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Air Traffic Impact Analysis Design for a Suborbital Point-to-Point Passenger Transport Concept

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ABSTRACT

Space flight activities are growing on an international level, thereby creating an evident need for a safe and efficient integration of space vehicle operations into the air traffic system. For concepts like very high-speed intercontinental passenger transport via suborbital point-2-point flights, as it is proposed by the DLR SpaceLiner, this integration issue is becoming especially relevant. As part of a case study approach to analyse the effects of space vehicle operations on air traffic and to evaluate mitigation strategies and optimized ATM integration, a traffic impact analysis has been prepared and conducted for the SpaceLiner return trajectory towards a European landing site. First results of the analysis will be presented together with the methodology and modeling approach which has been applied.

1. INTRODUCTION

According to ICAO [1], under the Chicago Convention, each State has complete and exclusive sovereignty over the airspace above its territory. That being said, Europe has around 51 independent states, out of which 41 Member States of Eurocontrol and approximately 63 Area Control Centers (ACC). The daily operations in the European airspace vary around 25,000 flights. In comparison with USA [2], where there is only one national service provider and one regulator with approximately twenty two ACCs, in Europe the situation looks more complicated. Eurocontrol has fourty one member states and besides EASA as a regulatory body for the European Union, each of the countries has their own national regulators. With around sixty three ACCs it creates pretty unharmonized airspace.

Introducing new type of operations in saturated and complex airspace can be a big challenge. But commercial space operations are rapidly increasing in other parts of the world and therefore are expected to enter the European airspace as well. Each launch and reentry that requires to pass through the European airspace will require special airspace for Space Vehicle (SV) operations to protect the daily aircraft operations.

How the introduction of space vehicle operations will affect the European ATM and how many flights are expected to be affected, we will try to address within this study.

For the purpose of this study, the specific traffic scenario over Europe is designed and related to the trajectory of the DLR SpaceLiner, a two-staged suborbital Reusable Launch Vehicle (RLV) which aims at future high-speed intercontinental passenger transport. This simulated trajectory of the SpaceLiner is created by the Space Launcher Systems Analysis (SART) group of DLR [1]. An analysis of impact of SV operations on the ATM system in Europe is performed with the fast-time simulations (FTS) tool.

2. Space Vehicle operation and the SpaceLiner use case

2.1 Characteristics of Space Vehicle operations

With regard to the interaction between SV 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 have to be assured. Certain types of SV operation require consideration of additional flight phases. Those are, for example, suborbital flights, which might either return to their launch site at the end of a more or less parabolic flight trajectory or connect to a different location (suborbital hypersonic point-to-point). They have to be considered during their whole flight. Reusable first stage rockets also have to remain separated from other traffic during their flight and return to the ground.

Space Vehicles are operated under a significant lower target level of safety than commercial airplanes, therefore mishaps and debris generating events have to be considered for regular operations. Potential hazard areas in case of malfunctions have to be considered regarding separation assurance. Gliding approaches and high approach speeds require prioritized handling of SV and might stress airport approach operations when thinking about mixed mode operation for hypersonic flights. It is yet unknown how to incorporate a SV into Trajectory based Operations (TBO), while TBO actually might facilitate the integration process under application of SWIM related services [2][3].

Currently, SV still challenge the established Communication, Navigation and Surveillance (CNS) requirements as they can't get tracked by conventional ATC surveillance. They are usually not equipped with conventional transponders and the capability of current systems to handle high supersonic aircraft speeds is unclear. ATC and the air traffic controller's tools and working positions are not yet prepared to handle space vehicles[4].

2.2 SpaceLiner use case

That being said, the SpaceLiner concept, which has been developed by the Space Launcher Systems Analysis (SART) group of DLR, is representing a very interesting subset of SV operation. Its basic idea is to enable sustainable low-cost space transportation to orbit while at the same time revolutionizing ultra-long distance travel between different points on Earth. It is designed as rocket-propelled, two staged suborbital Reusable Launch Vehicle (RLV), which can service ultra long-haul distances like Europe – Australia in 90 minutes. Intercontinental destinations between Europe and North-West America could be reduced to flight times of slightly more than one hour.

The general baseline design concept of the SpaceLiner consists of a fully reusable booster and passenger stage arranged in parallel (Figure 1). After lift-off and separation from the booster stage, the orbiter stage will proceed with its power flight until Main Engine Cut Off (MECO) with a maximum speed of around 7.1 km/s at an altitude of 69 km.

Figure 1: The SpaceLiner reusable booster and passenger stage during separation (DLR SART)

The ambitious west-bound Australia – Europe mission (up to 17000 km) has been used as the reference case. As described, the propelled flight phase is followed by hypersonic gliding, through which the vehicle would travel more than 1000 km almost outside of the atmosphere at very low drag. The orbiter will approach its destination entering controlled airspace at an approx. distance of 70km / 37NM with its speed below FL600 being already less then Mach 3 and will decelerate further below Mach 1 down to an altitude of approx. 36.000ft or FL360.

The launch and ascent noise as well as the sonic boom reaching ground are most critical for a viable SpaceLiner operation in the future. The selection of potential SpaceLiner launch and landing sites will likely be influenced by constraints due to generated noise [5]. Trajectory optimization has to take into account such constraints of a realistic operational scenario which are restrictions in acceptable flight corridors and relative proximity to potential customers. Regarding the selected use case, such considerations combined with safety requirements, lead to a landing site in vicinity of the coast, which allows performing the majority of the atmospheric portion of the approach over inhibited areas, e.g. the Atlantic Ocean, as shown in Figure 2.

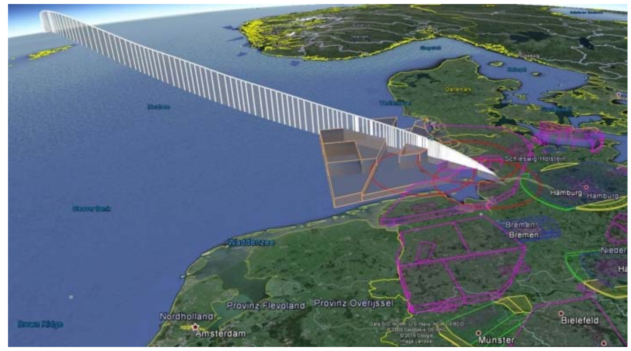

Figure 2: SpaceLiner descent trajectory for destination in northern Germany; showing also danger areas, restricted areas and temporary restricted areas within German airspace[1]

The final approach of the SpaceLiner is currently not modelled in detail. It is expected that a Terminal Area Energy Management (TAEM) maneuver will have to be added to get the SpaceLiner orbiter lined up with respect to the runway at the correct amount of energy. TAEM will require a cylindrical or cone-like area close to the landing site. The size of the TAEM cylinder will depend on the entry speed, which can have a radius of up to 15km if it is still supersonic. A turn with supersonic speed would cause high sonic boom effects on ground in the area of operation, which means it should be avoided close to inhabited regions. The design of the final approach segment of the SpaceLiner trajectory will therefore be subject of further optimization and is not yet considered in this study.

2.3 Air traffic control procedures

During all phases of the spaceflight through or close above controlled airspace, separation between aircraft and the space vehicle, including its potential hazard areas in case of malfunctions, have to be assured. Most of the 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. 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.

A yet much larger portion of air-space has to be managed regarding the risk of non-nominal events. This can be falling debris from an in-flight explosion or a breakup event. The debris fragments can cover a relatively large area, its size being dependent on the velocity and altitude of the vehicle during its disintegration [6].

As a result, Hazard Areas have been introduced to extend the area protecting surrounding aircraft beyond the pure space vehicle separation area or operating zone (see Figure 3). Their size is calculated by a debris dispersion prediction against an acceptable risk threshold (which is related to public safety standards). A hazard areas lateral extension is accordingly determined, using a

[1] Airspace visualization using GoogleEarth and OpenAir-data from Deutscher Aero Club (DAeC)

fragmentation model specific to the individual space vehicle. The vertical extension of the hazard area typically reaches from ground to FL600 (and beyond) throughout regular airspace. The top ceiling might be reduced, e.g. for a reentering space vehicle when it already has reached lower altitudes.

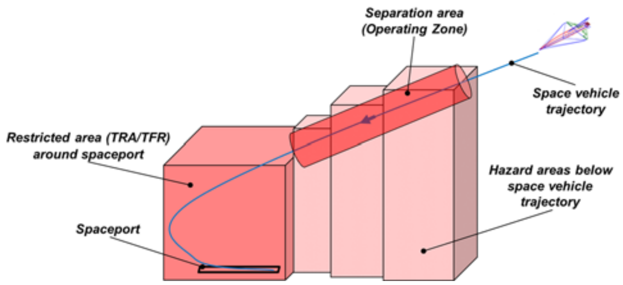

Figure 3: Simplified schematics of restricted areas, separation areas and hazard areas related to a space vehicle trajectory (during re-entry)

Hazard areas are also limited in time, which means that they are active at the actual position of the space vehicle on its trajectory, while they have to be as well considered for air traffic planning and control significantly before the actual flight event. The effective period of a given Hazard Area extends from the time that the first fragment of hazardous debris will enter the Area, to the time that the last fragment of hazardous debris will exit the bottom of it.

To ensure the safety of airspace users during space vehicle operation, airspace restrictions have to be put in place. As size and duration of the hazard area is significant for the effect of space vehicle operation on the air traffic, their impact has to be determined carefully. It will be directly related to the applied operational concept for space and air traffic integration, which defines for example the activation / cancelation of hazard areas and if a hazard area gets closed for other aircraft or remains open with measures for timely evacuation in place.

The following analysis will consider the interaction of air traffic with those hazard areas for the selected SpaceLiner use case.

3. METHODOLOGY

3.1 Research question

Several questions have yet to be answered about the possible impact Space Vehicle Operations from, to or within Europe could have on the air traffic system, based also on the specific type of operation to be considered. How can this impact be minimized, especially when these types of operation become more frequent? What kind of information have to be made available and how shall it be composed, conditioned and applied on strategical and tactical levels within the ATM? The overall purpose is to ensure a safe, efficient and sustainable way on how to operate space and air traffic together.

The questions that should be answered using traffic impact analysis are the following:

- What kind of influence do space vehicle operations have on the airspaces alongside the restricted areas especially during peak hours in the European ATM?
- Is it possible to integrate SV operations in the current ATM?

To be able to understand, evaluate and answer scientific questions that have arisen with the introduction of the commercial space vehicle operations in the European ATM, we have chosen a very common way by introducing these type of operations in a fast-time simulation (FTS) suite. Thereby, the simulation is close to reality. This kind of tool is used in many case studies as a first and reasonable approach to answer questions on how different modifications in the airspace may influence the capacity and traffic flow. The FTS simulations in this study will be performed with the AirTOp (ATC Fast Time Simulator and Air Traffic Optimizer) fast-time simulation suite. It is a new generation fast-time simulation platform, which allows gate to gate simulation of air traffic. Among other properties it includes en-route traffic and ATC modelling, 4D trajectory based operations and air traffic flow management.

3.2 Parameters to be analyzed

The methodology behind this kind of impact analysis integrates several areas: analyzed days, air traffic data, and applied airspace model and simulation environment.

All these areas will be implemented in the fast-time simulation tool as input data. As a product of the fast-time simulations it is expected to get the following parameters:

- <u>Entry count</u>
  This parameter represents the number of aircraft entering a specific airspace during the rolling period.
- <u>Exit count</u>
  This parameter represents the number of aircraft exiting a specific airspace during the rolling period.
- <u>Total flight duration</u>
  This parameter represents the total flight duration in a specific airspace by all aircraft passing through
- <u>Total distance flown</u>
  This parameter represents the total distance flown by all the aircraft in the specific measured airspace
- <u>Sector occupancy</u>
  <u>This parameter represents a 15 minute period sector capacity</u>

The analysis of these parameters will provide information of how many flights will be affected to what extend by the space vehicle passing over and through the airspace on its way to its spaceport.

3.3 Analyzed day and traffic data information

The traffic impact analysis customarily simulates different traffic scenarios covering 24 hours scenario. As a main evaluation day 30th of March 2015 is chosen. It represents a typical day during a work week in a month with no additional traffic because of charter flights (summer period) or holidays. In addition, two more traffic days are simulated and compared as verification for the number of flights, one week before this date, 24th of March 2015, and one week after, 07th of April 2015. The three scenarios foreseen for this study which include the above listed simulation days contain around 25.000 flights each, or in total around 75,000 flights.

Figure 4 represents the traffic flow in the hazard areas during the rolling hour. The purpose of the chart is to visualize the peak hours of traffic in the hazard areas.

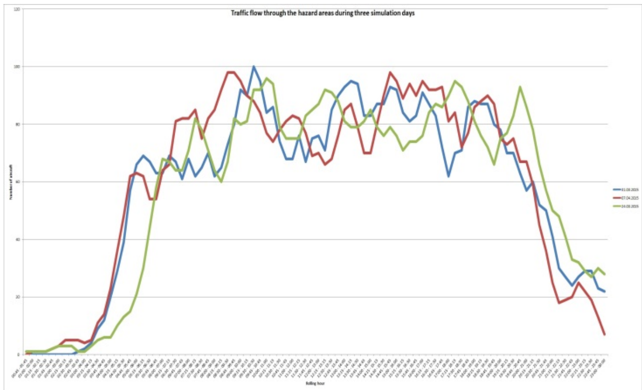

Figure 4 Traffic flow for the hazard areas during the rolling hour

The used traffic data has been received from EUROCONTROL for research purpose. The data consists of historical traffic demand, as well as the actual flown trajectories and are used to generate a specific air traffic scenario to suit the purpose of the investigation. Figure 5 represents twenty four hours air traffic simulation in Europe, with a flight plan containing more than 22,000 flights.

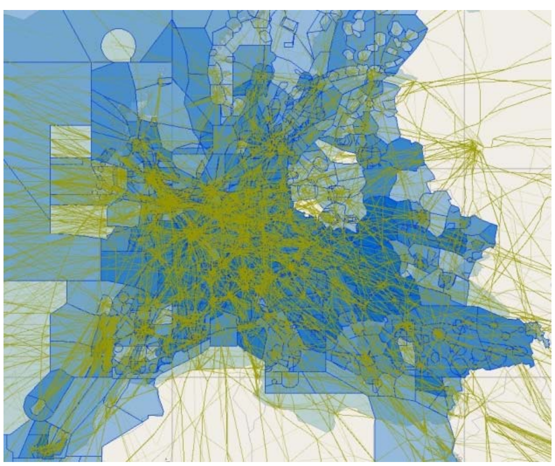

Figure 5: One day traffic scenario simulated with AirTOp

3.4 Tools and simulation characteristics

As mentioned above, simulation of the European air traffic as well as the airspace restrictions and hazard areas is performed with AirTOp fast time simulator. AirTOp is also an open modular and extensible tool, which allowed us writing of specific airspace restriction applications.

The common way to investigate a scientific question with FTS includes first creating a reference scenario, which correctly reproduces the existing air-side conditions. For calibration of the scenarios, recorded traffic data and ATM information is used. Afterwards, the specific traffic scenarios are generated and modified according to the research question. The simulation process is finished with a comparison of certain predefined parameters from the validation scenarios and assessment and analysis of the impact that certain changes had on the overall traffic and airspace capacity [13].

Additionally, to generate and implement flight trajectories within AirTOp, a tool named RouGe (Route generator) is used. RouGe is developed at DLR and it is used as a platform to convert the Eurocontrol's SO6 Data in a format directly readable by AirTOp and other internal DLR software programs. The information from SO6 is then exported into separate files compatible with AirTOp containing the following information: flight plan, aircraft, routings, waypoints and airports.

3.5 Applied airspace model

The airspace model is generated from the EUROCONTROL`s Demand Data Repository (DDR2) and the European AIS database (EAD) and it is represented in Figure 6. It contains around 1000 sector volumes depending on the day and airspace configuration and various types of ATC sectors: collapse sectors, elementary sectors, area control center group etc. Collapse sectors may tactically be split vertically or laterally. This is a dynamic process, which can be reproduced in AirTOp [14].

The appropriate airspace model for each simulation day will be included when setting up the simulation. In this study we focused on only one day scenario and therefore the same airspace model is applied to all simulation scenarios.

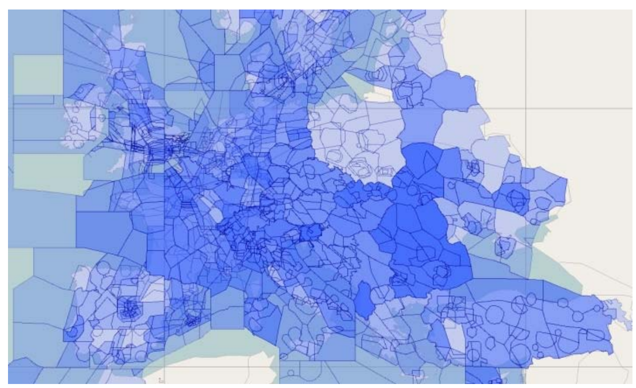

Figure 6: Representation of the European airspace structure in AirTOp

3.6 Definition and calculation of hazard areas

In general, airspace restriction areas represent a defined volume of an airspace in which operations face certain limitations. They can be defined as: (i) zones for different dangerous activities such as military regular exercises or (ii) simply for protection of areas with high value such as national parks etc. In the first case, the airspace is off-limits for all operations except for aircraft operations which are part of those activities. In the second case, prohibition of flying is applied to all users. The constraints of operation within restricted zones can be permanent or temporary meaning that in case of an inactive restricted zone ATC provides services in the zone normally allowing the aircraft to operate in it.

In this investigation, many dynamical hazardous areas along the space vehicle trajectory (as described in section 2.3) have been included in the simulation (Figure 7).

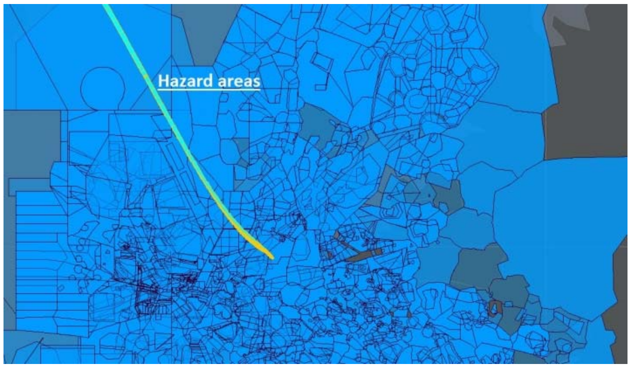

Figure 7: Hazard areas along the investigated SpaceLiner trajectory passing through European airspace

To generate the hazard areas along the SpaceLiner flight trajectory, a provisional hazard area model has been used, applying an inter-/extrapolation model based on the United States National Aeronautics and Space Administration's (NASA) Columbia space shuttle accident debris data [9]. For each data point of the trajectory, the hazard area has been calculated based on geographical position, altitude and heading, representative for a close to Space Shuttle like trajectory behavior. The simple altitude-area relationship of this used model can be summarized as in (1) and (2):

$$\text{Debris Area length}_{\text{in km}} = \frac{Alt_{\text{in feet}}}{1000} \quad (1)$$

$$\text{Debris Area width} = \frac{\text{Debris Area length}}{8} \quad (2)$$

For this study, the hazard areas have been considered within the simulation as open airspaces. No re-routing has been calculated and simulated.

4. ANALYSIS

This section will give an overview of the analysis and the fast-time simulations performed for the three simulation days.

It starts with a description of the method used to setup and capture the important input and output data respectively and continues on with a short overview of the limitations that were experienced during the studies as well as the assumptions on which the fast-time simulations are based.

The output data analysis will try to answer the research question and show the effects of the SV operations on the European ATM.

This section finishes with new ideas and short overview of future possible concepts and case studies.

4.1 Method description

The method description includes collection of the output files from AirTOp and further analysis of the received files. It is important to point out that no baseline scenario was used for the simulations. The reason for that is because in this study, the goal is to only evaluate the effect of the SV operations without closing any of the hazard areas. The number of flights that have an encounter with the hazard areas in a 60 minutes raster is the indicator of a possible effect on those flights and increased controller workload in the affected neighboring airspaces if a re-routing will be necessary.

Time	Scenario 1	Scenario 2	Scenario 3
00:00 - 01:00	1		
01:00 - 02:00	5		5
02:00 - 03:00	10	1	18
03:00 - 04:00	15	27	34
04:00 - 05:00	44	145	169
05:00 - 06:00	153	265	233
06:00 - 07:00	263	260	293
07:00 - 08:00	302	265	324
08:00 - 09:00	273	280	373
09:00 - 10:00	345	377	357
10:00 - 11:00	344	312	310
11:00 - 12:00	318	286	311
12:00 - 13:00	358	322	280
13:00 - 14:00	320	365	321
14:00 - 15:00	319	350	338
15:00 - 16:00	295	340	368
16:00 - 17:00	333	333	372
17:00 - 18:00	366	289	314
18:00 - 19:00	295	342	351
19:00 - 20:00	328	281	290
20:00 - 21:00	287	219	207
21:00 - 22:00	172	122	82
22:00 - 23:00	118	108	79
00:00 - 01:00	1		

Table 1 Morning (red) and afternoon (green) peak hours for each simulation scenario

Table 1 shows the number of flights which are flying through the hazard areas within an one hour time frame, also indicating the two peak hours for each of the scenarios – in the morning and in the afternoon. Although the same day of the week was chosen with a difference of one week in between, it may be noticed in the table and especially in Figure 8 below (which only shows peak hour traffic), that the assumption for similar peak hours is not correct, especially for the traffic samples in the afternoon.

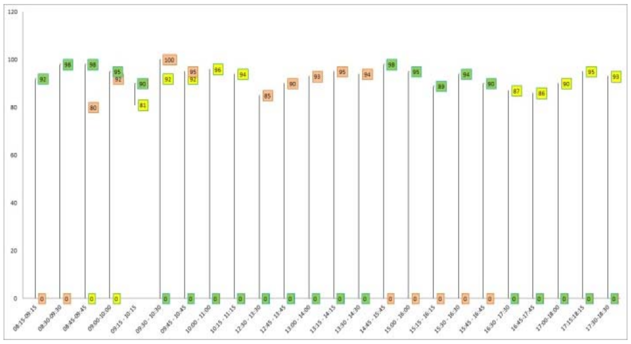

Figure 8: Distribution of the number of flights in a 15 minutes raster during their peak hours for Scenario 1 (yellow), Scenario 2 (green) and Scenario 3 (orange)

4.2 Assumptions and limitations

The list below will summarize the assumptions and limitations which occurred during the simulation of the three use case scenarios:

- The use case scenarios contain only historical flight plan data without any forecast models for the years 2025 and beyond when the actual SpaceLiner operations are planned.
- The total time, the SpaceLiner needs to fly above and later through the related European airspace, is about 30 minutes. For a first conservative approach, an additional 15 minute is added before and after the planned flight event. This leads to an overall 60 minutes for which the hazard areas would be active.
- The hazard areas remain open during the rolling hours of the simulation because it is important to calculate the number of flights that actually have encounter with these areas. The consequences of closing or evacuating a hazard area have not yet been considered.
- The controller workload was also not taken into account in this first step, because the assumptions are that the workload within historical traffic scenarios is in its limits.
- The flight dynamic has not yet been implemented into the used AirTOp model. Therefore the conflict resolution algorithm or the air traffic flow management function of the simulator to resolve potential conflicts with the scheduled traffic could not be used. For this study, the SpaceLiner flight trajectory has been imported into the fast-time simulation tool together with the calculated hazard areas.
- No weather or atmospheric data was included in any of the use cases
- Conflicts between aircraft were not resolved in any of the simulations. But, having historical data in the simulation scenarios, the conflicts were reduced to a minimum.
- The SpaceLiner trajectory was only chronologically modified, with different start and end time in the simulation, but without any modification of its location.

4.3 Simulation Results

This section presents the collected and processed output data from the fast-time simulations. Figure 9 below shows the number of aircraft that have entered the hazard areas during the rolling hour of the simulation 00:00:00 until 23:59:00 (as also shown in Table 1). The peak hours of traffic are also in the morning between 08:45 until 09:45 and for the afternoon they are spread in the period between 15:00 until 16:00. This is a good indicator for planning the start and landing times of the space vehicle in the European ATM. Avoiding the peak hours of traffic for the scheduled flights will result in less possible encounters with the hazard areas and less flights that might be affected during a space vehicle operation in the European ATM.

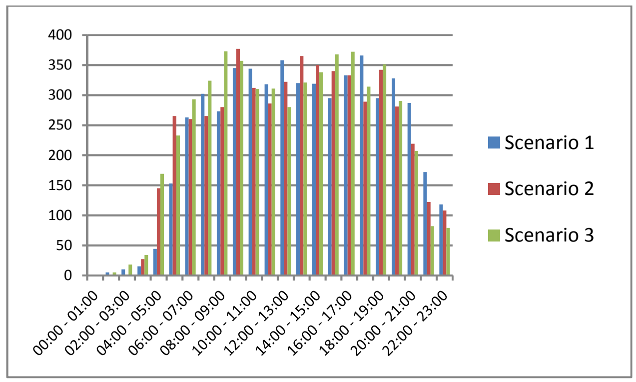

Figure 9: Entry count for scenarios 1, 2 and 3 during the rolling hour

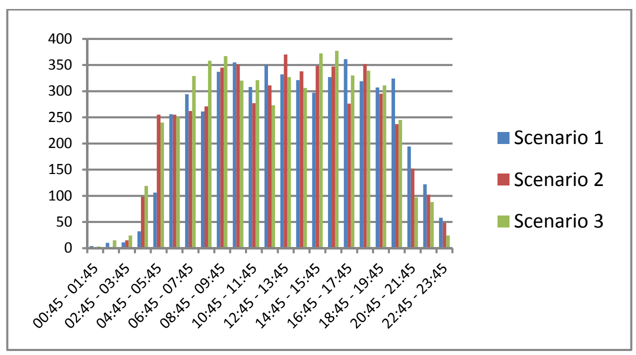

Figure 10: Exit count for scenarios 1, 2 and 3 during the rolling hour

Figure 10 represents the exit count of aircraft from the hazard areas. It slightly differs from the entry count because there are aircraft which are landing in the airports that lie in the hazard areas. This leads us to the assumption that during the operation of the SpaceLiner, some of the departing or landing aircraft from those airports might need to be delayed (depending on the operational concept which defines the handling of the hazard areas). Figure 11 gives an insight into the situation of the actual airspace activity in Europe and the exact location of the hazard areas. As it can be seen in this figure, the chosen SpaceLiner trajectory and its related hazard areas are interacting with routes connecting several hub airports in Europe and are in close vicinity of the entry and exit points for the North Atlantic traffic.

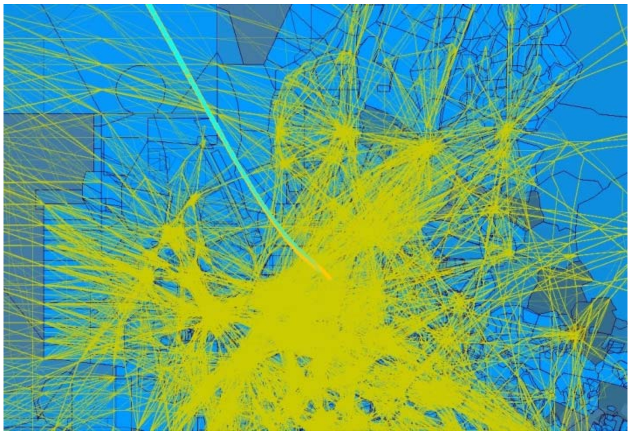

Figure 11: Integration of the SpaceLiner trajectory in the European ATM during a rolling hour

As mentioned above, another parameter which is a product of the fast time simulations is the total value of NM flown in the hazard areas by the scheduled traffic (Figure 12). It differs depending on the traffic in the rolling hour and for the three scenarios it varies between 12580NM and almost 1300NM (cumulated values).

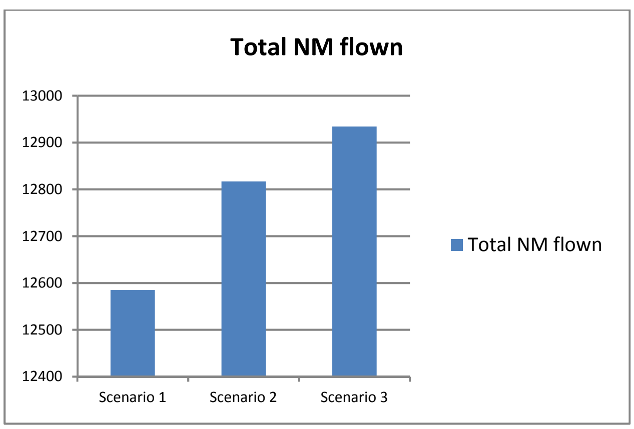

Figure 12: Total NM flown in the hazard areas

The next parameter which was a product of the simulations and gives an overview over the occupancy of the hazard areas with scheduled traffic during the rolling hours is the total flight duration. Figure 13 represents this parameter in which it can be seen that the flight duration in each of the scenarios varies between slightly between 29 hours and 30 hours during the rolling hour.

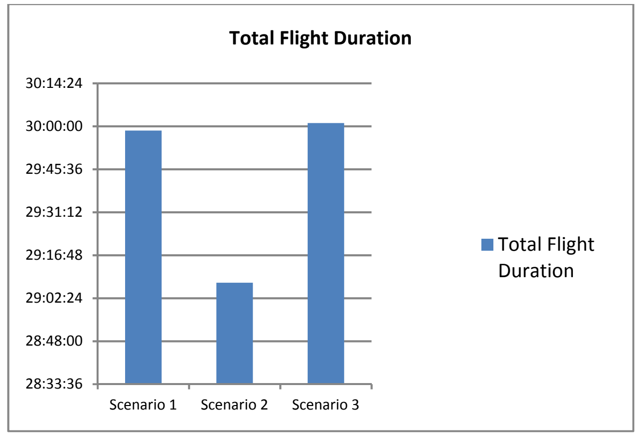

Figure 13: Total flight duration of the scheduled traffic in the hazard areas

4.4 Effects of SV operations on the European ATM and future planned dynamic airspace

After conducting this initial study on the effects of the specific SpaceLiner use case on the European ATM and performing several fast time simulations with different historic traffic samples, an overview of the possibility of integration of these type of operations was received.

It has to be mentioned that the use cases of the simulation scenarios have a relatively conservative approach. The hazard areas are assumed to be active during the complete timeframe of the SpaceLiner flying through European airspace plus an additional 30 minutes of buffer time, meaning a large a large portion of European airspace has been “affected” for about 60 minutes. The amount of traffic that has an encounter with the hazard areas during this time is relatively large and it varies between 350 and 400 aircraft for the peak hour operations.

The implications on the affected flights which have been identified to pass through the calculated hazard areas now depend on the way these hazard areas are handled. When considering a high risk scenario, like for first test flights of a new vehicle, a complete closure of the hazard areas could be an option. The amount of affected flights then equals the numbers described above in chapter 4.3. This approach would be comparable with the measures first considered during the Space Shuttle return to flight procedures, for which a preemptively closure of an airspace corridor of a width of 20 to 50 miles below the re-entry trajectory for a duration of 35 to 60 minutes was first suggested [10]. It would mean that the already complex and saturated European airspace has to cope with reduced flight efficiency because of the rerouting of the affected flights. That also would affect the flying time of the aircraft, as well as the fuel burned (which have not yet been determined but can be accessed using the same simulation setup which has been used within this initial study). For the ATC capacity of the surrounding airspaces in the vicinity of the hazard area, the rerouting would result in an increased number of flights and potential conflicts that need to be resolved, as well as significant increment of the controller workload for the affected airspaces. With such expected massive effects on the European air traffic system, this approach does not seem to be realistic.

Adopting the general approach to keep the airspace of hazard areas open for aircrafts passing below the space vehicle, while implementing procedures to ensure timely evacuation of aircrafts from those areas in case of a mishap, the effects on the air traffic system should be significantly limited. Assuming for example a closure of only the hazard areas within the final part of the SpaceLiner approach, at which the orbiter is flying through controlled airspace below FL600, the maximum number of directly affected flights in the chosen use case scenarios will drop significantly. This for still following a conservative approach which closes this whole airspace, which will be passed by the SpaceLiner in a flight time of approx. 8 minutes, for an amount of 45 minutes. It has to be considered though, that the vast amount of aircraft trajectories crossing the SpaceLiner trajectory and passing through its hazard areas are located towards the later phases of flight close to the space port (see Figure 11).

That being said, the results of this first set of fast-time simulation use cases give an overview on the current ATM performance and the possibility for integrating SpaceLiner operations in it. To reduce the described effects, a more advanced concept needs to be considered and one of those concepts includes dynamic hazard areas. The idea is that the portions of hazard areas will be activated and deactivated with the movement of the SpaceLiner through them, which means that each hazard area will be only active for several minutes, That will prevent the closure of large amounts of ATC sectors as well as closure of airport operations which are in the vicinity of the SpaceLiner trajectory. Another approach is to optimize the shapes and volumes of hazard areas, along with their dynamic activation, to further limit the necessary interaction with the adjacent air traffic. There have already been several studies performed [11][12], which results will be taken into account for future work.

5. CONCLUSION

The research questions that were raised at the beginning of this study were analyzed for the SpaceLiner use case. Based on the simulations performed and analysis carried out, some first conclusions can be made.

As a reminder the questions posed in this study were the following:

- What kind of influence do space vehicle operations have on the airspaces alongside the restricted areas especially during peak hours in the European ATM?
- Is it possible to integrate SV operations in the current ATM?

To answer the first questions, we have generated the hazard areas along the SpaceLiner flight trajectory, applying an inter-/extrapolation model based on the NASA's Columbia space shuttle accident debris data. The hazard areas have been calculates based on geographical position, altitude and speed vector.

The hazard areas were then imported in the fast-time simulation tool as a preparation for the simulations to be carried out. Three days were chosen as use cases: 24th of March 2015, 31st of March 2015 and 07th of April 2015. The corresponding airspace structure of the European airspace was imported in the fast time simulation tool as well. Each scenario use case contains between 23,000 and 25,000 flights.

As mentioned above, the use case scenarios in the first run are relatively conservative, meaning that the hazard areas are active, but not closed, and are used in the simulation to get an overview of how many flights in the European ATM will be affected by such operations.

The parameters which were defined to be analyzed as output from the simulations were the following: entry count, exit count, total NM flown and total flight duration.

The post simulation analyses have given some first answers to the above mentioned questions for the specific use case of the chosen SpaceLiner trajectory, but can already be extrapolated for operation of space vehicles related to European airspace. The influence that the space vehicle operations would have on the overall operations in the European ATM when following a conservative approach in closing airspaces below the space vehicle trajectory will be relatively substantial. The trajectory of the SpaceLiner and thereby the hazard areas are distributed in the vicinity of several large European airports, as well as the entry and exit points of the North Atlantic trajectories, which during peak hours of traffic would have a vast impact on the affected flights.

The integration of the space vehicle operations in the current European ATM therefore has to follow an approach, which keeps hazard areas well below the space vehicle trajectory open, but implements measures to clear those airspaces from air traffic in case of a mishap in time to avoid any casualties. Reducing the remaining effects of airspace closures for parts of the space vehicle trajectory within lower altitudes might be possible with more advanced concepts for calculating and handling hazard areas. This kind of approach will include dynamic opening and closing of the hazard areas and better planning of the space vehicle trajectory.

6. NEXT STEPS AND OUTLOOK

Based on this study's research, some recommendations for future research use cases were made. Integration of dynamic hazard areas is the first step towards more advanced concept of use cases for this kind of study. This means that the hazard areas when active will be closed for any other type of traffic, which will lead to rerouting of the flights affected by the SV operations, but their size and the duration of theirs closure has to be optimized.

Integration of sector throughput for the surrounding ATC sectors around the hazard areas is another step. This also means that such a comprehensive study will include detailed analysis of the controller workload in the affected sectors where most of the rerouting is performed.

Although this kind of study is colossal and it includes a great number of flights and accompanying integration of airspace structure and calculations for the hazard areas, it would be of great importance to expand the scope of the study in future and examine the effect of the SV operations not only on the airspace throughput, but also on arrival and departure traffic at airport, especially the hub airports in the vicinity of the hazard areas.

The future use cases could also include forecast traffic scenarios for Europe from 2025 and beyond, as well as integration of several SV operations throughout 24 hours simulation scenario.

Fast time simulation tool is a very good and fast approach to get the insight of the study and trigger some minor issues, but the human behavior and the questions that will arise in more complex scenarios could be in future examined on a deeper level with the help of real time simulations.

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