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Towards Efficient Integration of Rocket Launches and Re-entry Operations in European Airspace: Development and Testing of a Launch Coordination Center

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Abstract

In Europe, the integration of rocket launches and re-entry operations into the air traffic management framework poses unique challenges. This paper presents the development and testing of an operational concept and accompanying software tools aimed at facilitating the coordination and monitoring of such activities. Initiated by the German Aerospace Center (DLR) through the Spacetracks project, the Launch Coordination Center has been developed to coordinate planning and execution between space companies, air traffic control facilities and additional stakeholders. The paper elucidates the current status of development efforts, focusing on the adaptation and preparation of software solutions for upcoming launch events. Through planned and implemented testing setups, the paper showcases the potential and experience gained thus far, underscoring the system's efficacy in complex operational environments. Furthermore, it outlines future plans to leverage these insights for European air traffic network management applications. This work not only addresses immediate operational needs but also lays the foundation for efficient integration within the broader airspace management framework, offering insights into further development avenues and opportunities for seamless operational integration.

Keywords: Launch Control Center (LCC), Microservices Architecture, Real-time Mission Monitoring (RMM), Commercial Space Transportation, Higher Airspace Operations (HAO), Integrated Air and Space Traffic Management

1. Introduction

This chapter begins by providing a concise overview of the key challenges involved in integrating rocket launches and re-entry operations into European airspace. It highlights the complexities of balancing space activities with the safety and efficiency of European aviation. Following this, the chapter introduces the SpaceTracks project, outlining its role in addressing these challenges and its potential impact on future aerospace management systems.

1.1. Overview of the Challenges in Integrating Rocket Launches and Re-Entry Operations into European Airspace

The increasing frequency of space operations, including rocket launches and re-entry missions, has introduced new complexities to the management of European airspace. Traditionally dominated by civil aviation, European airspace has been carefully structured to support the safe and efficient movement of aircraft across national borders. However, with the growing involvement of both private and public entities in the space sector, this established framework is now facing significant challenges.

Rocket launches and re-entry operations follow different trajectories and velocities compared to conventional aircraft. They traverse multiple layers of the atmosphere at rapid speeds, which can create conflicts with commercial flight paths. Especially as space operations can involve dynamic risks such as falling debris from re-entry and unpredictable mission events like delays or emergencies. These factors, combined with the limited historical experience of managing space activities within European airspace, underscore the need for better integration.

The current air traffic management (ATM) system was not designed to accommodate spaceflight operations, leading to potential bottlenecks in coordinating between space missions and commercial air travel [1]. Consequently, European airspace faces risks of airspace closures or restrictions that disrupt civilian aviation, increase fuel costs, and create delays [2][3]. Moreover, these disruptions may intensify as more private space companies emerge, each requiring specialized attention from air traffic control (ATC) [1]. This surge in aerospace activities has made it imperative to develop new operational procedures that can support both industries without compromising safety and efficiency.

As space operations become more frequent and complex, the need for coordinated efforts between various stakeholders is evident. These stakeholders include space companies launching rockets, re-entering spacecraft, national and regional air traffic control (ATC) authorities, civil aviation operators, and government regulators. Developing a clear and robust operational concept is critical for ensuring seamless communication and cooperation among these parties.

Without coordination, space missions could cause significant disruptions to air traffic, requiring entire sections of airspace to be closed for extended periods [1]. This is not only inefficient but also economically damaging. Air traffic controllers and airlines must have real-time, transparent information about the timings and trajectories of space operations to mitigate unnecessary delays and reroutes.

An operational concept that outlines clear roles, responsibilities, and communication channels will ensure that space activities can coexist efficiently with regular aviation. This concept should integrate advanced technologies such as real-time trajectory monitoring, predictive modelling for re-entry debris, and automation tools that enable faster decision-making. Additionally, the operational framework should allow for flexibility, considering the often-unpredictable nature of rocket launches due to weather conditions or technical issues.

Coordination is also essential for safety. Space operations pose unique risks, such as falling debris or malfunctioning spacecraft. ATC and other stakeholders must be able to swiftly respond to contingencies to minimize the impact on air traffic and ensure the safety of people on the ground and in the air [4]. Developing a unified operational concept is therefore critical not only for maintaining the efficiency of air travel but also for ensuring public safety.

1.2. The SpaceTracks Project Initiated by DLR

In response to those challenges, the German Aerospace Center (DLR) launched the SpaceTracks project [6][7]. This initiative aims to address the challenges posed by these operations while ensuring minimal disruption to air traffic, maritime activities, and overall transportation networks. Central to this effort is the development of a Launch Coordination Center (LCC), intended to help manage and optimize the integration of space activities with air and sea traffic systems.

The LCC [6][7] is designed to serve as a hub for coordinating launch and re-entry activities across multiple spaceports, providing services that facilitate the efficient and safe integration of space operations into existing transport systems. A key focus of the LCC is enhancing the exchange of real-time information between all stakeholders involved, including launch operators, spaceports, air traffic control (ATC), and maritime authorities. This coordinated exchange of data is essential for synchronizing space missions with civil aviation, ensuring that airspace closures or restrictions are minimized, and allowing for more precise planning and execution of launches and re-entries.

The LCC's objectives are twofold: to optimize the planning and execution of space missions and to ensure rapid and effective responses to both routine and disruptive events. In the planning phase, the LCC will streamline the reconciliation of space mission requirements with air traffic operations, incorporating data from both aviation and maritime sectors to create an integrated picture of the transport system as a whole. In the execution phase, the LCC will provide real-time networking capabilities, as a key enabler for stakeholders to respond quickly to non-nominal events such as trajectory deviations or unexpected hazards.

To achieve these goals, a suite of software tools and interfaces has been built that support real-time data exchange. This will allow for the automated and standardized distribution of critical information, such as calculated Hazard Areas (HAs), to the relevant stakeholders. By integrating data from space, air, and maritime domains, the LCC can enable precise monitoring and coordination throughout all phases of a launch or re-entry mission, ensuring that both space and air traffic are managed efficiently and safely.

The LCC has been built upon DLR's experience from recent research projects focused on integrating aircraft and spacecraft operations, e.g. the Data Exchange Project (DEP) in collaboration with FAA AST, that explored mechanisms and technologies for real time data exchange during rocket launches for cross-border type of operations [5]. Drawing on this knowledge, the SpaceTracks project intends to contribute to the development of future operational concepts that minimize the impact of increased space activity on air traffic. As space launches become more frequent, the LCC concept can play a central, managing, and coordinating role in aerospace operations, ultimately laying the groundwork for future advancements in air and space traffic integration.

2. Methodology for Development and Testing of the LCC

This chapter delves into the development of the operational concept, focusing on the creation of software tools and the supporting infrastructure necessary for effective implementation. It further outlines the testing and evaluation processes for the Launch Control Center (LCC) and its software solutions, providing insights into how these systems are refined and validated for real-world applications.

2.1. Operational Concept Development

At the heart of the Launch Coordination Center’s (LCC) operational concept is its role as a central, coordinating interface that supports the seamless integration of spacecraft into the broader transport ecosystem. The LCC acts as a hub, where data from various stakeholders—including space operators, air traffic control (ATC), maritime authorities, and external sources like weather data—are collected, processed, and disseminated back to the relevant actors.

This real-time coordination is essential for ensuring safe and efficient operations throughout all phases of a launch or re-entry mission, from preparation through execution to post-mission analysis. During preparation, the LCC analyzes the potential impacts of space operations on air traffic, while also enabling enhanced communication between stakeholders. During execution, spacecraft trajectory data is continually monitored, and real-time information is shared to allow for rapid responses to non-nominal events and adaptive airspace management. After the mission, the LCC serves as the central contact point for post-operational processes, ensuring efficient and streamlined communication.

By automating and integrating data flows throughout these phases, the LCC ensures that coordination between space, aviation, and maritime operations is smoother, more efficient, and less prone to errors compared to current operational methods. The detailed design of the operational concept is described in [7], below it is summarized to provide an overview of the key elements:

Operational Concept of the Launch Coordination Center (LCC): Planning Phase

In the planning phase, the Launch Coordination Center (LCC) plays a critical role in coordinating between space operators and stakeholders from aviation and maritime sectors to ensure safe and efficient operations. The core elements of the planning phase are as follows:

- Stakeholder Coordination: The Launch/Re-entry Operator (LRO) conducts detailed mission planning in coordination with the Launch/Re-entry Site Operator (LRSO), while aviation and maritime sectors carry out their own operational planning. The LCC continuously reviews and shares the planning status to improve situational awareness among all stakeholders.
- Hazard Area (HA) Determination: The LCC analyzes data from the LRO, Air Navigation Service Providers (ANSPs), and the Network Manager (NM) to determine potential Hazard Areas (HAs) for both nominal and non-nominal scenarios. This analysis identifies affected airspace regions and sectors to mitigate the impact on air traffic.
- Impact Minimization: The LCC optimizes airspace restrictions by analyzing the size, location, and duration of restricted areas to minimize disruption to scheduled air traffic. It also considers maritime traffic, especially for sea launches, to avoid conflicts with maritime infrastructure.
- Iterative Refinement: The LCC compares its findings with LRO data and refines plans through an iterative process, aiming for high automation and standardization to satisfy all parties involved.
- Information Dissemination: The LCC generates and distributes notices (e.g., NOTAM, AIXM-compliant messages) to relevant aviation and maritime authorities, enabling seamless integration with existing data distribution systems, like the System Wide Information Management (SWIM).

These processes ensure that the planning phase is thoroughly optimized to balance the needs of space missions with the requirements for safe and efficient aerospace and maritime operations.

Operational Concept of the Launch Coordination Center (LCC): Execution Phase

In the execution phase, the LCC ensures real-time coordination and situational awareness for all stakeholders involved in a space launch or re-entry operation. Key elements of the execution phase include:

- Synchronization with Air Traffic Flow and Capacity Management (ATFCM): Starting up to 24 hours before the launch/re-entry, the LCC integrates real-time data exchanges with all stakeholders, including the Launch/Re-entry Operator (LRO), Launch/Re-entry Site Operator (LRSO), Air Navigation Service Providers (ANSPs), the Network Manager (NM), and other relevant authorities.
- Monitoring and Evaluation of Air and Sea Traffic: Prior to the operation, the LCC monitors air and maritime traffic, evaluating the impact of the upcoming space operation. The processed data is shared with stakeholders via a web-based dashboard to support decision-making. The LCC also monitors go/no-go messages from stakeholders and can issue its own go/no-go based on traffic, environmental, and space weather conditions.
- Real-Time Spacecraft Tracking: From the start of the operation, the LCC processes live state vector data (position, velocity, acceleration) of the spacecraft, providing real-time predictions for Instantaneous Impact Points (IIPs) and Hazard Areas (HAs). The LCC compares actual trajectory data with nominal values, notifying stakeholders of any deviations, and tracks key events like stage separations and re-entry burns.
- Airspace and Maritime Traffic Management: The LCC continuously monitors air and sea traffic to ensure safety. It provides warnings if aircraft or vessels are detected in restricted areas and updates ANSPs when these areas are clear, allowing for immediate airspace release and traffic resumption.

- Response to Non-Nominal Events: In the event of an anomaly (e.g., Loss of Signal (LOS), trajectory deviation, or explosion), the LCC informs all stakeholders, calculates Refined Hazard Areas (RHAs) using risk modeling, and transmits updated information to ANSPs, the NM, and other authorities. This helps ATC initiate airspace evacuation and manage risks to other airspace users.
- End of Operations: The LCC concludes its role once the spacecraft reaches orbit or lands, all components are accounted for, and airspace is cleared following the mission.

By ensuring real-time coordination, monitoring, and rapid response, the LCC optimizes safety and efficiency during the execution phase of space operations.

Operational Concept of the Launch Coordination Center (LCC): Post-Mission Phase

In the post-mission phase, the LCC supports comprehensive analysis and evaluation of the space operation, focusing on improving future missions. Key elements of this phase include:

- Data Analysis: The LCC provides recorded data from the planning and execution phases, enabling comparisons between forecasted and actual values (e.g., trajectory, Hazard Areas (HAs), schedules). The LCC helps identify the causes of any deviations, such as unexpected meteorological conditions.
- Impact Evaluation: The LCC evaluates the space operation's effects on the air traffic system, analyzing aspects like airspace capacity, route lengths, and time or financial impacts. This analysis helps to quantify the broader influence of space missions on aviation.
- Process Optimization: The LCC reviews the effectiveness of established processes and identifies areas for improvement, especially in communication and coordination among stakeholders. Feedback is collected in a standardized format to assess the performance of the coordination efforts during the previous phases.
- Data Sharing and Storage: The results of these evaluations, including feedback and quantitative analyses, are stored in a standardized format and shared with all stakeholders. The LCC also maintains a central repository of data, accessible to interested parties, while ensuring compliance with data protection regulations.

By facilitating post-mission analysis, the LCC ensures continuous improvement of space operations, enhancing both safety and efficiency for future missions.

2.2. Software Tools and Infrastructure

The microservice architecture approach was chosen for the LCC software solution to ensure scalability, flexibility, resilience, and ease of maintenance. It has already been described in detail in [8]. The system is designed by breaking down applications into smaller, modular services that can be independently developed, tested, and deployed. Each service is tailored to perform a specific function, allowing for targeted improvements and scaling based on individual needs. Communication between services is achieved through lightweight protocols such as Representational State Transfer (REST) or messaging over a message broker, enabling seamless and efficient data exchange. This architecture enhances the system's ability to handle increased traffic, improve performance, and ensure resilience by isolating failures within specific services. Furthermore, microservices provide flexibility in technology choices, faster updates, and simplified management, making the system more adaptable, modular, and responsive to changing operational demands.

The LCC software architecture is based on a microservice architecture to ensure modular, scalable, and resilient operations. Key functionalities include:

- Service Gateway: Acts as the entry point for all microservices, handling traffic monitoring, security, and service discovery.
- Authentication and Authorization Service: Uses token-based security frameworks (like OAuth2) for secure user access.
- Service Discovery: Manages the identification of services within a distributed architecture, enabling scalability and resilience.
- PMP Service and Client: Supports pre-mission planning by importing mission data, conducting risk calculations, and coordinating with stakeholders to predict and minimize impacts on air traffic.
- RMM Service and Client: Monitors real-time missions by tracking spacecraft trajectories, managing air and sea traffic, and handling non-nominal events.
- PMA Service and Client: Provides post-mission analysis by evaluating performance, impacts on air traffic, and collecting stakeholder feedback for future optimizations.
- Risk Calculation Service: Central to calculating hazard areas and potential impacts of spacecraft launches and re-entries.
- Vehicle Information Service: Manages data on space vehicles and spaceports, supporting planning and risk assessments.
- EFB Client and SWIM Service: Facilitates pilot access to aeronautical and hazard information via

cockpit alerts, integrated with the SWIM infrastructure.

- Logging Service: Logs events across the system for monitoring, debugging, and post-mission analysis.
- Interfaces to External Systems: Dedicated interfaces for multi-stakeholder coordination with systems like EUROCONTROL, ANSPs, maritime authorities, and weather services.
- Message Broker: Manages communication between services and external systems using message patterns like publish/subscribe or queuing.

This microservice-based architecture allows the LCC to provide scalable, flexible, and secure services for managing complex aerospace operations (Fig. 1).

To provide a user interface (UI) for the LCC, several additional developments were needed, particularly the creation of an advanced Human-Machine Interface (HMI) tailored for real-time mission monitoring during the execution phase. This HMI also serves as the foundation for interfaces used in the pre-mission and post-mission phases. The design process adopted a user- and task-centered approach, focusing on aligning system features with the specific needs and tasks of the users. This methodology ensures that the system supports users' work tasks effectively.

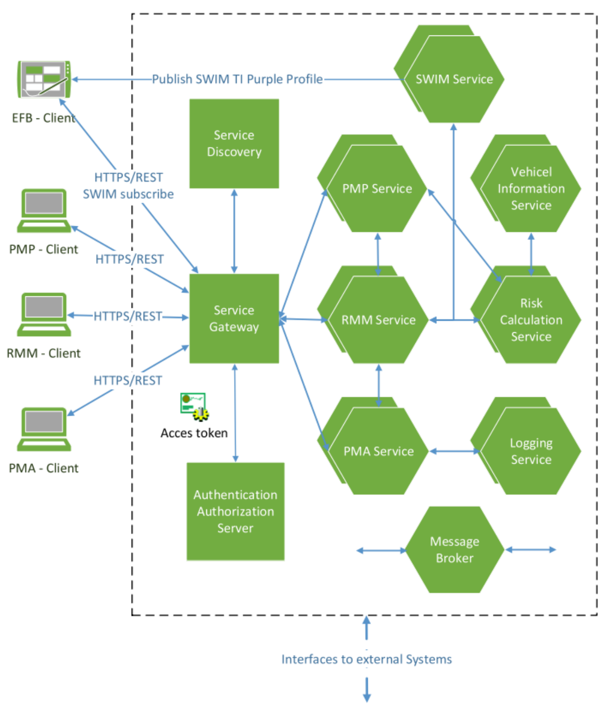

Fig. 1: Microservice architecture of the LCC software solution [8]

The overall layout of the Real-time Mission Monitor (RMM) Human-Machine Interface (HMI) is designed to enhance situational awareness and operational efficiency by organizing mission-critical information in a clear and accessible manner (Fig. 2) [9]. Its core elements and layout focus on real-time monitoring and status tracking, with the following key features:

- Connection Status Information: Displayed at the top of the interface, this uses color coding to show connection statuses with stakeholders and alerts for air and sea traffic warnings.
- Central Map: The central element of the HMI is a 3D-rendered geographical map which provides spatial data in real-time, enhancing users' situational awareness.
- State Vector Diagrams and Event List: Positioned on the left, these diagrams show the space vehicle's state vectors, while an event list below provides detailed event tracking.
- Event Timeline: Located at the bottom, this timeline provides a comprehensive overview of mission events in chronological order.
- Right-Side Information Panels: The right side of the interface displays additional information, including a video monitor, mission details, weather updates, and a list of Hazard Area (HA) information.

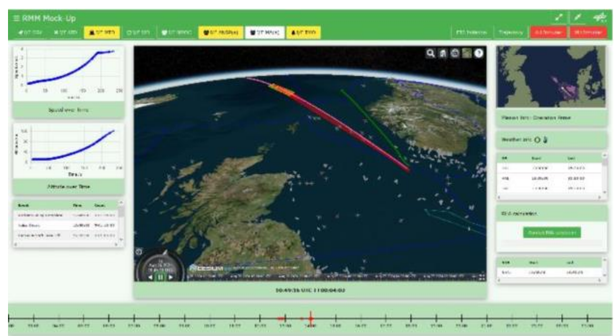

Fig. 2: HMI of the Real Time Mission Monitor (RMM)[9]

This layout focuses on providing real-time visualizations and status updates, ensuring operators have immediate access to mission-critical data like vehicle status, hazard areas, and traffic alerts, all of which are crucial for decision-making during space operations.

2.3. Testing and Evaluation

The test and evaluation activities for the LCC and its software solutions have been structured into several phases. Initially, functional tests were conducted in a simulated environment at the DLR Air Traffic Validation Center, where the LCC prototype was integrated into the Airport and Control Center Simulator (ACCES)[10]. This setup enabled thorough testing of the system's basic functionalities under controlled conditions.

Following this, a theory-based formative evaluation was carried out by developer experts. This evaluation focused on assessing the design, functionality, and potential effectiveness of the real-time mission monitoring system without real user involvement. By applying Human-Computer Interaction (HCI) principles, the experts evaluated the system's usability, interface design, and user experience. They noted strengths in its clarity, ease of use, and customization options, though real user feedback is considered crucial for confirming these findings and addressing any practical challenges that may emerge during actual use.

Future evaluations will involve workshops with real users to validate the assumptions made during the expert evaluation. This step is essential for refining the system based on user interactions and ensuring it meets operational needs. Additionally, a live launch mission will be used to test the LCC's operational functionalities and technical capabilities in real-time. During this phase, the system will first operate in shadow mode, allowing for comprehensive testing in a real-world scenario without directly influencing mission operations. Preparations for such an evaluation have been taken already during the spring and summer period in 2024 with the intention to use the LCC and its systems during a first pilot mission. These efforts are described into more detail in the following chapter.

Together, these phases are designed to iteratively enhance the LCC's performance and ensure it aligns with both operational requirements and user expectations.

2.4. Pilot Mission

As part of the SpaceTracks project, a pilot mission was planned to evaluate the operational concept and tools of the LCC in a real-world setting. The pilot mission, designed to run in a shadow mode setup to avoid impacting the mission's success, had several objectives. These included testing the overall functionality of the LCC using live data from stakeholders involved in a rocket launch, verifying data interfaces, and assessing real-time data provision and computation capabilities. The mission also aimed to test the procedures for operating the system within established mission and launch control processes, while gathering usability feedback from mission operators during shadow mode operations.

For this mission, a series of suborbital rocket launches in the Northern Sea was selected. In preparation, the DLR gathered performance data from the associated launch vehicles, pre-planned risk areas, and NOTAM information during the planning phase. Additionally, detailed launch timelines and event data were compiled to configure the LCC systems for the planned launch dates.

To ensure the real-time operation of the LCC, telemetry data from the rockets needed to be transmitted from the launch site to the LCC services with minimal delay. For this, data requirements were harmonized, interfaces designed, and data transfer protocols established, allowing the LCC to receive and process the telemetry data in real time. To provide independent air traffic surveillance, an ADS-B receiver was installed at an offshore station linked to the launch site. Maritime surveillance was also ensured by accessing satellite-based surveillance data.

Moreover, the SpaceTracks system interfaces and HMIs were set up within the Mission Control Centre to gather feedback from the launch service provider. Despite thorough preparations for the scheduled launch, the campaign was postponed due to delays in obtaining the necessary operating licenses. As a result, the testing of the LCC systems had to be rescheduled and was not completed at the time of this publication.

3. Future Implications for European Air Traffic Management

As part of the broader efforts to enhance air traffic management (ATM) in Europe, the development of a European Concept for Higher Airspace Operations (HAO) has emerged as a critical initiative under the SESAR project ECHO [11]. This initiative is focused on the safe and efficient integration of new types of operations, including space launch and re-entry activities, into the existing European aviation framework. The initial phase of ECHO laid the groundwork by developing a conceptual framework for these operations, recognizing the growing need to manage increasingly complex airspace environments as the number of space-related activities continues to rise.

In autumn 2023, the second phase of the project, known as ECHO-2 [12], was launched to build on the work of the initial concept of operations (ConOps)[13]. ECHO-2 addresses the various types of higher airspace operations, including the growing challenges associated with launch and re-entry activities at a network-wide level. The project represents a significant step toward translating the theoretical ConOps into practical ATM applications that can support the safe integration of these activities into European airspace [14].

With respect to launch and re-entry operations, ECHO-2 tackles the critical challenges posed by the increasing frequency of space missions and their potential impact on the European air traffic network. By focusing on network-level coordination and solutions, the project aims to ensure that space operations can coexist with commercial aviation in a manner that minimizes disruptions and maximizes efficiency.

This effort to integrate space activities within European ATM aligns with the objectives of the SpaceTracks RMM, which will be adapted to meet these challenges with a specific perspective on air traffic network related operational requirements (becoming a Network Real-time Mission Monitor, N-RMM). Traditionally, large airspace volumes are reserved for extended periods to ensure the safety of launches or re-entries, which can disrupt regular air traffic, causing inefficiencies and even cancellations. However, as the number of launches increases, particularly with daily operations projected by 2040, it is essential to reduce the airspace segregation that hampers flight operations.

To address this, the SpaceTracks RMM will be expanded to support new data exchange capabilities between the aviation and space domains, fostering greater integration and coordination. The system will be adapted to manage both planned and unplanned events at a European network level, ensuring that airspace can be dynamically shared between space operations and regular commercial traffic. Real-time monitoring of mission-critical parameters will be a central feature of this adaptation, allowing for more responsive airspace management and quicker release of reserved airspace once it is no longer needed.

The RMM will also be tailored to support cross-border procedures, particularly for high-speed operations like space launches and hypersonic flights. These adaptations will focus on contingency management, traffic coordination, and real-time situational awareness, enabling key stakeholders—including air traffic control and the Network Manager Operations Center (NMOC)—to respond to non-nominal events swiftly and effectively. By incorporating prototypes such as the Space Data Integrator (SDI) and refining them to fit the European context, the RMM will enhance the integration of space operations into the European ATM environment. This will optimize the strategic, pre-tactical, and tactical phases of airspace management, ensuring a smoother integration of space activities into the growing European aviation network.

The ECHO-2 project is still in the early stages of its three-year development timeline, with its final goal set to reach Technology Readiness Level 6 (TRL6). This indicates that by the end of the project, the developed solutions will have undergone significant testing and demonstration in relevant operational environments. As the project progresses, its advancements will be supported by ongoing insights and lessons learned from related initiatives, such as the SpaceTracks project.

In particular, the experiences gained from the pilot mission under SpaceTracks are expected to contribute valuable practical data, especially concerning the integration of real-time mission monitoring and space operations into the European air traffic network. These combined efforts will provide critical feedback, enabling ECHO-2 to refine its approach to managing the growing demands of higher airspace operations, ultimately laying the groundwork for the future of launch and re-entry management in Europe.

4. Summary and Conclusions

In conclusion, the SpaceTracks project has made significant strides in advancing the development of a Launch Coordination Center (LCC) designed to integrate space operations into the European air traffic network. Through a microservices-based architecture, the LCC offers modular, scalable services to support mission planning, real-time monitoring, post-mission analysis, and risk management. These services provide seamless communication between stakeholders, enhance situational awareness, and facilitate safer and more efficient management of launches and re-entries within congested airspace.

Key developments include the creation of an advanced Human-Machine Interface (HMI) to support mission-critical operations, along with real-time data processing capabilities designed for integration with existing air traffic management systems. Early evaluations, both theoretical and practical, have laid the foundation for ongoing enhancements, with a pilot mission providing critical testing and feedback on the system's performance in a real-world context. Despite delays due to external factors, the pilot mission is expected to yield essential data for further refinement of the LCC.

Moreover, the SpaceTracks project's contributions are significant in support of the development of the ECHO-2 solution, particularly in addressing the challenges posed by the increasing frequency of space operations within the European aviation network. Further results from SpaceTracks evaluation and demonstration activities will provide valuable insights that can benefit the development of the ECHO-2 solution. The lessons learned from SpaceTracks can feed into the broader goal of establishing a comprehensive framework for Higher Airspace Operations, including launch and re-entry activities, at a European level.

Overall, the SpaceTracks project represents a pivotal step toward future-proofing airspace management in Europe. Its results, combined with the ongoing efforts under ECHO-2, will pave the way for more dynamic and integrated solutions, ensuring that both aviation and space traffic can coexist safely and efficiently in increasingly crowded skies.

References

[1] Air Line Pilots Association. ALPA White Paper: Addressing the Challenges to Aviation from Evolving Space Transportation. Washington. 2018. p. 10.

[2] Kaltenhaeuser, S., Luchkova, T., Klay, N., Ang, R.; Assessment of the Impact of Air Launch Operations on Air Traffic in Europe. 5th Annual Space Traffic Management Conference "Progress through Collaboration", 2019-02-26 - 2019-02-27, Austin, USA

[3] Luchkova, T., Kaltenhaeuser, S., Klay, N., Ang, R., Schultz, M.; Integration and Evaluation of the Impact of Space Vehicle Operations in the European ATM. HiSST: International Conference on High-Speed Vehicle Science Technology, 2018-11-26 - 2018-11-29, Moskau, Russland.

[4] Frodge, R., Murray, D.; "Space data integration", Journal of Space Safety Engineering, Volume 9, Issue 2, 2022, Pages 182-188, ISSN 2468-8967, URL: https://doi.org/10.1016/j.jsse.2022.02.015.

[5] Kaltenhaeuser, S., Kluenker, C., Schmitt, D.-R.; Interoperable data exchange for safe and efficient launch and re-entry operations in an international environment. Acta Astronautica, 214, Seiten 137-146. Elsevier. doi:10.1016/j.actaastro.2023.10.021. ISSN 0094-5765.

[6] Stahnke, A., Rabus, T., Kaltenhaeuser, S.; Supporting the safety and efficiency of airspace transition for launch and re-entry operations in Europe, in: Proceedings of the 2nd International Conference on Flight Vehicles, Aerothermodynamics and Re-entry Missions & Engineering (FAR), Heilbronn, Germany, 2022.

[7] Stahnke, A., Rabus, T., Hampe, J., Kaltenhaeuser, S.; Mechanisms supporting improved multi-stakeholder coordination of launch and re-entry traffic integration. In: Proceedings of Ground-Based Space Facilities Symposium, GBSF. 3rd Ground-Based Space Facilities Symposium (GBSF) 2022, 2022-12-06 - 2022-12-08, Marseille, Frankreich.

[8] Hampe, J., Stahnke, A.; Improving air and space safety through enhanced coordination with the SpaceTracks Suite microservice architecture. Journal of Space Safety Engineering. Elsevier. doi: 10.1016/j.jsse.2024.01.005. ISSN 2468-8967.

[9] Hampe, J.; DESIGN CONSIDERATION AND EVALUATION OF A HUMAN-MACHINE INTERFACE FOR REAL-TIME MISSION MONITORING OF A LAUNCH AND RE-ENTRY COORDINATION SYSTEMS, 13th IAASS Conference, Prague, Czech Republic – 8-10 October 2024

[10] Suikat, R., Kaltenhaeuser, S., Hampe, J., Timmermann, F., Weber, B.; ACCES - A gaming and simulation platform for advanced airport operation concepts, AIAA Modeling and Simulation Technologie Conference, Toronto, Ontario Canada, 2010.

[11] ECHO project consortium, "ECHO Project - European Concept of Higher Airspace Operations," [Online]. Available: https://higherairspace.eu/echo-project/. [Accessed 19 September 2024]

[12] SESAR Joint Undertaking, "ECHO 2 Project", 2023. URL: https://higherairspace.eu/echo2-project/ [accessed 21 June 2024]

[13] 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 [retrieved 21 June 2024]

[14] Radke, J. et.al.; Integrating Air Traffic Management and Space Traffic Management: Concepts, Challenges, and Solutions for the Evolving Aerospace Landscape in Europe, AIAA ASCEND, Las Vegas, USA, 2024