig. 13.

[5] To cover contingencies.

Prediction time (before re-entry)	Orbit altitude (at time of prediction)	Uncertainty range (for time of re-entry)	Timing uncertainty (for a given location)
48 hrs	230 km	+/-14 hrs	**+/- 3.5 min**
24 hrs	210 km	+/- 7 hrs	**+/- 1.5 min**
12 hrs	190 km	+/- 3.5 hrs	**+/- 45 s**
6 hrs	175 km	+/- 1.6 hrs	**+/- 30 s**

Fig. 13 – Typical uncertainties for an uncontrolled re-entry (B = 42 kg/m² +/- 30%)

This clockwork regularity of the orbital motion, regardless of the large aerodynamic and atmospheric uncertainty (which essentially only extends the time slot when re-entry might happen), could help defining in advance a travelling "protection box" outside of which no hazardous debris would ever be found. Excluding traffic from this box would guarantee against any risk to aircraft.

The analysis looked at how big that protection box would have to be, to provide decision-makers and regulatory bodies with meaningful data for assessing how much disruption such a scheme might cause.

A 'breakup track' has been defined, which is a pseudo-trajectory built from the succession of potential re-entry locations and re-entry times within the uncertainty range. Since the re-entry can occur anywhere in the uncertainty range, we have to protect against all possible events. Such a superimposition of all possible breakup events can then be imagined as a ghost satellite constantly dropping ghost debris from 80 km altitude as it flies along the breakup track at 7.5 km/s, Fig. 14.

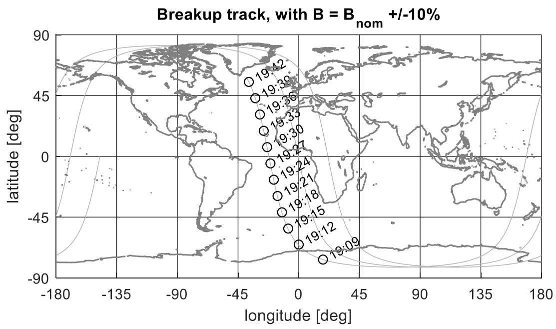

Fig. 14 –An example of a breakup track, with time stamps for all the potential re-entry locations

By simulating the descent path of all types of debris falling from the breakup track, with ballistic coefficients of the surviving fragment ranging from 10 kg/m² (a thin aluminium plate) to 1000 kg/m² (a 4-kg solid steel ball), we can determine the *envelope of all possible hazardous debris*.

This envelope looks large (9000 km long at ground level) but considering how fast it is travelling, no location on the ground is affected for more than 19 minutes. At cruising altitude, the along-track extent is half as much, and the dwell time is thus only 9 minutes, Fig. 15, Fig. 16.

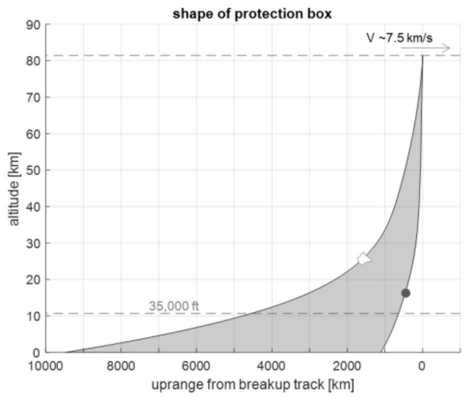

Fig. 15 – Envelope of all possible hazardous debris – spatial extent. This envelope travels at ~7.5 km/s, following the breakup track. Ahead of the envelope, there can be no debris yet. Behind the envelope, even the lightest hazardous debris have already fallen to lower altitudes (or hit the ground).

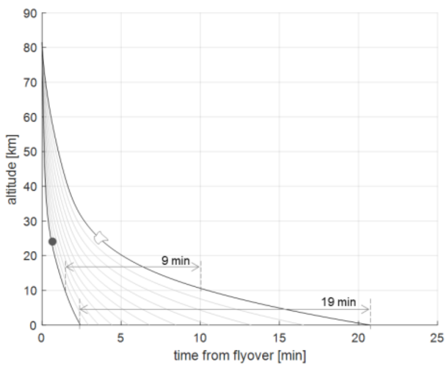

Fig. 16 – Envelope of all possible hazardous debris – time extent. At 10 km altitude, there are only 9 minutes between the first and last fragments that might be of concern. At ground level, this 'dwell time' is still less than 20 minutes.

In terms of across-track extent, the breakup footprint for a re-entry is typically considered to cover +/- 50 km either side of the ground track.

Therefore, an aircraft in cruise should simply avoid finding itself within a 100-km wide corridor, from the time the predicted breakup track flies over the intended flight path, until ~10 minutes later. And since the timing would be known at least 24 hours in advance, this 10-minutes restriction window could be taken into account before take-off.

For an uncontrolled re-entry with portions of the breakup track flying over continents and over airports in particular, the airspace would have to be closed for 20 minutes at each of those airports in succession.

It has to be noted that these are merely technical inputs for decisions that are completely outside the perimeter of Airbus Defence and Space and are by no means an official recommendation.

Note also that the cut-off value of 10 kg/m² for the lightest fragment of concern is mostly arbitrary at this stage. It is extrapolated -allegedly with ample margin- from typical values of 20-30 kg/m² observed as the ballistic coefficient of the lightest fragments of concern for human casualty risk (from DRAMA software runs). As it directly determines[6] the dwell-time of the protection box, it absolutely needs to be consolidated by further R&D effort, examining actual vulnerability of the airliner fleet.

8. Legal framework and guidelines

The areas of application of air, space, and telecommunication laws depend on which authorities are responsible and what are the existing laws and best practices to prevent risks related to space traffic that threaten airspace or land. These specialized laws may have different objectives, particularly with respect to liability for damage. They may also prove to be insufficient to address all the requirements related to civil protection, the safety of property and persons, or the protection of the environment in the areas concerned. Consolidation should be sought at the level of States through their jurisdiction and primary responsibilities to ensure the safety and well-being of their populations and the preservation of the environment on their territory, by all possible legal means, i.e. law, regulation, or concession or public procurement to private sector, customary international law or intergovernmental treaties.

International air, space and telecommunications laws are different. The first was established after the Second World War in 1944 with the Chicago Convention creating the International Civil Aviation Organization (ICAO) to support the development of global air transportation. This convention applies to civil transportation that uses well-defined international corridors between two areas under national jurisdiction. Each government remains sovereign over its territory and airspace. On a practical level, aviation law as established by the ICAO's SARPs (Standards and Recommended Practices) applies primarily to vehicles that are maneuverable and piloted under the responsibility of humans on board (except for drones) and that are involved in the transport of people or goods between two points on Earth. These vehicles use a reserved portion of the international radio frequency spectrum (through ITU's rules[7]) for their service, anti-collision, navigation, and on-board services. Liability in the event of an accident is primarily borne by the carrier concerned, which is basically a private airline, whether on board towards passengers, on the basis of the contract of carriage, towards crew members as an accident related to their employment contract, or towards third-party victims on the ground or in the airspace, under civil liability for damage. This liability may be extended to the manufacturer if the defect in question is attributable to a design or manufacturing fault in the vehicle. The liability of the public authorities can only be invoked in the event of gross negligence in the performance of their duties of authorization and control within their jurisdiction.

[6] Halving the value essentially doubles the dwell time.
[7] International Telecommunication Union, an independent UN space law organization created in 1865.

Space law was first developed at the intergovernmental level, in the context of the Cold War and the race to the Moon, in the service of peaceful competition between major powers seeking primarily to demonstrate their scientific and technological leadership to the rest of the world. This competition does not exclude intergovernmental cooperation, which becomes necessary in order to share information essential to security. This law concerns space objects which are subject to registration under the 1975 United Nations convention. This registration has the effect of assigning jurisdiction and responsibility for the space object to the State that registered it. The maneuverability of spacecraft remains limited and costly, whether in propelled, ballistic, or orbital phases.

Among the major differences in treatment compared to aviation law, it should be noted that all operations on a space object, whether public or private, remain under the international responsibility of the State of jurisdiction or launch. The States concerned must therefore give prior authorization (license) and control the activities of the national companies[8]. As the Launching State, they are jointly and severally liable for any damage caused to third parties[9]. Under domestic law, States may transfer on all or part of the corresponding compensation to the private operator responsible or guarantee coverage in the event of legal action by third-party victims.

Another specific feature of space law is the prohibition on States appropriating or placing under their jurisdiction any part of outer space or extraterrestrial territory. National jurisdiction can only be exercised over the vehicle or space station via their registration, and of course over the crew, passengers or inhabitants on board. This solution is derived from that of the flag for a ship, which has been applied for several centuries in maritime law. The other criterion for jurisdiction is based on the nationality of the national engaged in this activity on Earth or in space. Under these conditions, the criterion based on the altitude of the vehicle at a given moment around the Karman limit is of little legal interest for space-related liability in the event of damage. Space liability may indeed be invoked for an accident caused during the ascent phase of the launch vehicle, before reaching outer space, by victims located on foreign territory nearby, on the ground or in airspace.

Convergence of law in the service of the safety of persons and property and the protection of terrestrial and extra-terrestrial environments is currently taking place in the evolution of national legislation on space activities which, beyond traditional international space law originating from UNOOSA-COPUOS for operations and vehicles, now more explicitly take into account the requirements of ICAO, ITU or other bodies of law more generally concerning safety, the environment and the economy.

It would be futile in such an article to provide an overview of the progress of these national laws around the world, as most are still in the process of being developed or have not yet been consolidated. However, they can be classified into three main categories on a Space-Earth scale, starting with (a) regulation applicable to space operations and vehicles; (b) regulation governing launch facilities and their tracking and control networks. The latter (b), which fall entirely within national territorial jurisdiction, must necessarily incorporate cross-cutting regulations and standards relating to the safety and protection of persons, property and the environment. Finally, all of the above (c) must be consolidated across sectors (space, aviation, telecommunications, and downstream services) at the national, regional, and intergovernmental levels to preserve free and fair access for operators to competitive markets, frequencies, digital applications, and other derivative services on Earth that are also subject to government authorization.

a)Regulation applicable to space operations and vehicles

A number of Countries developed legislation to frame space activities and prevent associated risks following the international treaties and agreements. This process started in the Sixties and is still continuing. As an example, the French Space Operations Act of June 2008, supplemented by decrees, orders and a Technical Regulation (TR), establishes the legal framework for space activities in France. The French Space Operations Act (FSOA) sets up an authorization and continuous supervision process of the space activities of the French operators. This is in accordance with the international treaties, in particular the treaty of January 27th, 1967 on the principles governing the activities of States regarding exploration and use of outer space, the convention of March 29th, 1972 on national liability for damage caused by space objects. This process allows mastering the liability of France for the space activities for which it is responsible in accordance with the aforementioned international treaties.

The French Space Operations Act leads to authorize and supervise all the space operations performed by French operators operating anywhere in the world or others operators operating on the French territory (e.g. for launches from French Guiana). It takes into account the long-term development of space activities. In particular, the Technical Regulation (RT) was developed with due consideration paid to the Space Debris Mitigation Guidelines (adopted by the COPUOS and endorsed by the UNGA), the recommended practices and voluntary guidelines proposed by the Inter-Agency Space Debris Coordination Committee (IADC) and the Committee on Space Research (COSPAR) as well as the existing international technical standards, including those published by the International Organization for Standardization (ISO) and the Consultative Committee for Space Data Systems (CCSDS), generally accepted by the international space community for the safe conduct of outer space activities [4].

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[8] Article VI of the 1967 United Nations Outer Space Treaty.

[9] Pursuant to Article VII of the aforementioned 1967 Treaty and the 1972 Convention on Liability. The launching State is the State which carries out or procures a space launch or which owns or controls its base.

In France, the authorization to perform a space operation (launch or in orbit control) is given by the ministry in charge of Space only after evaluation of compliance with the Technical Regulation. The detailed analysis of compliance with the Technical Regulation is performed by CNES on behalf of the ministry. This Technical Regulation comprises requirements ensuring that any space operation:

- limits the number of fragments and performs end of life operations respecting the protected regions,
- limits ground risks to populations and properties during the launch and re-entry of space objects,
- limits risks to public health and the environment associated with the launch operations, the elements coming back to Earth or the effects induced by launch failure,
- is compliant with applicable nuclear safety prescriptions via a specific plan, in case of use of radioactive materials.

The Space Act provides that every operator has to carry out, for any space operation, an impact assessment on the environment and a hazard study with a plan to manage risks and ensure safety of populations, properties, public health and the environment. The authorization process and the assessment of compliance with the technical regulations provides assurance that the operators have the means, resources, necessary skills and are appropriately organized to perform the operation in compliance with the Space Act. It also allows competent authorities to verify that compliance is maintained throughout operational life of the space object until disposal, through the processing of the technical and organizational events. In summary, the French Space Operations Act establishes a legal basis protecting the activity of space operators while maintaining the high level of safety requirements essential, due to the unique nature of space activities. For those launch operators wishing to use the Kourou European Spaceport, the Kourou Safety Rules (REI) is the main order to express ground and Flight Safety rules.

The TR has been updated in 2024 in order to include the important stakes for the future of the French and European space sector, implying actors of the NewSpace, new kinds of services and innovative missions. The new topics include, among other subjects,

- Improved requirements to mitigate further the debris generation with provisions to deal with Space Traffic Management,
- Re-entry of space vehicles or launcher recoverable stages,
- Autonomous flight safety systems (AFSS)
- Airborne launchers.

The sub-orbital activities and transit through airspace are included, at least partially, in the above subjects.

b) Regulation governing launch facilities, tracking and control networks

The launching State potentially responsible for damage caused to a third party on Earth or in outer space may be, in addition to the State which launches the space object (and is already covered by the above regulations), the State whose territory or facilities are used for the launch[10]. If we exclude launch facilities from space[11], a launch base may be on land, which is currently the most common situation, on a platform at sea (see Sea-Launch) or on an aircraft (see the Pegasus system in the US) or suborbital aircraft. In the latter three cases, the Launching State will be the one with territorial jurisdiction over the land base, or maritime jurisdiction in its EEZ (exclusive economic zone), or the State that registers the maritime platform or aircraft used for the launch. Given its international responsibility, the "launch base State" has every interest in adopting appropriate national regulations to authorize and control all public and private activities carried out from its facilities. The authority responsible for the base must therefore, not only have the necessary authority to ensure the safety and security of the launcher on the ground and in flight, but also to coordinate the safety of the industrial activities taking place there. In this capacity, it ensures compliance with all relevant legislation on civil protection and the environment, in particular the Seveso Directive on high-risk installations in Europe. It is therefore the main point of contact for the relevant external authorities, in particular the aviation authorities (NOTAM), the armed forces and civil protection services. As a result, responsibility for the base must be entrusted to a body that is fully competent and recognized by the national jurisdiction. For the European launch base in Kourou, located in French Guiana under French jurisdiction, this competence has been recognized by CNES since 1975 through a dedicated intergovernmental agreement with ESA and formalized in domestic law by the aforementioned law of June 3, 2008 on space operations. This law confers on the president of CNES administrative police authority (i.e., "preventive" police authority) within the base. These regulations were adopted in 2009 under the name "Regulations for the Operation of Facilities" (REI) of the Guiana Space Center (CSG).

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[10] See Article 1 of the aforementioned 1972 Convention.

[11] Example: a mini satellite launched from another satellite vehicle. In this situation, the *Launching State* responsible for the damage will by default be the one that registered the vehicle in orbit.

c) Intersectoral consolidation at the national, regional and international levels

This consolidation is necessary to ensure global security between the various sectoral authorities at the national[12], regional (especially in Europe[13]) and international[14] levels. It incorporates other cross-cutting considerations related to the economy and fair competition between the private actors involved or, with regard to individuals, fundamental legal and ethical issues. This consolidation must also be guided by the UN's key principles on space, such as responsibility, peaceful cooperation and the interests of future generations. It should be remembered that the operational responsibility for preventing risks upstream and, where necessary, punishing those responsible for infringements or damage can only lie with the government authorities having full jurisdiction over their territory, the populations and businesses concerned. In the frame of the European Commission a first issue of the EU Space Act has been recently made available. One of its goals consists in harmonizing European national regulations to avoid distortions of competition for all companies operating in the EU while maintaining a high standard of safety for people and systems and protection of the environment.

9. Conclusion and recommendations

The purpose of the working group on "Context and perspective of sub-orbital activities and transit through airspace/future operations / ground support activity" is mainly to provide an overall view of the state of the art concerning the technical and legal aspects, track the recommendations and current available guidelines at national and international level.

The main observation is that a global legal framework does not exist, but guidelines are provided by different organizations (such as UN-COPUOS, IADC and Montreal Declaration). In addition, national space laws allow to define some rules which depend on the Countries. These are not homogeneous. The consequence is that the launch state is actually stating the regulation on the basis of its specific safety/security constraints and the context of its space activity development. Prediction tools help forecasting potential risk of collision due to transit through airspace and constitute an input for decision makers. This aspect has been developed in this paper by showing some methods.

The group has identified some domains to be further investigated and which could be the subject of recommendations and further investigations:

- Setup a certification requiring guarantees on the mastering of a full space mission, from launch up to re-entry.
- Provide evidence of improved mastering of the spacecraft missions in terms of re-entry precision and/or complete demise of the object.
- To develop a standard re-entry debris risk estimation methods taking into account the risks to population on ground, civil aircraft traffic and maritime traffic.
- Setup an international agreement on the fallout area, namely in the South Pacific Ocean(ic) Uninhabited Area (SPOUA).
- Provide rules of the road for interaction between space traffic management and air traffic management and setup a coordination between spacecraft and aircraft traffic management.
- Provide standardized warning from space regulators, clearly understandable by aircraft traffic management organisms.
- Improve liability rules in case of damage or fatal accidents.

It is clear that the future space will be busier. Spaceports, spacecraft and aircraft traffic will be increasing with a number of different missions (orbital, suborbital, point to point…). More operators, both the historical institutional and private ones, will be increasing and the sustainability of outer space activities will be a matter of all. In this context regulation is essential to guarantee the continuity of these activities in the respect of a common precious environment. Recommendations of the working group can provide a first step to state shared frame of regulation and technical guidelines.

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[12] In France, the CNES and the ministry responsible for space operations, the DGAC (civil), the DSAE (defense and institutional) for air traffic, the ANFR for frequencies, the ARCEP for telecommunications, the ARCOM for television broadcasting, the SGDSN for interministerial coordination of national defense, etc. In the United States, the FAA for aviation and space, the FCC for telecommunications, the NOAA for observation and weather satellites, the Department of State for registration and export licenses, the Department of Defense (DOD) for defense, and NASA for its own programs and launches, etc.

[13] The European Space Agency for its programs, the European Union for its own programs through its agency EUSPA or through its own legislative competence or shared with Member States.

[14] The UN, OOSA, ITU, WTO, OECD, etc.

Acknowledgements

This work is part of the activity done in the frame of the working group on space traffic management implying different organizations (agencies, industries, internationals organizations – IAF International Academy of Astronautics, IAA International Academy of Astronautics, IISL International Institute of Space Law) and people having different background and experience.

References

[1] P. Baiocco, B. Chemoul, S. Martinez, S. Moore, F. Payot, K. Lagadec, F. Santoro, C. Gregori, P. Marzioli, *Context and perspectives of sub-orbital activities and transit through airspace/ground support activities*, Acta Astronautica 225 (2024) 285–294
[2] C. Pardini, L. Anselmo, *The risk of casualties from the uncontrolled re-entry of spacecraft and orbital stages*, Journal of Space Safety Engineering 11 (2024) pp. 181-191.
[3] Hans de Haan, *Re-entry Risk Discussion*, Eurocontrol editor
[4] B. Chemoul, P. Baiocco, B. Feïn Doumenc, J.-P. Etienne, Ph. Clerc, *Risk Management at CNES*, IAC-22-E6.4.10
[5] ESA Space Debris Office editor, *ESA's annual space environment report*, 12 September 2023
[6] EU Space Surveillance and Tracking Service Portfolio. Second edition. 2021. https://portal.eusst.eu/portalng/public-download/ServicePortfolio
[7] EU SST News Room. *EU SST supports ESA on the re-entry of Aeolus*. https://www.eusst.eu/newsroom/eu-sst-supports-esa-reentry-aeolus/
[8] OSI Editor, *Montreal Recommendations on Aviation Safety and Uncontrolled Space Object Reentries*, 2023.
[9] Th Cheney, L. Napier, *Policy analysis: air versus space, where do suborbital flights fit into international regulation*, J. Sci. Pol. Govern., JSPG 7 (1) (August 2015).
[10] Tanja Masson-Zwaan, Rafael Moro-Aguilar, *Regulating private human suborbital flight at the international and European level: Tendencies and suggestions*, Acta Astronautica, 92(2013) pp. 243–254.
[11] A.Y. Julie, *In Need of a European Regulation for Private Human Spaceflight*, ESPI, Vienna, Austria, 2008.
[12] UNOOSA, *Guidelines for the Long-Term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space*, 2021. Vienna.
[13] UN-COPUOS editor, *Suborbital flights and the delimitation of air space vis-à-vis outer space: functionalism, spatialism and state sovereignty*, 29 March 2018, A/AC.105/C.2/2018/CRP.9
[14] Guest Editorial, *Letter to space agency leaders on reducing risks from uncontrolled reentries of rocket bodies and other space objects*, J. Space Safe. Eng. 10 (2023) 1–6.
[15] UK pathfinder launch from spaceport Cornwall, *Lessons Learned Report*, December 2023.
[16] https://cityroma.com/all-of-the-worlds-spaceports-on-one-map/.
[17] https://payloadspace.com/2024-orbital-launch-attempts-by-country/
[18] ESA Space Debris Office editor, *ESA's annual space environment report*, 31 March 2025
[19] Pardini C., Anselmo L., *Orbital re-entries of human-made space objects: drawbacks for the atmosphere and safety of people*, 13th IAASS Conference 2024, Prague, Czech Republic – 8-10, pp. 2-11, October 2024
[20] Pardini C., Anselmo L., *Casualty risk assessment of uncontrolled reentries after the deployment of the first large satellite constellations*. In: *Proc. 9th European Conference on Space Debris*, Bonn, Germany, 1–4 April 2025, published by the ESA Space Debris Office, Editors: S. Lemmens, T. Flohrer & F. Schmitz, (http://conference.sdo.esoc.esa.int, April 2025).
[21] Eurocontrol Editor, *European Higher Airspace Operations – Concept of Operations*, Draft Version 05.
[22] ECHO project consortium, *ECHO Project - European Concept of Higher Airspace Operations*, https://higherairspace.eu/echo-project/.
[23] EUROCONTROL, DLR, Dassault, ENAC, ENAV, Airbus, Thales, CIRA, and DSNA, *European Higher Airspace Operations (HAO) - Concept of Operations*, 2022. URL: https://www.sesarju.eu/sites/default/files/documents/reports/D4.3_ConOps_1.0_public.pdf
[24] SESAR Joint Undertaking, *ECHO 2 Project*, 2023. URL: https://higherairspace.eu/echo2-project/
[25] Kaltenhaeuser,S., Hampe, J., Rabus, T., Morlang, F., Losensky, L., *Towards Efficient Integration of Rocket Launches and Re-entry Operations in European Airspace: Development and Testing of a Launch Coordination Center*, 75th International Astronautical Congress (IAC), Milan, Italy, 2024
[26] Daniel P. Murray and Megan Mitchell, *Lessons Learned in Operational Space and Air Traffic Management*, AIAA 2010-1349, 4 - 7 January 2010, Orlando, Florida
[27] Nick N., Buchaillot L., *Probabilistic risk assessment: hazard impact study of safety-critical space launch events onto world air traffic & creation of ADIONA*, Journal of Space Safety Engineering 11 (2024) 230-242
[28] Kwon J-J, Hong J-E, Chung L., *Collision detection and resolution of hazard prevention actions in safety critical systems,* Journal of Systems and Software, Volume 118, August 2016, Pages 1-18

[29] Anselmo L. and Pardini C., *Satellite re-entry predictions for the Italian civil protection authorities, Acta Astronautica*, ISSN: 0094-5765, Vol. 87, pp. 163-181, 2013, DOI: 10.1016/j.actaastro.2013.02.004.

[30] Pardini C. and Anselmo L., *Satellite re-entry prediction products for civil protection applications*, Session 17: "Re-entry safety", Proceedings of the 7th IAASS International Space Safety Conference "Space Safety is No Accident", Friedrichshafen, Germany, 20-22 October 2014, DVD, ISBN 978-3-319-15981-2, T. Sgobba & I. Rongier (Eds.), Springer 2015.

[31] Pardini C. and Anselmo L., *The uncontrolled re-entry of progress-M 27 M*, Journal of Space Safety Engineering, ISSN: 2468-8967, Vol. 3, No. 3, pp. 117-125, December 2016.

[32] Pardini C. and Anselmo L., *Re-entry predictions of potentially dangerous uncontrolled satellites: challenges and civil protection applications*, in Stardust Final Conference: Advances in Asteroids and Space Debris, Edited by: M. Vasile, E. Minisci, L. Summerer, P. McGinty, Springer International Publishing AG 2018, Astrophysics and Space Science Proceedings, ISBN: 978-3-319-69955-4, DOI:10.1007/978-3-319-69956-1, pp. 265-282, 2018.

[33] Pardini C., Anselmo L., *Overview of some basic requirements for a re-entry prediction service for civil protection applications*, Proc. 1st NEO and Debris Detection Conference – Exploiting Synergies, Darmstadt, Germany, 22-24 January 2019, published by the ESA Space Safety Programme Office, Ed. T. Flohrer, R. Jehn, F. Schmitz (http://neo-sst-conference.sdo.esoc.esa.int, January 2019).

[34] Buchaillot L., Garcia A., Richard JG, *Improvements of embedded operational solutions for studying launch and re-entry impacts on air traffic*, 13th IAASS Conference 2024, Prague, Czech Republic – 8-10, pp. 12-24, October 2024

[35] Paul D. Wilde Ph.D., P.E., *Risks to aircraft from the mishap during the second starship integrated flight test (IFT-2)*, 13th IAASS Conference 2024, Prague, Czech Republic – 8-10, pp. 12-24, pp. 116-129, October 2024

[36] Federal Aviation Administration (2023), *Report to Congress: Risk Associated with Reentry Disposal of Satellites from Proposed Large Constellations in Low Earth Orbit*, Department of Transportation, Washington (DC)