MECHANISMS SUPPORTING IMPROVED MULTI-STAKEHOLDER COORDINATION OF LAUNCH AND RE-ENTRY TRAFFIC INTEGRATION

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ABSTRACT

In the context of the growing commercial space sector, future launch range facilities are facing changing conceptual and operational constraints. Thus, in order to be able to carry out a high frequency of launches and re-entries in the future more finely tuned processes will be needed to coordinate with all the stakeholders involved in and affected by space operations. Therefore, the German Aerospace Center (DLR) is developing a Launch Coordination Center (LCC) to provide services for efficient integration of launches and re-entries into the air traffic system for all spaceport types. In addition, an interface to maritime authorities is considered. 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 and multi-stakeholder coordination will be provided. Coordination and data exchange will also be supported by automated functions during execution to increase stakeholder situational awareness and ensure safe and efficient operations. At the same time, the spacecraft trajectory and the surrounding air and maritime traffic are monitored. For postprocessing, functions are provided to analyze planned and actual data from the previous phases.

1. INTRODUCTION

When designing future spaceport infrastructures, attention must be paid to changing constraints for operation and design. In the future, many spaceports will have to support multiple launcher types that vary in their operational constraints and requirements. On the part of the spaceport operator, this will make cost-effective and efficient use of resources even more challenging. At the same time, a higher launch frequency can be expected. Today, a single space operation can already have a significant impact on air traffic, as shown by the Federal Aviation Administration (FAA) for a rocket launch conducted by SpaceX at the Kennedy Space Center in 2018 that effectuated a total number of 34,841 additional nautical miles and 4,645 minutes of delay [1]. Based on this, a growing impact on other transport systems can be assumed for future and more frequent space operations, especially when it comes to regular space operations in Europe. This increases the requirements for an efficient and future-proof design of the airspace integration processes as a function of future launch range facilities to ensure safe and efficient operations for all involved stakeholders but also to balance the commercial interests of space and aviation as well as of the maritime industry.

Against this background, the integration of data from space and aviation as well as shipping is essential to realize an integrated transport system of the future. Therefore, the German Aerospace Center (DLR) has started the development of a Launch Coordination Center (LCC) to provide services for efficient integration of launch and re-entry operations into the air traffic system for spaceports of all kinds. In addition to optimizing planning processes for reconciling the operational requirements of air traffic operations and space missions, the LCC aims at an efficient exchange of information between the stakeholders involved. This applies not only to the planning phase but also to optimal real-time networking between launch and re-entry operators, spaceports, air traffic control facilities, and other authorities in the execution phase. Crucial for this are functions for real-time data exchange in nominal and non-nominal operational situations in order to be able to react quickly and effectively to disruptive events. With the LCC, DLR is not only developing a contribution to safe and efficient operations, but is also creating the basis for future optimized concepts to minimize the impact on air traffic by increased launch and re-entry activities. Thereby, DLR can build on experiences and knowledge from recent research projects related to integrated aircraft and spacecraft operations and collaborative data exchange [2; 3; 4].

The LCC intends to have a central, managing, and coordinating role with regard to future integrated aerospace activities with an additional link to the maritime domain. Space data will be fed to the LCC, enriched with aeronautical and maritime data, and used for planning processes, real-time monitoring, and postprocessing. Relevant outputs, such as calculated Hazard Areas (HAs), will be made available to users accordingly. To realize the proposed services, software tools are developed and suitable interfaces are implemented to enable required data feeds and the distribution of the LCC's service products to the relevant stakeholders in an automated and standardized way.

2. LAUNCH AND RE-ENTRY TRAFFIC INTEGRATION REQUIREMENTS

In order to develop solutions that support the coordination of launch and re-entry activities with other modes of transport, knowledge of the operational framework and safety requirements is essential.

2.1. Operational Framework

Space activities may be governmental or commercial, serving economic, scientific, touristic, or military purposes. Thereby, the flight profile of a spacecraft transitioning the airspace depends on the mission characteristics, e.g. whether it is an orbital or suborbital launch or a planned or unplanned re-entry. Rockets launched into orbit usually show a larger horizontal movement compared to suborbital flights performed at a single spaceport, for example. In addition, the propulsion type and the configuration influence the controllability and maneuverability of a spacecraft in airspace. This results in different requirements for the integration into the existing air traffic system as well as different effects on other airspace users, depending on the spacecraft and its trajectory.

Usually, launches and landings are performed at land-based and fixed integrated 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, mobile platform concepts exist to perform launches and landings. Further, in special 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.

Currently, no orbital launches are conducted from central Europe but various countries are pursuing plans to expand their national and thus also European access to space. So, it is necessary to consider the specific European characteristics for future space operations when developing tools and procedures to support these activities.

One the one hand, evolving commercial European launch providers and site operators currently face the challenge of country specific space laws and licensing legislations, partly still under development or even not existing. On the other hand, there is an established European air traffic framework. It consists of an airspace with a complex structure and with a large number of airspace users and service providers. The airspace is divided into a lower and an upper airspace consisting of several Flight Information Regions (FIRs), which in turn are subdivided into multiple sectors. The FIRs are managed partly by the European Network Manager (NM), the European Organization for the Safety of Air Navigation (EUROCONTROL), and partly by national Air Navigation Service Providers (ANSPs). In cooperation with the national ANSPs, EUROCONTROL is responsible for the European Air Traffic Management (ATM). ATM is designed to enable all stakeholders to operate air traffic safely and efficiently. ATM comprises Airspace Management (ASM), Air Traffic Flow Management (ATFM) and Air Traffic Service (ATS) as well as several sub-services.

In order to adequately integrate launching and re-entering spacecraft into the 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) can be met. Thereby, the four phases (strategic, pre-tactical, tactical, and post-operational) of ATFM, or Air Traffic Flow and Capacity Management (ATFCM), should be addresses to synchronize and streamline the operational procedures of space and aviation. In addition, it is necessary to guide aircraft with regard to the notifications issued by a Launch and Re-entry Operator (LRO) or the corresponding Launch and Re-entry Site Operator (LRSO) as part of ATS's Air Traffic Control (ATC) service and airspace changes might be required as part of ASM.

With regard to current launch and re-entry operations, usually coordination already takes place between launch providers, site operators, ANSPs, maritime authorities, and other stakeholders, like licensing and approval authorities. In this context, the site operator often holds an intermediary position as coordinator between the launch provider and the aviation and maritime authorities transferring relevant information about planned activities. Moreover, the current processes can be roughly divided into three phases: preparation, execution, and postprocessing. However, present operational procedures established for coordination and data exchange among involved parties face some challenges with regard to data integration, system integration, and process automation. For example, no real-time data is available for ANSPs during current launch and re-entry operations. Instead, relevant information is handed over via e-mail or telephone by the LRO or LRSO. These challenges are addressed by the Launch Coordination Center.

2.2. Safety Requirements

Mission safety is ensured by assessing the risk, on ground or in flight, associated with the launch or re-entry. The LCC will offer the functionality of determining the flight risk for all different mission types in real-time or a priori to a mission. The term risk hereby refers to the risk of people getting seriously injured or the risk of damaging other vehicles, infrastructure, nature protection areas, etc. When determining the risk, nominal events, for example stage separation, as well as non-nominal events, e.g. on-trajectory explosion, are taken into account.

The calculations are based on vehicle parameters, the flight trajectory, environmental conditions, and information about the people or assets at risk. The first three are used to assess the probability that the rocket itself, its components, or any debris of it impacts in a specific area. For this, all potential failure modes and their probability of occurrence, the potentially resulting fragments and their characteristics, and the state of the vehicle are considered. All rocket fragments are then propagated to the ground and based on the resulting impact location and the uncertainty of the input parameters a probability distribution is estimated. Using the distribution, the probability of an impact in a specific area can be determined. The atmospheric conditions and especially present winds can strongly influence the descent trajectory of the fragments and therefore the resulting impact distribution. [5]

To assess the risk itself, a consequence has to be specified. Regarding people, this is normally the risk of becoming a casualty or a fatality. For assets or infrastructure, the consequences can be more diverse. An example would be damage severity. Additionally, risk is often divided into individual risk and collective risk. The first one describes the risk for a hypothetical present individual at a specific location/area to become a casualty/fatality. The second factors in the number of people at risk. Thus, to calculate the collective risk, information about population density is necessary. Those two risk categories can also be used for the risk assessment regarding assets or infrastructure. [6]

For a typical rocket launch there is an increased probability of failure during and in the first seconds after firing an engine [7] and therefore an increased risk at the launch site. When performing a vertical launch, the time where the launch area is at risk is rather long due to the initial nearly vertical ascent. In case the risk is deemed too high, safety measures to protect mission-critical infrastructure, personnel, and third parties should be implemented. Additional to the safety measures on ground, any kind of air vehicle should be prohibited from the airspace in the vicinity of the launch site and initial part of the trajectory. This is to ensure the safety of the air vehicle but also of the rocket itself.

Another risk factor, especially for uninvolved parties, are dropped stages, fairings, or boosters [7]. As these events often happen far downrange, installing safety measures is more difficult and the impact on other traffic increases considerably. The reason being increased areas in size and impact locations often in areas outside of the jurisdiction of the launcher state. Nevertheless, the timing and the circumstances of these events are known beforehand and therefore suitable safety measures can be installed. An example are aircraft and maritime hazard areas published in advance of a mission, to ensure there is no traffic present in these areas at the time of launch. Thereby, NOTAM (Notice to Airmen) and NOTMAR (Notice to Mariners) are issued to inform airmen and mariners about hazard areas accordingly.

Risk calculation in real-time is needed in case something non-nominal occurs during the ascent or descent. Areas at risk will be determined by the same procedure described above. In this case the relevant trajectory point is known and therefore not all points on the trajectory have to be included in the calculations. A main challenge is the time limitation. The calculations have to be performed and the results distributed to the relevant stakeholder as fast as possible to maximize the reaction time for endangered traffic. The affected parties should be enabled to abandon the areas at risk before the first rocket fragments reach the airspace or ground.

3. MULTI-STAKEHOLDER COORDINATION

To better understand the benefits and mechanisms of multi-stakeholder coordination in the context of future space operations, the need of an LCC and the proposed services and corresponding procedures will be highlighted in the following.

3.1. The Need for Multi-Stakeholder Coordination

The previous chapter demonstrated the high degree to which the execution of launch and re-entry operations and related aerospace activities depend on the involvement of a wide variety of stakeholders in different positions. With regard to Europe, particular challenges arise due to the fragmented airspace structure with a multitude of ANSPs, heterogeneous ATM systems, and inconsistent national regulations for space flight operations. Furthermore, due to an overabundance of NOTAM, it is becoming increasingly challenging for pilots to identify the information that is truly relevant to them along their planned flight paths [8]. Similar constraints apply to the European maritime environment and organizational responsibilities. Against this background, increased situational awareness of space operations in airspace and the maritime domain would be beneficial to all actors involved.

To meet this challenge, the idea of a Launch Coordination Center was developed serving as an interface for the consolidation, processing, and distribution of relevant data for various stakeholders. Crucial to this is the development and provision of appropriate services that could be integrated into existing structures and managed in a decentralized way or provided centrally via an independent center. Thereby, the following core stakeholders exist: Air navigation service providers, airspace users, spacecraft operators, and spaceport operators. Secondary stakeholders include: Regulators, maritime authorities, space traffic management organizations, airspace change authorities, and other approval authorities.

The services of the LCC should enable quantitative assessments of the impacts of launch and re-entry operations on the air traffic system and provide modern and refined procedures for the optimal planning and execution of space flight activities in coordination with all stakeholders. An important element is the ability of all stakeholders to share and receive data on space operations in an efficient manner. Through the services of the LCC, timely and efficient decision making during nominal and non-nominal operations should be enabled. Critical to this is responsiveness supported by the identification and communication of delays, deviations, and disruptions early during launch and re-entry operations and the establishment and execution of appropriate nominal and contingency procedures. Moreover, the coordination among stakeholders with respect to airspace restrictions should be facilitated enabling ANSPs to activate and deactivate airspace restrictions and reroute air traffic in a timely manner. In addition, it should be possible to capture and share lessons learned and best practices among stakeholders to further elaborate the established services and procedures.

3.2. Mechanisms for Multi-Stakeholder Coordination

The LCC intends to serves as a central, coordinating interface to support the operational integration of spacecraft in the future. Therefore, data from various stakeholders and other sources, such as weather data, are integrated and processed. The results are then transferred to the stakeholders again. Specific services are provided for all phases of a launch or re-entry where coordination between space, aviation, and shipping is necessary to ensure safe and efficient operations for all actors involved. This starts with preparation and continues through execution to postprocessing.

During preparation, especially the potential effects of the planned space flight on the expected air traffic will be analyzed. In addition, optimized planning processes are given while at the same time enabling enhanced exchange between the stakeholders. In the subsequent execution phase, spacecraft trajectory data will be evaluated and real-time information will be given to all parties involved. This enables a fast response in case of non-nominal events and emergencies as well as an adaptive control of airspace restrictions during nominal operations. The LCC also provides the central point of contact for all stakeholders for post-operational activities. 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 representation of the LCC is shown in Fig.1.

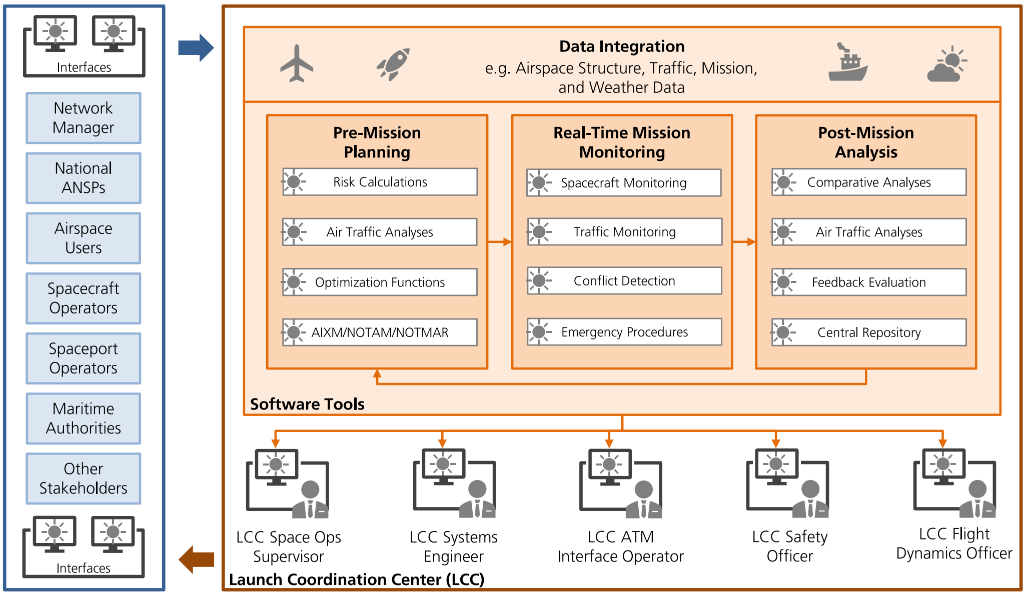

Fig. 1. Schematic Representation of the LCC

3.2.1. Mechanisms During Planning and Preparation

If an operating license has not yet been issued for the planned operation, it must be applied for accordingly by the LRO. In this process, support can be provided to the LRO by the LCC in adapting to national and local requirements, especially with regard to operations in European airspace. In addition, LCC services can assist licensing authorities in verifying specific criteria, such as HAs.

If a license is in place, the LRO can carry out a detailed planning for a specific launch or re-entry. This is done according to the mission and system-specific requirements, such as the trajectory, the spacecraft, and the launch/landing site. Thereby, coordination between the LRO and the LRSO takes place. In parallel, aviation and shipping also carry out their own operational planning. Therefore, during the preparation phase, the planning status of the LRO and LRSO is continuously reviewed and shared to increase situational awareness at stakeholder level.

Further, data from the LRO and the ANSPs or the NM are combined and analyzed in the LCC (compare Fig. 2). Based on the provided LRO data, potential HAs for all nominal and non-nominal operational scenarios during the ascent or descent of the spacecraft are determined using risk calculation functions. Based on this, the affected FIRs and sectors as well as the associated ANSPs are identified. Taking into account the size, location, and duration of the relevant airspace restrictions, the effects of the launch/re-entry on the air traffic planned for that day can be determined in a further step. In addition, optimizations are carried out with regard to the extent and duration of the airspace restrictions as well as the launch/landing location and the time of the operation in order to minimize the impact on the air traffic. Both aviation planning data and historical traffic data are used for these analyses and evaluations. Further, especially when planning a sea launch, potential interferences and optimization measures can be identified with regard to maritime infrastructures and traffic. Depending on which data is provided by the LRO, the findings of the LCC are compared with the corresponding LRO data. The results of the calculations and analyses are then made available to the LRO, LRSO, and the ANSPs as well as the NM and are refined in an iterative process coordinated by the LCC until the results are satisfying for all parties involved. Thereby, a high degree of automation and standardization is aimed for. The evaluations and processes described should thus enable optimized planning of a launch or re-entry, considering the requirements necessary for safe and efficient aerospace operations.

Other services and functions of the LCC can further support the integration of spacecraft operations by generating NOTAM or AIXM[1]-compliant messages and NOTMAR and making them available to the ANSPs, the NM, and maritime authorities.

[1] Aeronautical Information Exchange Model

In this context, for example, service functions can be created for the data distribution infrastructure of the System Wide Information Management (SWIM) that is currently being set up.

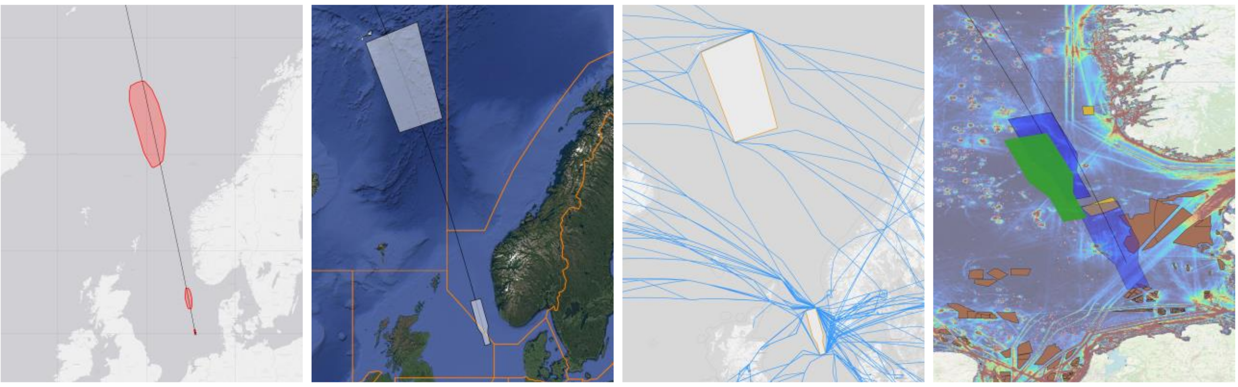

Fig. 2. Examples of Risk Calculation, FIR/ANSP Determination, Impact Analysis, and Optimization[2]

3.2.2. Mechanisms During Flight Execution

The operational phase begins up to 24 hours before the planned launch or re-entry, aiming for synchronization with the processes of the ATFCM. The operating procedures developed for this are oriented towards integrating the LCC into a real-time data exchange with the LRO, LRSO, NM, ANSPs, and other parties involved.

Prior to the launch/re-entry (T < T0), the air and sea traffic situation is monitored and evaluated with regard to the upcoming operation. This serves to increase the situational awareness of all stakeholders and enable decision making based on data processed by the LCC, which can be made accessible to users via a web-based dashboard, for example. Furthermore, potential clearances and restrictions (go/no-go messages) from various actors are monitored by the LCC during the immediate preparation of the operation. Based on agreed operational procedures and defined criteria for assessing traffic and environmental conditions (weather, space weather, etc.) the LCC can also issue go/no-go messages itself.

From the start of the operation (T ≥ T0), the LCC processes the live state vector data of the spacecraft and provides the connected actors with real-time predictions for Instantaneous Impact Points[3] (IIPs) and HAs. The LCC monitors the spacecraft's trajectory (position, velocity, acceleration) and compares the values to the nominal trajectory and the approved flight corridor. If the data deviate from the nominal values, indications are given. In parallel, the LCC monitors the time schedule of the expected events related to the space operation such as stage separations and re-entry burns. In addition, depending on the availability of telemetry and tracking data, the trajectories and IIPs of the spacecraft components are (approximately) determined after the separation of stages and payload fairings.

Furthermore, the current traffic situation at sea and in the air is monitored and analyzed by the LCC. If, for example, the system recognizes that aircraft are in designated safety zones, appropriate warnings are given to ANSPs. Certain functions of the LCC also verify that restricted areas are clear of the spacecraft and its components and provide appropriate information about clear airspaces to ANSPs to support immediate airspace clearance to air traffic as soon as possible.

In case of a non-nominal event (e.g. Loss of Signal (LOS), trajectory deviation, explosion on trajectory), the LCC will display the status of the spacecraft and inform all stakeholders involved. When a LOS is confirmed, for example via a dedicated hotline, the LCC's risk modeling functions start calculations to determine a Refined Hazard Area (RHA) based on the last state vector received and the results are displayed on the dashboard. If the loss of the spacecraft is confirmed, the coordinates of the RHA can be immediately transmitted in digital form and via pre-defined protocols to all parties involved, in particular to the NM, the affected ANSPs, their ATCs, and other authorities that could benefit.

Based on procedures to be implemented, the provided information may be used by ATC to react on the confirmed non-nominal event and attempt to evacuate the affected airspace, thereby reducing the risk to other airspace users. To further mitigate risks, additional LCC functions could analyze and assess the situation of aircraft and vessels in relation to the RHA and provide further assistance in clearing the RHA.

The tasks of the LCC during the operational phase end when the spacecraft has reached orbit or has landed and all components have reached their designated locations or the airspace has been cleared after a terminated flight.

3.2.3. Mechanisms for Post-Mission Analysis

The LCC provides recorded and processed data from the preparatory and operational phases for analyses and evaluations as part of the follow-up activities to an operation. These data can be used to compare forecasts and real data, especially with regard to trajectory, HAs, and schedule. Specific functions of the LCC also support the identification of possible causes for differences and deviations. Potential causes could be, for example, unexpected meteorological conditions or events.

[2] Basic maps: Esri, HERE, Garmin, USGS and Google and OpenStreetMap, Programs: MATLAB and QGIS
[3] Landing point of a spacecraft assuming an immediate engine stop on its trajectory.

In particular, the LCC supports the analysis and evaluation of the impact of the space operation on the air traffic system. For example, effects on airspace capacity and the length of routes as well as time and financial aspects are examined. Furthermore, the actual execution and performance of the established processes within the two previous phases is evaluated and analyzed for optimization potential, for example with regard to communication and cooperation between the individual stakeholders. For this purpose, standardized feedback is collected from the stakeholders.

The findings and quantitative results obtained on the basis of user feedback and data evaluations are stored in a standardized format and made available to all stakeholders so that they can be taken into account for future activities. In addition, according to the LCC concept, all the knowledge, results, and raw data are stored in a central repository to which all interested parties can have access. Thereby, all necessary and mandatory data protection restrictions are considered.

4. SOFTWARE ENGINEERING CONSIDERATIONS

Analyzing the current operational background and procedures and generating a vision of a new operational concept is one part of the system development. Another part is the implementation in software and hardware to first set up a prototype of an LCC and later transfer it to regular operations. Therefore, an appropriate procedure model for the development process and a suitable software architecture must be chosen.

In modern innovative software development, it is advisable to start by designing the most important requirements for a system in rudimentary form. With these requirements, a prototype or a Minimum Viable Product (MVP) can be developed. With subsequent feedback from stakeholders, the first draft can be revised and improved. New requirements are derived from the feedback. The existing requirements can be re-evaluated and prioritized. At the end of the process, the prioritized requirements are implemented in the architecture. In doing so, both, the equally important software requirements and the system architecture, are refined based on user feedback throughout the development process. This is a rough description of the iterative Twin Peaks procedure model. Together with a tailored agile SCRUM approach, it delivers the flexibility and the possibility to develop requirements and the architecture in an iterative, agile, and parallel manner. The characteristic iterative approach described here, involving the addressed stakeholders, is the reason why this development procedure is chosen for implementing the mechanisms of multi-stakeholder coordination. [9; 10; 11]

Further, choosing the right software architecture is essential, because once an architecture is in place, it is very hard (and expensive) to change. Generally, software architecture can be defined as all the fundamental parts that establish the structure, operation, and interaction between the software components. Another general and simple definition to fit the essence of the term software architecture is given by [12]:

$$software\ architecture := \sum of\ all\ important\ decisions$$

Thereby, important decisions can be characterized as being fundamentally, difficult to change in the further process, and crucial for the success of the software system [12]. Hence, the software engineering and design process has to tackle the following aspects [12]:

- Task Analysis
  - Definition of context
  - Understanding quality objectives
  - Clarifying general conditions
- Decomposition
  - Modules and dependencies
  - Component structure
- Technology Stack
  - Programming language(s), libraries, frameworks
  - Middleware (communication, application server, etc.)
  - Cross-cutting topics (persistence, interface, etc.)
- Standards and Documentation
- Definition of Minimum Viable Product

When implementing an architecture for an LCC supporting multi-stakeholder coordination of future space operations, the operational environment and the constraints and challenges faced by the stakeholders must be considered. For example, many spaceports will have to support various launcher types and thus meet varying operational constraints and stakeholder requirements. Similar applies for launch providers using multiple launch sites and related infrastructures and coordinating with various alternating site operators and additional parties. Hence flexibility, resilience, extensibility, application scalability, and security are very important requirements regarding to choose the right architecture pattern. Designing an architecture based on the microservice concept is a direct response to many of these challenges.

Microservices are characterized being small, loosely-coupled, and distributed. They enable a modular structure of software applications tackling the well-known challenge of complexity in a large codebase by decomposing a large monolithic application in to small components with distinct defined responsibilities that are easy to manage. Thereby, small, simple, and decoupled services can be equated with scalable, resilient, and flexible applications. Particularly in the case of an innovative, challenging project, such as the development of a future LCC, it offers the necessary flexibility to be able to react to changes without having to change the basic architecture. [13]

5. SUMMARY AND OUTLOOK

The space industry is currently growing very rapidly and new challenges are arising for all players. By developing an LCC and associated services, DLR intends to provided solutions to face some of these challenges. The aim of the LCC is to enable safe and efficient 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 especially relevant against the background of an increase in space operations in Europe, so that not only the integration into the air traffic system but also the coordination of space activities among each other is enabled. Both aspects are particularly relevant for site operators providing the ground-based infrastructures to perform launches and re-entries on a regular basis.

The provided services will be applicable for all types of spacecraft and mission variants (e.g. air launch, vertical launch, suborbital flight) in the phases in which an interaction with air traffic takes place as well as for the corresponding planning and postprocessing. Thereby, the dissemination of essential information to all connected stakeholders will enable fast and appropriate actions during nominal and non-nominal operations. In doing so, 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. In the long term, this approach could also serve site operators because a more seamless integration could enable even more frequent space flights.

In order to demonstrate the described functionalities, a prototype of the LCC is currently build up at DLR's Institute of Flight Guidance in Braunschweig. As part of this development, a Concept of Operations (ConOps) has already been defined to describe the system from the user's point of view, covering various use cases. Based on this ConOps, system requirements have been defined. The aim is to further develop the requirements and the corresponding system concept based on discussions with potential stakeholders of the LCC in an iterative way. In parallel, software components of the LCC are being implemented. Thereby, as described, an appropriate architecture is used to build up the system. The objective is to operate and evaluate the LCC prototype in the context of a pilot mission.

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