Enhanced Controller Working Position for Integrating Spaceflight into Air Traffic Management

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Abstract. Commercial space transportation is raising the number of space activities and space vehicles are increasingly traversing the civil airspace. During such activities, aircraft need to be protected from possible non-nominal events, particularly from those generating debris. To respond effectively to malfunctions operators and air navigation service provider (ANSP) need to collaborate and exchange operational data. In the data exchange project (DEP) the German Aerospace Center (DLR) cooperates with the Federal Aviation Administration (FAA) to demonstrate such a data exchange. Based on the data exchange, DLR has developed a concept to visualize information at the controller working position (CWP). This enables the controller to initiate appropriate measures to protect aircraft from falling debris. The concept was implemented and evaluated at DLR's Air Traffic Validation Center. The goal was to identify, if the information presented is the information required by controllers to manage the situation.

Keywords: Commercial space integration · Air traffic management · Controller working position · Real-time simulation · Human machine interface

1 Introduction

On their way to space and back to Earth space vehicles are traversing through the airspace where air traffic operates [1]. Since space activities are carried out at a lower target level of safety than aviation activities [2], they present a potential risk to the airspace system [3]. Therefore, large volumes of airspace around the nominal trajectory are currently blocked to protect other airspace users [4, 5]. Such inconveniences are tolerated since the number of space activities is currently limited [5]. However, due to the commercialization of space transportation, space operations are shifting from rare to regular events [6]. Furthermore, they will increasingly operate in the vicinity of highly frequented airspaces, as new spaceports are no longer located only in remote regions [7]. As a result, the conventional approach, which restricts flights from large areas, for a significant amount of time, will not last [8]. Instead, space operations need to be better integrated into the air traffic management (ATM). This should ensure that a safe and efficient service is provided to all airspace users. In order to achieve this, it is

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indispensable that operators and ANSPs cooperate and that key information is accessible at all times. An automatic data exchange could help to realize this. If the data is then made available to controllers, it will increase their situational awareness and allow them to react appropriately to non-nominal events.

2 DLR-FAA Data Exchange Project (DEP)

The Institute of Flight Guidance of the DLR and the Office of Commercial Space Transportation of the FAA are cooperating to identify the data that may need to be exchanged between operators and ANSPs prior to, during and after space operations. Furthermore, they strive to enable and demonstrate such a data exchange. This data exchange should facilitate improved situational awareness and hence, allow a safe and efficient management of global airspace during launch and re-entry operations. Moreover, US and European ANSPs should be able to respond appropriately to non-nominal events during space operations.

The technical solution of the data exchange will leverage existing international data standards and infrastructure by using an approach based on System Wide Information Management (SWIM). The SWIM concept emerges from both, the Single European Sky ATM Research (SESAR) program and the NextGen program. "It consists of standards, infrastructure and governance enabling the management of ATM related information and its exchange between qualified parties via interoperable services" (ICAO Doc. 10039) [9]. SWIM was developed for ATM. Its use within the DLR-FAA cooperation will show whether and to what extent SWIM can be used to facilitate the integration of space operations into ATM.

3 Demonstration Scenario

DLR and FAA demonstrate the automatic data exchange by simulating different generic operation scenarios with non-nominal events. One of these generic scenarios, the on-trajectory explosion of a space vehicle after launch at Cape Canaveral, is selected to provide the situational context for the concept development. Thereby the planned north-easterly trajectory of the space vehicle crosses the Atlantic Ocean and Northern Europe. During the joint collaborative demonstrations, the FAA will monitor the simulated launch and continuously receive generic data on the condition of the space vehicle. The state vectors will be transmitted every second via SWIM-push to the corresponding European ANSPs, here represented by DLR. When the space vehicle is well above the controlled airspace, the on-trajectory explosion will occur. The resulting debris will penetrate European Irish airspace, whereas it will take some time to reach aircraft altitudes. Based on the last received state vector a hazard area (HA) is calculated, which is defined as the area below the flight trajectory of the space vehicle for which the risk from potential debris impact exceeds acceptable risk limits. Once calculated the HA is also transmitted via SWIM-push. It is now the task of the ANSPs to process the received data and to use it effectively for ATM enabling controllers to re-route aircraft out of the HA.

4 Concept

Data exchange and the resulting data availability is important, but a benefit for air and space traffic management will only arise if concepts and technologies are able to process this data [10]. Hence, based on the data exchange, DLR has developed a concept that visualizes specific data at the CWP. This shall enable controllers to initiate appropriate measures to protect air traffic from falling debris.

The event under consideration is time-critical and occurs rarely. Controllers will not use procedures for non-nominal events every day, but they need to react to such events in a limited amount of time. Therefore, the concept should be based on known elements so that the right actions are intuitively provoked and experience can be drawn on. Additionally, the system should be designed to be user-friendly.

Fragments weighting as little as one gram can already cause considerable damage to an aircraft, and potentially lead to fatal consequences [11]. Therefore, it is imperative that controllers guide aircraft out of the HA to ensure that air traffic safety is always maintained. To perform this task, the following information is essential to a controller: The location of the HA, the period of activation and the aircraft, which are potentially at risk. The concept must provide all this information.

During space mission planning, so-called contingency hazard areas (CHA) are calculated based on the planned trajectory. These indicate the parts of an airspace that could be affected by debris if the explosion occurs within a certain time interval. If no malfunction occurs during the space activity, the knowledge about the CHA might not be relevant for the ANSPs. However, in the event of an incident, the CHA will be the first indication for estimating the affected area. Therefore, having the CHA stored in the system may be useful. When the non-nominal event occurs, the coordinates of a more precise HA are calculated from the last known state vector for the exact time of the occurrence and transmitted to the ANSPs as it gets available.

Even if it is based on planning data and therefore only represents an estimate, the controller should have access to the CHA when needed, as it can be used for initial orientation. The HMI concept therefore provides a button, which when activated displays the contour of the CHA in grey. Within the contours, a short description is shown (e.g. CHA + time interval). The button is placed with the other buttons for special used airspaces (SUA).

Once the coordinates of the HA are received, they must be displayed to the controller so that he can begin to clear the airspace. Initially the contours of the HA are shown in a blue dotted line. This is the common way of displaying SUA that will be activated shortly. When the HA is active, the contour appears as a blue solid line. Within the contour a description (ICAO country code + **R**estricted + **S**pace **V**ehicle **E**xplosion) is given, informing the controller about the type of airspace and the cause of its existence. The vertical dimensions of the HA are also shown. Since the debris traverses all flight levels as it reaches the ground, it extends from ground to unlimited.

The relevant time indications relating to the HA appear underneath the Coordinated Universal Time (UTC) at the top of the radar screen. This includes the activation and the release time of the HA. The first one will appear straightaway with the HA, and once it is reached it is replaced by the release time. All times are shown in the same blue color as the contours of the HA.

In order to determine which aircraft will be inside or will fly into the active HA, the controller builds up a mental model of the future air traffic situation. The identified aircraft require new clearances. To expedite this process, an algorithm will perform this exact analysis and highlight affected aircraft in yellow. In addition, the aircraft targets start flashing. The controller can now use his capacities to issue new route clearances. If a route change puts an aircraft out of risk, it stops flashing and is no longer shown in yellow. Figure 1 shows a generic radar screen including the elements of the concept presented above.

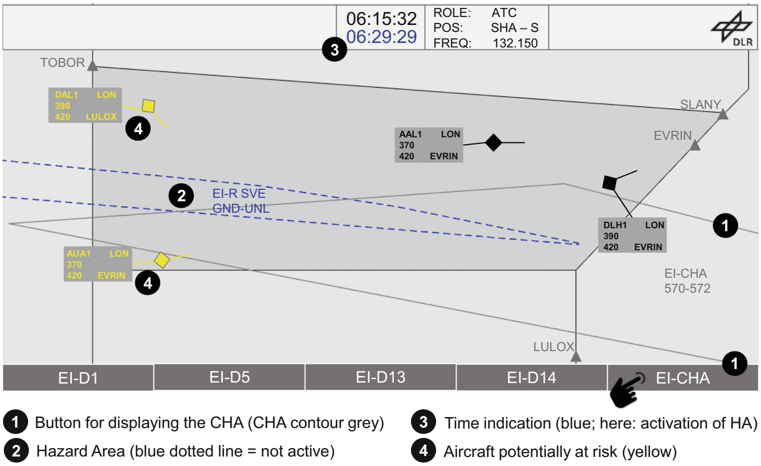

Fig. 1. Integration of new elements into a generic radar screen of controller (concept)

5 Simulation

For an evaluation of the concept, a 40-min simulation scenario is developed at DLR's Air Traffic Validation Center to allow experts to work on the enhanced radar screen.

Before the concept can be implemented, the specific simulation environment must be configured. This specifically includes the airspace design, the traffic scenario, the creation of a CWP as well as the configuration of a pseudo-pilot position and a radio telephony system.

For the scenario, the Irish Shannon airspace needs to be modelled. This is achieved with the help of the NARSIM [12] software. Modelled are the required sectors, to which corresponding frequencies as well as entry and exit waypoints are assigned. Airspace users can freely plan their routes between these waypoints, as Shannon is a free route airspace [13].

In addition, SUA structures are implemented, which now include not only the established ones but also the CHA and the HA. In the final system the HA would not be entered into the system in advance, as it would be received via SWIM-push during the simulation. However, in the following the concept is evaluated and not the SWIM connection, hence the coordinates are already available in the system.

After all airspace parameters have been modelled, the resulting airspace file is processed with DLR's Traffic and Trajectory Visualization (TTV) tool. This software tool allows the design of controller radar screens. The TTV has been adapted to represent the essential design and functionalities of a typical en-route CWP. The developed concept for handling non-nominal events during space operations was then incorporated into the generic CWP. Furthermore, a traffic scenario was implemented which is oriented on the actual traffic situation as of January 31, 2019 between 0600 and 0700 UTC.

The movements of the simulated aircraft are controlled by pseudo pilots. They obtain clearances and execute them by changing aircraft's altitude, heading and speed. To enable this process pseudo pilot positions and a radio telephony system is set up.

6 Evaluation

The design objective of the concept is to enable controllers to intuitively guide aircraft out of a HA, whereby the used elements should be familiar to controllers from daily operations. To determine if this objective is achieved and to reveal mayor strength and weaknesses of the concept, five DLR experts are consulted for evaluation. They will assess whether the information provided supports the controller enough to protect aircraft from falling debris and whether the situation is manageable.

6.1 Methods

To evaluate the concept, experts were asked to complete a questionnaire and to participate in a semi-structured interview.

The questionnaire consists of two parts. In the first part, the system usability is evaluated by means of the system usability scale (SUS). The SUS is a simple, ten-item scale giving a global view of subjective assessments of usability. On a Likert scale respondents indicate their degree of agreement/disagreement with the statements [14]. The second part consists exclusively of dichotomous questions that specifically ask for individual aspects of the concept and the general handling of the situation. In total the questionnaire consists of 30 questions, whereof 10 originate from the SUS.

In addition, a semi-structured interview with 15 open questions is developed to gather opinions, attitudes and suggestions on the concept. These questions intend to highlight the positive aspects of the concept and to identify potential improvements.

6.2 Results

The concept adds four elements to the radar screen: a button to display the CHA, a representation of the HA, time indications relating to the HA and an algorithm that identifies aircraft at risk and highlights them. The questioning has shown that all elements are necessary in order to manage the situation and to initiate appropriate actions. All experts confirm that with the given elements the situation within their own sector is ascertainable. Effects beyond the boundaries of one's own sector cannot be captured, as adjacent sectors and coordination processes are not simulated in this study.

The highlighting of affected aircraft is by all interviewees considered to be particularly helpful for task accomplishment, whereas the flashing is perceived only peripherally or not at all. The color yellow has increased awareness regarding the potential danger to aircraft and has led to flight routes being reassessed and adjusted.

However, once the aircraft label is highlighted, the information about the current aircraft status (accepted/not accepted), which is indicated by the label's color, is lost.

Most respondents consider the presentation of the HA according to SUA reasonable. This applies also to the presentation of the CHA. However, little use is made of this option as the participants do not want to plan on assumptions and therefore wait for the coordinates of the HA. Nevertheless, knowing about the CHA was important to everyone, as it helps to prepare mentally for the eventuality and to better assess the effects. Some experts, though, would have been satisfied if they had only been notified about the CHA in the briefing.

The time representation in UTC is practicable, since a comparison with the overflight times of the waypoints is easy and thus accelerates the traffic management planning.

The design of the radar screen is not unnecessarily complex, which is why it can be operated intuitively. To evaluate the usability of the system, data was collected by the SUS. Four of the five participants rated the system as good to very good in terms of usability (SUS score: 75–95). The last score was in the middle range with 65. To reinforce this result, more people need to be surveyed.

6.3 Improvements

The concept is at the start of its design phase and needs to be further developed, as the importance of integrating commercial space flight into the air transport system rises.

From the interviews, two adjustments for the concept can be derived. The first one concerns the color representation of affected aircraft, which currently results in a loss of information. Consequently, aircraft labels should be shown in a combination of two colors. Call signs could convey the aircraft status, while the rest of the label would remain yellow.

The second adjustment refers to the time representation, related to the HA. It is recommended to label the time to avoid a misallocation when other SUA are also active. It remains to be discussed whether it might be more useful to show the duration of the activation instead of two specific times. At this point, it is also uncertain whether there will be a fixed deactivation time at all or whether authorities may have to release the HA first. The release can be communicated via SWIM in any case.

An additional functionality to calculate and display alternative routes for aircraft at risk should also be considered.

7 Conclusion and Outlook

This paper presented and evaluated a concept that allows controllers to respond flexible and effectively to an in-flight failure during launch and re-entry operations. The concept is based on a data set from the DEP, a cooperation project between DLR and FAA. If airspace is, due to falling debris, temporarily restricted for aircraft, controllers need three information: First, where the HA is located; second, when the area is active; third, which aircraft are at risk. The concept makes this information accessible through four additional elements on the radar screen: a button to display the CHA, a representation of the HA, time indications relating to the HA and an algorithm that identifies aircraft at risk and highlights them. Experts rated positively that the concept focuses on the essential information for controllers and is not unnecessarily complex in design. The identical presentation of the HA with other SUA is supported as the areas are handled equally. The use of known elements also has the advantage that controllers interpret them correctly and that the desired reactions are caused. Highlighting aircraft which are potentially at risk helps to increase situational awareness and is rated as a supportive tool.

Further research should consider the coordination processes between controllers, as this may result in new requirements for such a concept. DLR will integrate the developed concept into the DEP demonstrations and use it in other scenarios with non-nominal events. Giving the increasing frequency of commercial space operations, research on integrating these operations into the air traffic system must continue.

References

1. Kaltenhaeuser, S., Luchkova, T., Klay, N., Ang, R.B.R.: Assessment of the Impact of Air Launch Operations on Air Traffic in Europe (2019)
2. Quinn, A.: Acceptable levels of safety for the commercial space flight industry. IAC-12-D6. 63rd IAC, Naples, Italy (2012)
3. Larson, E., et al.: Protecting aircraft in real-time from a launch or re-entry failure. In 34th Space Symposium. Colorado Springs, United States of America (2018)
4. Murray, D.P.: The FAA's Current Approach to Integrating Space Operations into the National Airspace System (2013)
5. Bilimoria, K.D., Jastrzebski, M.: Space Transition Corridors in the National Airspace System. In 2013 Aviation Technology, Integration, and Operations Conference, p. 4248. Los Angeles, United States of America (2013)
6. Kaltenhäuser, S., Morlang, F., Luchkova, T., Hampe, J., Sippel, M.: Facilitating sustainable commercial space transportation through an efficient integration into air traffic management. New Space **5**(4), 244–256 (2017). https://doi.org/10.1089/space.2017.0010
7. Murray, D.P., Ellis, E.: Air traffic consideration for future spaceports. In: International Association for the Advancement of Space Safety (IAASS) Conference (2007)
8. Colvin, T.J., Alonso, J.J.: Near-elemination of airspace disruption from commercial space traffic using compact envelopes. In: AIAA Space 2015 Conference and Exposition, Pasadena, United States of America, p. 4492 (2015)
9. Doc, I.C.A.O.: 10039-Manual on System Wide Information Management (SWIM) Concept. International Civil Aviation Organization 999
10. Kaltenhaeuser, S., Morlang, F., Schmitt, D.R.: A concept for improved integration of space vehicle operations into ATM. In: 33rd Space Symposium, Colorado Springs, United States of America, pp. 3–6 (2017)
11. Murray, D.P.: Space and air traffic management of operational space vehicles. In: AIAA Atmospheric Flight Mechanics Conference and Exhibit, p. 6890. Honolulu, Hawaii (2008)
12. Neatherland Aerospace Center. https://www.nlr.org/civil-aviation/ansps/air-traffic-management-simulation/

13. Eurocontrol. https://www.eurocontrol.int/publication/free-route-airspace-fra-implementation-projection-charts
14. Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, I.L.: Usability Evaluation in Industry. Taylor & Francis, Great Britain (1996)