A CONCEPT FOR IMPROVED INTEGRATION OF SPACE VEHICLE OPERATION INTO ATM

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Commercial Space Transportation (CST) is stimulating increased activities in spaceflight and suborbital launches. With the implementation of mega constellations for space based broadband coverage, further growth is expected. Space vehicles will more frequently pass through civil airspace and will evolve from rare special events to regular airspace users. This development is creating an evident need for a safe and efficient integration of space vehicle operations into the air traffic system. DLR is addressing this topic applying a case study approach to analyze the effects of space vehicle operations on air traffic and to evaluate mitigation strategies and optimized Air Traffic Management (ATM) integration, as it will play a key role in the effort to ensure a sustainable CST system. The current state of the art of integrating spaceflight into ATM has to evolve to a concept that facilitates the requirements of trajectory based operations under the regimes of modern ATM systems in Europe and the US. A conceptual approach has been developed to utilize service oriented information distribution as backbone for improved planning and operational integration of space flight activities within an airspace and near-space environment.It will enhance the situational awareness for all relevant stakeholders while implementing procedures for a safe and efficient management of both – air traffic and space flight operation.

1 INTRODUCTION

As the number of launch and re-entry operations is increasing and numerous new operational concepts for space transportation (like suborbital spaceplanes) are emerging, the conventional way of managing air traffic around space operations is getting stressed. The expansion of spaceports all over the world and new users for the airspace above 60.000ft / FL600 (like high altitude platforms or orbiting balloons) are posing additional challenges. In the past, the task of space vehicle integration into the air transport system has been tackled by applying concepts of traffic separation through the definition of restricted areas around the expected space vehicle trajectory for a certain period of time of the space operation event. The size of the restricted areas (usually defined as a Temporary Restricted Area, TRA or Temporary Flight Restriction, TFR) corresponds to calculated areas along the operational event or flight track, for which the acceptable risk threshold in case of a mishap is exceeded. This applies around launch and landing site (spaceports) or the expected areas for capsule or rocket stage landing / splash down. Those areas might also be protected by so called Special Use Airspaces (SUA), which are not mission specifically shaped but designed to allow for general operations like rocket launches. Areas in front and below of a flying spacecraft are protected by so called hazard areas, basically following the same approach of risk calculation. For flight phases passing through regular airspace, these hazard areas typically are closed for air traffic. For flight phases above an altitude of 60.000ft, airspace covered by the hazard areas below the flight track and below FL600 typically will not be closed, as long as protective measures are in place to ensure timely evacuation of airplanes within those areas through Air Traffic Control (ATC) [1]. But due to the increased number of space operations, interference with regular air traffic is increasing while the operational interests of both, space vehicle and airplane operators have to be balanced. New solutions for efficient and sustainable integration of all types of airspace users have to be developed, evaluated and implemented.

2 DLR CASE STUDY APPROACH

To work on the challenges of space vehicle integration into the Air Transport System and Air Traffic Management, DLR has established a case based approach, which intends to consider various kinds of air traffic related space operations as well as the development of general space traffic integration concepts [2].

The following prerequisites have been established:

- a framework for CST traffic impact analysis for European airspace, and
- a framework for testing and evaluation of procedures and functionalities for an improved handling of CST on ATM stakeholder level, including the required data exchange and tactical air traffic interaction with humans in the loop (Space and ATM operational testbed).

The use cases to be analyzed are covering operations like

- Land-based rocket launch to orbit
- Air launched rockets to orbit
- De-orbiting Space Vehicle
- Suborbital Flights
- Suborbital Point-to-Point Travel
- High altitude operations

The case studies will analyze traffic impact and integration concepts for those types of space vehicle operations (SVO) with a specific focus on operations affecting European airspace (while not leaving out the global perspective). Planning and execution of the evaluation is following the European Operational Concept Validation Methodology (E-OCVM) [3] and is in line with the Operational Concept Validation Strategy Document (OCVSD) [4].

The mission concept of the DLR SpaceLiner, a future high-speed suborbital intercontinental passenger transport vehicle, has been chosen as first case study. The SpaceLiner is designed as rocket-propelled, two staged suborbital Reusable Launch Vehicle (RLV), servicing ultra long-haul distances like Europe – Australia in 90 minutes [5][6]. A traffic impact analysis has been prepared and conducted for the SpaceLiner return trajectory towards a European landing site (Figure 1), which gave evidence about the neuralgic segments regarding air traffic integration during the high- and low altitude phases of its proposed flight trajectory [7].

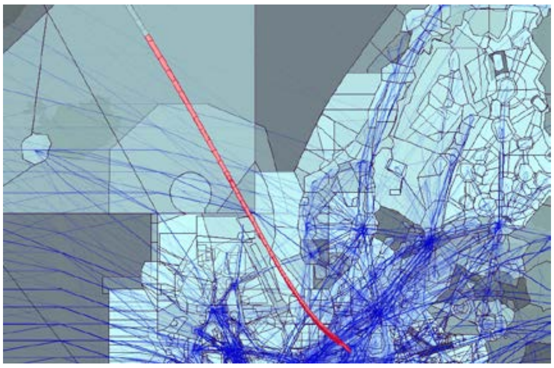

Figure 1: Integration of the SpaceLiner trajectory into a European air traffic scenario [7]

In conclusion of the performed traffic impact analysis, the need for advanced integration concepts became evident. The implications of incorporating high-speed re-entry trajectories towards spaceports within the European airspace seem to be too significant when applying conservative measures like extended restricted areas and closed airspaces.

While research currently is performed on an optimized design and handling of hazard areas, a broader view on exploiting the specific advantages of future new ATM concepts may help to advance towards an integrated management of space and air traffic operations.

3 INFORMATION EXCHANGE FOR EFFICIENT SPACE VEHICLE INTEGRATION

An important element of improved integration of space operations into ATM is a timely and reliable access to essential operational data of the space vehicle by all relevant stakeholders, and vice versa. The System Wide Information Management (SWIM) concept can be used to fulfill this requirement. SWIM is part of the European and U.S. ATM development programs, called Single European Sky Air Traffic Management Research (SESAR) and Next Generation Air Transportation System (NextGen). It can be seen as an intranet for ATM, aiming at providing all relevant information at the right time and with the right quality to the right stakeholders. SWIM is based on a net-centric approach for connecting multiple stakeholders, each running its own information system, and using SWIM to communicate. It consists of standards, infrastructure and governance enabling the management of ATM information and its exchange between qualified parties via interoperable services.

It has been demonstrated earlier how a SWIM-based space vehicle integration prototype can be used to provide on-time information like hazard area locations to subscribing data consumers [8]. Furthermore it facilitates an architectural solution which can provide interoperability between SESAR and NextGen and a European / U.S. harmonization for such a service based information distribution has been shown [9].

By providing all kind of relevant data, this SWIM based information exchange can foster the planning, coordination, monitoring and common situational awareness through all phases of SVOs for its interfacing with air traffic.

4 NEW ATM CONCEPTS FACILITATING THE INTEGRATION OF SPACE VEHICLES

As important as data availability is, its benefit depends on ATM concepts and supporting technologies which can use such information exchange during planning and execution of space flights for improved efficiency of the overall air- and space transportation system. As such, the transition of ATM towards trajectory based operations (TBO) under the regimes of the Single European Sky (SES) and the U.S. NextGen is an essential key element for this purpose. TBO is based on the use of a 4D-trajectorie for each aircraft, which precisely describes the flight of an aircraft in airspace and time. In the context of flight planning in the TBO based ATM environment, early planning in principle can start from years to 6 month before departure, using a so called Business Development Trajectory (BDT). From 6 month to hours before departure, the planning phase turns into the Shared Business Trajectory (SBT), which is used for refinement and negotiation between the ATM stakeholders. In the execution phase, it becomes the Reference Business Trajectory (RBT), which is then subject to authorization, revision and updating. While the BDT is user internal only, SBT and RBT are shared by all ATM participants, which can as well be facilitated by SWIM.

Implementing SVO planning and flight execution data into the SWIM based information distribution, TBO allows a specific evaluation of the impact of a space vehicles planned trajectory and its associated hazard areas on air traffic early on. By this, time and duration of the SVO can be optimized considering air traffic impact issues as well as mission related requirements. This approach expands the current ideas of using business trajectories as part of a flight planning and execution process by adding the space vehicle operator into the group of airspace users to agree on a preferred trajectory with Air Navigation Service Providers (ANSPs) and airport operators.

Considering TBO as the basic principle of future air traffic operations, the handling of space vehicles flying through and above airspaces might benefit from improved Airspace Management (ASM) and Air Traffic Control (ATC) concepts which are based on agreed and predictable flight trajectories. In the following, three concepts for improved ASM and ATC are discussed regarding their potential to facilitate an advanced space traffic management.

4.1 Advanced Flexible Use of Airspace

Flexible Use of Airspace (FUA) is a concept which has been developed by EUROCONTROL already in the 1990s. It is specifically addressing the three-level civil-military coordination tasks of ASM [10]:

- "Strategic Level 1 – definition of the national airspace policy and establishment of pre-determined airspace structures;
- Pre-tactical Level 2 – day-to-day allocation of airspace according to user requirements;
- Tactical Level 3 – real-time use of airspace allowing safe Operational Air Traffic & General Air Traffic (OAT & GAT) operations."

FUA essentially changed the allocation of airspaces from being either "civil" or "military" by considering it as one continuum, which specific usage will be allocated according to user requirements. Required airspace segregations are only temporary, based on real-time usage within a defined time period. Contiguous volumes of airspace are not constrained by national boundaries, which is of special importance within the partially dense and small-sectioned European airspace.

With this in mind, the FUA concept can also be applied on the use of space operation specific SUAs. It allows for a more flexible use of the SUA as it could provide at least partial use of the airspace by other stakeholders on temporary assignments. As a result, only just the relevant parts of the airspace would be restricted for special use (Figure 2).

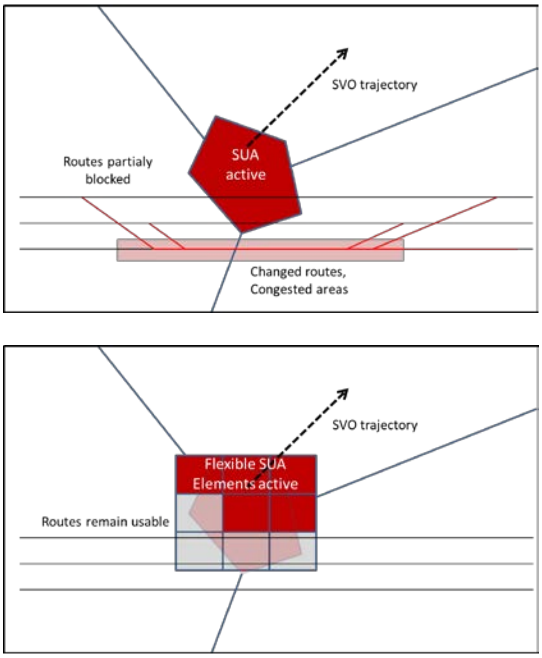

Figure 2: Simplified principle of a FUA concept applied to a SUA for SVO

By increasing the flexibility on how to use airspace segments by either military, civil (or space vehicle)

users, airspace capacity issues, air traffic route optimization and changing mission related requirements can be addressed successfully. This has been demonstrated as part of the routine civil/military coordination over Europe.
Nevertheless, practical application of the concept in the past was restricted by the capabilities of a timely planning and execution of changes in airspace usage and allocation of specific airspace segments to its designated users. Each change in airspace configuration has to pass through the Collaborative Decision Making (CDM) processes which have been implemented as part of the FUA concept.

To improve these processes, the FUA concept has been further evolved to an Advanced FUA (AFUA) and became part of the SESAR concept developments. AFUA addresses the need of faster information exchange and applying the principle of TBO to ensure dynamic airspace management in all phases of the flight, from the initial planning to the execution phase.

The centralized service 4 (CS4), one of 18 centralised services (CS) proposed by EUROCONTROL, is an AFUA enabler by centralizing all shared airspace management information and offering associated services to assist clients in their airspace optimization and usage process, thus the established collaboration is characterized by the following key attributes:

- dynamic,
- real-time,
- transparent,
- based on common situational awareness.

The interfacing with CS5 European ATM Information Management (EAIMS), which can be summarized as a single data reference for all flight operations in Europe and regarded as the bridge for system support based on SESAR SWIM concepts, will allow the agreement on as well as the negotiation of airspace allocations taking into account demands and constraints of all connected clients. SWIM enabled SVOs, especially in the context of protection zone / hazard area information provision, have the big potential of being integrated with minimized effort, established and motivated by the fact that SWIM relies on interoperability standards.

4.2 Dynamic Sectorization

Today's airspace organization is still characterized by a rather static definition of airspace sectors. To adapt to actual changes in traffic flow, existing sectors usually will be divided or merged with each other. The concept of "Dynamic Sectorization" aims at an adaptive, more flexible design of airspace sectors with respect to a harmonized task load of the controller. As opposed to the traditional way, at which the traffic flow has to follow the structure, dynamic airspaces shall adapt their structure to that flow. As a result, a more efficient use of the airspace becomes possible, as has been demonstrated for example by SESAR solution #66, called Automated Support for Dynamic Sectorization, which has shown specific benefits when adapting sectors dynamically to significant weather effects, temporally restricted areas or other operational constraints [12].

Considering the requirements for efficient space traffic integration, dynamic sectorization may further expand the aforementioned benefits of a concept like FUA. Flight restricted areas for SVO are defined by the thresholds of acceptable risks, associated to the specific vehicle and type of operation, or even by a generic definition for special usage (e.g. SUA). The size of restricted areas typically is calculated with conservative risk assessment approaches, debris models and sufficient safety margins. They remain rather static over the duration of the SVO, including activation of TFRs already in preparation of the actual manoeuvers in accordance to the defined window of operation (e.g. launch- or re-entry window). This leaves a significant amount of airspace unused for a significant period of time (for reasons very well justified) and reduces either the traffic flow (due to cancelations of flights) or increases the traffic load of the adjacent sectors.
Research has been performed to optimize the shapes, volumes and duration of hazard areas. One approach which has been studied is the use of so called compact envelopes and dynamic hazard areas, decreasing the volume and time the restriction is active as a no-fly zone for other airspace users [13].

Within a SWIM enabled TBO environment, the trajectories of planned and currently executed flights are known to all relevant ATM stakeholders in real time and therefore can be part of a continuous improvement process. As such, dynamic sectorization can adopt the optimized hazard area and space vehicle induced airspace restriction shapes & volumes into their calculation to determine an appropriate sectorization of the airspace regarding to the controller task load (Figure 3).

New approaches on adapting the optimal position and shape of each sector regarding to the actual necessities and restrictions, like AutoSec (Automatic Sectorization) [14], have the potential to further increase the efficiency of space vehicle integration. They optimize the handling of surrounding traffic and increase the capability of the air traffic system to cope with dynamic restrictions.

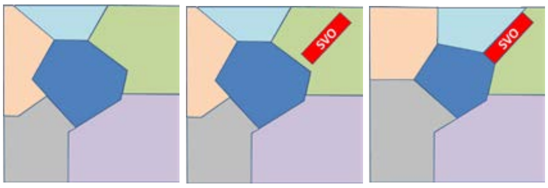

Figure 3: Concept idea for dynamic sectorization around SVO restricted areas

4.3 Flight Centric ATC

Flight Centric ATC or Sectorless ATM is an innovative concept which has been adopted by the SESAR 2020 research program as part of the Separation Management En-Route and TMA project PJ10 [15]. As for dynamic sectorization, the development is driven by the task to adjust air traffic controller workload to the current traffic demand. The idea is to eliminate sector boundaries and changing air traffic controller responsibility from managing the entire traffic in one sector towards being in charge to guide several flights through a large volume of airspace whereas other controllers are responsible for a certain number of different aircraft within the same airspace. Nevertheless, the controller still has to ensure a conflict-free flight of the aircraft he is responsible for [16].

Flight centric ATC is currently envisioned as a solution for a low complexity en-route environment, especially for upper airspace. Later on, a possible expansion into a medium to high complexity en-route environment will be analyzed, including as well fixed route- as free route concepts.

The concept as well is based on precise trajectory information, which allows the controller to look ahead in time and detecting and resolving possible conflicts with other aircrafts. The work of the controller is getting supported via intelligent tools, including a new type of situation display which supports conflict detection and conflict alerts, helping the controller to maintain situational awareness.

As the concept is based on assigning the responsibility of guiding individual vehicles through large sized airspaces, it is by design creating the possibility to have dedicated controllers for managing flights with very specific characteristics. This would allow for example a dedicated controller for a space vehicle, monitoring its trajectory and ensuring it to be free of conflicts with other flight trajectories, taking into account real-time data on the space vehicles status (also in pre-launch situations inside of the launch window). While the space vehicle trajectory itself may not be adapted in flight to avoid other traffic, the flight centric concept provides all necessary elements to optimize individual flights in the vicinity of the SVO (Figure 4).

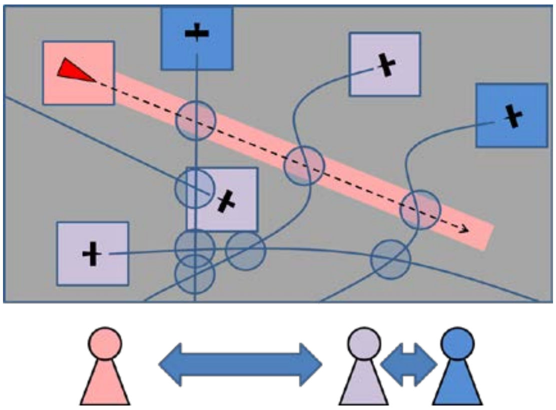

Figure 4: Illustrating the allocation of responsibility for individual flights within a flight centric ATC concept, assigning the space vehicle to a dedicated controller

Furthermore, the trajectories of aircraft passing through planned hazard areas (during space vehicle overflights) could be provided with predefined escape trajectories, allowing for immediately clearing a hazard area in case of a mishap. Those escape trajectories could be pre-checked by the responsible controller, adapted continuously during progress of the flight and individually advised in case of off-nominal events. As the responsibility for aircraft would not be concentrated on one controller operating the affected sector, aircraft could be guided individually and under permanent monitoring of their designated controllers without exceeding their workload.

The concept of sectorless ATM could also be used to address the upcoming challenges of increased use of airspace above FL600 (60.ooo ft). This so called Near Space region might soon be populated by airspace users operating under very different characteristics. While again space vehicles will pass through the Near Space region with very high speeds, the same applies for air transport concepts like sub-orbital hypersonic intercontinental passenger flights. On the other hand, the operational concept of High Altitude Platforms (HAPS) includes missions that require long duration station keeping [17]. High altitude balloons like the Google Loon concept [18] might form constellations that travel within atmospheric wind fields, following comparably difficult to predict trajectories with comparably low speed profiles. In addition to these examples, many more new operational concepts are getting proposed and examined. All these new types of vehicles are challenging the current ATM, as they are very different from traditional aircraft operations [19]. Therefore, considering the vast size of the Near Space region and the variation in vehicle performance and mission requirements, a sectorless, flight centric control regime for operations also well above FL600 might be a conceptual approach worth exploring further.

5 SUMMARY AND CONCLUSION

The increase in number and types of space vehicle operations and airspace users for regions above altitudes of 60.000ft increases the requirement for an efficient integrated space and air traffic management. The implementation of trajectory based operations and system wide information management can be used as a foundation for this matter, as it allows accurate, predictable and reliable planning and management of flights as well as on-time data availability for all relevant stakeholders. New ATM concepts facilitated by TBO and SWIM provide potentials to be fostered improving the efficiency of space vehicle integration. The concept of Advanced Flexible Use of Airspace may provide improved efficiency for Special Use Airspace during SVO. By implementing the centralized services CS4 and CS5, Europe is creating essential enablers for SVO integration into an AFUA environment. Dynamic sectorization can lead to an increased efficiency of air traffic management adjacent to the restricted areas required by the SVO, thereby reducing its impact on the air transport system. By dissolving the need for sectorized traffic control, the flight centric ATC concept offers interesting possibilities for controlling individual space vehicles during their flight through airspace as well as for optimizing the handling of flights interfering with the space vehicles trajectory. The sectorless approach might also be an option to address the challenges of controlling vehicles within the Near Space region above 60.000ft with all their diverse operational characteristics. It is suggested to further explore the capabilities of the above mentioned ATM concepts regarding their usability for an improved integration of space vehicles into air traffic management.

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