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Assessment of the Impact of Air Launch Operations on Air Traffic in Europe

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ABSTRACT

The development in commercial space transportation is strongly driven by a growing demand for payload capacities and cost efficient access to space. Accordingly, there is also a demand for further launch opportunities in the European region. Factors such as short waiting times for launches, rapid response capabilities, proximity of production sites to the launch site and independence from established and highly utilized launch systems are increasingly playing a role. Air launches are discussed as a way to meet this demand. They also offer the particular advantage of relatively low requirements on infrastructure and location of the spaceport compared to conventional vertical launch systems. Since the actual launch is not bound to the spaceport, this method also offers a high degree of flexibility with regard to the design of the launch trajectory and the associated interaction with air traffic. This paper examines the interaction between proposed air launch operations and air traffic for a previously selected mission profile in Northern Europe. Data from historic launch events are used as an input for modeling of the required flight restriction areas. The analysis provides information on the expected extent of air traffic impairments and existing optimization capabilities.

1. Introduction

The commercialization of space transportation is expected to significantly reduce the cost of transporting people and payload into space. Conventional launchers are getting accompanied by novel concepts for launching upper stages of orbital aircraft, high altitude balloons or flying launch platforms. The dynamics of this process can be seen in a rapidly growing number of commercial launches. Novel concepts for spacecraft takeoff and landing, new mission profiles and space applications, and an increased need for launch capacity are leading to a growing interest in expanding space activities and enabling them to operate from locations in Europe.

On their way into space and back to Earth, spacecraft fly through airspaces that are also used by regular air traffic. Space vehicles are operated under a significantly lower target level of safety than commercial airplanes, therefore mishaps and debris generating events also have to be considered during regular operations. Potential hazard areas in case of malfunctions have to be considered regarding separation assurance. To ensure safety, parts of the airspace must be blocked for this purpose or other precautious measures have to be taken. The numerical and spatial expansion of space flight activities therefore represents a challenge for air traffic control and air traffic management [1].

2. Air Launch operations within the context of European access to space

An air launch is a method of delivering a payload by rocket from the air into space. Typically, air launch rockets are able to deliver payloads of up to 500 kg into low earth orbit (LEO). What is special with this type of method is that the rocket launches are carried out horizontally from a carrier aircraft. The advantages of this type of launch operation are its flexible launch position (in the air) and reduced launch related requirements at the spaceport – the airport used to prepare carrier aircraft and launch vehicle before its flight. Air launch operations provide a rather high flexibility and independence from specifically installed ground infrastructures.

With the shrinking size and mass of satellites, satellite components available of the shelf, new production lines of micro satellites and cubesats, requirements for launch capabilities are changing as well. Not only may the payload mass be significantly lower but also time to launch is required to become significantly shorter, especially for companies of the New Space segment with leaner financial buffer and high market agility. The desired mission profiles often target constellation of satellites or orbits with high inclinations up to polar and sun-synchronous characteristics. The launch location therefore not necessarily has to be close to the equator. Those developments are a driver for an increased interest also within Europe, one of the leading space regions worldwide, in offering launch capabilities not only from established launch sites but now also from the European continent as such.

Air launch therefore becomes an attractive option to provide launch capability close to manufacturing sites of satellites and spacecraft, especially if the location of those sites is not particularly suitable for vertical launch operations. As a vertical launch comes with certain requirements regarding the launch corridor and associated risk zones, air launch operations allow for a spatial separation between the spaceport and the actual launch...
location and its associated launch corridor. The characteristics of air launches makes them specifically attractive for nations which otherwise would not be able to provide suitable geographical locations for conventional launch facilities.

As a consequence, the Northrop Grumman Pegasus launcher, an existing air launch operator with a very reliable track record of currently 43 successful launches, offering a payload of max. 460kg (LEO) [2], will soon be joined by additional air launch providers. Virgin Orbit is about to provide launch capabilities based on its LauncherOne rocket with a payload of 500kg (LEO) out of a Boeing 747 carrier airplane [4]. Stratolaunch is developing its own carrier aircraft and is planning to provide multiple launch vehicle options (including the above mentioned Pegasus rocket) with payloads of up to 3,400kg [3]. On the other side of the payload range, air launch concepts based on small jet engine aircraft such as the Dassault DANEO concept are targeting on rockets with payloads of about 50kg to be used specifically for the launch of individual micro satellite missions [5].

3. Air Launch use case description

The objective of the performed analysis is to examine how the implementation of air launch operations within the European airspace and the associated airspace restrictions affect the surrounding air traffic. This is the second use case of a number of analysis performed to evaluate the potential impact of space vehicle operations on the European Air Traffic Management (ATM) [6]. To launch into a polar orbit from Europe, a launch corridor over large inhabited areas in north-south direction can be accepted as a realistic option, e.g. the North Sea region between Great Britain and Scandinavia. Therefore, a use case has been designed that foresees a carrier aircraft to depart from a potential spaceport at the German North Sea coast and transfers to a military danger area (EGD323C&D, temporary flight restriction applied) at the east coast of Great Britain, from where the air launch will be performed. The resulting trajectory of the rocket points north with an inclination of 97.8° (Figure 1).

![Figure 1: Flight trajectory for the carrier aircraft before / during launch (red) and return to the spaceport (black); launch with an inclination of 97.8° (green).](image)

In the context of this work, the characteristics of a Pegasus XL rocket air launch from a carrier aircraft is used to represent a realistic example of such an operational type. To estimate the related flight restriction zones, historical data from the Pegasus launch of the IRIS research satellite on June 28th, 2013 over the Pacific Ocean off the coast of California has been used. The launch targeted a sun-synchronous orbit with an inclination of 97.8°. As described this orbit has a high relevance for this use case because it represents a very high commercial demand, e.g. for satellite constellation and remote sensing missions. For the creation of the restricted airspace, historical flight restriction areas are used as a reference [7]. The data has been acquired from a published NOTAM from the named Pegasus ISIS launch. The launch corridor is mirrored from the US Pacific Ocean to the North Sea.

![Figure 2: Air launch polygons – US Pacific Ocean (left), North Sea (middle), Mirroring the baring angle (right).](image)

Figure 2 on the left shows the historic flight restriction areas associated with the launch of ISIS (black rimmed areas). The two red outlined areas are the flight restriction zones for which data was available through the NOTAM (June 27, 2013, NOTAM Facility ZAK Oakland, NOTAM Number: 06/134). The northernmost of the four areas is the drop launch area of the rocket. The start runs in the southern direction. The next two areas are reserved for the first stage burnout and second stage burnout, which fall back into the sea.

![Figure 3: Fine adjustment of the polygons based on actual trajectories in AirTOp (red: originally calculated; yellow: adjusted polygons).](image)
Figure 2 in the middle shows the red outlined launch corridors from the left mirrored into European airspace, assuming the drop launch area being located within the aforementioned EGД323C&D. Figure 2 on the right shows the polygons after an adjustment with the baring angle as an alignment line has been performed. Figure 3 shows the final launch corridor used for the simulation after the originally calculated location of the polygons (red) have been adjusted (yellow) against the oceanic traffic routes to avoid unnecessary major conflicting.

Since EGД323C&D is frequently used as a temporary restricted airspace for military training operations [8], the consequences of the use of these danger areas performing the launch has not been assessed in this study. Also, the fourth restricted area from the historic launch is not further investigated as it would not be located within European airspace. As a result, the main two polygons are considered as temporary flight restriction areas and used to calculate its impact on a European air traffic scenario.

4. Traffic impact assessment methodology
To analyze the potential impact of the described air launch operation scenario on European air traffic, a methodology is used which has been previously described in [9]. For the purpose of modeling, simulation and analysis of air transportation concepts DLR uses model-based (fast-time) simulation tools. The simulation tool used in this study is AirTOp, which is capable of performing gate to gate simulation of air traffic, including en-route traffic and ATC modelling, 4D trajectories and air traffic flow management.

To measure the effects, which come along with different airspace modifications or integration of new entrants and how these may influence the traffic flow and capacity of the airspace, a reference scenario is defined at the beginning, which correctly or as close as possible reproduces the status quo situation in the area of interest. Afterwards, specific traffic scenarios are simulated and modified according to the research question, in this case including the described flight restriction areas of the air launch. Comparing the outputs of these scenarios with the reference scenario, the impact of the changes can be assessed and can become part of detailed further investigations (e.g. sensitivity analyses). The used traffic scenario covers 24 hours of air traffic operations in Europe.

This study uses air traffic data from 1st of July 2016 with around 36,000 flights. The corresponding airspace model is generated for the same simulation day including different sector volumes and various types of ATC sectors with the original structure, opening times and traffic volumes for that day. The airspace and traffic data is received from EUROCONTROL’s Demand Data Repository (DDR2) and is used for research purposes only.

The simulation consist of three scenarios: a baseline scenario which represents the status quo situation in the air, scenario two with air launch polygons active during minimum air traffic movements and scenario three, where the air launch polygons are active during peak hours.

5. Results
The simulation of the base scenario incorporates 36,097 flights over 24 hours. Over this time period, 68 flights have been detected that would have a potential conflict with the flight restriction polygons. Figure 4 shows the flight trajectories cumulated over 24h together with the two flight restriction polygons.

The entire daily operation is divided then in time frames of 60 minutes (duration of the potential closure of restricted flight areas). These time frames are spaced apart in 10 minutes intervals, adding up the number of flights that would fly through the restricted areas within those frames (Figure 5).

Figure 4: Accumulated flight trajectories generated with AirTOp for the traffic scenario on July 1st 2016; analyzed flight restriction areas depicted in red

Figure 5: Number of aircraft (a/c) within the two flight restriction areas over 1 hour time frames

The maximum total occupancy within the two polygons is 17 flights. This period with the highest traffic within the polygons is from 11:50-12:50 and therefore is of a special interest for our study.

In contrast, the results also show several periods with no or only small traffic flow through the polygons during the observation period. In particular, periods of daylight are of importance, as good visibility conditions most likely will be required when performing the launch (e.g. for the time period between 13:40 – 14:40 no flight would be affected during the whole launch window).

Further analysis has been performed to identify the potential impact of an operation being performed at the identified “worst case” time period, to access the highest potential impact of the required launch window. It is assumed that affected flights would have to circumnavigate the flight restriction areas. Therefore those flights have been re-routed (Figure 6) and with this modification the simulation has been run again (Scenario 3). Table 1 represents specific parameters to analyze the impact on
those 17 rerouted flights. The analysis covered the total distance flown in the baseline scenario, total distance flown in scenario 3 (re-routing), the difference of the distance flown between both scenarios and the delay in minutes.

![Trajectories for the time frame with highest number of affected flights (yellow) and re-routing (green)](image)

In order to better illustrate the findings on the total distance travelled, the percentage increment in the distance flown is calculated. For this purpose, first the difference between the total flight path of the base scenario and the total flight route of scenario 3 is formed. Subsequently, the difference between the distances traveled and the percentage increase is calculated. The results are given in Figure 7.

Figure 8 depicts the arrival delay for the rerouted flights in scenario 3 compared to the baseline scenario. It can be noticed that all the flights except for WOW443, WOW903 and WOW761 have a delay which is less than 4% compared to the baseline scenario. For these 3 flights, considerable extra distance amounting up to 12% more was travelled due to rerouting. This was attributed to the fact that during the full simulation, with reasons unknown at the moment, these 3 flights did not abide by the manual rerouting implemented but instead, created an automatic rerouting.

![Increase of the original distance flown in percentage](image)

![Arrival delay expressed in percentage](image)

![Fuel consumption difference](image)

Table 1: Parameters analyzed for time frame with highest number of affected flights

<table>
<thead>
<tr>
<th>Callsign</th>
<th>Total distance flown Baseline scenario (NM)</th>
<th>Total distance flown scenario 3 (NM)</th>
<th>Difference of the distance flown (NM)</th>
<th>Delay (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QTR739</td>
<td>7426,5</td>
<td>7508,4</td>
<td>81,9</td>
<td>10:04</td>
</tr>
<tr>
<td>UAE201</td>
<td>6141,8</td>
<td>6148,9</td>
<td>7,1</td>
<td>00:54</td>
</tr>
<tr>
<td>UAE237</td>
<td>5987,1</td>
<td>6094,1</td>
<td>7</td>
<td>00:53</td>
</tr>
<tr>
<td>SAS935</td>
<td>4834</td>
<td>4844,5</td>
<td>10,5</td>
<td>01:23</td>
</tr>
<tr>
<td>QTR725</td>
<td>6363,2</td>
<td>6386,1</td>
<td>22,9</td>
<td>02:52</td>
</tr>
<tr>
<td>QTR743</td>
<td>5914,9</td>
<td>5922</td>
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<td>6330,3</td>
<td>51,5</td>
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<tr>
<td>QTR701</td>
<td>6109,9</td>
<td>6161,4</td>
<td>51,5</td>
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</tr>
<tr>
<td>UAE235</td>
<td>6406,9</td>
<td>6429,8</td>
<td>22,9</td>
<td>02:53</td>
</tr>
<tr>
<td>QTR763</td>
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<td>5904,5</td>
<td>51,4</td>
<td>06:33</td>
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<td>4739,7</td>
<td>53,5</td>
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<td>1241,5</td>
<td>42,4</td>
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</tr>
<tr>
<td>DLH410</td>
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<td>3848</td>
<td>18,4</td>
<td>02:21</td>
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<tr>
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<td>4513,1</td>
<td>4537,7</td>
<td>24,6</td>
<td>02:48</td>
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</table>
Finally, the related potential increase in fuel consumption has been assessed for the high impact launch window. It is based on comparison of the fuel consumption within the two simulated scenarios. The excess consumption of fuel is shown as a percentage in the diagram in Figure 9. As the fuel consumption model stored in AirTop does not allow a sufficiently realistic indication of the absolute fuel consumption, only the percentage increase in fuel consumption is determined in this analysis.

While the aforementioned results have been assessed particularly for the time period related to the maximum number of affected flights, an additional analysis has been performed focusing on the total amount of flights potentially being affected due to the location of the flight restriction areas and the launch corridor itself.

Therefore the category, origin and destination of 68 potentially affected flights have been examined. The necessary information was derived from the flight plans used for the simulation scenario. Of the 68 flights, there are 16 medium-haul flights and 52 long-haul flights, with the distribution shown in Figure 10. No short haul flights are potentially affected.

From this information, it becomes clear that only half of the affected flights will take off in Europe and the other half overfly the area over the North Sea only as part of their route. The majority of flights originating in Europe depart from Germany and Scandinavia.

Almost 70 percent of the flights are on their way to North America, which is no surprise as the flight restriction areas are close to the North Atlantic Organized Track System.

6. Summary and Conclusion

In this use case study, a potential air launch scenario within the North Sea region between Great Britain and Scandinavia has been analyzed. The use case foresees the carrier aircraft to depart from a potential spaceport at the German North Sea coast and transfers to a military danger area at the east coast of Great Britain, from where the air launch will be performed.

Certain assumptions and limitations are applied. The use case scenario contains only historic traffic data. The controller workload was not included in the analysis. No weather or atmospheric data was included as well. Conflicts were not resolved, but they are reduced to a minimum by using historical traffic data.

The flight restrictions areas were active during the complete rolling hours as described for the historic launch, no dynamic opening and closure was performed. Additionally, only 2 out of 3 launch polygons were modelled, because for the simulation scenario the third polygon was assumed to be not within the European airspace. The rerouting of affected flights has not been performed with optimal rerouting criteria and no alternative measures have been taken to avoid rerouting like Air Traffic Flow Management (ATFM) rules. Nevertheless, when neglecting the unfavorable re-routings of the 3 mentioned WOWAir flights, caused by errors in the modeling, the resulting route extensions for the worst case period with 17 affected flights are essentially below 2%. The same applies to the arrival delay and changes in fuel consumption.

All in all, the results show that air launch operation in the chosen area can be performed with only limited additional impact on European air traffic operation.

In order to further improve integration concepts and the detail level of related air traffic impact analysis, several measures can
be taken and should be considered within future studies. First of all, the integration of ATFM can provide alternatives to simple re-routing activities around flight restriction areas. This adds the option to hold a flight at the gate or to perform airspeed control, where applicable, in order to reduce costs and flying time and avoid necessary re-routing action. Dynamic airspace management and sectorization [10] as well as dynamic opening of flight restriction areas [11] have been identified in previous studies as promising measures to cope with the addition of space flight activities. This is expected to lead to a further reduced impact of air launch operations on the surrounding airspaces and flights. It will prevent closure of large amounts of ATC sectors for unnecessary long periods of time and limit the necessary amount of re-routing of scheduled traffic.

7. REFERENCES