Safe and Flexible Volcanic Ash Operation

Issue
Current regulations for volcanic ash measurement and certification do not fulfil the operational and safety needs. Aircraft are not certified for flight into volcanic ash simply because airworthiness requirements are not specified with regard to volcanic ash. There is presently no clear threshold for the concentration of ash that is hazardous to aviation, so the current recommended practice is to avoid all volcanic ash. This has led to complete airspace closures, restricting all flight operations.

ICAO specifies that the position of the ‘ash cloud mass’ should be forecasted, but does not define any threshold limits for ash concentration. Threshold ash concentration values vary over the world, with no clear relationship between threshold values and aviation hazards. A zero-tolerance policy is not realistic, therefore acceptable levels of exposure to defined ash concentrations must be established. This depends on specifications of increased tolerance levels from manufacturers which can be related to measurement levels and reporting practices from e.g. Volcano Watch institutes and National Air Service Provider. The appropriate authority should establish refined threshold values for exposure to volcanic ash concentration, which must be based on aircraft hazards: a so-called hazard threshold. Furthermore operational and maintenance procedures must be subsequently adapted. Taking into account those newly assigned aviation limits the airlines/operators should be able to bear the responsibility for planning safe flights. Finally, the ultimate responsibility to conduct a safe flight rests with the captain. The captain should therefore be given adequate tools, information and guidelines. This position paper addresses these topics.

Background.
Of the more than 1,330 volcanoes worldwide that have demonstrated activity over many thousands of years, approximately 500 of them have recent histories of events and action, resulting in 55 to 60 eruptions per year. However constant seismic monitoring is only available on 174 volcano’s. From 1980 to 2005, more than 100 turbojet aircraft have sustained volcanic ash damage, with repair costs in excess of $250 million dollars. Seven of these encounters caused temporary engine failure, and three of the aircraft involved temporarily lost all engine power. Whereas most documented engine failure events have occurred not in downstream ash clouds, but in the overhead plume relatively close to the eruption, some engine failures took place as far away as 600 miles from the erupting volcano.
According to IATA, NLR, ECA and VNV, Europe is lacking guidelines and regulations for Volcano ash particle measurements and acceptable limits for aviation. Aircraft and engine certification criteria for volcanic ash lack. Common guidelines are to avoid volcanic ash since acceptable ash thresholds are not specified.

The European Transport Ministers adopted a short-term solution for the eruption of Eyjafjallajökull and the subsequent closure of all NW European airspace on April 20th:

Accordingly the States concerned will establish a limited “No-fly zone”, based on forecasts from the VAAC. EUROCONTROL will provide the data and the forecast to States every 6 hours.

Aircraft Operators will be permitted to operate outside this zone. In their decision as to whether to fly, they will be supported by shared data including advice from the scientific community (meteo, volcanic ash proliferation etc.) – including safety assessments supported by tests under the oversight of the competent Safety Authorities.

Recommendation: A new policy is needed to ascertain safe and uninterrupted air travel in case of future eruptions.

IAVW
ICAO has instated in 1991 an international system for volcano watch called IAVW, the International Airways Volcano Watch, responsible for a coordinated detection, tracking and alerting service for aviation. ICAO doc 9691, Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds explains the current status of aircraft hazard knowledge and the role of the IAVW, VAAC and AIS. Nine selected Volcanic Ash Advisory Centres, VAACs, around the world are responsible for advising MWO and international aviation via AIS of the location and expected movement of clouds of volcanic ash. Based on this advice, the MWO issues warnings in the form of SIGMET messages and AIS issues NOTAMs concerning airspace restrictions or closure.

The IAVW comprises observations of volcanic ash from selected observatories and other organisations, from satellites and from pilot reports.

Aircraft Hazards.
Several short-term and long-term hazards can be identified and have been encountered in real life in relation to ash encounters. The ones that warrant most attention are those affecting aircraft engines.

Short-term hazards:

- Engine failure
- Multiple engine malfunctions, such as surge, stalls, increasing Exhaust Gas Temperature (EGT) and torching
- Slow or no engine restart
- Pitot-static instrument failure
- Communication failure
- Electrical failures
Impaired vision
Impaired breathing
degraded landing performance
limited ground operations

Long-term hazards:
- Abrasion of fan blades, engine inlet, and compressor
- Abrasion or contamination of pneumatic ducting,
- Damage to aircraft exterior e.g. windshields, wing leading edge,
- landing lights
- Contamination of pitot tubes and static ports
- Health risks
- Corrosion of exterior
- Corrosion interior

**Hazardous substance.**
Each volcano creates its own specific eruption content. From a geophysical standpoint, it is likely that the hazard threshold would vary according to plume altitude, ash composition and mean particle size. From an aviation standpoint, the duration of exposure of aircraft engines to ash and their thrust settings at the time of the encounter, both have a direct influence on the hazard threshold.
In general the following hazardous substances can be identified:
- dust/rock particles
- glass particles
- Sulphuric acid
- HCl (hydrochloric acid)

In their gaseous form the latter two constituents of the volcanic ash cloud are not thought to cause significant harmful effects to aircraft. Following the eruption, however, oxidation and hydration of the SO2 forms H2SO4 (sulphuric acid) droplets, which are quite a different matter. The resulting ash/acid mix is highly corrosive and can cause damage to jet engines and pitting of windscreens, and may well present a long-term maintenance expense for aircraft operating regularly in airspace contaminated with even relatively low concentrations of such ash/acid.
Volcanic aerosols provide a catalyst for ozone depletion.

**Certification**
There are no aircraft certification requirements for volcanic ash. Manufacturers have produced guidelines for avoidance and emergency procedures for escape. Recently Boeing and Airbus have published operator guidelines for additional guidelines for flight in low ash concentration.
Current regulation compiled in ICAO doc 9691 contain procedures covering observation and reporting of volcanic activity, eruptions and ash clouds, the issuance of warnings to aircraft, closure of airspace and pilot reporting.

National Aviation Authorities together with ICAO should set new criteria in cooperation with the engine and aircraft manufacturers. These criteria should meet the requirements of the operator and pilot for planning, avoidance and maintenance purposes. Furthermore it is preferable to develop regulations
enabling to only close that part of the airspace containing unacceptable hazardous levels of ash.

Recommendation: VNV strongly supports the introduction of standardised refined limitations to create a safe and practicable boundary for acceptable ash concentration exposure. These limitations must be operational, flexible and based on a risk assessment.

Measurement
The ICAO specifies that the position of the ‘ash cloud mass’ should be forecasted, but does not define any limits for ash concentration. Relevant parameters to be measured or forecasted are plume altitude, ash composition, ash concentration and mean particle size.
Present and near-future ground-based, airborne and satellite sensors are mainly based on Doppler radar, LIDAR and satellite imagery/spectrometer systems. These systems are designed for research, observation and model validation purposes, not for real-time onboard use.
The 2000 eruption of Hekla demonstrated that even very low concentrations of ash, undetectable visually or by satellite sensors, can cause substantial damage to aircraft. The terms ‘visible’ and ‘visual’ (implying detectable) ash cloud have been previously used to describe areas of volcanic ash to the aviation community. These slightly ambiguous terms should be used with care, as the ash cloud may be neither visible to the eye nor detectable by present remote sensing.
There is currently no consistency in the way that the participant VAACs define the ash–cloud boundary with thresholds depending variously on the source release rate used, availability of satellite data for comparison and forecaster judgement. Neither is there a clear threshold for the concentration of ash that is hazardous to aviation, so the current recommended practice is to avoid all volcanic ash.

Modelling.
Several models for volcanic ash dispersion are in place and used by the Volcano Ash Advisory Centre. Validity, accuracy and robustness of modelling efforts are still being refined. Validation of individual models requires observations of multiple eruptions, but these data can be scarce, particularly given the low frequency of volcanic eruptions.
The amount of ash that should be modelled, per source, for a given interval is not specified by the International Civil Aviation Organization (ICAO) and, in reality, will vary according to the specific eruption. This has resulted in very different values being used by the VAACs. Some VAACs have a fixed release rate for all eruptions (e.g. London, Washington), while others (e.g. Montreal) have a variable rate determined from the eruption magnitude.
The definition of volcanic ash (particle size and density) in a model will influence the dispersion results. Unfortunately, there are few actual measurements of in-plume ash particle size distributions, on account of the risks involved with such measurements.
In general one can conclude that the modelling threshold is quite rough with respect to its goal: to determine the hazard for an aircraft.
Recommendation: VNV believes that additional refinement of the model will indicate more reliable and precise defined area’s (3D) of ash hazards.
Airspace Management

The National State could decide to close (parts of) airspace due to unaccept- able hazardous ash levels. This should be based on unambiguous validated data and done preferably with international uniform ‘closure criteria’.

Since these hazardous levels are difficult to establish in general, a tailor– made approach is needed. Like other weather phenomena volcanic ash is variable in time and place and dependent on the operation. Operators are primarily responsible and thus general no–fly restrictions should be minimised and operations should be left subject to an operators’ risk assessment.

VNV supports the definition of a “low contamination or concentration ash” airspace, which is not unrestricted but not closed either. In distinction from regular unsafe volcanic ash airspace, low concentration airspace can support air traffic under special operational provisions. This will limit the con- sequences for air traffic efficiency and capacity. These areas should be clearly defined, and communicated in the same manner as a volcanic ash notifica- tion of the ICAO International Airways Volcano Watch. Experience from around the globe should be gathered in flying through low- density ash concentration and dynamic airspace management. The advent of operator’s flight tracking services and seamless global communication en- ables dynamic flight planning to circumnavigate ash plumes. The Air navigation service provider is responsible for alerting services and creation of a safe and orderly air traffic flow. A coordinated and effective air– space management should take place in case of a volcanic warning.

Recommendation: The VNV believes that a tailor–made approach is needed. Operators and crew are primarily responsible and thus general no–fly restrictions should be minimised. Operations should be left subject to the operators’ and additional to this the crews risk assessment.

Aerodromes

Volcanic ash may have a serious effect on aerodromes located downwind of a volcanic ash plume. For the flight operation additional factors pose an oper- ational risk: reduced availability of airport services, reduced runway friction, lower visibility, changing winds and electro–magnetic interference. The planning of an alternate airport should be upwind of the ash cloud and should always avoid having to cross the ashcloud.

Operator

The operator is responsible for safe flight operations, for an airworthy air– craft, for operational support facilities and qualified crew for the area and type of operation. Operators are required by ICAO Annex 6 to have a Safety Management System to minimize all hazards. The National Supervisory Au- thority has the responsibility to approve this SMS and to supervise its execu- tion. In concert with the manufacturer, operational procedures for intended
flight in a low-density ash area must be specified. These procedures must include an explicit guideline on the acceptable exposure times and ash concentration. Safety implications must be resolved by increased maintenance inspections and possibly earlier part renewal. Data monitoring, inspection and maintenance checks should be adopted in order to monitor possible damage related to volcanic ash.

For the high concentration ash encounter standard escape procedures are established. The escape manoeuvre is based on minimising the duration of exposure of aircraft engines to ash and the thrust setting to avoid hazards. With regard to planning, the general policy is to avoid high-density volcanic ash.

Low concentration ash can be unnoticeable to the pilot. For low concentration ash encounters, long-term negative effects are significant: pollution, abrasion and corrosion of airframe, engine and ducting. These long-term effects constitute more an economical than flight safety aspect if proper maintenance and monitoring action is conducted.

**Recommendation:** The post holder must conduct a risk assessment prior to planned operations in the vicinity of volcanic ash.

**Flight Planning/Flight Operation**

The operator and flight dispatch are responsible for a safe and realistic flight plan free from significant ash hazards. This requires a tailor made risk assessment for the specific flight operation. Also contingency routes, alternate aerodromes (e.g. upwind) and decompression must be considered. The flight crew must have continuous information of relevant NOTAMs and SIGMETs and consider other means such as three dimensional map(s) reflecting the observed ash cloud location, extension and/or trajectory forecast, upper wind analysis and forecast at selected flight levels and satellite images. Required maintenance procedures must be completed and notified to the crew. Specific MEL items must be serviceable. Possibly extra fuel should be considered. The captain is ultimately responsible for safe flight.

During flight, dispatch and flight crews should seek for updating of the preflight information when en route. Flight crew should report any observation of volcanic activity to the ATC. If encounter with volcanic ash cannot be avoided, the flight crew should immediately apply the procedure recommended by the aircraft manufacturers’ documentation.

**SUMMARY**

The zero tolerance policy on ash cloud is not realistic and restricts air operations to an unnecessary level. The lack of certification criteria however makes it unclear what an acceptable ash level and exposure could be. The lack of accurate modelling, detection and measuring devices makes it impossible to clearly define three dimensional specific ash concentration areas. Several issues must be resolved to assure safe flight and avoid unnecessary complete airspace closure at the same time in case of a volcanic eruption. Subdivision of ash concentration airspace, minimising no-fly zones, dynamic flight planning and operator’s risk assessment will provide relief. The challenge will be to define 3D area’s with an unacceptable high ash hazard (black), area’s of no limitations (green) and area’s of an acceptable limited exposure to ash
Uncertainties:

- Certification and tolerance ash limitations for aircraft and engine.
- Measurement of relevant particle size and concentration and acid contents.
- Modelling.
- Management of limited use airspace

Conclusion and Way forward.

VNV strongly believes that several issues have to be addressed to guarantee safe flight in a volcanic ash environment with maximum flexible use of the available airspace. The underlying assumption must remain intact that the flight path is planned free from significant ash hazards.

1. Identify the hazards.
   a. Perform adequate research on the effects of volcanic ash on aircraft.
   b. Conduct an in–depth hazard analysis for the aircraft operation.
   c. Establish generic engine ash tolerance levels for relevant ash parameters: content, concentration, particle size, acidity.

2. Identify the contaminated airspace.
   a. Improve modelling, measurement and/or sensing accuracy of ash particle size and density in downstream volcano ash clouds. Compile experience and data from present and past unpremeditated encounters and test flights. Validate modeled ash concentrations.
   b. VAAC must deliver relevant data/ danger areas in an accurate, timely and robust way from measurement, imaging, modelling and validation.
   c. Uniform airspace closure criteria should become available in case of unacceptable hazardous ash concentrations (the no–fly black zone)
   d. Implement possibly one or more intermediate levels of ash hazard/concentration with restrictive use and additional operating rules and maintenance requirements (e.g. red, orange zone).

3. Operation.
   a. Responsibility of operation should remain with the operators, except for hazardous high–density ash levels exceeding aircraft and engine tolerance limitations (black zone). These should be defined by the National Supervisory Authorities responsible for regulating flight operations, not by Air Traffic Management authorities or Air Navigation Service Providers.
b. The operator must fulfil this responsibility for a safe flight and conduct a risk assessment prior to operation in low-density ash (red, orange zones).

c. The captain must remain ultimately responsible for safe flight and must therefore have insight in all relevant ash data and specific aircraft procedures. As the ultimate responsible, the captain bears the final decision whether a flight can be conducted safely.

d. Operators should refrain from disciplinary actions when crews take their flight safety responsibility.

e. “See and avoid” is the last defence barrier and has limited operational use for tactical flight planning.

Reference
1. ICAO doc 9691 ICAO Manual on Volcanic Ash and Radioactive Material
2. EASA Safety Information Bulletin 2010–17
4. FSF publication Volcanic Hazards and Aviation Safety, may 1993
5. Comparison of VAAC atmospheric dispersion models, RMetS, 2007
9. IAVWOPSG, 2005

Appendix A

Recent developments of volcanic ash dispersion modelling include:

1. Dispersion model: a new version of MOCAGE (Large Scale Chemical atmospheric Model), developed for nuclear or chemical accidental releases, is currently operational. The volcanic ash dispersion version will be tested from summer 2008 and is planned to be fully operational from early 2009 to replace the current MEDIA model. The meteorological parameters are given by the French model ARPEGE or the model of ECMWF (European Centre for medium range Weather Forecast) on a global domain and at a resolution of 0.5 degrees. The range of forecast can reach 72h for ARPEGE and 180 h for ECMWF with two runs a day (00, 12 UTC)

2. MOCAGE, a semi-lagrangian model, integrates convection and 3D precipitations to calculate washing. Future developments include taking into account vertical and horizontal distribution of ash particles size.
3. PERLE is made of MESO–NH, a meso scale non–hydrostatic weather model, plus a high–resolution dispersion model SPRAY. It can provide data within the European geographic domain at a resolution of 8km on a 240/240 km area, centred on the volcano source. The dispersion model can be tuned to provide a final resolution of 1 km.

4. MétéoFrance as a RSMC (Regional Specialized Met Centre) designated by MWO is involved in the project 'Ensemble' leaded by the Joint Research Centre in Italy. This European project launched in 2000 has now gained maturity. Designed for nuclear accident dispersion model–lers, it provides a platform for any model comparison and even for multi–models production based on different single models. MEDIA, MOCAGE and PERLE outputs have already been provided for comparisons on the platform. It could be the place to continue model inter–comparisons as the one run after the Grimsvötn Icelandic eruption or to make tries on multi model prediction.