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WORKING PAPER

INTERNATIONAL VOLCANIC ASH TASK FORCE (IVATF)

FIRST MEETING

Montréal, 27 to 30 July 2010

Agenda Item 5: Development of ash concentration thresholds (AIR sub-group) 5.2: Establishment of regulatory provisions

MANAGING SAFETY OF FLIGHT ISSUES ASSOCIATED WITH VOLCANIC ASH

(Presented by United Kingdom)

SUMMARY

This paper recommends that ICAO leads the development of a globallystandardized safety assessment approach that makes optimum use of a wide range of information. This may include avoidance of visible ash when the volcanic source is in view, enhanced hazard information expressed in terms of airworthiness effects, as well as a range of enhanced forecasts to be produced by VAACs globally that will need to be used and interpreted in a consistent manner. This paper suggests that sole reliance on this criterion provides a less robust safety assurance regime than is desirable.

1. **INTRODUCTION**

1.1 Iceland's Eyjafjallajokull volcano erupted on 14 April 2010, ejecting a debris plume over 30 000 feet into the atmosphere. Guidance contained in the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (Doc 9691) states that there are no agreed values of ash concentration that constitute a hazard to jet aircraft engines. Therefore the current ICAO recommendation is that aircraft should avoid exposure to volcanic ash, regardless of the ash concentration. The plume extended over Northern Europe such that, by 18 April, commercial air traffic had ceased in 23 European countries and 75 per cent of the European aerodrome network was closed. Although the maintenance of safety was then, and remains, the over-riding consideration, the economic and social consequences of this closure were far-reaching and cannot be ignored. The importance of the need to strike a balance between safety and efficiency was recognized at the second meeting of the European and North Atlantic Volcanic Ash Task Force (EUR/NAT VATF) in Paris in June 2010. 1.2 In response to the initial eruption of Iceland's Eyjafjallajokull volcano, Volcanic Ash Advisory Centre (VAAC) London issued ash advisories, including graphics, based on the forecast extent of the ash plume. Following extensive consultation with industry, supplemental forecast ash concentration charts were introduced. These have allowed operators to develop safety cases to fly in potentially ash contaminated airspace. Significant effort continues to reduce and mitigate uncertainties inherent in the underlying forecast to make it of the most practical value to operators.

1.3 Accordingly, work has continued across a very wide range of disciplines within Europe, with support from other ICAO Contracting States, to develop improved requirements, plans and techniques, that allow the safe management of air traffic in airspace in the presence of ash. This work has resulted in a harmonized and common methodology that is applicable in both the EUR and NAT Regions.

1.4 In order to develop flight operations in potential ash contaminated environments further, a formalized standardized risk management approach is required that allows all available data sources to be considered in determining the actions the operator is going to take. This includes additional forecast information from the VAAC and improved information from Original Equipment Manufacturers (OEM) about the hazard. This paper will detail some of the issues that need to be addressed.

2. **RISK MANAGEMENT – THE VISIBLE ASH CRITERION**

2.1 Background

2.1.1 The major airframe and engine manufacturers have specifically authorized operations into predicted ash densities of $2x10^{-3}$ g/m³ and almost all have specified no particular engineering interventions associated with such operations. The major airframe and engine manufacturers have confirmed that they are content for operators to make the decision to operate in predicted ash densities beyond $2x10^{-3}$ g/m³ provided that encounters with visible ash are avoided. The OEMs have stated their belief that visible ash occurs at actual ash densities of $2x10^{-3}$ g/m³. It is important, therefore, to consider the practicability of the recommendation to avoid visible ash and to assess its place in future arrangements for safety assurance of flights in the vicinity of ash contamination.

2.2 **Defining Visible Ash**

Visible ash, when originally suggested as a criterion for managing flight near areas 2.2.1 contaminated with ash, was understood by the experts at the time to mean "visible to the naked eye" (either from the ground or the flight deck) (an expert commentary noted on UKCAA hosted teleconference 2 June 2010 refers). Today, it is clear that the term has come to mean "detectable by any means" as evidence (National Volcanic Ash Operations Plan for aviation and Support of the ICAO International Airways Volcanic Watch" Section 5.1 Alaska Area Forecast example and Section 5.8 VAAC Washington example; published as FCM-P35-2007 by US Office of the Federal Coordinator for Meteorological Services and Supporting Research, Washington DC, August 2007 refer) by sample forecast and alert texts "ASH VISIBLE IN STLT IMAGERY" and "MSH CAMERA AND G-10 VISIBLE IMAGERY SHOW A MODERATELY DENSE PLUME OF VA NW OF THE VOLCANO There are differences in the level of information that can extracted from ABOUT 30NM". instrumentation; typically space-based instruments will only provide information on the horizontal extent of the "visible" ash, whilst instruments such as LIDAR can provide information on the distribution of ash in the vertical plane.

2.2.2 In issuing volcanic ash advisories and graphical products complying with the ICAO standards and recommended practices set out in Annex 3 — *Meteorological Service for International Air Navigation*, (Chapters 3.1 and 7.1, Appendix 1, Model VAG, Appendix 2, 3.1 and Appendix 6, 1.1 refer), VAAC London defined the extent of the ash plume, which has been verified with satellite imagery and other observations from previous eruptions.

2.2.3 Guidance (*FAA Aeronautical Information Manual* (11 Feb 2010), 7-5-9 (h) refers) issued for use in North America seeks to discriminate between airborne ash and ash deposited on the ground, relating the visible ash criterion only to airborne ash. This states, "When departing from airports where volcanic ash has been deposited, it is recommended that pilots avoid operating in visible airborne ash. Allow ash to settle before initiating take-off roll".

2.2.4 It would seem necessary to conclude that there is no internationally agreed definition of the term "visible ash". It is particularly important to note that in some circumstances the consequences of failing to avoid visible ash have been severe – including multiple engine shut-down and loss of all motive force. Yet it is also clear from experience (Debrief of UK Atmospheric Research Aircraft sortie on 14 May 2010 refers) that such an outcome may not necessarily result in all conditions where ash is visible. The resultant uncertainty will, logically, lead to the curtailment in some airspace of flight operations that could otherwise have operated safely, with consequent unnecessary financial and social consequences.

2.3 **Identifying "visible ash" in flight**

2.3.1 When establishing the advice to avoid "visible ash", experts at the time envisaged that the volcanic source would be in the field of view to facilitate identification. Experts attest that it is difficult to reliably ascertain that a particular cloud feature is of volcanic origin without additional contextual information such as a smoking volcano on the horizon (typically not beyond 100 NM) or pilot reports of a drifting cloud from a volcanic source.

2.3.2 Ash does not always remain close to the volcano source; the ash cloud from the 1992 eruption of Alaska's Mount Spurr, for example, travelled more than 3 000 NM downwind over three days (Evidence of USGS presented to *Volcanic Hazards – Impacts on Aviation* Senate hearing March 2006). US expert advice is that "ash clouds may extend for hundreds of miles and pilots should not attempt to fly through or climb out of the cloud" (FAA Aeronautical Information Manual (11 Feb 2010) Section 5-5-9 (c) refers).

2.3.3 The KLM B747 crew in the 15 December 1989 Mount Redoubt incident, when asked by Anchorage ATCC "do you have good sight on the ash plume at this time" reported sighting "cloud a little browner than the normal cloud" (RT transmission record presented to *Volcanic Hazards – Impacts on Aviation* Senate hearing March 2006 refers) but misidentified it as a meteorological phenomenon and entered it. The aircraft was 154 NM from the volcanic source which was not in their field of view. Similarly, the crew of a UK meteorological research aircraft encountered visible ash on 14 May 2010 during a test flight at a measured density of 0.5×10^{-3} g/m³ but commented (Verbal debrief to UK CAA 14 May 2010 refers) that even though the layer was 5 000 ft deep, they would not have identified it accurately as ash were it not for their on-board instruments directing their attention to it and confirming its true nature.

2.3.4 There are limitations to the usability of the visible ash criterion. Experts attest that "the ash plume may not be visible, especially in instrument conditions or at night; and even if visible, it is difficult to distinguish visually between an ash cloud and an ordinary weather cloud [...] The pilot must

rely on reports from air traffic controllers and other pilots to determine the location of the ash cloud and use that information to remain well clear of the area" (FAA *Aeronautical Information Manual* (11 February 2010) Section 7-5-9 (b) refers). "As volcanic ash clouds disperse, they intermingle with meteorological clouds in the atmosphere and thus have a similar appearance when observed in infrared and visible images" (*Reducing the threat to aviation from airborne volcanic ash*, presented at 55th annual international air safety seminar, 4 to 7 November 2002, Dublin; Marianne Guffanti USGS and Capt Edward Miller ALPA refers).

2.3.5 In addition, there is a strong likelihood that crew may not notice a volcanic ash cloud when the volcanic source is not in the field of view. For example, a comment from VAAC London Chief Scientist at Volcanic Ash Conference, in London, on 13 May 2010 indicates that, at $2x10^{-3}$ g/m³, a 300 ft deep layer would not be seen, a 3 000 ft layer might just be visible from above on a slanted viewing angle whereas a 15 000 ft layer would block out the sun.

2.3.6 It would seem logical to conclude that it can be difficult for crews to notice and correctly identify volcanic ash at night, in the presence of meteorological cloud formations, and when the volcanic source is not in their field of view. Consequently, over reliance on in-flight pilot reports as a deterrent to entering contaminated areas is not likely to create a robust understanding of the limits of the area. Furthermore, evidence from instrumented flight test aircraft operating in the UK during April and May indicated that in this particular event, ash was present in clearly defined level bands, although their lateral extent was never defined. It is clear that the term "visible ash" covers a wide range of conditions and associated potential effects and has limitations as a reliable means of avoiding ash contaminated areas, both vertically and laterally.

2.4 Managing the flight hazard using the "visible ash" criterion

2.4.1 In order to manage the flight hazard, it is necessary to know what the hazard is. Relating visible ash to airworthiness effects would enable an assessment to be made as to whether the proposed flight path would result in:

- a) an unsafe condition (aircraft unable to continue to planned destination);
- b) a safe condition (high confidence that the aircraft will complete its flight to the intended destination) but with airworthiness consequences such as accelerated wear of components which require enhanced engineering interventions; or
- c) a condition representing normal operations.

2.4.2 The crew of the KLM B747 crew in the 15 December 1989 Mt Redoubt incident (RT transmission record presented to *Volcanic Hazards – Impacts on Aviation* Senate hearing March 2006 refers)" entered a visible ash cloud, added power and all 4 engines suffered compressor stall within 1 minute damaging engines and airframe. A probable causal factor cited by NTSB was "lack of available information about the ash cloud to all personnel involved" (Data from FSF Aviation Safety Network, USGS and *Impact of volcanic ash from 15 December 1989 Redoubt volcano eruption on GE CF6-80C2 turbofan engines*; Zygmunt J Przedpelski and Thomas J. Casadevall; *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, July 1991 refer). Despite knowledge of the eruption, reports of the locations of the ash clouds and procedures in place for avoidance, the aircraft suffered loss of engine power, and engine damage costing many millions of dollars (*The 1989-1990 eruption of Redoubt Volcano, Alaska: impacts on aircraft operations*, Thomas J. Casadevall refers). The volcanic ash concentration encountered by the KLM B747 has been estimated (Doc 9691 Draft

incorporating Amendment 1 Section 2.2.2.2 refers) at $2g/m^3$; Similarly, the ash clouds produced by the 1991 eruptions of Mount Pinatubo were well known and described in NOTAMs and SIGMETs and yet there were 16 reported ash encounter events, many of them resulting in damage to the aircraft even at distances from the volcanic source of up to 1 150 km (*The 1991 Pinatubo Eruptions and Their Effects on Aircraft Operations*; Thomas J. Casadevall et al. refers).

2.4.3 Some other assumptions about airworthiness effects have been recorded. "Beyond three days, it is assumed that if the ash is visible by eye or from satellite data, it still presents a hazard to aircraft" (Doc 9691 Draft incorporating Amendment 1, Section 4.1 refers). And again, "The threshold concentration at which ash poses no harm to aircraft is not known, and indeed, may never fully be characterized for all situations involving aircraft. It is usually assumed that ash identifiable on satellite images continues to present a hazard to aircraft. Accordingly, the consensus of the aviation community is that if an ash cloud can be discerned, it should be avoided" (*Reducing the threat to aviation from airborne volcanic ash*, presented at 55th annual international air safety seminar, 4 to 7 November 2002, Dublin; Marianne Guffanti USGS and Capt Edward Miller ALPA refers).

2.4.4 "The question at issue is (Doc 9691 Draft incorporating Amendment 1, Section 2.2.2.4 refers) – when does the concentration of ash in the contaminated airspace decrease to a level considered safe for aircraft? Moreover, flying through even very low ash concentrations considered safe from the standpoint of immediate engine damage may [...] still cause long-term engine damage with significant economic consequences or worse if not detected by normal maintenance inspections and interventions".

2.4.5 "Unfortunately, at present (Doc 9691, Draft incorporating Amendment 1, Section 3.4.8 refers) there are no agreed values of ash concentration which constitute a hazard to jet aircraft engines. [...] in view of this, the recommended procedure in the case of volcanic ash is exactly the same as with low-level wind shear, regardless of ash concentration – AVOID AVOID AVOID."

2.4.6 Manufacturers have been clear that they cannot endorse flying into a visible ash cloud.

2.4.7 In the absence of clarity of the hazard, in terms of airworthiness effects, associated with flight in visible ash, the balance of safety favours pilots avoiding flight into readily identifiable visible ash. However, service experience has demonstrated that sole reliance on the "avoidance of visible ash" as a criterion does not completely protect the aircraft from encountering unsafe flight conditions or from damage; experience also suggests that avoiding flight in visible ash may be unnecessarily conservative in some cases.

2.5 The role of "visible ash" in a future safety management approach

2.5.1 The avoidance of readily identifiable visible ash would appear to be a necessary part of the approach to the assurance of safety for flights in the vicinity of volcanic ash. A clear distinction needs to be made between the application of the criterion in sight of the source of the volcano and its use to avoid hazardous ash encounters in the en-route phase of flight beyond visual range of the source.

2.5.2 The limitations of the use of the "visible ash" criterion render it ineffective in certain circumstances as the sole means of managing flight safety or potentially unnecessarily restrictive, particularly within densely populated volumes of airspace away from the volcanic source. An approach is desirable that relates the effects on airworthiness of encounters with ash at a given level, to the probability of encountering ash at that level. Such an approach would not only protect aircraft from encounters with

levels of ash that compromise flight safety, but would also prevent unnecessary curtailment of safe operation in any type of airspace.

3. **RISK MANAGEMENT – PROMULGATING ASH** CONCENTRATION INFORMATION

3.1 **Introduction of a new approach**

3.1.1 On 20 April 2010, following a series of teleconferences, the OEMs, supported by scientists and other aviation experts, concluded that aircraft and engines could safely tolerate operations in predicted ash densities up to $2x10^{-3}$ g/m³. This new threshold was recognized and adopted by the European authorities, and reflected in products provided by VAAC London in addition to those required by ICAO standards; flights in airspace forecast to contain ash up to these levels was enabled.

3.1.2 Following the agreement to promulgate revisions to forecast ash density boundaries, OEMs issued guidance to operators of their products, regarding the enhanced procedures to be applied. Authorities placed requirements on operators intending to implement this guidance which included the need to prepare safety cases. Safety risk assessment is inherent in a regime whereby airline operators have responsibility for the decision to operate in areas affected by volcanic ash. As an example, as of 31 May 2010, 69 operators, including 9 major carriers, had lodged safety cases with the UK CAA to operate in forecast ash densities between $2x10^{-4}$ g/m³ and $2x10^{-3}$ g/m³.

3.1.3 The focus of these safety cases is the risk to flight safety (the risk of the aircraft being unable to continue safely to its destination). It is recognized that even for flights that can be safely undertaken, operators will have an interest also in understanding the economic consequences of operating in ash contaminated airspace in terms of accelerated component wear and increased engineering interventions.

3.1.4 Further discussions between operators, OEMs, air navigation service providers and regulators resulted in the introduction of a tolerable predicted ash density of 4×10^{-3} g/m³ on 18 May 2010. Operator requests to OEMs for support for safety cases to operate in this higher predicted ash density resulted in additional guidance to operators. In supporting operations in forecast conditions beyond 2×10^{-3} g/m³, OEMs drew a clear distinction between operating in predicted ash densities as opposed to actual ash densities. The guidance emphasized the overriding importance of avoiding visible ash and suggested a definition of visible ash related to densities of 2×10^{-3} g/m³. As an example of this approach in operation, as of 31 May 2010, 21 operators, including 9 major carriers, had lodged safety cases with the UK CAA to operate in the higher predicted ash density areas. The safety cases cover Airbus, BAE Systems, Bombardier, Boeing, Dassault, Embraer, Lear, Saab, GE, IAE, P&W, PWC, RR and Snecma products.

3.1.5 This initiative marked the introduction of a different approach to managing flight safety in the vicinity of volcanic ash. However, although offering the advantage of relating ash concentrations to airworthiness effects, the approach depended solely on forecast ash densities. Experience of using this approach revealed significant uncertainties in the predicted ash values due to the nature of the modelling process and the assumptions on which it was based. It would appear that sole reliance on this approach could result in a suboptimal solution to the management of the volcanic ash hazard.

3.2 **ICAO Recognition of the new approach**

3.2.1 On 12 July 2010, the ICAO European and North Atlantic Regional Office Director issued a State Letter in which he noted that following consultation, the revised *Volcanic Ash Contingency Plan – European and North Atlantic Regions* had been endorsed by the member States of the European Air Navigation Planning Group (EANPG) and the North Atlantic Systems Planning Group (NAT/SPG) for application in the ICAO EUR and NAT Regions with immediate effect. Within the plans, a three-zone approach for the EUR and NAT Regions, differentiating these areas by ash contamination levels defined as follows:

- a) Low Contamination equal to or $< 2x10^{-3}$ g/m³;
- b) Medium Contamination $-2x10^{-3}$ but $<4x10^{-3}$ g/m³;
- c) High Contamination equal to or > $4x10^{-3}$ g/m³

3.2.2 The meeting further agreed that States should continue to exercise oversight duties, both in their role of State of Service Provision and or as State of Operator/State of Registry, and impose certain requirements and restrictions for flights to operate in contaminated airspace; however the issue would be subject to further examination by ICAO, to avoid, inter alia, potential inconsistencies at FIR boundaries.

3.3 The role of enhanced VAAC products in a future safety management approach

3.3.1 VAAC trajectory and dispersion models calculate the dispersion of pollutants by tracking simulated particles through an atmospheric model. The model allows a detailed description of the pollution source to be specified and then uses a range of meteorological information from the weather forecast model, to describe the transport and dispersion of the emitted pollutant away from the source region. One of the key benefits of such models is that they allow complex atmospheric motions to be taken into account and allow forecasts of the volcanic ash plume to be provided many hours in advance to assist with flight and operational planning. These prediction and dispersion models are used for a wide variety of purposes and are, as a consequence, constantly being refined and updated.

3.3.2 However, the VAAC London's procedure at the start of the Eyjafjallajokull eruption was to forecast only the extent of the ash plume. Given the long-lived nature of the eruption, this resulted in widespread airspace closures and severe disruption throughout European airspace. Following extensive consultation with industry, supplemental forecast ash concentration charts were introduced, corresponding to likely peak concentrations of ash that may be encountered within the areas and layers depicted. An additional concentration level was later added, as OEMs, operators and regulators were able to gain experience with the use of such information and conduct appropriate analysis, which resulted in increased tolerance levels that aircraft may be permitted to fly in.

3.3.3 The model is generally conservative in its final output, due to a number of uncertainties and approximations in the modelling process. Further work since the eruption ceased has been carried out to try to reduce and mitigate uncertainties to make it of the most practical value to operators. This has included work to obtain better information on the source emission strength, measurement of ash density downwind using instrumented research aircraft, lidar and other supporting observations. In addition, work is ongoing to produce predictions which represent the average concentration values for deep layers coupled with more detailed information about the vertical structure of the ash layers. 3.3.4 The uncertainties and conservatism implicit in the process of generating the ash concentration forecast contours as they relate to the OEM tolerable ash density levels, suggest that reliance solely on these forecast contours could produce a situation where, although at the boundaries of the plume away from the volcanic source, safety of life is unlikely to be put at risk, once again, considerable disruption could be caused that will have significant economic and social consequences for air travel.

3.3.5 Nevertheless, the tiered ash concentrations forecasts have given operators additional information which has helped them to better determine where they fly. It is clear that a "one size fits all" approach is not appropriate and it is suggested that the ash concentration charts should be used to form the basis for developing new advisory products for implementation by VAACs globally in a standardised manner that is based on a common understanding by operators.

4. **OVERALL CONCLUSIONS**

4.1 The avoidance of readily identifiable visible ash, when the volcanic source is in the field of view, would seem to be a necessary part of the approach to the assurance of safety in the management of aircraft encounters with volcanic ash. This delivers positive benefits when operating close to the source (less than 100 nms) of the volcanic activity, however, it offers less benefits in the en-route phase of flight away from the source.

4.2 Thereafter, it would seem necessary to maintain flight safety by adopting a formalized risk management framework, suitable for use by operators and standardized to an extent that facilitates ready adoption by States globally; ARMS (Aviation Risk Management Solutions) (http://www.easa.europa.eu/essi/documents/Methodology.pdf refers) is an example of such a framework.

4.3 To avoid unsafe operations and to prevent unnecessary curtailment of safe operations, the formalized risk management approach must be based on a clear understanding of the airworthiness effects of flight in known conditions of ash contamination expressed in terms of tolerable ash density levels and exposure times. The risk assessment requires the airworthiness effects to be made available by OEMs to operators in such a manner that will allow operators to assess the likely consequences of exceeding certain defined thresholds for periods of time as part of the overall accumulation of ash and hence risk.

4.4 To ensure that the outputs of operators' risk assessments can readily be translated into operationally useful information, it is necessary that tolerable ash density levels be promulgated in a series of enhanced products adopted by VAACs globally in a consistent and standardized manner that is understood by all operators.

4.5 Further enhancement of the accuracy of both the predicted ash density information and of information about actual ash density levels in the atmosphere is critically important to the development and success of the risk management approach.

4.6 The risk of further eruptions and the necessity to identify a common global approach to prevent confusion or misinterpretation makes continued progress a matter of urgency.

5. **ACTION BY THE IVATE**

- 5.1 The IVATF is invited to:
 - a) note the information of this paper;
 - b) invite the AIR sub-group to consider:
 - recommending the use by operators of a formalized volcanic ash risk management framework standardized to an extent that facilitates ready adoption by States globally and based on a clear definition of the ash hazard expressed in terms of airworthiness effects; and
 - 2) endorsing the use of the "avoid visible ash" criterion when the volcanic source is in the field of view;
 - c) invite the IAVW coordination group to:
 - 1) consider the need for developing new advisory products for publication by VAACs, recognising the requirement for a globally standardised and consistent format that will be readily useable and understood by the operators when applying the risk management approach; and
 - 2) take account of OEM-defined ash tolerance information when developing new provisions and guidance for VAACs; and
 - d) invite the Science sub-group to further encourage the scientific and aviation communities in their work to further enhance the accuracy of the predicted ash density level, actual ash density levels in the atmosphere and to identify the airworthiness effects of ash exposure.

-END-