SUPPORTING THE SAFETY AND EFFICIENCY OF AIRSPACE TRANSITION FOR LAUNCH AND RE-ENTRY OPERATIONS IN EUROPE

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ABSTRACT

Due to increased demand and developing business opportunities, new potential spaceports on the European continent are being discussed and developed. It will be essential in the future to ensure a balance between the commercial interests of civil aviation and those of commercial space flight. With the establishment of a Launch Coordination Center (LCC), the German Aerospace Center (DLR) is working on the development of a service with which missions can be supported and monitored in real time from launch to handover to space traffic management (or vice versa for re-entry and landing). The LCC will support traffic integration as early as the planning phase and allow minimization of impact on air traffic while considering mission requirements. In doing so, efficient procedures for scheduling launch and re-entry activities will be provided. For post-mission analysis, mission parameters will be processed and evaluated in relation to the impact on the air traffic system.

Index Terms— Integrated Air and Space Traffic Management, European Space Flight, Launch, Re-entry

1. INTRODUCTION

With regard to the growing commercialization of space flight, an increase in spacecraft activity in European airspace is to be expected. Corresponding spacecraft are primarily small launch vehicles (micro-launchers), space planes, and air launched rockets. Compared to current launch solutions, such systems enable, for example, faster, more flexible, and more cost-effective delivery of small satellites (< 500 kg) into Low Earth Orbits (LEOs) as well as orbital and suborbital flights for scientific experiments or for touristic purposes.

Though, depending on the configuration of the launch or re-entry trajectory, there are different interactions with air traffic. In the past, airspace was therefore closed during rocket launches for air traffic control purposes. In doing so, the mostly governmental space actors were given preference over commercial aviation. However, as soon as the players in both domains pursue commercial interests, it is necessary to develop more finely tuned processes for integrating spacecraft into the existing air traffic system.

In this context, the merging of data from aviation and space, as well as shipping, is essential for the realization of an integrated transport system. For this purpose, the DLR is currently developing a Launch Coordination Center. Thereby, DLR can build on experiences and knowledge from recent research projects related to integrated aircraft and spacecraft operations and collaborative data exchange [1; 2].

The LCC intends to have a central, managing, and coordinating role with regard to integrated aerospace activities. Space data is fed to the LCC, enriched with aviation data, and can be used for planning processes, operational monitoring, and wrap-up. Relevant outputs, such as calculated hazard areas (HAs), are provided to users.

The objective of the LCC is to collect relevant input data, process it, and distribute the outputs to stakeholders during the pre-mission, execution, and post-mission phase. Thereby, the LCC shall enable improved and harmonized processes for aerospace activities. In addition, the LCC shall enable "launch-on-demand" and it shall be applicable for all types of spacecraft and mission variants. Appropriate tools will be provided for mission planning, support, monitoring, and subsequent analyses. Specifically, these tools shall enable the following essential tasks:

- **during pre-mission phase**, assessment and verification of various stakeholder data and space mission specific parameters, including trajectories, HAs, and time schedule; assessment and optimization of the space operation influences on the air traffic system
- **during execution phase**, monitoring and processing of launch/re-entry specific data and air traffic information for increased stakeholder situational awareness; real-time generation and provision of Refined Hazard Area (RHA) data to all relevant stakeholders for non-nominal events
- **during post-mission phase**, analysis and evaluation of space operation impact on (inter-)national air traffic system and analysis of the forecast and planning performances

For these purposes, implemented interfaces shall enable required data feeds and the distribution of the LCC's service products to the relevant stakeholders in an automated and standardized way.

2. OPERATIONAL BACKROUND

When developing software solutions to integrate spacecraft into European airspace, various aspects must be considered, especially different space flight characteristics and the existing complex air traffic framework.

2.1. Launch and re-entry operations

Spacecraft can be designed to perform vertical or horizontal launches and landings. Usually, launches and landings are performed at spaceports, whereat vertical operations are conducted at launch pads and horizontal operations require runways. Horizontal operations, in particular, are also suitable to integrate space activities into an airport infrastructure (dual-use airport). Additionally, in some cases, landing activities, e.g. landing of a capsule under parachute after re-entry, are performed over open land and water areas, like it is done for impacts of jettisoned rocket stages or payload fairings during launch.

Furthermore, spacecraft transitioning the airspace can move in different ways. For example, unpowered flights, like parachute descend or gliding, are used for vertical and horizontal landings, respectively. Besides, spacecraft can be rocket powered or assisted by an aircraft, as in case of captive carrier flights (air launch). Thereby, for instance, a vehicle, such as a small rocket, is carried to a certain altitude by a carrier aircraft. The vehicle is then released and it uses its own rocket engines to continue on its flight path. In addition, rocket power is usually used to perform vertical launches. Depending on the used type of power and the maneuverability of a spacecraft, this results in different requirements for its integration into the air traffic system as well as effects for other air traffic participants.

Space activities may be governmental or commercial, serving economic, scientific, touristic, or military purposes. Moreover, space flights can be performed crewed and uncrewed as well as orbital or suborbital. In addition, spacecraft and their components can be re-usable.

Currently, various European countries, like the United Kingdom, Norway, Germany, and Italy, are pursuing plans to expand their national and thus also European access to space. Under discussion are vertical as well as horizontal launches and landings from European spaceports for orbital and suborbital flights by governmental and commercial actors. [1; 3; 4; 5; 6; 7]

2.2. Air traffic management

Europe is characterized by a complex airspace structure with a multitude of national and international actors moving in European airspace and organizing it. To ensure safe and efficient operations in such a complex airspace, various flight control services are required. Those encompass Air Traffic Service (ATS), Air Traffic Flow Management (ATFM), Airspace Management (ASM), and multiple sub-services, summarized under the term Air Traffic Management (ATM). ATM tasks are performed by Europe's Network Manager (NM) EUROCONTROL and national actors, such as Air Navigation Service Providers (ANSPs). [8; 9]

In order to adequately integrate spacecraft operations into the existing air traffic system, information on space activities must be considered within the areas of ATM so that the requirements of ATM and Space Traffic Management (STM) demands can be met.

As part of ATS, Air Traffic Control (ATC) is provided by national ANSPs and EUROCONTROL to coordinate air traffic and provide relevant information to Airspace Users (AUs) [8]. During space operations, for example, it might be necessary to redirect aircraft to other flight routes according to notifications filed by the Launch and Re-entry Operator (LRO). In addition, flight clearance might be issued for previously restricted areas as soon as space activities in those areas have been completed.

Furthermore, an essential part of the ATM is the ATFM, or Air Traffic Flow and Capacity Management (ATFCM), performed by EUROCONTROL. The ATFCM consists of four phases encompassing different planning stages, real-time modifications, and postprocessing: strategic phase, pre-tactical phase, tactical phase, post-operational analysis. [10] Those phases have to be addressed when incorporating spacecraft launch and re-entry operations.

In addition, to operate a spacecraft in airspace, airspace changes might have to be done as part of ASM. Longer-term relevant information on airspace changes and special events is published in the national Aeronautical Information Publication (AIP) by the national ANSP. Short-term information not (yet) published in the AIP is published via NOTAM by the ANSP. [8; 11]

3. CURRENT OPERATION PROCEDURES

Similar to ATFCM, spacecraft operations in airspace can be divided into several phases.

3.1. Pre-mission phase

In order to perform a launch or re-entry, the LRO usually needs a license or permit from the responsible authority of the country in whose territories the operation will take place. In addition, if necessary, applications for airspace changes are also part of the long-term planning during the pre-mission phase. [12; 13]

The launch/re-entry license application contains, among other things, information about the proposed launch/re-entry vehicle, designated launch/re-entry site, and the proposed trajectory as well as various analyses, such as for debris distributions, toxic hazards, and blast overpressure phenomena. These analyses are usually part of the overriding flight safety analysis. The objective of the analyses is to ensure the safety of mission participants, external stakeholders, such as civilians, AUs, and mariners, and property. To inform all affected stakeholders sufficiently, agreements with Launch and Re-entry Site Operators (LRSOs), mariners, airmen, and emergency response providers are to be established. [14; 15; 16]

To ensure safety with regard to hazardous debris during flight, HAs in the air, on land, and at sea for nominal and off-nominal events, like for jettisoned rocket stages and payload fairings as well as in case of an on trajectory explosion, are identified by the operator. Airmen, mariners, and other relevant stakeholders are informed accordingly about these HAs prior to a mission. NOTAMs and NOTMARs are used for this purpose to inform airmen and mariners, respectively. [14; 17]

The data NM and ANSPs receive from the operator is analyzed with regard to air traffic impact by the planned mission. In addition, potential conflicts are identified and resolved. Thereby, the HAs are consistently revised throughout an iterative process while launch/re-entry is prepared. Furthermore, pilots and airlines can use the information on HAs for their flight planning. [8; 17; 18]

3.2. Execution phase

The execution phase may begin up to 24 hours prior to launch/re-entry. ATC begins to reroute air traffic timely sufficient close to the start of a launch or re-entry. In this process, ATC receives updated information about the operational status via mail or telephone by the LRO according to the terms of the letter of agreement defined beforehand. [14; 19]

During flight, real-time monitoring must be performed by the LRO. The state vector of the spacecraft is continuously recorded. On the other hand, there is currently no real-time information available to ATC. Instead, relevant information is handed over via mail or telephone by the LRO. In case of a non-nominal event the relevant RHA needs to be generated and communicated to the affected ANSP, where for example a traffic manager transcribes the RHA coordinates and passes them to the air traffic controllers. The controllers contact and redirect each affected aircraft and the pilots readback and execute. The distributed RHA is static and does not change during emergency procedures. [14; 19; 20]

At the end of the operation, previously restricted airspace is cleared by ATC.

3.3. Post-mission phase

During post-mission operations, reviews and analyses are conducted. Recorded data and monitoring information of the real-time operation are compared to predictions and assumptions defined prior to the mission. In addition, the mission impact is evaluated. Lessons learned are recorded and the outcomes are considered for future operations. The outcomes are also stored in reports, but there is no central repository to collect and access the data. [19]

4. THE NEED FOR AN LCC

As shown, many stakeholders in different positions are involved in and influenced by launch and re-entry operations and related aerospace activities. For the European scenery, particular challenges arise from fragmented airspace structures with a multitude of ANSPs, heterogeneous ATM systems, and inconsistent, national regulations for space operations. In addition, it is also increasingly challenging for some stakeholder groups, e.g. pilots, to identify relevant NOTAMs due to an overabundance of NOTAMs along their planned flight trajectories [21]. In this context, increased situational awareness for space operations would be desirable for all stakeholders.

Establishing an LCC as an interface for the aggregation, processing, and distribution of relevant data for different stakeholders intends to address shortfalls of current operations by:

- Enabling quantitative assessments of the impact of launch and re-entry operation on the air traffic system.
- Providing efficient processes to plan launch and re-entry operations in an optimal way in coordination among all stakeholders.
- Providing the ability to all stakeholders to efficiently receive and distribute data on launch and re-entry operations.
- Supporting timely and efficient decision making during nominal and off-nominal operation.
- Providing the ability to identify disruptions and deviations during launch and re-entry flight progress early and respond efficiently to critical events.
- Simplifying coordination among stakeholders with regard to airspace restrictions.
- Improving capabilities to develop and distribute lessons learned and best practices among all stakeholders.

5. LCC OPTIMIZED OPERATION PROCEDURES

From the perspective of the LCC, the following core stakeholders are identified: Airspace Users, Air Navigation Service Providers, Network Manager, Launch and Re-entry Operator, Launch and Re-entry Site Operator (incl. Launch and Range Safety). Additional complementary stakeholders are Maritime Authorities (MAs), Regulation Entities, Space Traffic Management Organizations, Airspace Change Authorities, and other Operational Permit Authorities.

At the core of the LCC are software tools that enable the following activities by integrating various data streams and providing sophisticated functionalities.

Unlike current operations, the LCC is used as a central, coordinating interface to support operational integration during the preparation phase. During the mission, the LCC monitors the trajectory and provides real-time information for all stakeholders. Therefore, in case of non-nominal events and emergencies, this enables fast and suitable actions. The LCC also provides the central contact point for operational wrap-up for all stakeholders involved. Streamlined and automated processes take place during all phases that are expected to be less error-prone, time-consuming, and costly compared to current operation methods. A schematic visualization of the LCC is shown in Figure 1.

The LCC might be operated by a single service provider or an organization. For example, the LCC could be integrated into the existing structure of the NM. Alternatively, certain functions of the LCC might be performed by various responsible parties or an LCC operator could provide specific services for various institutions.

5.1. LCC services during pre-mission phase

If no license already is available, the LRO goes through a launch/re-entry licensing process first. As part of this process, the LRO typically arranges agreements with LRSOs, NM, ANSPs, and MAs. The LCC may support adaptation to national and local requirements, especially with regard to operations within European and country specific airspace. LCC functions may also be made available to support licensing authorities during evaluation of license requirements.

With a license in place, LROs will determine a potential launch/re-entry scheduling according to mission and system requirements (e.g. launch window, trajectory, etc.). Within aviation and maritime transport, AUs and maritime operators are constantly planning flights and routes within their own domain.

LCC functionalities will allow for a monitoring of LRO and LRSO mission preparation status to increase situational awareness on stakeholder level. Data from LRO and ANSPs/NM can get merged and analyzed within the LCC. Potential HAs associated with nominal and off-nominal events during the ascent/descend trajectories will be determined through risk model calculations by the LCC (and/or based on data provided by the LRO itself), determining affected Flight Information Regions (FIRs) and sectors and identifying associated ANSPs. Considering the size, location, and duration of airspace restrictions, the impact of the planned spacecraft operation on the planned air traffic for the operational day is determined and evaluated based on available flight plan information and historic air traffic data. This analysis can support optimized scheduling of launch and re-entry operation, considering efficient air traffic operation as well as space mission requirements.

Additional services and functionalities may further support the integration of spacecraft operation by generating NOTAMs and/or AIXM-compliant messages and NOTMARs and providing them to ANSPs/NM and MAs, e.g. by creating service functions for the established data distribution infrastructure of the System Wide Information Management (SWIM).

5.2. LCC services during execution phase

The pre-mission phase ends at the day (24 hours) before launch/re-entry and the execution phase starts at the day of launch/re-entry (assuming alignment with ATM planning processes). The designed operating procedure for the execution phase of a launch or re-entry operation is based on the integration of the LCC in real-time data feeds of LRO, LRSO, NM, ANSPs, and potential additional stakeholders.

Prior to launch/re-entry ($T < T_0$), the LCC already starts evaluation of air traffic and maritime situation to support stakeholder situational awareness and decision making through provision of processed information, e.g. via a web-based dashboard. It also monitors potential no-go/hold statements from various stakeholders like LRO and ANSPs. Based on agreed operational procedures, the LCC itself might issue a no-go/hold statement based on defined criteria for evaluation of air traffic, maritime traffic, or other environmental conditions (weather, space weather, etc.).

With $T \geq T_0$, the LCC processes the live feed of state vector data from the space vehicle and provides connected stakeholders with real time predictions for Instantaneous Impact Point (IIP) and HAs. It monitors the space vehicle trajectory (position, velocity, acceleration) and compares values with the nominal (planned) trajectory and the approved flight corridor. Indications are given if data deviate from nominal values. In parallel, the LCC monitors the relevant space vehicle related events (like staging, re-entry burns, etc.) and provides relevant air traffic and maritime traffic data. For stage/fairing separation, the component trajectory and IIP is determined (approximately) depending on the availability of individual telemetry and tracking data.

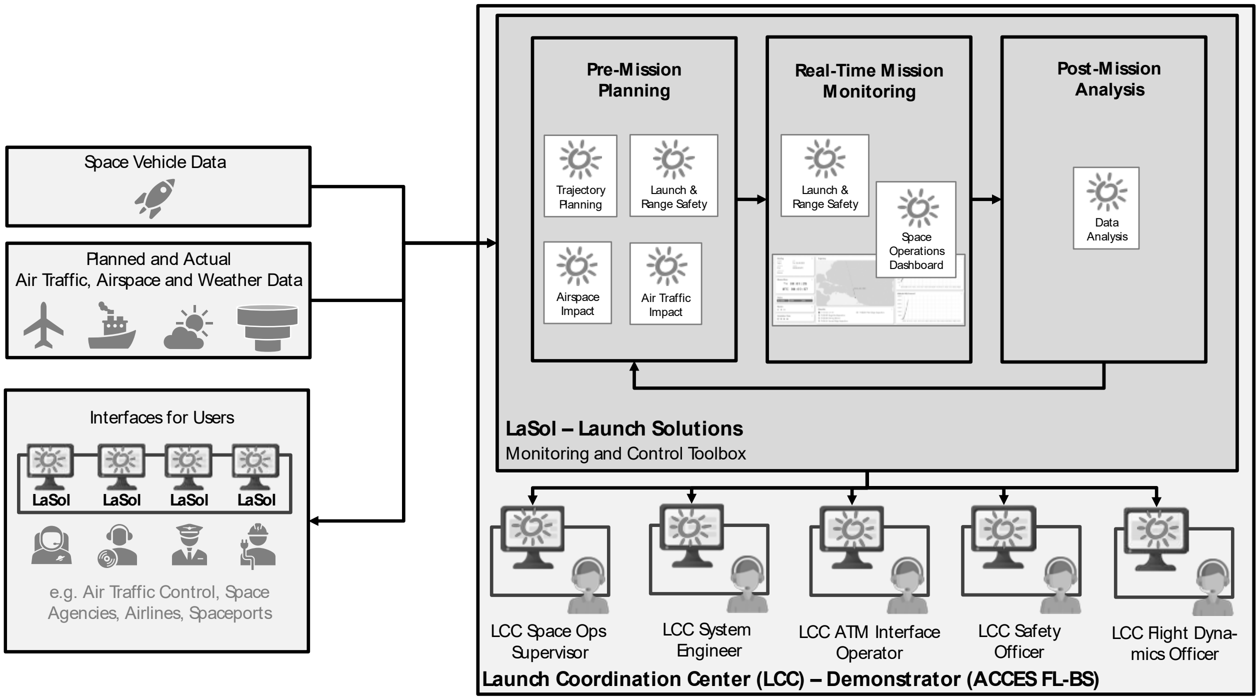

Figure 1: Schematic Visualization of the Launch Coordination Center

LCC functions are monitoring if airspace restrictions and danger areas are clear of spacecraft elements and issuing information if area is clear to support timely releases of airspace and restricted areas.

In case of a non-nominal event (e.g. Loss of Signal (LOS), trajectory deviation, on-trajectory explosion), the LCC will display and inform connected stakeholders about the received status of the spacecraft. If a LOS is confirmed (e.g. via the space operations hotline), the LCC risk modelling functions are beginning calculations to determine an RHA based on the last vehicle state vector received and will show the results via the dashboard. If the loss of the vehicle is getting confirmed, RHA data can be provided instantaneously through predefined protocols to all connected stakeholders, specifically to NM, the affected ANSPs, their ATC facilities, and other related authorities who may benefit.

Based on procedures yet to be implemented, this information can be used to act on the confirmed non-nominal event and attempt to clear the affected airspace, mitigating hazards for other airspace users. To further support mitigations, advanced LCC functions may evaluate aircraft and maritime vessel situation in relation to the RHA and provide further assistance in clearing the HA.

The LLC ends its tasks of the execution phase when orbital insertion (or landing) has been achieved and all components have achieved their target destinations or the airspace has been cleared after a terminated flight.

5.3. LCC services during post-mission phase

For post-mission analysis, the LCC provides recorded and processed data supporting a comparison of assumptions and predictions, specifically regarding the predicted and actual trajectory, predicted and actual HAs, and assumed and actual time schedule, and supports the identification of reasons for differences and deviations, e.g. unexpected wind and weather conditions or incidents.

The LCC specifically supports the evaluation of the impact of the performed space operation on the international air traffic system, for example by evaluation of airspace capacity effects, effects on route lengths, temporal effects, or monetary effects.

This can be complemented by a standardized collection of stakeholder feedback regarding organizational and communication aspects and the utility of shared information (NOTAMs, NOTMARs, etc.).

Based on the user feedback as well as the data evaluation and analysis results, lessons learned can be identified. The lessons learned and the numerical outputs are stored in a standardized format and provided to all stakeholders to be considered for future operations. In addition, the LCC may store all lessons learned, outputs, and raw data in a repository and provide a central access for all stakeholders interested (while applying all necessary and mandatory data protection restrictions).

6. CONCLUSIONS AND OUTLOOK

By developing an LCC and associated services, DLR intends to support streamlined space and air traffic integration for all mission phases. Thereby, the dissemination of essential information to all connected stakeholders shall enable fast and appropriate reactions, e.g. to non-nominal events, to ensure the safety of other airspace users and vehicle operators. In this way, it is intended not only to increase the situational awareness of all stakeholders, but also to lay the foundation for future advanced integration procedures that will make it possible to optimize the required protection zones to the minimum dimensions that are really necessary.

During the planning phase of launch and re-entry operations, efficient procedures for scheduling launch and re-entry activities with respect to air traffic and airspace requirements will be provided. The services should be available for all types of spacecraft and mission variants in the phases in which they interact with the air transport systems (air launch, vertical launches, suborbital flights).

The aim of the LCC is to increase the efficiency and safety of space operations in European airspace. However, in order to meet this requirement, joint, cross-border collaboration is needed to use the LCC to coordinate international space activities. This is particularly relevant against the background of an increase in space operations in Europe, so that not only integration in air traffic but also coordination of space activities among each other (different spaceports) is enabled.

The conflict-free nature of launches and re-entries and their related trajectories must be ensured for both, the aviation and the space domain. This has to be covered already in the planning phase, within the processes of ATM and STM. During launch and re-entry, changes which are affecting the four-dimensional flight trajectory in the originating domain will very likely have an impact on operation within the following domain. An interactive and integrated ATM/STM interface should therefore be supported by the LCC already in the planning phase. During the execution of launch and re-entry these requirements increase further. Deviations from the planned trajectory must be checked for their impact in both domains and appropriate measures must be initiated with the help of the respective processes of ATM and STM. Potential non-nominal behavior must already be considered in planning and evaluated within both regimes with regard to ensuring the required safety margins. The LCC will incorporate such requirements and adapt its functionalities according to the development of joint ATM/STM operational procedures.

To demonstrate the described functionalities, an LCC prototype is currently under development at the DLR Institute of Flight Guidance. In this context, a Concept of Operation has already been defined and system requirements are currently specified. These requirements will be streamlined by discussions with different stakeholders and a system design will be developed. The objective is to operate and evaluate the LCC prototype in the context of a pilot mission.

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