AIR TRAFFIC MANAGEMENT AGAINST STRATOVOLCANO ERUPTION: OVERVIEW OF THE POLICY

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In this work, we review the current state of the policy in areas of Air Traffic Control, Disaster Prevention, and Air Safety in relation to volcanic ash contingency, and find current guidelines to be insufficient. In Japan, possible eruption of the Sakurajima volcano poses a serious threat to local airspace operations and North Pacific Route System. Volcanic ash plumes cause jet engine failure, hence International Civil Aviation Organization ensures complete avoidance of airspace contaminated with volcanic ash. In 2010, the Eyjafjallajökull volcano eruption in Iceland led to European airspace closure for weeks, which became the largest air traffic shut-down in the modern history of civil aviation. However, contingency guidelines are not consistent in different regions, including Asia/Pacific region. Final decisions are left to pilots operating aircraft, and general rules of ATC operations are not clear. Due to the rareness of eruptions, we faced lack of historical data, but recent Taal volcano eruption in the Philippines in 2020 brought new possibilities for analysis. With new data we hope to discover common patterns in decision-making processes, thus making the next step towards improving the policy.

Key Words: *Volcanic Ash, Air Traffic Control, Aviation Safety*

1. Introduction: Effects of Volcanic Ash on Aviation

Among other possible types of adverse weather conditions that threaten flight operations, volcanic ash is considered one of the most dangerous. Throughout the history of civil aviation, few encounters with volcanic ash proved that flying through the ash plumes cloud can result in serious damage to the aircraft, while the main threat to flight safety is possible engine loss and complete destruction. Stratovolcanoes are characterized by periodic, explosive eruptions. During the eruption, such volcanoes inject ash and corrosive gases into the upper troposphere and lower stratosphere. Ash is a combination of pulverized rock, minerals, and glass, all less than 2mm in diameter. Together with gases, it converts into droplets of sulphuric acid and other substances that pose an extreme danger to aircraft and people on board. The worst effect is caused by ash melting into glass inside the engine: ash melting point is about 1100°C, while jet aircraft turbine core operating temperature is at least 1400°C at normal thrust settings; core temperature might increase with next-generation improved engine designs. When ash melts in the engine, it then fuses into glass coating on engine components and causes loss of thrust, therefore possible engine failure1).

Most well-known incidents with volcanic ash encounters include British Airways Flight 9 in 1982 and KLM Flight 867 in 1989. On June 24th, 1982, a British Airways Boeing 747-200 en route from Kuala Lumpur to Perth entered a dense cloud of volcanic ash in the vicinity of an eruption from Mount Galunggung, resulting in all four engines failure. After reaching the altitude with clean air, the crew successfully restarted three of four engines and diverted. On December 15th, 1989, a KLM Boeing 747-400M en route from Amsterdam to Tokyo, flew through a cloud of volcanic ash from Mount Redoubt, Alaska, which led to all four engines failure and emergency landing(2).

Due to the obvious dangers of flying through volcanic ash clouds, it seems best to avoid contaminated areas completely. ICAO Aviation safety rules ensure complete avoidance of contaminated airspace(3). However, in case of an enormous eruption, such a precautionary approach has obvious economic issues that come with it since rerouting or cancellation of flights is costly: in April 2010, ash from the big eruption of the Eyjafjallajökull volcano in Iceland interfered with heavily used intercontinental airways, which let to major airspace closure in Europe and resulted in the disruption of over 100,000 flights and 10 million passenger journeys. Such an adverse impact on aviation led to the biggest air traffic disruption in modern civil aviation history. Global economic damage is estimated at 5 billion USD(4).

The 2010 event in Europe showed that complete airspace closure is not the optimal way to deal with enormous eruptions, therefore policies have been reviewed and improved in many ways. The main change was made in the area of decision making on airspace status in Europe. Prior to the 2010 event, European states would completely close airspace contaminated with ash. Under the new guideline, the airspace mainly remains open, while the decision on whether to fly should be made by the aircraft operators. In the Asia/Pacific region the same approach was adopted(5). In order to conduct a flight in a contaminated or forecasted to be contaminated airspace, operators are required to implement appropriate mitigation measures in accordance with their Safety Risk Assessment (SRA). Safety oversight procedures are used for the evaluation of operators' capability to conduct flight operations safely into airspace forecast or known to be contaminated with volcanic ash and has to be completed and evaluated by according State Civil Aviation Authority(6).

However, we believe that, based on these crisis management developments, further improvement in Air Traffic Control operations is needed in order to have more effective contingency procedures.

Some academic researches discuss the actions that should be taken in case of a volcanic ash disaster. For example, Reichardt et al. (2018) discuss the lack of communication between stakeholders and possible outcomes through the workshops organized for air transport professionals. The workshops covered not only the Eyjafjallajökull case but also the Öræfajökull case. The study highlights the vulnerability of air transport in case of a serious volcano eruption and stresses the need for further research in the area, as well as the importance of the Safety Risk Assessment approach and its coordination across nations(7). Reichardt et al. (2019) follow their earlier research and summarize the suggestions by the air transport professionals regarding the disaster scenarios related to the case of Eyjafjallajökull. The study suggests that aviation stakeholders need to properly exercise their response to a possible volcano eruption event, and use more challenging scenarios for such exercises in order to reveal weaknesses under long-duration events of larger scale(8).

Without a common understanding of actions to be taken, the risk that volcanic ash poses to aviation would not decrease. At least, common knowledge between ATC and pilots should be established. This is a highly challenging and broad problem, so first, we need to show how establishing the common knowledge about the actions in case of a big eruption affecting the airspace could be reached.

This research is the first step to establish the common rules for the actions to be taken in case of airspace contamination with volcanic ash. The first step is the data analysis for suggesting the possible actions of ATC.

2. Problem Outline: Current ATC Guidelines

Since the 1982 accident, International Civil Aviation Organization (ICAO) established a system of nine Volcanic Ash Advisory Centres (VAAC) as a part of International Airways Volcano Watch (IAVW) that monitor volcanic activity around the world and provide meteorological charts and Volcanic Ash Advisories and Graphics (VAA and VAG) that include information on the location and flight level of ash clouds(9).

Each VAAC is responsible for the issuance of VAA and VAG within its area of responsibility, and advising local Meteorological Watch Office if volcanic ash is present, or forecast to enter, corresponding Flight Information Region (FIR), so a SIGMET can be considered. SIGMET stands for Significant Meteorological Information and is used to prepare the flight plan. Aircraft should not be routed through ash clouds, rather routing should be upwind of the ash cloud, if possible. Pilots flying over areas known for volcanic activity are expected to review all relevant advisories and forecasts prior to departure and monitor updates en route. However, long-term forecasting of volcano eruptions is not possible[10)], therefore all stakeholders should be prepared for reactive actions anytime.

Unfortunately, due to the size and nature of ash plume particles, ash clouds are not detected by aircraft weather radar nor ATC radars. The crew might not be able to distinguish the ash cloud from other clouds. Especially at night, when visual conditions are limited, it is impossible for the aircraft crew to anticipate the encounter. Indicators of the volcanic ash encounter include smoke or dust in the cockpit, fine ash collecting on flat surfaces, sulfur/acrid smell, lightning-like visions and St Elmo's Fire around the aircraft at night, bright orange glow around jet engine inlets, torching from the tailpipe and flameouts, engine surges and power fluctuations. When penetration of an ash cloud was unavoidable, the escape maneuver must be performed immediately considering terrain circumstances. The main objective of escape actions is to prevent silicate ash particles melting in the engine and to regain clear air. In order to prevent ash particles melting, the engine core operating temperature should be reduced, therefore reduction of engine thrust is the optimal action. According to ICAO, considering terrain conditions, the fastest way out of contaminated air is a descending 180-degree turn — reverse track and descend. A climb should not be attempted as an escape option under any circumstances. The crew should prepare aircraft systems for recovery from potential engine failure and monitor the airspeed carefully since airspeed indications may become unreliable due to the damage in various systems[1)].

Since volcanic ash is not detectable by ATC radars, such an event of aircraft entering ash contaminated air might be unexpected for Air Traffic Control, too. Aircraft are expected to take the shortest way out, which is usually a descending 180-degree turn, so ATC is supposed to clear the airspace around the aircraft in accordance with an expected reverse of the aircraft. In addition, an aircraft affected by engine malfunction may not be able to maintain height. Communication difficulties may occur because of the electrical charges within the ash cloud, as well as due to the usage of oxygen masks. Aircraft's ability to climb may be limited due to reduced thrust. ATC's main goal is to ensure clear space around the aircraft for the crew to be able to perform preferred maneuvers and to provide necessary information such as Minimum Safe Altitude and suitable diversion aerodromes. Air Traffic Service (ATS) provider should accommodate many requests for rerouting or level changes; suggest reroutings to avoid or escape endangered areas when requested by the pilot or deemed necessary by the controller; when possible, request special air-report from the aircraft in order to provide such report to the stakeholders[1)].

In a case of a possible eruption of an enormous scale, ATS workload might grow rapidly in a short time, consisting of responding to rerouting requests and supporting aircraft attempting escape maneuvers. When the eruption is not predictable, there is not enough room to effectively manage endangered airspace and the airspace around it when the flight crew manoeuvring for ash cloud avoidance may potentially conflict with other aircraft.

One of the most possible enormous eruptions in the Asia/Pacific region is the case of the Sakurajima stratovolcano in Kagoshima, Japan. Sakurajima is the most active volcano in Japan. In 2016, experts suggested that the volcano could have a major eruption within 30 years, and two eruptions already have occurred since then in 2016 and 2019. Based on the historical analysis, Takebayashi (2019) addressed that half of the flights in the airspace above Japan (Fukuoka FIR) could be affected by the enormous eruption of Mt. Sakurajima. The number of affected flights reaches 2000 flights per day[11)].

In an attempt to prepare for such events, the practice of conducting exercises on possible ATS providers' actions was implemented — Volcanic Ash Exercise (VOLCEX)[12)]. Exercise is designed to demonstrate the globally and regionally applicable procedures including the provision and exchange of volcanic ash information in support of flexible airspace management, improved situational awareness and collaborative decision making, and dynamically-optimized flight trajectory planning. Various possible scenarios with different volcanoes are studied, then probable rerouting options are developed, however VOLCEX might not be enough to prepare for an enormous eruption[8)]. We believe the development of generalized procedures is needed for better preparedness.

3. Methodology and Expected Results

Due to the rareness of big eruptions, there was a lack of historical data. Recent Taal volcano eruption in the Philippines in January 2020 brought new possibilities for analysis. With new data we hope to discover common patterns in decision-making processes, thus making the next step towards improving the policy.

Data analysis of historical flight data during the Taal eruption might undercover common factors and trends in ATC decision making. By comparing the data of regular operations and emergency state operations we might find patterns in rerouting and escape trajectories in and around the ash contaminated area.

On January 12th, 2020, the eruption of Taal volcano which is located about 70 kilometers far from Manila Ninoy Aquino International Airport (MNL) resulted in the suspension of flights in the area[13)]. We acquire historical data for the day of the eruption as well as data for days of "normal" operations, build flight trajectories, and compare them in order to demonstrate the change in trajectories on the day of the eruption. Below is the sample of the data for the flight JL711 from Tokyo to Singapore operated by Japan Airlines on January 11th, 2020.

Table 1 JL711 flight data sample

Timestamp	UTC	Callsign
1578736006	2020-01-11T09:46:46Z	JAL711
1578736041	2020-01-11T09:47:21Z	JAL711
1578736047	2020-01-11T09:47:27Z	JAL711
1578736053	2020-01-11T09:47:33Z	JAL711
1578736060	2020-01-11T09:47:40Z	JAL711
1578736066	2020-01-11T09:47:46Z	JAL711

Table 1 (continued) JL711 flight data sample

Position	Altitude	Speed	Direction
35.769459,140.371826	0	88	149
35.747463,140.387451	575	182	150
35.743042,140.390427	850	181	151
35.738152,140.393814	1125	181	150
35.733685,140.397034	1425	181	149
35.729446,140.400192	1750	177	148

Historical flight positions data files contain timestamps and corresponding time in UTC format, information on position (latitude and longitude), altitude, speed, direction, callsign for each flight. In addition, other significant information including flight number, aircraft type, origin and destination, flight status is available, as well as meteorological information. We are discussing appropriate machine learning algorithms to undercover trends in trajectory changes. Updated information will be presented at the presentation.

Based on the future findings, we hope to suggest improvements in guidelines for ATS providers and thus contribute to the complex process of developing volcanic ash contingency plans of the future.

REFERENCES

1) International Civil Aviation Organization: Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds (Doc 9691), Second Edition, 2007.
2) Casadevall, T.J.:Volcanic hazards and aviation safety — Lessons of the past decade, *FAA Aviation Safety Journal*, v. 2, no. 3, p. 9-17, 1992.
3) International Civil Aviation Organization: Flight Safety and Volcanic Ash (Doc 9974), First Edition, 2012.
4) IATA: IATA economic briefing: The impact of Eyjafjallajokull's volcanic ash plume, 2010.
5) ICAO Asia and Pacific Office: Asia/Pacific Region ATM Contingency Plan, Version 2.0, 2017.
6) European and North Atlantic Office of ICAO: Volcanic Ash Contingency Plan (EUR Doc 019, NAT Doc 006), Edition 2.0.0, 2016.
7) Reichardt, U., Ulfarsson, G.F., Pétursdóttir, G.: Volcanic ash and aviation: Recommendations to improve preparedness for extreme events, *Transportation Research part A* 113, 101-113, 2018.
8) Reichardt, U., Ulfarsson, G.F., Pétursdóttir, G.: Developing scenarios to explore impacts and weaknesses in aviation response exercises for volcanic ash eruptions in Europe, *Journal of Air Transport Management*, 79, 101684 (1-10), 2019.
9) ICAO: Handbook on the International Airways Volcano Watch (IAVW) (Doc 9766).
10) Australian Government, Bureau of Meteorology: Hazardous weather phenomena — Volcanic ash, Brochure, 2019.
11) Mikio Takebayashi: Impact analysis on the extra large-scale volcanic eruption on air transportation: case of Mt. Sakura-jima, *Journal of Japan Society of Natural Disaster Science*, 131 No. 38-3, 336-341, 2019.
12) ICAO: Information paper — Sixth Meeting of the Asia and Pacific Volcanic Ash Exercises Steering Group (APAC VOLCEX/SG/6), 2019.
13) Civil Aviation Authority of the Philippines: CAAP suspends flights at NAIA due to Taal explosion, *Philippine Information Agency*, 202