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Integration of UAS in Air Traffic and Commercial Space Management

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Commercial Space Transportation and Air Traffic Insertion - SESAR Requirements and the European Perspective

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ABSTRACT

Commercial Space Transportation becomes an international business and requires landing opportunities all over the world. Hence the integration of space vehicles in other airspace than the US NAS is an important topic to be considered. The Single European Sky ATM Research Programme (SESAR) is preparing the implementation of a new ATM system in Europe. The requirements are defined by the concept of the Shared and Reference Business Trajectory as well as System Wide Information Management (SWIM).

Space vehicle operations are associated with the requested need for submitting a Mishap Investigation Plan (MIP), containing responding and reporting procedures referring to possible reentry or launch incidents or accidents. This leads to the submission of an Emergency Response Plan (ERP), addressing information procedures about a planned Reusable Launch Vehicle (RLV) mission of the airspace alerting and emergency services in the areas of:

- *Emergency Detection*
- *Response Organization*

This paper describes the integration of the above mentioned services in the Air Traffic Management (ATM) information exchange concept of SWIM. It proposes an implementation concept via the world wide use of Remote Tower Operations (RTO) for surveillance of safe landings at spaceports far away from the launch/start site.

1. INTRODUCTION

With the commercialization of Space Operations under way, the number of Space Vehicle Operation is expected to increase significantly in the upcoming years. Areas of operation will expand from the current established and well known space ports (e.g. Cape Caneveral, Vandenberg AFB, etc) towards new operational sites. A development not only expected to take place in the United States but as well in other countries.

If the expected cost reduction for Space Vehicle Operation can be realized and commercial space operation established beyond support of national research and space programs, the number of launch and reentry activities will increase together with the number of possible launch and landing sites.

While operating a space port at a remote area with low density population might be an adequate approach in the early stages of expanding commercial space vehicle operation, the launch and reentry trajectories of space vehicles nevertheless will most probably have to interact with air traffic operations. As air traffic has increased over the last decades and is expected to continue its growth, this aspect will gain further importance and integrating both kinds of operations should be as seamless and efficient as possible.

During operation of the US Space Shuttle program, FAA and NASA gained extensive experience in coordination measures between space and air traffic management operation. The procedures used during the final phase of the Space Shuttle operation have resulted from revised concepts and use of tools initiated with the STS-114 "Return to Flight" mission [1] [2].

With regard to the interaction between Space Vehicle Operation and regular air traffic, two phases of space flight have to be considered: Launch Operation and Reentry Operation. During both phases, separation between aircraft and the space vehicle, including its potential hazard areas in case of malfunctions, have to be assured. Most of the typical launch and re-entry flight trajectories require only relatively small size of restricted airspace surrounding the launch- and landing sites to remain clear of the space vehicle (whereas the size and shape of the restricted airspace is dependent on the applied launch and re-entry procedure). Those kinds of restrictions have to be in place over the duration of the launch or re-entry operational window and cover a vertical area from the surface to an unlimited altitude. Especially for launch operation the actual airspace closure then can be limited to only a short period of time.

In addition to that, a much larger portion of airspace has to be managed regarding the risk of falling debris from an in-flight explosion or a breakup event. The resulting fragments can cover a relatively large area, depending on the velocity and altitude of the vehicle during its disintegration [2]. As already small particles (e.g. steel fragments of about 1 gram) can cause severe damage to flying aircraft, precautionary measures have to be taken to protect air traffic participants from such catastrophic events [3]. The possible distribution of debris following vehicle disintegration has to be calculated along the predicted flight trajectory, resulting into sequence of overlapping so called hazard areas. The size of each hazard area depends on the actual state vector (including altitude and velocity) of the space vehicle as well as its intended maneuvering and several environmental conditions as the wind forecast. Those areas then can be cleared from other traffic during the actual launch or re-entry operation.

The segregation of airspaces on the other hand has to be limited to a minimum in size and time, considering the need for an efficient and economic joint operation of space- and air traffic vehicles.

Adequate information management for all stakeholders within the air traffic system (ATS) alongside efficient procedures for planning and executing space operations in close cooperation with air traffic management therefore is essential. In Europe the interfaces between space and air traffic management have not been considered so far. However, the SESAR program has started and has already initiated significant steps and technologies to improve the efficiency of operation of the ATS, the predictability and robustness, including an optimized information management within ATM. SESAR can supply the necessary assets for implementing space operations seamlessly into the European ATS. Therefore the concepts and ideas of SESAR have to be followed.

In this context, the necessity for the submission of an Emergency Response Plan (ERP), addressing information procedures on Emergency Detection has to be addressed. This includes information relay between the Commercial Space Transportation (CST) vehicle operator and the Traffic Flow Management (TFM). Further-on, the emergency detection has to be followed by a Response Organization. As most CST will operate globally and missions may need to be aborted anywhere around the earth, a global alerting function has to include segregated foci of the involved response organizations, from international down to regional or even local reaction units.

2. SESAR REQUIREMENTS

The European Union aims in the context of the Single European Sky (SES) on the harmonization of the European Air Traffic Management (ATM). The objective is to efficiently utilize the limited capacity of European airspace through innovative techniques and operational procedures while improving the safety and environmental impact of air transport considerably. The SES schemes for the creation of the Single European Sky regulations include, among others, the provision of air navigation services, the organization and use of airspace and interoperability of ATM systems. The technical and organizational requirements for SES is investigated as part of the SES ATM Research Programme (SESAR) and developed in the course of three phases to the application stage. The current development phase is organized by the SESAR Joint Undertaking (SJU). The coordinated management of air traffic and situation-specific response is based on information exchange between all stakeholders in this system. It will be implemented by the concept of a System Wide Information Management (SWIM) which integrates for example also Controller-Pilot Data Link Communication (CPDLC) and other communication systems. In addition to the architecture of SWIM, the interoperability requirements for SWIM-compliant ATM systems are of great importance, Figure 1.

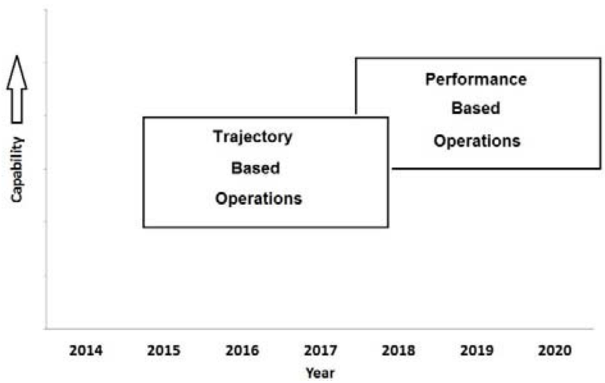

Figure 1. General SESAR requirements development

2.1 SWIM in SESAR

SWIM is one of the key concepts of the SESAR initiative. In the context of safety, cost efficiency and environmental impact getting the right information at the right time with the right quality to the right stakeholder is essential. It can be seen as the intranet for the future ATM and also Space Traffic Management (STM) system to provide seamless information interchange. SWIM will provide consistent information to different users that support active decision-making: Pilots, Airport Operations Centers, Airline Operations Centers, Air Navigation Service Providers, Meteorology Service Providers, Military Operations Centers, etc.

The SESAR defines the SWIM system as follows:

SWIM consists of standards, infrastructure and governance enabling the management of ATM information and its exchange between qualified parties via interoperable services. [4]

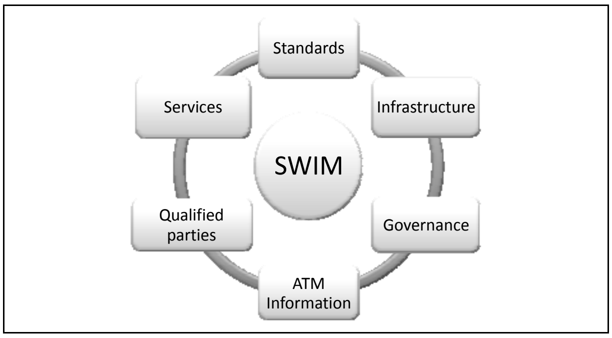

Figure 2 What defines SWIM

SWIM is and will be further developed as a Service Oriented Architecture (SOA). That will allow the flexible use of different separate systems from several business domains with registered and qualified partners due to general governance and a SWIM registry service. The SWIM registry is a trusted, managed, complete and consolidated source of reference for service information and related regulations (policies, standards, certifications) [5]. The architecture allows loose coupled components to interact in flexible an independent manner, Figure 2.

Using standards allows adding new SWIM conform services with ease and ensure that exchanged data share the same meaning at both their origin and their destination to enable systems to combine and process received information from other resources the semantic interoperability is vital for the ATM System development and interoperability. The basis for implementing SWIM enabled application are the ATM Information Reference Model (AIRM) [6], which will provide an implementation neutral definition of all ATM information and the Information Service Reference Model (ISRM) [7] which provides the logical breakdown of required information services and their behavioral patterns [4]. The logical meta model AIRM covers different domains like: Air Transport Operations, Flight, Meteorology, Surveillance, Airspace Infrastructure, Aircraft etc.

For the SWIM bzw. AIRM conform service implementation logical models like the Aeronautical Information Exchange Model (AIXM) [8], the Flight Information Exchange Model (FIXM) [9] and the Weather Information Exchange Models and Schema (WXCM-WXXM-WXXS) [10] results in physical data.

The SWIM technologies are classified into subsets (technology stacks) called profiles for the sake of interoperability and for design and development simplification. Every ATM operational service will fit to at least one SWIM profile considering their operational and non-functional requirements (performance, reliability, security).

SESAR SWIM has defined three different profiles:

- Blue profile: Flight Object using DDS (Data Distribution Service) [11].
- Yellow profile: AIXM/WXXM using Web Services Notification (WS-N) / Simple Object Access Protocol(SOAP) and the Advanced Message Queuing Protocol (AMQP) [12]
- Purple profile: Air to Ground via AMQP

Within the SWIM development process, SESAR initiated a series of SWIM Master Classes in 2012, 2013, and 2014. Objective was to demonstrate and evolve the reality of SWIM SESAR. SWIM-enabled applications and/or information services were developed and tested within a non-operational environment including access to the other SWIM developments, services and governance through the SWIM Registry [13] . It was demonstrated how SWIM will ATM Collaborative Decision Making processes.

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2.2 Shared & Reference Business Trajectory

The shared and reference business trajectory represent two stages in the general planned idea of the business trajectory's lifecycle, which is associated with the following timeline:

- From years to 6 months before departure, the stage refers to the business development trajectory (BDT).
- From 6 months to hours before departure, the planning phase turns it into the shared business trajectory (SBT).
- Then, the execution phase is reflected by the reference business trajectory (RBT).

Whereas the BDT is user internal only and characterized by corporate business planning actions, the SBT and the RBT are shared by all ATM participants, the SBT in terms of refinement and negotiation, the RBT by authorization, revision and updating. RBT authorization is segment oriented and can be compared to ATC clearances. The latest trajectory predictions are the source for RBT updates, where trajectory management requirements (TMR) specify frequency and accuracy of updates as well as aircraft requirements for sharing the predicted trajectory in case of a $delta_{time}$ and/or $delta_{lateral}$ and/or $delta_{level}$ is detected from previous predictions. Update transparency to pilots and controllers forms a fundamental benefit potential for sequencing, monitoring and conflict detection. RBT revision is mainly triggered by aircraft inabilities to fulfill RBT constraints or weather events causing a change need, but operational constraints can also drive a revision, e.g. airspace segregation. Unless ruled by time critical conditions, RBT revisions are subject to a collaborative process, too. The business trajectory principle can be summarized as a contract of objectives, where the institutions like airports, ANSPs, network managers and airlines collaborate to agree an optimum in efficiency and safety and the pilots and controllers as actors collaborate to manage disturbances (constraints) to that agreement in the most flexible manner possible, Figure 3.

3. INTEGRATION OF CST OPERATION INTO ATM

Considering as well current as proposed CST projects, a variation of mission profiles and space vehicle flight trajectories might have to be implemented into an operational context. For launch operation, not only classic vertical trajectories of expendable launch systems have to be considered. Multi stage in-flight launches or returnable/reusable rocket stages are under development and will come into operation within the foreseeable future. For reentry operations, new vehicle designs and suborbital mission profiles will join classic capsule reentries and shuttle-like landing procedures.

Launch and reentry operations are planned and executed well in advance, allowing for timely and thorough information sharing and implementation of required restrictions for the related airspaces and control zones. As most CST will operate globally and missions may need to be aborted anywhere around the earth, implementation, communication and enforcement of hazard areas and airspace restrictions should also be possible on relatively short notice and throughout the whole ATS. To allow this, the information sharing shall address pilots and air traffic control alike, including pre-flight preparation tools, in-flight updates and air traffic control systems. On the European level it shall use and facilitate the services and regulations defined by SESAR as described above.

The future SESAR SWIM "Intranet for ATM" concept requests all the air traffic participants acting as communicating sub-systems. Against this background, CST operations have to be taken into SWIM consideration for fulfilling this ATM integration need.

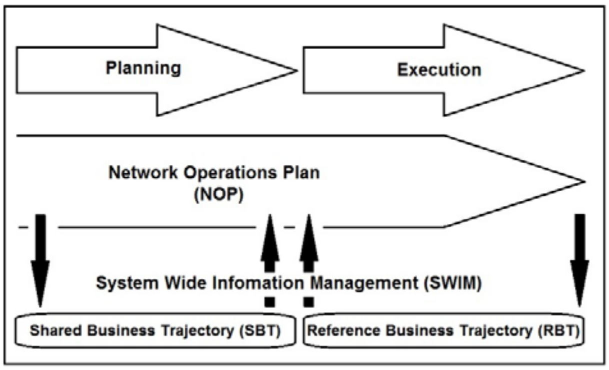


Figure 3. Business Trajectory process

3.1 General Approach

This paper proposes the general approach according to Figure 4 and in line with an information service solution for the SWIM Master Class 2013 dealing with local and global disturbance of the air traffic [14] as an “enabler” of making CST operations “swim” in a future European airspace. Its main part is represented by the SpaceCraftEmergencyInformationServer which is hosted by the Spacecraft Emergency Information Provider (e.g. the CST vehicle operator). The associated SWIM SpaceCraft-EmergencyInformationService shows conformity to the Open Geospatial Consortium (OGC) standards by implementing the services Web Map Service (WMS) and Web Feature Service (WFS). Consumers like Digital NOTAM and other ground users can “swim” in this context via WMS Request/Reply web service consumption. Users outside the “swimming pool” can consume the relevant information via standard http request to a chart web server, providing pre-formatted web charts. Foreseen onboard Electronic Flight Bag (EFB) feeding is supported by a WFS to Advanced Message Queuing Protocol (AMQP) gateway server, where AMQP is proposed because of the following reasons:

- Fulfills an anticipated EFB/onboard request for a binary protocol
- Covers message oriented middleware (MOM) support
- Fulfills the SWIM request for programming language independency

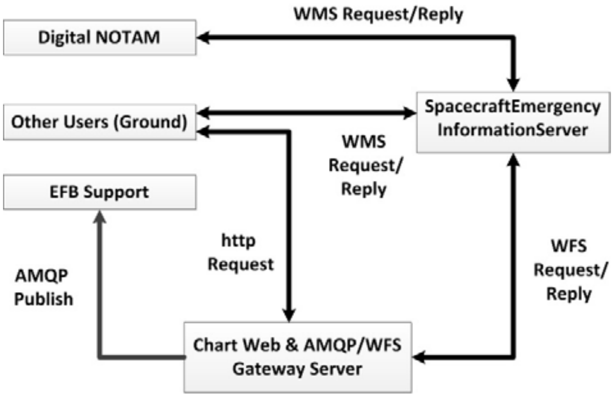


Figure 4. General approach

A more detailed functionality of the Spacecraft Emergency Information Provider side and its associated SpaceCraftEmergencyInformation-Server is shown in Figure 5, benefiting from the open source server software GeoServer [15], purely using open standards. A proposed Data-Fuser application acts as a geographical emergency zone data feeder to a PostGIS database. In case of an emergency event, last retrieved telemetry live data will be fused with forecast data from simulations to generate the actual situation picture. The DataFuser application may benefit from existing tools like the FAA's SWIFT tool and its own SWIM compatibility [16].

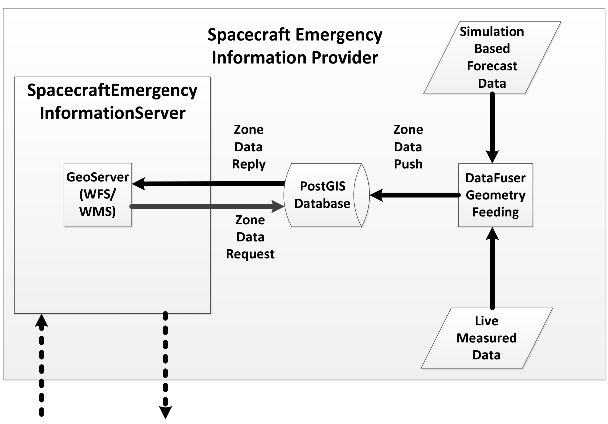


Figure 5. Spacecraft Emergency Information Provider

3.2 Flight Planning

Prior to official submission, flight plans could be checked against potential hazard areas of planned CST missions by making the IFPS Validation System (IFPUV) [17] a SpaceCraft-EmergencyInformationService consumer, thus enhancing the Flight Plan Pre-validation Service with consistency checking in the Aeronautical Information Management Special Use Airspace (SUA) Data Exchange context [18].

3.3 Flight Execution

Flight execution adaptation to potential CST emergency incidents can be realized by letting air traffic controller surveillance assistant tools consume the SpaceCraftEmergencyInformation-Service, enabling controllers to react to actual hazard zone information data by issuing associated voice commands to the concerned aircrafts of relevance. Integration possibilities in the integrated filtered data access service [19] are given by its service interface (Figure 6), which could be enhanced and/or adapted to become a SpaceCraftEmergencyInformationService consumer, too. Apart from SpaceCraftEmergency-InformationService consuming, hazard zone information reception can be achieved via standard http requests for pre-formatted web charts to a chart web server (Figure 4.), as a SWIM principle alternative or in a transition phase to it. Parallel to the hazard zone plane reaction loop via air traffic control (ATC), direct onboard information update can be established by EFB software acting as an AMQP subscriber to the gate way server AMQP publishing (Figure 4). In addition, Aircraft Access to SWIM (AAtS) [20] enhancement is foreseen to be generally reachable by consumption of the SpaceCraftEmergencyInformationService on the National Airspace (NAS) data provider side for aeronautical data service [20] extension purposes.

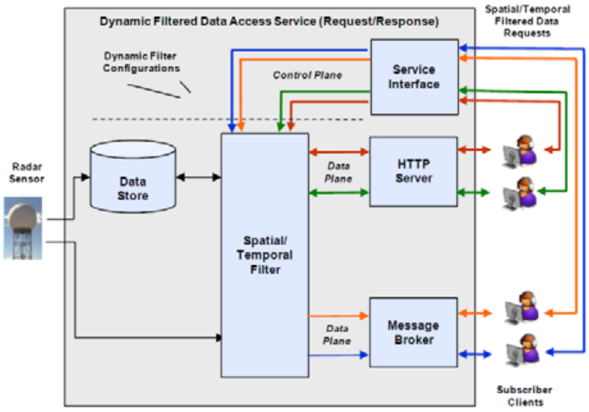


Figure 6. Integrated filtered data access service [19]

4. IMPLEMENTATION CONCEPT FOR REMOTE TOWER OPERATIONS OF CST

CST will operate globally, and missions will be finished on schedule anywhere in the world. This will even be more valid in an emergency abortion. Remote Tower Operations (RTO) could supply a cost efficient possibility to control remote airfiels all over the world from the CST base without dispatching personal to remote locations.

The RTO concept has been developed for a more cost-effective control of small and low traffic density airports [22][23]. The concept relies on the replacement of the conventional Air Traffic Controller workplace (CWP-tower) by a remote controller working position (CWP-remote). For short- and midterm realization of a CWP-remote the out the window (OTW) view will be a digitally reconstructed panoramic view using high resolution video cameras and transmitting those video surveillance data to the CWP-remote, which, thus, is not tied to a certain place. The DLR project RapTOr (Remote Airport Tower Operation Research, 2005-2007) focused on remote tower control of a single airports, while the project RAiCe (Remote Airport traffic control center, 2008-2012) focused on the idea to control multiple small airports from one remote center [23].

From an US perspective there is a strong motivation to work out operational and functional requirements, technical requirements, and the integration of concepts [24], to ensure the safety when applying RTO. Their concepts on staffed NextGen Tower also explore alternative surveillance systems for the OTW [25]. The same perspective applies for Europe, especially within the Single European Sky ATM Research Program (SESAR). There, Remote Tower is addressed under a separate Operational Focus Area (06.03.01). This Operational Focus Area comprises the different Remote Tower Activities assigned in the Operational Projects [21]. A typical set-up of a Remote Tower System is shown in Figure 7 and Figure 8.

Figure 7. Camera on the top of an airport tower

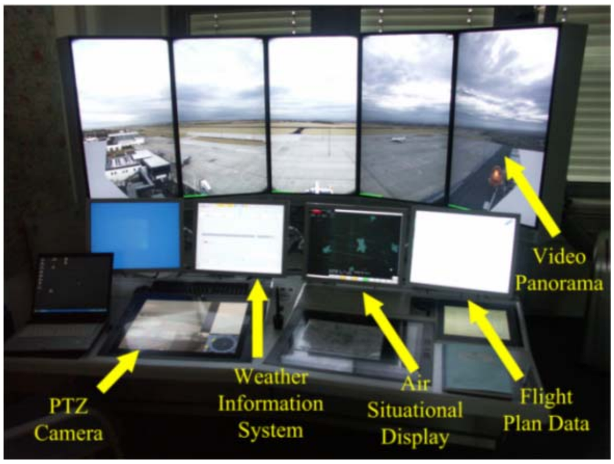
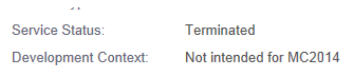


Figure 8. CWP-remote for an airport

Figure 7 shows the camera system which, for a SESAR test campagne, was installed on Erfurt airport. The video data were transmitted to DLR Braunschweig via a distance of 200km for technical tests and to the CWP-remote in the base-



ment of the Tower building for human in the loop shadow mode trials [27]. The CWP-remote comprises of a weather information display, an air situational display (approach radar) and the relevant flight plan data. A high resolution video panorama shows the “tower” view to the airport or airfield. By those SESAR trials with real traffic and real air traffic controllers it could been proven that the remote tower concept is a viable concept [24] [27]. Also it is proposed to include RTO in the SWIM services. The EUROCONTROL SWIM Registry - Aerodrome Remote Tower Service of 31 July 2013 [15], lists: “The Aerodrome Remote Tower Service aims to provide full ATC services as remote Tower or NO-Tower… The service is enabled by the infrastructure offered by the AAATC application (see Airport automated ATC System). Within the scope of SWIM Master Class, the demonstration will use the ATC HMI used within the AAATCS to prove the viability of a remote ATC Tower operations, supporting both manual ATC / semi-automated functionality…it is not (yet) intended for the Masterclass 2014.” Hence, the Aerodrome remote Tower Service ensuring availability and exchange of information to facilitate semi-automated ATC functionalities is underway, will be included in SWIM and will be available in the future. Adapting the RTO concept towards support of CST landing operations together with its integration into the SWIM context may offer various advantages for the efficiency of commercial space operations. The benefits have to be investigated.

5. NEXT STEPS AND OUTLOOK

The described components of a SWIM based world wide CST operating system need to be investigated to build a future system. SESAR supports projects to bridge the gap between research and applicable operations. The SESAR research activities are linked to the European Operational Concept Validation Method (E-OCVM), which describes the development and validation activities as an iterative process within a seven step model [28], [21]. Three steps (V1 to V3) within the seven step model were developed to formalize the process of concept validation for industrialization (Figure 9).

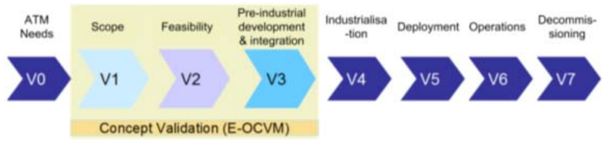


Figure 9. The Lifecycle V-Phases, validation and other ATM systems development activities [28]

Looking to that scheme, validations of the proposed concept on phase V2 and V3 will be the next steps.

- Clarification about further details of available space operation related Aeronautical Information Management tools and their SWIM compatibility for integration purposes referring the Spacecraft Emergency Information Provider
- Development of a Spacecraft Emergency Information Provider prototype
- Flight planning phase testing in a validation system simulation with Integrated Initial Flight Plan System (IFPS)
- Flight execution phase testing in a human-in-the-loop ATM simulation with air traffic controller surveillance assistant tools acting as individual SWIM SpaceCraftEmergencyInformation-Service consumers
- Flight planning and execution testing in a complex RTO ATM human-in-the-loop simulation under full traffic conditions for human factors assessment purposes

6. SUMMARY

The paper presents the time line of the SESAR requirements and the associated need of integrating future CST operations in the SWIM context. A further detail description of SWIM is given in combination with first CST implementation concepts and their evolvement potential covering the phases of flight planning and execution in the shared and reference business trajectory environment. The RTO concept usage is described as a future SWIM CST benefiting use case. Next steps in the area of basing further work on existing implementation ideas are identified, especially against the US/European harmonization background.

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