Analysis of Impacts an Eruption of Volcano Stromboli could have on European Air Traffic

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The current regulatory situation in Europe is that flying in forecasted, differently contaminated volcanic ash zones is allowed as long as airline’s specific Safety Risk Assessment for volcanic ash events (SRA) is approved. This regulation has the goal to reduce adverse impact of volcanic ash on air traffic management (ATM). There are three different types of SRAs and it is, however, not yet clear what effects on air traffic operations each type eventually has. In this contribution, we concentrate on analysis of those effects: posed number of encounters with volcanic ash cloud as well as the generation of optimized flight trajectories around the cloud. More importantly, we introduce an airspace re-opening scheme during ash crisis situation and investigate its effect. The accent is put on capacity analysis of the air traffic control (ATC) sectors estimated to be more affected by the necessity of re-routing around the areas of contamination. The analysis of the work-load of the controllers responsible for providing services in those sectors is due to the complexity planned for the future work. Important to mention is that European states do not implement this approach and that it therefore presents the novelty in the field. Moreover, European states do not have a unique understanding of SRA approach meaning that, in a few cases, states still decide to close their airspace in case of ash presence. We do not concentrate on that problem in this investigation and treat the European airspace as airspace with harmonized, unique regulatory set up. Volcanic ash data from the International Civil Aviation Organization’s (ICAO’s) volcanic ash exercise (VOLCEX14/01) and EUROCONTROL’s daily traffic data are used as input data for simulations.

Keywords: Volcanic Ash, Air Traffic Management, Fast-time Simulation

I. INTRODUCTION

The ICAO recommendation [1] during the volcanic ash crisis happened in Europe in 2010 was to completely avoid airborne volcanic ash regardless on concentration. The European States followed such a recommendation and as a result closure of some parts of the airspace was introduced for several days. By the end of the crisis the new approach to volcanic ash issue in Europe was introduced as this kind of conservative approach was strongly criticized by passengers and airlines. This new approach included presentation of forecasted volcanic ash in three zones (low, medium and high concentration) and subsequently allowed flying in those zones as long as adequate Safety Risk Assessment (SRA) was approved [2]. The individual European States, after all, have different opinions on such an approach and some of them despite introduction of a new regulation still decide to close their airspace in case of airborne volcanic ash. We however, in this investigation treat the European airspace as airspace with harmonized, unique regulatory set up that recognize the approach to volcanic ash issue based on SRA. In that respect, there are three different types of SRAs represented in Europe:

- SRA that allows operations in areas forecasted to be contaminated with low ash concentration (< 2 mg/m³)
- SRA that allows operations in areas forecasted to be contaminated with low and medium ash concentration (< 4 mg/m³) and
- SRA that allows operations in areas forecasted to be contaminated with low, medium and high ash concentration (> 4 mg/m³).

As it is still not clear what effects on air traffic operations each type of SRA has, in this contribution we concentrate on in depth analysis of those effects. The specific simulation set-up is created in order to answer the question what is the difference in posed number of encounters with volcanic ash cloud when different SRA is applied as well as to discuss differences that proposed optimized flight trajectories around the area of specific ash concentration have on airspace capacity.

Additionally, we introduce a novel approach to the crisis situations such as presence of volcanic ash in the air that implies opening of restricted zones for traffic. This approach allude the willingness of European states to relinquish any portion of airspace that is on standard days planned for activities that require designation of that airspace as a restricted (such as military regular exercises, probation of flying over national parks etc.) to the civil air traffic. The question how this kind of approach to the crisis situations would affect the operation is of most interest for us. The accent is put on capacity analysis of the air traffic control (ATC) sectors
estimated to be more affected by the necessity of rerouting around the areas of contamination. The European States unfortunately still do not implement this approach end therefore the undertaken investigation may be exploited as an aspiration towards that implementation.

II. BACKGROUND

To answer the questions mentioned above, the specific traffic scenario over Europe is designed and related to simulated eruption of Stromboli volcano ( Aeolian Islands, Italy). This simulated eruption is created by the organization committee of the ICAO’s regular volcanic ash exercise (VOLCEX14/01) in Europe and North Atlantic region. An analysis of impact on airspace capacity and traffic flows is performed with the fast-time simulations (FTS) tool.

A. Characteristics of the Volcano

Volcano Stromboli (Number 0101-04; position 38,789 N 15,213 E; elevation 924 m [2]) in Aeolian Islands (Italy) is chosen by the organization committee as the simulation of its eruption gives an opportunity to analyze the effect on air traffic in southern part of Europe. Additional attribute for choosing it is the vicinity of Etna volcano in Sicily (Italy). It is assumed that the effects on the air traffic would be similar in case of a big eruption of any of these volcanoes. According to Smithsonian Institute, Etna and Stromboli are two of Earth’s most active volcanoes [3].

B. Characteristics of the Eruption

A continuous eruption of Stromboli volcano covers a consecutive two days (1st and 2nd of April 2014) with different ash distribution characteristics.

The first day plum attributes are described as: (i) movements from surface to FL200 - from Stromboli towards north affecting all Italian flight information regions (FIRs), Croatia, Albania, Macedonia (Former Yugoslav Republic of Macedonia), Serbia, Slovenia, Hungary, Romania, Bulgaria, Bosnia and Herzegovina and (ii) movements from FL200 to FL450 - from Stromboli towards south to Malta, East to Greece, Cyprus, Turkey, Bulgaria, Ukraine and Moldavia.

The second day plum attributes are described as: (i) further movements of ash cloud from surface to FL200 towards the north of Italy and finally till France and (ii) movements from FL200 to FL450 towards the north of Italy reaching Croatia, Bosnia, Slovenia, Austria, Switzerland, Hungary, Poland, Germany, Belgium, Netherlands, Luxembourg, Slovakia and Czech Republic [4].

C. Simulation Environment

Simulation of the European air traffic as well as the volcano eruption is performed with the AirTOp fast time simulator. AirTOp is a new generation of fast-time simulation platform, which allows gate to gate simulation of air traffic. The term fast-time means here that thousands of flights can be computed in less than a minute. Among other properties it includes en-route traffic and ATC modelling, 4D trajectory based operations and air traffic flow management [5]. It is also an open modular and extensible tool, which allowed us writing of volcanic ash specific applications. Fast-time simulation 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. However, setting up a sophisticated model in fast-time simulation tool is always a challenge itself but as a result very precise outputs are delivered. The validity of the findings, of course, strongly depends on how close the simulation matches the reality.

We here, implement the common way of using FTS results to investigate a scientific question by first creating a reference scenario, which correctly reproduces the status-quo situation in the air. To achieve this, recorded traffic data and ATM information is required to calibrate the FTS scenario. Afterwards, the specific traffic scenarios are generated and modified according to the research question. Comparing the outputs of these validation scenarios with the calibrated reference scenario, the impact of the changes are assessed and discussed.

Additionally, to generate and implement flight trajectories within the AirTOp simulator a tool named RouGe (Route generator) is used. The RouGe is a tool 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.

III. METHODOLOGY

This section outlines the following information: (i) the day chosen for the analysis, (ii) volcanic ash and traffic data used, (iii) applied types of SRAs, (iv) applied airspace model and (v) definition of an airspace capacity.

A. Analyzed Day

As the exercise simulates different directions of movements and areas covered by low, medium and high concentration of volcanic ash during 1st and 2nd April 2014, due to the pattern of ash cloud that is much more spread out on the second day the 2nd April 2014 is the day chosen for the analysis.

B. Volcanic Ash and Air Traffic Data

These data are acquired (for research purpose only) from the Volcanic Ash Advisory Centre (VAAC) Toulouse and EUROCONTROL.

The VAAC Toulouse thus provides three sets of CSV data files containing forecasts of volcanic ash, in three different concentration zones and height ranges. The first set of data at 06:00 UTC, the second set of data at 12:00 UTC and the third set of data at 18:00 UTC are provided. The validity period of each set is six hours. For the end users, these sets of data are presented in the form of modelled ash concentration charts.

The EUROCONTROL provides the air traffic data for the period of 24 hours. The data comprise number of flights entering the Network Management Operations Center (NMOC) area and are used to generate a specific air traffic scenario to
suit the purpose of the investigation. As the VAAC Toulouse sets of CSV data show no applicable volcanic ash clouds before 06:00 UTC and after 18:00 UTC only flights active between 06:00 UTC and 18:00 UTC are included in the traffic scenario. Around 24,000 flights are simulated in total.

C. Applied Types of SRA

To analyze the effects that different airline approaches to the volcanic ash issue can have on the European air traffic, we look into the number and type of SRAs approved within the Europe. As this information may be subject to change the results gained are applicable for the defined days and are to be taken with the caution in case of further exploitation.

<table>
<thead>
<tr>
<th>SRA for Volcanic Ash Events</th>
<th>Number of Airlines (%)</th>
<th>Type of SRA</th>
<th>Number of Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>77.9</td>
<td>L(^a)</td>
<td>36.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L/M(^b)</td>
<td>62.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L/M/H(^c)</td>
<td>1.6</td>
</tr>
<tr>
<td>NO</td>
<td>22.1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

a. L stands for SRA that allows operations in areas forecasted to be contaminated with low ash concentration

b. L/M stands for SRA that allows operations in areas forecasted to be contaminated with low and medium ash concentration

c. L/M/H stands for SRA that allows operations in areas forecasted to be contaminated with low, medium and high ash concentration

The investigation shows that the major number of airlines in Europe (77.9%) has their SRA for volcanic ash instances. The rest 22.1% of airlines have therefore no rights to fly in vicinity of any ash contaminated areas in the air. Among those airlines having their SRA for volcanic ash events the type of the SRA that is the most present (62.2%) is the SRA that allows operations in areas forecasted to be contaminated with low and medium ash concentration (< 4 mg/m\(^3\)). The second most present (36.2%) type of SRA is the one that allows operation in areas forecasted to be contaminated with only low ash concentration (< 2 mg/m\(^3\)). Those SRAs that allow operations in areas forecasted to be contaminated with low, medium and high ash concentration (> 4 mg/m\(^3\)) are, as expected, present with the lowest percentage of (1.6%). Based on such results we make a decision to analyze only effects on European posed by the approaches defined within SRAs that allow operations in areas contaminated with only low ash concentration (< 2 mg/m\(^3\)). Those SRAs that allow operations in areas contaminated with low and medium ash concentration. The overview of the results is presented in Table I.

D. Applied Airspace Model

The airspace model is generated according to the chosen scenario of the respective day. It has been extracted within the work-flow of DLR’s Network Flow Environment (NFE) [6], which is an ATFM tool environment to optimize and validate network-wide ATFM decisions regarding slot allocation and pre-flight rerouting. Airspace data is gathered and consolidated from EUROCONTROL’s Demand Data Repository (DDR2) [7] and the European AIS database (EAD) [8]. The airspace model is depicted in Figure 1. It contains around 640 individual sector volumes depending on the day and airspace configuration, representing approximately 1400 traffic flows of the European ATM network. It contains two types of ATC sectors: collapse sectors and elementary sectors. Collapse sectors may tactically be split vertically or laterally. This is a dynamic process, which is not reproduced in our model yet. It is rather important to generate a most realistic airspace representation of capacitated sector volumes. The static model also contains elementary sectors representing smallest capacity airspace volumes.

E. Definition of the Restricted Zone

Restricted zones 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, except for aircraft operations which are part of those activities, for all other operations the airspace is off limits. In the second case, probation of flying is applied for all users. The restriction of operation within restricted zones can be permanent or temporary meaning that in case of inactive restricted zone the ATC provides services in the zone normally allowing the aircraft to operate in it.
The European airspace contains many restricted zones, which are normally published by each individual European state in a Notice to Airman (NOTAM).

In case when the complete airspace is already disrupted by another cause like volcanic ash cloud, having the previously defined restricted zones temporarily open might prevent the delays, cancellation of flight operations and even reduce the capacity issues on the surrounding airspaces.

In this investigation, two generic restricted zones are created in the vicinity of the volcanic ash cloud. In the first set-up, these restricted zones are closed and in the second they are open. The objective of the two set-ups is to analyze the number of flight operations which might be carried through and ultimately to answer the question whether the temporary opening of the previously defined restricted zones brings a benefit in terms of increased number of flight operations despite existence of volcanic ash in the air.

F. Definition of the Airspace Capacity

The airspace (ATC sector) capacity can be defined as the maximum number of aircraft per unit of time that can be safely handled by controllers. This includes all the constraints that are part of such process: controller and pilot work-load, weather constraints etc.

In 2010 with the eruption of the Eyjafjallajökull volcano, the European airspace was completely or partially closed, causing cancellation of thousands of flights over a period of few days. Because of an external constraint, in this case the volcanic ash cloud, the capacity of most of the airspaces over France, Germany, Ireland, Sweden, Norway, Belgium, Denmark, Poland and the Netherlands was reduced to a minimum or even zero.

At this point where the most of the airlines in Europe have approved SRA, the question raised is whether the impact of a potential volcanic eruption on the ATM as well as the airspace capacity can be reduced by allowing flight operations through the zone of low or both low and medium volcanic ash concentration (according to airline’s approved SRA). The second question that arises in this investigation is whether in such disruptions of the ATM, opening of the restricted zones can bring benefit to increasing the airspace capacity in Europe.

Figure 2. Restricted zones in the vicinity of volcanic ash cloud

In 2010 with the eruption of the Eyjafjallajökull volcano, the European airspace was completely or partially closed, causing cancellation of thousands of flights over a period of few days. Because of an external constraint, in this case the volcanic ash cloud, the capacity of most of the airspaces over France, Germany, Ireland, Sweden, Norway, Belgium, Denmark, Poland and the Netherlands was reduced to a minimum or even zero.

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Figure 3. Airspace A, B and C selected to measure the capacity

IV. Aim of the Analysis and Setup of Fast-time Simulation Scenarios

To be able to describe the aim of the analysis we first in detail describe the process and background of creating the simulation scenarios. For the purpose of this investigation, seven simulation scenarios are created.

The first or baseline simulation scenario is based on the air traffic scenario for the chosen day. It includes around 24,000 flights (due to the eruption characteristics flights before 06:00 UTC and after 18:00 UTC are omitted from investigation). The goal in this scenario is to measure the capacity in the sectors A, B and C with an assumption that there is no disruption in the system.

A scenario two through seven takes into account the disruption posed by volcanic ash cloud. Additionally, scenarios two and three take into account the same traffic volume as the one applied in the baseline scenario, application of no SRA and restricted zones (A and B) open and closed, respectively. These two simulations show that the certain number of flights has to be rejected from the further simulation steps. The rejection happens due to the fact that their arrival or departure airport lies in the area where the volcanic ash is spread. The number of those flights is 819.
Scenarios four and five again take into account the same traffic volume as the one applied in the baseline scenario, application of SRA that allows operations in areas forecasted to be contaminated with low ash concentration (< 2 mg/m³) and restricted zones (A and B) open and closed, respectively. The number of rejected flights in this simulation is 460.

In the last two scenarios created and run in the fast-time simulation tool, scenarios six and seven, one more time take into account the same traffic volume as the one applied in the baseline scenario, application of SRA that allows operations in areas forecasted to be contaminated with low and medium ash concentration (< 4 mg/m³) and restricted zones (A and B) open and closed, respectively. The number of rejected flights in this simulation is 187.

The aim of creating scenarios in this way is to determine the baseline capacity of the airspaces (without any disruption, no volcanic ash in the air) and compare it to the capacity when volcanic ash is present in the air. Besides the main goal, the results which are expected from this first simulation campaign are the number of flights that have an encounter with the volcanic ash.

Figure 4 represents a screenshot of the scheduled traffic as well as airspace structure for the selected day, without any volcanic ash disruption.

Figure 5 shows a single trajectory as an example of a flight which is re-routing in case of application of SRA that allows operations in areas forecasted to be contaminated with low and medium ash concentration (< 4 mg/m³). In this particular example, the aircraft is allowed to fly over a smaller portion of volcanic ash cloud contaminated with high concentration due to the fact that this ash cloud is spread only from the surface to the FL250. The aircraft in that particular moment is cruising at FL370.

V. RESULTS AND DISCUSSION

In this section we present the results gained from the above explained simulations.

Table II shows the posed number of encounters with volcanic ash cloud when different types of SRAs are applied. As it can be seen, the application of the SRA that allows operations in areas forecasted to be contaminated with low (< 2 mg/m³) or both low and medium ash concentration (< 4 mg/m³) brings the obvious benefits in terms of number of flight operations able to be performed despite the airborne volcanic ash.

It is thus confirmed that the impact of a potential volcanic eruption on the ATM as well as the airspace capacity can be reduced by allowing flight operations through the zone of low and medium volcanic ash concentration (according to airline’s approved SRA).
Table II shows capacity analysis of the air traffic control (ATC) sectors estimated to be more affected by the necessity of re-routing around the areas of contamination. The re-routing of the aircraft affected by the volcanic ash cloud is performed by the AirTOp’s shortest route logic meaning that some of the observed sectors face higher traffic demand than the others (Fig. 6).

Table III shows capacity analysis of the air traffic control (ATC) sectors estimated to be more affected by the necessity of re-routing around the areas of contamination. The re-routing of the aircraft affected by the volcanic ash cloud is performed by the AirTOp’s shortest route logic meaning that some of the observed sectors face higher traffic demand than the others (Fig. 6).

The undertaken investigation gives us the results that are not sufficient to answer the question whether in case of disruption of the ATM opening of the restricted zones can bring benefit (prevention of the delays, cancelation of flight operations and even reduction of the capacity issues on the surrounding airspaces) to increasing the airspace capacity. In that respect and to justify the above statement we are showing the following example (Fig. 7). Further investigations are required to clarify that question in detail.

VI. COCLUSION

We would like to emphasize that results presented in this contribution are preliminary as this is the first try to perform such a complex investigation with multiple simulations within the fast-time simulation tool AirTOp. Although, these preliminary results do not give us the expected benefits in terms of prevention of the delays, cancelation of flight operations and even reduction of the capacity issues on the surrounding airspaces there is still a possibility for further developments of simulation scenarios set-up.

Finally, not to be forgotten, the undertaken investigation takes into account simulated eruption of volcano Stromboli and therefore further analysis taking into account realistic explosive eruptions (especially the latest ones) are highly required for utter understanding of the effects on the European air traffic.

![Image](image_url)
REFERENCES