



HEEDING EYJAFJALLAJÖKULL'S LESSONS



The eruption of Iceland's Eyjafjallajökull volcano in 2010 clearly demonstrated the vulnerability of aviation to volcanic eruptions that occur in or near to high density airspace. More than 100,000 commercial flights were cancelled during the volcano's eruptive phase and over \$5 billion¹ in global GDP was lost due to what eventually became the largest shut-down of European air traffic since World War II. IATA estimated that its airlines alone lost \$1.7 billion due to this single volcanic event.

In light of the scale of these impacts, ambitious programmes were undertaken in 2010 to draw lessons from Eyjafjallajökull. These efforts have helped ensure the smoother handling of similar eruptions such as the Puyehue-Cordón Caulle eruption in Chile in 2011, where the ash plume circumnavigated the southern hemisphere several times, affecting many flight information regions.

Karsten Theil, former ICAO Regional Director Europe and the North Atlantic (EUR/NAT), summarizes the work and achievements of ICAO's International Volcanic Ash Task Force in this special submission to the *ICAO Journal*, with support from ICAO's Meteorology Section and from Peter Lechner, Chief Meteorological Officer at the Civil Aviation Authority of New Zealand and Chairman of ICAO's International Volcanic Ash Task Force (IVATF) and International Airways Volcano Watch Operations Group (IAVWOPSG).

The eruption of the Eyjafjallajökull volcano, situated in the Southern part of Iceland, started with a flank eruption on 20 March 2010. The explosive phase of the eruption began on 14 April and lasted 39 days. A volcanic ash plume was first observed in the early morning of 14 April, and it gradually rose during the day, reaching around 10 km above sea level by evening. North westerly winds carried the ash towards the southeast with ash reaching Europe in the following days.

In accordance with ICAO provisions, upon receiving notification from the Icelandic Meteorological Office and armed with a necessary set of eruption source parameters, the London Volcanic Ash Advisory Centre (VAAC) activated its atmospheric transport and dispersion model and, supported by an observational analysis, began issuing volcanic ash advisories on the extent and movement of the volcanic ash cloud. Several other VAACs, within the framework of ICAO's International Airways Volcano Watch (IAVW), provided further advice, assistance and coordination where the volcanic ash cloud extended beyond the London VAAC's area of responsibility.

IMMEDIATE REACTIONS

Since 2004, and in support of the IAVW structure outlined above, Air Traffic Management (ATM) Volcanic Ash Contingency Plans had been established for the European (EUR) and the North Atlantic (NAT) Regions of ICAO. Similar procedures were in place for aircraft operators with recommendations stipulating that air traffic control should not allow flights through volcanic ash-contaminated airspace and that pilots should avoid volcanic ash.

Eyjafjallajökull's volcanic ash was relatively fine-grained and ejected high into the atmosphere. The ash could therefore potentially be carried over long distances. This was correctly forecast by VAAC London and aircraft operators responded by cancelling flights in contaminated and potentially contami-

THE INTERNATIONAL AIRWAYS VOLCANO WATCH

The International Airways Volcano Watch (IAVW) was established by ICAO in close coordination with the World Meteorological Organization (WMO) in November 1987. It helps civil aviation mitigate the significant hazards posed by volcanic eruptions and volcanic ash in the atmosphere on safe and efficient aircraft operations.

Since the late 1980s, through a global, collaborative approach led by ICAO, the IAVW has matured into a comprehensive worldwide monitoring and notification system consisting of volcanological observatories, meteorological offices (including volcanic ash advisory centres), air traffic service units and users.

ICAO provisions relating to the IAVW ensure the necessary monitoring of active or potentially-active volcanoes, the observation, reporting and predicted movement of volcanic ash in the atmosphere, the issuance of information to aircraft in flight and to aerodromes warning of the presence or expected presence of volcanic ash, information regarding the closure of air routes and aerodromes, the activation of alternative contingency routes, and the reporting by pilots to air traffic service units of any observed volcanic activity or encounters with a volcanic ash cloud.

nated airspace. Based on the procedures, guidelines and level of experience available at the time, this was the only option that would adequately ensure flight safety.

"The IVATF has been a very important catalyst in galvanising globally the volcanic ash event mitigation effort. The Task Force has produced a number of important guidance documents and clarified many areas of concern and confusion in the international aviation sector.

Most importantly, the Task Force brought together for the first time under the ICAO umbrella, a global representation of disciplines including pilots, airlines, scientists, aircraft engineers, ATM, and infrastructure and operations experts. This inter-disciplinary approach was a fundamental key in rapidly advancing the issues and achieving the outcomes sought. It serves as an excellent model for solving other international aviation issues.

The Task Force's recommendations will now be implemented and further developed by the ICAO IAVWOPSG in an accelerated and re-energised work programme. However, it needs to be

emphasised that work on the mitigation of volcanic ash safety and economic risk is no small thing. It is effectively about continuing to build a global system and perspective on geophysical and meteorological phenomena that is relatively new to aviation.

So while the Task Force achieved much, there is more to do. In particular, work in areas like defining engine and airframe tolerance and design criteria, as well as reducing uncertainties in ash reporting and plume modelling is expected to eventually provide critical warning system enhancements in the future.

Importantly, the objective remains to provide increasingly granular and robust information that will allow aircraft to operate safely and economically proximal to volcanic ash in the atmosphere."

- Civil Aviation Authority of New Zealand

In light of the resulting disruption to aviation across Europe, the North Atlantic and beyond, not to mention the significant new perspectives on volcanic ash that Eyjafjallajökull was generating, a change to the European aviation regulation on permissible volcanic ash concentration levels for operation of commercial aircraft was made on 19 April 2010.

This decision allowed for the reopening of limited commercial air traffic routes in Europe to better balance flight safety and economic regularity. A great deal of new data and experience was gained by aircraft operators, ATM officials and aviation regulators in Europe during these first weeks of limited operations and ICAO reacted swiftly in having it reflected in updated guidance material.

ICAO RESPONSE

The Eyjafjallajökull eruption was a strong reminder that most issues related to flight safety and volcanic ash have wide, global implications. This realization emphasized that measures to mitigate the effect of volcanic eruptions on international

“While the well-established ICAO IAVWOPSG, in which WMO has been a long-term partner and contributor, had helped to keep aviation safe in the presence of continued volcanic activity around the world, it was the recent protracted eruption scenario of Icelandic and Chilean Volcanoes that demonstrated that, for an optimized balance between safety and operational regularity and efficiency, further efforts by all stakeholders were needed.

The IVATF process rested on a number of pillars, one of which was the Science effort which was very much relying on the new IUGG-WMO effort of the Volcanic Ash Scientific Advisory Group. The Science group excelled by providing highly relevant guidance and clarification on all aspects of volcanology, the science of atmospheric transport and diffusion of volcanic ash, and vastly improved the common knowledge base on all these aspects of volcanic ash.

WMO and its partner organization, IUGG, are indeed proud to have played an active role in this process, assisting and/or facilitating a highly successful series of workshops and events that, by sharing best practices and scientific methodologies, established an improved basis for the decision support needed by the industry and regulators. The foundations were laid for a much improved capacity to provide a quantitative estimate of volcanic ash present in the atmosphere. This resulted in an improved readiness to design, produce and provide tailored information to decision makers if and when the successful conclusion of technical experiments provides reliable guidance on the ash tolerance of airframes and engines.”

- World Meteorological Organization (WMO)

aviation be globally applicable and well understood by aviation and related technical, scientific and operational communities.

ICAO’s first response was to establish a common EUR/NAT Volcanic Ash Task Force (EUR/NAT VATF) to review and revise the EUR and the NAT ATM Volcanic Ash Contingency Plans taking into account the experience gained. Alongside these EUR/NAT-specific efforts, ICAO established an International Volcanic Ash Task Force (IVATF) at the global level to ensure the EUR/NAT experience and recommendations would benefit other regions as well. The work of the IVATF was complementary to ICAO’s existing International Airways Volcano Watch Operations Group (IAVWOPSG) that oversees the operation and the development of the IAVW.

By the end of June 2010, the EUR/NAT VATF had completed its work and delivered a draft amendment of the revised contingency plans to the European Air Navigation Planning Group and to the North Atlantic Systems Planning Group for adoption. During and following its inaugural meeting in July 2010, the IVATF worked to address the issues highlighted by the Eyjafjallajökull eruption. Further meetings of the Task Force were held in 2011 and 2012. In late-2011, ICAO convened a meeting of senior-level decision makers to provide guidance to the Task Force on a number of fundamental issues. In June 2012, at its fourth meeting, the Task Force delivered the results of its work to the ICAO Secretariat and was dissolved thereafter. It had completed work on the majority of the issues before it, and provided advice for existing or future ICAO work programmes on any outstanding work that was required. Much of the remaining work and recommendations fall to the IAVWOPSG that meets to further this work, amongst its other responsibilities, in March 2013.

IVATF ACCOMPLISHMENTS

In order to develop a safety risk management framework that would achieve maximum regularity of flights during a volcanic eruption without compromising flight safety,



Passengers rest on cots at the airport in Frankfurt, Germany, as they wait for the resumption of air travel

you're cleared to land

the IVATF divided its work programme into four sub-groups:

- Atmospheric sciences.
- Airworthiness and aircraft operations.
- Air Traffic Management.
- IAVW coordination.

As most of the issues considered were of a highly multi-disciplinary nature, teleconferences were convened at regular intervals between meetings to ensure effective, comprehensive coordination. The Task Force work programme was updated and revised at each meeting.

Eruption situational awareness factors

Most volcanic eruptions can be predicted in advance to some degree. Advance knowledge of impending volcanic eruptions is essential with regards to alerting the aviation community, in particular the flight planners and the airspace managers, that 'normal' flight operations might be disrupted.

In the case of Eyjafjallajökull, the first indications of magma movements were detected as early as 1992-94, and deep earthquakes were detected in 1999-2000. An eruption on 20 March 2010 was preceded by intense seismic activity and the rapid inflation of one of the volcano's flanks. As a result of the volcano's monitoring, the explosive eruption on 14 April was by no means a surprise to volcanologists.

The IVATF therefore performed an evaluation of the volcano monitoring gaps worldwide and recommended a future work plan in this area for the IAVWOPSG, in close cooperation with the Smithsonian Institution and the United States Geological Survey. Also in this regard, the World Organization of Volcano Observatories, through the International Union of Geodesy and Geophysics, developed initial guidelines to promote aviation-specific terms and pre-eruption information.



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Volcanic ash detection and avoidance

Once an eruption has started, detailed knowledge of an ash cloud's three-dimensional size, density, composition, etc., is vital. This is true not only for flight planners and airspace managers but also for pilots and air traffic managers who need to avoid hazardous ash in real-time. This information is also helpful to Volcanic Ash Advisory Centres as they seek to more accurately forecast ash cloud movement.

For some time, the *avoid visible ash* concept has been employed by flight planners and pilots, while the concept of *avoid all ash* has been relied upon by airspace managers and air traffic managers. Each of these approaches only has limited practical applicability, in as much as:

- The concept of *avoid visible ash* only functions effectively under good daylight conditions. It therefore cannot guarantee that a flight occurring at night or in poor visibility conditions will not enter an ash cloud, posing a risk to flight safety.
- The concept of *avoid all ash* compromises flight economic regularity since it might prevent flights from operating through airspace for which the concentration of ash poses no significant flight safety risk.

In the early days after the eruption of Eyjafjallajökull, regulatory authorities in Europe, in coordination with engine manufacturers, established a threshold value of $2\text{mg}/\text{m}^3$ with respect to a volcanic ash concentration level that is likely to be visible and could therefore form the basis for a decision to operate a given flight or not.

A scientific analysis performed by the Task Force, however, demonstrated that there exists considerable range in concentration values – two or three orders of magnitude – that could be used to represent visible ash, even under good viewing conditions. In addition, the Task Force found that current technologies for ash cloud detection do not support determination of the actual or forecast concentration levels with an accuracy that would assist operators in mitigating flight safety uncertainties.

The Task Force therefore identified technologies and recommended system requirements pertinent to ground-based, airborne and satellite-based volcanic ash detection systems. It furthermore made recommendations on the types of volcanic materials that should be used to conduct airframe/engine testing.

"Volcanic contamination seriously affects the operation of aircraft and therefore pilots need accurate knowledge about its existence in airspace planned for their flight. IFALPA was an active participant to the IVATF, providing papers and presentations to the sub-groups and full task group.

IFALPA appreciates that the IVATF had achieved a great number of improvements to the existing knowledge about the safe operation of flights despite the occurrence of volcanic contamination. However, the inevitable silos of information need to be integrated into a comprehensive strategy involving the whole ATM Community (as defined in ICAO Doc9854) and further effort is required to ensure all aviation decision makers are aware of the outcome of IVATF.

ICAO needs to focus on developing globally harmonized Volcanic Ash Advisories (VAAs), also in graphical form, and to rationalize SARPs that currently create information overload during eruptive events. Development of technical provisions would ensure that the most accurate information concerning volcanic hazards are displayed on the flight deck in a way that can be easily used by pilots.

It is essential that pilots are given clear instructions as to what information is required for flight planning and execution of the flight and how to comply with the conditions of their operator's safety risk assessment."

- International Federation of Air Line Pilots' Associations (IFALPA)

"The 2010 eruption in Iceland constituted a wakeup call on the disastrous economic downfall natural events can bring to aviation. Although safety was guaranteed, it turned out that the model, actions and procedures at the time, implied unnecessary closure of immense portions of airspace leading to unacceptable financial losses. At the call of the industry, ICAO acted swiftly. The convening of IVATF and the opening of the Volcanic ash end-to-end process to examination and assessment, was the right decision. The intense discussion between representatives of regulators, operators, specialized organizations and the scientific community made it clear this would constitute a complex task; handling a daunting number of variables. Within tight timelines, the IVATF produced core recommendations which were widely supported by the industry. It developed actions commensurate with the capability of the ICAO IAVW to detect and warn for visible volcanic ash."

The initial guidance developed will certainly improve the evaluation and decision-making process, not only for regulators, but also operators and ANSPs. However, this is a first step with further development and implementation still to occur. Much of this work lies within the realm of the revamped IAVWOPSG process as well as operators' SMSs. The enhancement of these will steadily improve the efficiency achieved in dealing with eruptions while allowing operations with the required level of safety."

- International Air Transport Association (IATA)

New guidance in these areas will be included in the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (ICAO Doc 9691) and the *Handbook on the International Airways Volcano Watch – Operational Procedures and Contact List* (ICAO Doc 9766).

Health effects of volcanic sulphur dioxide

The Task Force completed an assessment which highlighted that, during a volcanic eruption, a number of toxic gases – including sulphur dioxide (SO₂) – may be emitted in addition to volcanic ash, and that it may exist quite separately from the volcanic ash cloud itself.

Sulphur dioxide was considered to be of particular importance since it may be emitted in large quantities and potentially has significant health effects. The Task Force determined that more research is necessary to better understand the potential risk of sulphur dioxide to aircraft occupants, airframe and engine components and any associated expeditious mitigation of the risk. This research is on-going through the International Airways Volcano Watch Operations Group (IAVWOPSG).

Risk management by aircraft operators

One of the most important mandates given to the Task Force was to develop a global safety risk management framework that makes it possible to determine safe levels of operation in airspace reported or forecast to be contaminated by volcanic ash.

It therefore developed comprehensive guidance material which resulted, in early 2012, in the publication of ICAO Doc 9974 – *FLIGHT SAFETY AND VOLCANIC ASH – Risk management of flight operations with known or forecast volcanic ash contamination*. The new manual was co-branded by ACI, CANSO, IATA, ICAO, ICCAIA, IFALPA and IFATCA and it will be updated through the ICAO Operations Panel as further experience and knowledge arises on related hazards.

ATM contingency planning

Realizing that ATM contingency planning needed to address regional or sub-regional nuances, the Task Force developed an ATM Volcanic Ash Contingency Plan template taking such factors into account. The template was developed on the basis of European experiences in the early days after the eruption, as well as further findings of the Task Force. It was distributed to the ICAO Regional Offices to assist the Planning and Implementation Regional Groups (PIRGs) in the development of region-specific volcanic ash contingency plans, in particular for those ICAO Regions where no such plan had existed before.

In this context, and considering that newer safety risk assessment guidance for aircraft operators and regulatory authorities was now available through Doc 9974, the Task Force recommended that *Danger Areas* should not be used to manage airspace, potentially or actually contaminated with





volcanic ash. With this recommendation and others in mind, ICAO is proposing an amendment to the *Procedures for Air Navigation Services – Air Traffic Management* (Doc 4444) regarding procedures to be utilized by air traffic services units when a volcanic ash cloud is reported or forecast. The proposed amendment reinforces existing ICAO provisions concerning special air reports of volcanic activity from the flight crew – thus improving the observation and tracking of a volcanic ash cloud – and highlights that the flight crew, based on safety management system principles, has the final authority as to the disposition of the aircraft (i.e. whether to avoid or to proceed through a reported or forecast volcanic ash cloud).

IAVW operational recommendations

The Task Force made significant progress in assisting to enhance the operating efficiency of the International Airways Volcano Watch. In parallel with additional Task Force activities in this area, two Best Practices Seminars were conducted in 2012 with participation from all nine Volcanic Ash Advisory Centres, and from the user and manufacturer communities. The main results achieved were:

- Identification of tools and procedures to help foster more collaborative decision-making and consistent responses to volcanic eruptions, wherever they occur.

"The IVATF divided responsibilities into four groups, one of which was Air Traffic Management Sub-Group (ATM-SG). The IVATF ATM-SG was initially lead by NAV CANADA's Larry Lachance and shortly thereafter to NAV CANADA's Ted Fudge.

The most notable accomplishment of the IVATF ATM-SG was the collaboration of its members who agreed on a global understanding on the provision of air traffic services during a volcanic ash event. Interestingly, the group naturally employed a Safety Risk Management approach which focused and enabled the group to achieve its success.

To facilitate its global implementation, the group agreed to put forward a proposal for amendment to the ICAO PANS-ATM section 15.8 (Procedures for an ATC Unit When a Volcanic Ash Cloud is Reported or Forecast). The group also agreed to create a Volcanic Ash Contingency Plan Template for global harmonization. In addition, the ATM experts recognized that there was a need to address the information overload of a volcanic ash event and provided suggestion for change to the appropriate ICAO group.

The ATM-SG did an excellent job; the group was engaged throughout the process and were anxious to see the results of our hard work progressed as quickly as possible."

- Civil Air Navigation Services Organisation (CANSO)

- Supporting the requirements of a future system-wide information management (SWIM) environment, a recommendation that ICAO provisions be amended to enable the availability of volcanic ash advisories in a digital form.
- Proposals for amendments to ICAO provisions and guidance to ensure appropriate volcanic eruption monitoring and volcano observatory response and notification.
- Development of a draft Concept of Operations for the IAVW to be reviewed and further developed by the IAVWOPSG.



"The IVATF was able to work quickly and intensely in response to a new paradigm with regard to Volcanic Ash. This work pointed out that while existing ICAO standards are designed to maintain the maximum level of safety, we are finding more and more often that they have not kept pace with changes in the state of aviation technology. As much of the discussion in advanced ATM considers the implementation of new technologies, the work of the IVATF illustrated that the modernization of standards and procedures is equally important. As we face increasing demands on the global aviation system and an increased need to manage capacity in adverse meteorological conditions, including volcanic ash, it is important to ensure that the policy framework keeps pace with technological innovation. In doing so, ICAO and its expert groups need to ensure that any new proposal includes a comprehensive review of existing language to prevent any inadvertent negative consequences."

- International Federation of Air Traffic Controllers' Associations (IFATCA)

ICAO DOCUMENTS RELATED TO VOLCANIC ASH

- **Annex 3** *Meteorological Service for International Air Navigation*
- **Annex 11** *Air Traffic Services*
- **Annex 15** *Aeronautical Information Services*
- **Doc 4444** *Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM)*
- **Doc 8126** *Aeronautical Information Services Manual*
- **Doc 8896** *Manual of Aeronautical Meteorological Practice*
- **Doc 9377** *Manual on coordination between Air Traffic Services, Aeronautical Information Services and Aeronautical Meteorological Services*
- **Doc 9691** *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds*
- **Doc 9766** *Handbook on the International Airways Volcano Watch – Operational Procedures and Contact List*
- **Doc 9854** *Global ATM Operational Concept*
- **Doc 9882** *Manual on Air Traffic Management System Requirements*
- **Doc 9965** *Flight and Flow Information for a Collaborative Environment – A Concept*
- **Doc 9974** *Flight Safety and Volcanic Ash – Risk Management of Flight Operations with Known or Forecast Volcanic Ash Contamination*

- Development of a revised Volcanic Activity Report form with supporting provisions adapted from both existing ICAO and non-ICAO sources.
- Identification of the complexities and co-existing roles between the different aeronautical and meteorological message types that relate to volcanic ash, resulting in a recommendation that the IAVWOPSG, in coordination with other relevant groups, continue to work on strategies to reduce or eliminate information overload.

LOOKING AHEAD

Given the two-year life span of the Task Force, its very ambitious work programme and the resources available to it, the related accomplishments were commendable. It was not surprising that all of its tasks were not completed by June 2012, especially since more data will be needed before conclusions can be derived on aircraft occupant susceptibility to volcanic gases and airframe and engine susceptibility to volcanic ash.

The recommendations and guidance developed by the Task Force on future work to be undertaken provides significant assistance to those working structures within ICAO (the IAVWOPSG and other forums) as well as within other international organizations and entities now vigorously pursuing further progress. ■

FOOTNOTE

¹ Oxford Economics.

