European Aviation Safety Agency

28 Nov 2012

ADVANCE NOTICE OF PROPOSED AMENDMENT (A-NPA) 2012-21

Possible courses of action for EASA to address the issue of

'Volcanic ash ingestion in turbine engines'

EXECUTIVE SUMMARY

The ICAO International Volcanic Ash Task Force (IVAFT), set-up in response to the Eyjafjallajökull eruption in April 2010 to review guidance for flight operations in volcanic ash, has now largely completed its tasking and has been disbanded. This international effort has contributed to a better understanding of the hazards to aviation posed by volcanoes, has generated greater awareness of the impacts resulting from flight operations in volcanic ash clouds, and has recommended changes to operational procedures, the implementation of which will reduce the potential disruption to flight operations in future volcanic events. This approach has been embraced by EASA and ongoing rulemaking activities will embed the recommendations into operational rules.

The IVAFT recommendations retain the underlying principle of avoiding flight in visible ash. This brings with it some uncertainties as to the robustness of the approach, as a clear definition of visible ash that can be used in all environments (e.g. at night and in IMC) does not currently exist, and ash can be difficult to distinguish from normal clouds, smoke, haze, etc. Furthermore, there is a view that the avoidance principle may be overly conservative, and that safe, robust procedures, that significantly enhance operational flexibility, could be established in the future if aircraft were permitted to operate into a known ash environment. Such an approach would require airworthiness standards and acceptable means of compliance to be established. Chief amongst these will be a focus on turbine engines, due to their susceptible to volcanic ash, and the significant implications to engine performance, environmental impacts and economic consequences, if such an approach were to be adopted.

This A-NPA has been produced by the Agency to gather information from stakeholders on the concept of moving towards airworthiness certification of turbine engines. It proposes a number of options that could be followed and outlines the various pros and cons. Stakeholders are asked to comment on these options and, in particular, to respond to various questions embedded in the A-NPA.

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A. Explanatory Note

I. General

1. This A-NPA has been developed by the Agency with support from manufacturing industry. Its primary aim is to solicit the views and experience of stakeholders on future options for addressing volcanic ash ingestion in turbine engines. The outcome of the A-NPA public consultation will be used to define an EASA action plan. If rulemaking is deemed necessary, then an NPA will be published for comments.

2. The European Aviation Safety Agency (hereinafter referred to as the 'Agency') is directly involved in the rule-shaping process. It assists the Commission in its executive tasks by preparing draft regulations, and amendments thereof, for the implementation of the Basic Regulation[1] which are adopted as 'Opinions' (Article 19(1)). It also adopts Certification Specifications, including Acceptable Means of Compliance and Guidance Material to be used in the certification process (Article 19(2)).

3. When developing rules, the Agency is bound to following a structured process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as the 'Rulemaking Procedure'[2].

4. This rulemaking activity is included in the Agency's rulemaking programme for 2012. It implements the rulemaking task RMT.0364 (MDM.089).

5. The text of this A-NPA has been developed by the Agency. It is submitted for consultation of all interested parties in accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

II. Consultation

6. To achieve optimal consultation, the Agency is publishing the draft Decision of the Executive Director on its website. Comments should be provided within **3 months** in accordance with Article 6(4) of the Rulemaking Procedure.

7. Please submit your comments using the **automated Comment-Response Tool (CRT)** available at **http://hub.easa.europa.eu/crt/**.[3]

8. The deadline for the submission of comments is **28 February 2013.**

III. Comment-Response Document (CRD)

9. All comments received in time will be responded to and incorporated in a Comment-Response Document (CRD). This may contain a list of all persons and/or organisations that have provided comments. The CRD will be available on the Agency's website and in the Comment-Response Tool (CRT).

[1] Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1), as last amended by Regulation 1108/2009 of the European Parliament and of the Council of 21 October 2009 (OJ L 309, 24.11.2009, p. 51).

[2] Management Board Decision concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material (Rulemaking Procedure), EASA MB Decision No 08-2007, 13.6.2007. Decision as last amended and replaced by EASA MB Decision No 01-2012, 13.3.2012.

[3] In case the use of the Comment-Response Tool is prevented by technical problems please report them to the CRT webmaster (crt@easa.europa.eu).

B. Possible courses of action

IV. Background

10. It has long been recognised that volcanic ash clouds can pose a hazard to aviation safety and have the potential to disrupt flight operations over large areas for prolonged periods of time. Precautions must therefore be taken to ensure that risks are controlled to an acceptable level.

11. As of today, there has been no aircraft loss or fatality attributed to flight in volcanic ash clouds. However, in-service experience[4] following a number of serious incidents in the 1980s and 1990s where aircraft unknowingly entered into airspace contaminated with volcanic ash, has established that flights into large quantities of volcanic ash (density estimated to be of the order of 1 gram/m^3) can cause immediate safety of flight concerns, with the potential for all engines to fail. As no rigorous assessment and testing to determine the potential impacts of volcanic ash on engines has been undertaken by engine manufacturers to date, it was perhaps only fortuitous that the flight crews were able to successfully recover the aircraft in each of the in-service occurrences.

12. The regulatory authorities' approach to ensuring safety oversight has generally been to apply ICAO guidance with respect to flight operations and volcanic ash, which is based on the principle of visible ash avoidance. The in-service experience emphasised the limitations of the visible ash avoidance principle, as a clear definition of visible (or discernible) ash that can be used in all environments (e.g. at night and in IMC) does not exist and hence operational procedures to avoid visible ash may consequently not be robust. In response to the in-service events, operators were required to develop and implement new procedures, or to more rigorously enforce existing procedures, including navigation procedures and flight crew training, so as to better apply the avoid principle. The ability to identify ash contaminated airspace was improved through strengthening of volcanic watch activities, although some areas of the globe remain unmonitored. Some Volcanic Ash Advisory Centres (VAAC) have developed models, in recent years, which can be used, within the limits of the model accuracy, to forecast the location and concentrations of volcanic ash within the airspace.

13. During the Eyjafjallajökull eruption in April 2010, forecasts based on models suggested that much of European airspace was impacted by volcanic ash. In congested airspace, there was a concern about loss of separation between aircraft as crews responded to the ICAO guidance to avoid ash. To assure safe separation, air traffic flows were progressively reduced until, in effect, airspace was no longer available for use. This had an adverse effect on the availability of European airspace and resulted in widespread disruption to flight operations.

14. The immediate solution to the problem was not to avoid all ash but, instead, to avoid ash that was at a concentration in the atmosphere that had significance to the safety of operations. To forecast where there might be volcanic ash clouds of significance to safety, modelling techniques were further refined and supplemented with satellite and other data. The problem which arose in Europe is that the inputs to the models are difficult to establish with any degree of confidence, and so while forecasts are indicative of areas which may be affected by ash across a region, when it comes to detailed predictions of affected airspace blocks in high density traffic the forecasts tend to be conservative given the significant level of uncertainty.

15. As a consequence of the European experience, the ICAO International Volcanic Ash Task Force (IVATF) was set up, involving manufacturers, authorities, ANSPs, Met Offices, VAACs and many others, with the objective of revising guidance on a wide range of issues, including contingency plans, development of ash concentration thresholds, and improvement and harmonisation of ash detection and dispersion models. One of the outputs from this initiative was revised guidance in Doc. No 9974, which retains the

[4] Encounters of Aircraft With Volcanic Ash Clouds: A Compilation of Known Incidents, 1953-2009. Marianne Guffanti, et al., U.S. Geological Survey.

existing principle that flight in ash visible to the naked eye should be avoided. Furthermore, advice from TC holders has been to limit exposure to volcanic ash by setting criteria such as 'not exceeding 2mg/m^3' to restrict flight operations, and that an ash concentration of 2 mg/m^3 could be used as indicative of visible ash for flight planning and night flying purposes. It was also established that flight in volcanic ash where the ash is not visible could be tolerated by turbine engines without long-term effects, although this figure was based on limited experience and testing. However, in the knowledge that VAAC forecasts still retain a significant level of uncertainty, and that this is likely to continue for the foreseeable future, procedures have been developed by ICAO that allow flight operations within areas forecast to contain volcanic ash clouds (even above 2 mg/m^3), and aerodromes known to be contaminated with volcanic ash, provided the operator has in place an identifiable safety risk assessment (SRA) within its management system. If an aircraft were to encounter volcanic ash in flight, the advice and current instructions from Type Certificate holders require that the aircraft vacate the contaminated airspace as safely and expeditiously as possible once the flight crew is alerted to the presence of the volcanic ash cloud. What remains unclear, however, is the degree to which the use of such criteria are conservative from a safety standpoint.

16. There is an inevitability that volcanic activity will at some future date impact European airspace and other high density traffic regions, so as to prevent normal flight operations from continuing. Volcanologists have confirmed that the Eyjafjallajökull eruption in 2010 was relatively small in comparison to possible eruptions from neighbouring volcanoes, and that an eruption of one of the larger volcanoes could result in higher ash concentration levels or more widespread distribution of volcanic ash in the atmosphere. The consequential disruption for airlines and the travelling public could, in the extreme, be even higher than that experienced in April 2010, despite the improvements in procedures having been adopted. To enable greater operational flexibility and utility during and following a volcanic eruption and resulting contaminated airspace, it has been questioned whether prolonged flight operations could be envisaged at ash concentration levels in excess of such criteria and at what costs in respect of accelerated wear or additional maintenance of airframe or engine components.

V. Aims and scope of this A-NPA

17. This A-NPA is targeted at large turbine engine powered aeroplanes and helicopters operating in commercial air transport. This sector of the market has the greatest commercial pressures to continue flight operations in contaminated airspace and possibly the most to gain through an airworthiness approach that significantly improves the understanding of the safety and economic consequences of exposure to volcanic ash clouds.

18. One of the main challenges facing airworthiness from volcanic ash hazards is related to turbine engine ash ingestion. The characteristics of turbine engines make them susceptible to volcanic ash, with resulting adverse effects such as engine surge or flame-out. Also, as the environmental conditions affect all engines simultaneously, there is a likelihood that all engines will fail in short succession. There are currently no numerical values defined for safe volcanic ash exposure (concentration levels and duration). It is also thought likely that if additional Certification Specifications are established to provide resilience to ash, then necessary design changes are likely to be detrimental to engine efficiency, leading to adverse performance, environmental and economic factors. Any new turbine engine Certification Specification will necessitate defining a means of demonstrating compliance, which would need to include testing. All of these factors need to be taken into account in determining the airworthiness approach to be taken forward.

19. Piston engines are excluded from the scope of this A-NPA. While piston engines are affected by volcanic ash, generally they have more benign failure characteristics than turbine engines due to the relative difference in operating temperatures, and the lower quantities of volcanic ash ingested on account of their significantly lower mass flow rates. Furthermore piston engine aircraft are not widely used for commercial air transport.

20. Aircraft systems, structure and also crew/passengers will also be affected by exposure to volcanic hazards. While not underestimating the effort required to amend the applicable

Certification Specifications to address these issues, it is not the intent to address these issues here. This will only be contemplated once a clear direction on the setting of turbine engine ash ingestion limits has been established.

21. In addition to the threat from ash, there are other identified threats from volcanic cloud constituents (e.g. CO_2, SO_2, H_2S, H_2, CO, HCL, HF, He, H_2SO_3, and H_2SO_4). These additional threats are added here for completeness but are not considered further in this A-NPA. If an airworthiness approach is to be taken forward, these threats will need to be considered in defining the airworthiness limitations and certification standards.

22. The focus of this A-NPA is therefore aimed primarily at gathering the views and experiences of stakeholders for consideration in determining future options related to turbine engine volcanic ash ingestion.

VI. Previous and ongoing EASA rulemaking actions

23. To put into context these proposals, this section summarises previous and ongoing EASA rulemaking activities:

    a) <u>Operational safety risk assessment</u>

    A-NPA 2011-06 was published on 3 May 2011 to formally consult European stakeholders on the ICAO IVATF (AIR 04) paper (Draft 7)[5] on the management of flight operations with known or forecast volcanic cloud contamination, and to collect feedback on future EASA actions. This task was completed in December 2011 with the publication of ED Decision 2011/014/R. Subsequently a new rulemaking task was initiated (RMT.0460) that will propose AMC/GM on SRA in Part-ORO (organisation requirements for air operations) and Part-ARO (authority requirements for air operations). As ICAO has in the meantime published Doc. No. 9974, this will be the basis of the changes.

    NPA 2012-07 on ‘Guidance material on volcanic ash safety risk assessment (VA SRA)’ was published on 19 July 2012. Changes to Part-ORO/ARO are based on the ICAO guiding principle that the operator is responsible for the safety of its operations. In order to decide whether to operate into airspace forecast or aerodromes known to be contaminated with volcanic ash, the operator must have in place a safety risk assessment as part of its management system.

    b) <u>Information to operators</u>

    NPA 2011-17 was published on 3 September 2011 proposing changes to the airworthiness CSs to better reflect existing type certificate holder’s obligations to supply information to operators, as required by the essential requirements of Annex I to the Basic Regulation (Regulation (EC) No 216/2008). This will allow European operators to better prepare the volcanic ash SRAs as part of their management systems for new/changed products ahead of any future volcanic ash encounters. The Comment-Response Document (CRD) 2011-17 was published on 8 October 2012 responding to comments received during the NPA public consultation. The task currently remains open.

VII. Objective of airworthiness limits

24. The essential requirements for airworthiness contained in Annex I to the Basic Regulation place an obligation on TC holders to show that their products can operate safely within the bounds of established limitations and information necessary for safe operations, including environmental limitations. Currently there are no certification limits for the performance of airframes or engines when exposed to volcanic ash, and compliance is by means of information.

25. The airworthiness codes already address most environmental hazards (e.g. birds, lightning, icing, rain and hail, etc.) but do not typically provide full protection against all

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5 An earlier draft of ICAO Doc 9974.

hazards. Instead the codes set a level of safety based on the probability of encountering the hazard. When the avoidance principle is applied successfully to volcanic clouds, there is a low probability of an ash encounter. Today's meteorological remote volcanic ash detecting capabilities are such that, where this capability is available, volcanic ash can be detected in concentrations before it becomes a hazard for aircraft turbine engines. However, this does not mean that the ash will always be detected. Volcanic ash can travel large distances from an erupting volcano and be suspended in the atmosphere for extended periods, so that encounters with low concentrations of volcanic ash can occur several times within the operational life of an aircraft. The question then is how much robustness for an aircraft/engine shall be demonstrated as a minimum, since avoidance is not always possible.

26. The concept of defining turbine engine airworthiness limits may require both an upper and lower limit to be established. The upper limit may be established by an ash exposure level (concentration + time), at which immediate safety of flight may be prejudiced. The upper limit could be determined for each product type by the OEM based on test and analysis, with a built-in safety margin applied, or by some other means. The lower limit would be established for prolonged flight into a contaminated environment. The lower limit could be based on the currently established figure of 2 mg/m^3 identified by engine TC holders, although this would not be in compliance with the advice to exit airspace containing visible ash in circumstances where the two were coincident, and the long-term effects of exposure would need to be better established. Alternatively, research may be able to establish a lower limit based on a knowledge of potential future hazards, expected probability of occurrence, likely exposure times, and a level of flight operation disruption which is deemed acceptable.

27. Based on previous events, it can be postulated that there exists a density of volcanic ash (between the range of 200 and 1000 mg/m^3), which represents an upper limit. However, adverse safety effects may also occur if the aircraft is exposed for long periods of time to lower ash concentrations likely to occur away from a volcano source. Other dependencies in defining an appropriate airworthiness limitation would also need to be established and would likely include ash particle sizes and composition.

28. Between the upper and lower airworthiness limits, there may be an 'economic band' where a trade-off between operational utility and operating costs exists. For example, the engine manufacturer could elect to develop an engine design with a high level of ash tolerance that enables operators to maintain safe flight operations and maximise operational utility during a volcanic event (and hence retain operational revenues), but probably at the expense of normal propulsive efficiency, environmental impact, and additional continued airworthiness costs, and vice versa. At some point there may be an economic/environmental optimum for each aircraft/engine combination and each operator.

29. An additional margin of safety would need to be applied by the operator to account for engine type variability (e.g. age in service) and the probability of unexpected encounters with higher ash density. The latter point would require a good understanding of the characteristics of volcanic ash clouds as they form, develop in the airspace and dissipate. The margin of safety may also be dependent on other factors, including the expected accuracy of forecast models or the availability of accurate real-time ash measurements through the installation of volcanic ash detection equipment. Aircraft/engines should never operate in a density of volcanic ash that could prejudice continued safe flight.

30. The objectives of setting airworthiness limits for turbine engine ash ingestion can therefore be summarised as follows:

- To establish an upper limit of ash exposure, which if exceeded could have immediate consequences on aircraft safety;
- To confirm that the current guidance and instructions from TC holders have sufficient safety margins built-in so as to provide a conservative approach;
- To establish the long-term effects on turbine engines due to exposure to volcanic ash clouds;

- As an enabler to permit future flight operations into a known ash environment;
- To better understand the consequences on engines of operating in a volcanic ash environment (e.g. additional engine wear and maintenance costs), so that operational decisions can be made based on informed judgement.

VIII. Turbine engine effects from volcanic ash

31. Experience has shown that turbine engine can be susceptible to volcanic ash and other volcanic cloud constituents in a number of ways. Below is a non-exhaustive list of some of those effects:
    - Erosion of fan, compressor blades and linings leading to loss of efficiency and surge margin.
    - Molten ash in the combustor and turbine sections can lead to:
        - clogging in the combustor and flame extinction;
        - blocking of turbine cooling channels leading to reduced component life;
        - deposits on HP nozzle guide vanes and turbine blades reduces the annulus area and restricts engine core flow.
    - Contamination of filters/seals/cooling channels/oil & fuel systems/sensors.
    - Corrosion of metallic components.
    - Ineffective engine restart capability.
32. The susceptibility of individual engines to the effects of volcanic clouds will depend on a number of factors, including:
    - Design — engine layout, core temperature, pressure ratio, turbine blade technology, cooling system design, bleed system.
    - Condition of the engine — engine surge margins will generally reduce depending on the number of flight hours accumulated since new or last overhaul.
    - Flight profile — effects will vary with engine thrust settings (climb, cruise and flight idle settings).

IX. The case against setting engine ash ingestion limits

33. The case against introducing new airworthiness rules rests on the fact that industry experience has previously shown that procedures based on avoidance of volcanic ash clouds have served the industry well. Changes introduced by the ICAO IVATF retain this basic avoidance principle but further elaborate procedures to compensate for uncertainties in volcanic ash forecasting models.
34. Depending on how it is done, setting of engine volcanic ash limits could be costly to industry and could impact on engine design in a way that would reduce overall efficiency and to the detriment of existing performance, economic and environmental factors. Furthermore, if it were possible to establish turbine engine volcanic ash limits and to certify the product, the use of such limits in practice would require much more accurate forecasting or direct measurement devices in the airspace (ideally installed on individual aircraft). Whilst work is advancing in both of these respects, the required standards are still some way off from regular use.
35. By focusing on certification standards, there will be a delay of tens of years before there is a step change in fleet utility, as the introduction of any airworthiness rules will not impact the current fleet. Only once the bulk of the fleet is replaced with new engines would these changes take effect.
36. With the newly adopted approach to flight safety and volcanic ash based on IVATF recommendations, the first question to stakeholders is the following:

Question 1

Is there any rationale to depart from the current ICAO approach: i.e. operation is the responsibility of the operator, based on a safety risk assessment and supported by existing data streams?

X. The case for setting engine ash ingestion limits

37. Today, guidance given to operators by engine and airframe TC holders is necessarily conservative for some engine types due to the absence of a defined upper airworthiness limit. This ultimately leads to unnecessary operational restrictions in the use of airspace. A test programme might be able to establish an upper limit for such engines, which coupled with enhanced ash forecasting or on-board sensing would enable an aircraft to fly in airspace that would be prohibited under the existing operator's SRA. Such limits would be more practical to apply in night/IMC operations than the current guidelines of 'avoiding visible ash' and test evidence would provide confidence that operations are conducted in an acceptable and safe manner. Without establishing the upper airworthiness limit for engines, there will always be uncertainties as to the levels of ash that a turbine engine may or may not safely consume.

38. Recognising that the ash density will contain inaccuracies, work has been done in the case of the London and Toulouse VAACs to greatly improve forecast charts: radars have been put in place to directly monitor volcano sources and improve the determination of the eruptive strength; improved modelling techniques supported by enhanced data from satellites; establishment of LIDAR networks and atmospheric test aircraft have improved the model's ability to accurately predict and track the dispersion of the ash in the atmosphere. To match these enhancements in defining where the ash is, it is becoming more relevant than ever to establish what ash is of operational significance. The situation can only be improved if airworthiness limits and engine safety margins are established. Knowing these margins could be essential during a major eruption that could be greater than the recent eruptions that were seen in 2010 and 2011 in Europe.

39. The lower airworthiness limit would become a certification standard for new or changed engines. As previously stated, avoidance of volcanic ash is not always possible and, under the new ICAO guidelines, flights into areas forecast to contain volcanic ash will be permitted. Therefore, it cannot be excluded that some aircraft during their service life will encounter low levels of volcanic ash and setting a lower limit will provide a level playing field for all manufacturers that is both safe and provides a level of flexibility for operators.

Question 2

Is there a clear, objective-based safety benefit that would be achieved by imposing a new certification standard?

Question 3

Given the high traffic densities of European airspace and the frequent requirement for operation in IMC, and given also the enhanced capabilities in Europe to detect and track volcanic ash, should EASA propose a standard applicable only in European airspace?

Question 4

Is harmonisation of EASA standards with those of other States of Design (e.g. USA and Canada) of such importance in respect of volcanic ash that it should take priority over a solution for Europe?

XI. Challenges associated with volcanic ash testing and in defining engine limits

40. There are a number of challenges associated with engine testing and defining engine volcanic ash limits. A non-exhaustive list is provided below that lists some of these issues:

- Selecting the airworthiness criteria;
- Variability in ash composition (density, particle size, melting temperature, mineral composition, etc.);
- Availability of ash (Are ground-collected volcanic ash samples representative of airborne ash?)
- Predicting surge margins;
- Accuracy and repeatability of tests;
- How to handle PMA and STC parts;
- Research needs.

XII. Options identified

41. The following options have been identified to address the airworthiness of turbine engines to the effects of volcanic ash. A provisional assessment of these options is undertaken in the Regulatory Impact Assessment (RIA) in Section XIII.

42. Under the patronage of the ICAO IVATF, the international aviation community has developed recommendations to States that can be adopted to assess the safety risk of flight operations in areas forecast to be affected by volcanic ash or aerodromes contaminated with volcanic ash. Operators are recommended to use all available sources of information to assure safety whilst optimising their operations when ash is a hazard. Given the current information and airborne technology available, operators largely rely on the avoidance of visible or discernible ash, definitions for which are still to be finalised. Due to uncertainties in forecasting, operators may plan flights into areas forecast to be contaminated with volcanic clouds, provided they have completed a specific SRA, as part of their overall management system, attesting to their capability to perform safe operations in a volcanic ash contaminated environment, and which is acceptable to the appropriate authority.

43. It is expected that a SRA approach will be maintained by operators in any future development of the regulatory framework. The options presented here are intended to show how engine airworthiness could provide information and technology in the future that would enhance the robustness of this process and enable operators to make informed decisions with increased levels of confidence.

44. Option 0: Do nothing

As part of an operator's SRA, advice from engine and airframe TC holders is sought regarding the susceptibility of their products for operation in airspace contaminated with volcanic clouds. This advice has been to avoid flight in known ash concentrations above 2 mg/m^3, or in ash that is visible to the naked eye or otherwise detectable by the crew (smell, St Elmo's fire, etc.). If an aircraft encounters volcanic ash in flight, then the flight crew is expected to vacate the contaminated airspace as safely and expeditiously as possible, as soon as they are alerted to the hazard. This advice has been largely established based on service experience, limited analysis, and engineering judgement. It presumes that the encounter with ash will normally be avoidable, but that if avoidance fails the aircraft will continue to be at a level of airworthiness where safe continued flight and landing is assured.

Unless engines are certified to a specific tolerance level, it would be necessary to continue with this approach.

45. Option 1: Sand testing

In the short term, option 0 could be supplemented by the systematic use of sand testing to support the analysis and in-service experience of volcanic ash. It is recognised that this option would provide some limited use with respect to erosion of blades and vanes, but would not provide valid representation of molten ash during engine testing.

Question 5
Could sand testing provide any benefit to enhance the information available to operators for use within their VA SRAs?

46. Option 2: Research programme

Identify a set of activities, potentially including engine research testing, to gain improvements in, or better understanding of, factors that influence the uncertainty of SRAs. This might lead to a more robust regime. It would not include additional Certification Specifications. It could include improved health monitoring.

Advances in volcanic ash airborne detection and engine health monitoring technology could be used together to assess both the short-term and long-term hazards of volcanic ash, in real time. The installation of VA detection equipment may allow flights into known areas of VA, provided the identified density is below the level at which immediate safety of flight is a concern, including a margin of safety. Engine health monitoring may be used to establish the continued airworthiness of the engines, including providing advice to maintenance staff (and possibly the flight crew) of incipient failures. This may be an option for currently certified engine designs.

Question 6
What activities could be considered in this context and which would merit prioritisation?

Question 7
What characteristics would on-board equipment need to have in order to deliver significant operational benefit?

47. Option 3: New Certification Specification in CS-E

New turbine engines would be required to demonstrate by test, or by analysis supported by in-service data on similar products, a built-in resistance to a defined level of volcanic hazards (lower limit). A test specification would include: an ash specification based on recommendations from the ICAO science group; and the minimum level and duration of volcanic ash exposure to be tested derived from previous experience and predicted future events.

The new Certification Specification would become the target benchmark for all new engine types undergoing the certification process. Engine TC holders would be at liberty to exceed the certification limit. In this case, the engine manual (and ALS of the AFM) would state the maximum certified volcanic ash concentration level and duration of exposure, which can then be used for operational flight planning purposes.

Instructions for continuing airworthiness could include a programme of post-event health monitoring (e.g. visual and borescope inspections), following an ash encounter to mitigate any risks associated with ingestion of ash levels higher than the certified limit or of an unknown nature.

A research activity would be required to establish a realistic and cost-effective lower limit based on a level of disruption which is both socially and economically acceptable. Account would be taken of predicted volcanic activity and the state of the art in measuring and forecasting techniques.

> ***Question 8***
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> **The introduction of a Certification Specification may drive engine manufactures to design an ash tolerant engine that detrimentally impacts emissions, fuel burn, required maintenance actions and cost. What would be an acceptable compromise to stakeholders?**

> ***Question 9***
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> **Can a certification test be adequately defined to address a globally applicable requirement?**

> ***Question 10***
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> **Have engine TC holders already foreseen the need to undertake specific engine volcanic ash testing? If so, can you give details of the test specification to be used?**

48. Option 4: Generic module testing

As a variation on option 3, compliance with any new Certification Specification could be established through generic module testing. The idea would be for all engine OEMs to jointly define and test representative engine modules for their mutual benefit. The susceptibility of individual engine designs could then be established by combining appropriate module results, perhaps with some limited testing/analysis of novel features. Like all things, computer modelling can provide some understanding as to the effects on an engine type, but would require validation by rig or some engine testing to prove authenticity, or more stringent safety margins applied to account for any uncertainties.

> ***Question 11***
>
> **What benefits could generic module testing produce and would those benefits merit taking this work forward?**

49. Option 5: Business case (Level of volcanic ash exposure set by the operator)

This option would require both upper and lower limits to be established by the engine TC holder. Within the range between the two limits (economic region), the TC holder would establish economic factors (reduction in component retirement lives, increased maintenance requirements, etc.) as a function of volcanic ash exposure. Operators could then be permitted to operate safely with an acceptable risk of in-flight shutdown in contaminated airspace at any point in the economic region provided the associated continuing airworthiness advice and restrictions were adhered to.

This option would provide the greatest operational flexibility and could potentially allow flight operations to continue in medium/high density volcanic ash environments.

> ***Question 12***
>
> **Would such information offer benefits sufficient to merit taking this work forward?**

XIII. Regulatory Impact Assessment

50. Purpose and intended effect

a. Issue which the A-NPA is intended to address

Revised procedures developed by ICAO for the safe management of flight operations with known or forecast volcanic ash contamination only goes so far in addressing the perceived hazard to volcanic clouds and the associated social and economic factors. Guidance provided by ICAO restricts flight operations to areas forecast to be affected by volcanic ash or aerodromes known to be affected by volcanic ash. Prolonged flight into known volcanic ash is not permitted, and instructions to flight crews is to vacate affected areas as safely and expeditiously as possible as soon as they become aware of the hazard. In order to plan operations in areas forecast to be contaminated with volcanic ash, the operator is required to develop a Safety Risk Assessment (SRA) as part of their overall management system. The robustness of the SRA relies upon airworthiness data input from both engine and aircraft TC holders to determine the susceptibility of their products to volcanic constituents, including ash. Turbine engines are susceptible to volcanic ash, and is a significant factor limiting the ability of aircraft to operate safely in contaminated airspace and restricting flight operations.

b. Scale of the issue

Over the period 1953–2009 there are 129 reported encounters of aircraft with volcanic ash clouds. Of these, 94 are confirmed ash encounters with 79 of those having various degrees of airframe or engine damage. In 7 severe encounters involving large airliners, multiple or even all engines have failed in flight. The average annual rate of damaging encounters since 1976 when reporting was common place, has been approximately 2 per year.

In addition to the safety impacts, the presence of volcanic ash in high density traffic can restrict or even prevent normal flight operations from taking place. This will affect all operators and can have high social and economic consequences that can run into billions of euros.

c. Brief statement of the objectives of the A-NPA

This A-NPA aims to identify and assess options to establish the level of engine airworthiness and improve the robustness of the SRA process; as an enabler that could then lead to additional operational flexibility during volcanic ash events; and to provide a way forward that is both realistic and cost-effective.

51. Options

See Section XII.

52. Sectors concerned

This A-NPA is aimed primarily at turbine engine manufacturers, but will also be of interest to manufactures and operators of aircraft used for commercial air transport.

53. Impacts

Listed below is an initial assessment of the pros and cons of each of the options identified above. Stakeholders are specifically invited to add to the lists and to propose additional options.

a. <u>Safety</u>

Option		Safety impacts
Option 0: Do nothing	Pros	• Has served industry well. • Avoids additional cost to industry in advance of an ash-related event.
	Cons	• Unclear as to what safety margins are built-in and so whether safety concerns are satisfactorily addressed.

		• Affected aircraft/engines must be inspected/monitored to ensure their continued airworthiness.
Option 1: Sand testing	Pros	• Will add to knowledge of airworthiness effects of ash provided dissimilarities to ash erosion characteristics can be characterised. • Test techniques known. • Could help understanding of the safety of the in-service fleet.
	Cons	• Unclear as to what safety margins are built-in. • Affected aircraft/engines must be inspected/monitored to ensure their continued airworthiness. • Not representative of molten ash characteristics.
Option 2: Research programme	Pros	• Improves understanding of risks. • Can be used to verify gas path component condition. • May be useful to have, even with the adherence to new certification limits. • Could pave the way for new methods and new technologies to increase capability to operate when ash is a hazard and so further reduce disruptions to operations.
	Cons	• May still be reliant on enhanced continuing airworthiness monitoring.
Option 3: New CS	Pros	• Improve understanding of risks. • Establishes a known engine tolerance level. • Would provide VAAC forecasters with the information they need as they seek to simplify ash forecasts to show only 'ash that matters'. • Would increase the usefulness of on-board technologies. • Will necessitate investigation of the long-term effects of ash ingestion.
	Cons	• Safety effects only evident after replacement of the existing aircraft fleet. • May still be reliant on enhanced continuing airworthiness monitoring. • Trade-off of improved ash tolerability against likely increases in noise, fuel burn and emissions. • Tolerance level is based on an ash type and composition that may not have global applicability.
Option 4: Generic module testing	Pros	• Improves understanding of risks. • Establishes a known engine tolerance level. • Will necessitate investigation of the long-term effects of ash ingestion. • Could provide a greater understanding of ash tolerance of existing turbine engines in service generically.
	Cons	• Safety effects only evident after replacement of the existing aircraft fleet. • May still be reliant on enhanced continuing airworthiness monitoring. • Uncertainties may still remain due to differences in component design characteristics from those tested.
Option 5: Business case	Pros	• Improves understanding of risks and engine capabilities. • Establishes both upper and lower engine limits. • Will necessitate investigation of the long-term effects of ash ingestion.
	Cons	• Safety effects only evident after replacement of the

		existing aircraft fleet.

b. Economical

Option		Economic impacts
Option 0: Do nothing	Pros	• Minimal initial cost impact.
	Cons	• Would impact operators/TC holders if aircraft were unable to fly. • May require both operators and engine TC holders to maintain an extensive process of continuing airworthiness monitoring.
Option 1: Sand testing	Pros	• Capability may already exist. • Likely to be less expensive than other options.
	Cons	• Would impact operators/TC holders if aircraft were unable to fly. • May require both operators and engine TC holders to maintain an extensive process of continuing airworthiness monitoring. • As results may be unrepresentative, it is probably not cost-effective.
Option 2: Research programme	Pros	• May be cheaper than compliance with a Certification Specification.
	Cons	• Would impact operators/TC holders if aircraft were unable to fly. • May require both operators and engine TC holders to maintain an extensive process of continuing airworthiness monitoring.
Option 3: New CS	Pros	• Cost equality for all applicants for certification. • Greater operational flexibility may reduce operational restrictions, thereby reducing lost revenue for operators and engine TC holders. • May have a positive benefit in terms of continuing airworthiness costs.
	Cons	• Would require significant engine testing. • It is likely that any clearance would be engine type specific. • High initial cost.
Option 4: Generic module testing	Pros	• Cost equality for all applicants for certification. • Greater operational flexibility may reduce operational restrictions, thereby reducing lost revenue for operators and engine TC holders. • May have a positive benefit in terms of continuing airworthiness costs. • Relatively cheap and quick method of modelling effects of ash on engines.
	Cons	• May still require some additional engine type specific testing. • It is likely that any clearance would be engine type specific.
Option 5: Business case	Pros	• Cost equality for all applicants for certification. • Greater operational flexibility will reduce operational restrictions, thereby reducing lost revenue for operators and engine TC holders. • May have a positive benefit in terms of continuing airworthiness costs. • Use of the 'economic region' would be optional and only

		utilised if it made economic sense to individual operators.
	Cons	• Would require extensive engine testing. • It is likely that any clearance would be engine type specific.

c. Practicality

Option		Practicality
Option 0: Do nothing	Pros	• Still required as operational control of risk in areas of known ash suspension in the atmosphere. • No impact on existing practices.
	Cons	• Not robust. • Lacks operational flexibility.
Option 1: Sand testing	Pros	• Could add to current understanding. • Capability may already exist.
	Cons	• Not robust. • Lacks operational flexibility. • Only partially representative of volcanic ash.
Option 2: Research programme	Pros	• Programme tailored to known risk areas.
	Cons	• Defining a programme (testing, modelling and/or analysis) that would allow a broad extension of the current guidance would be challenging. • Further research necessary to develop a practical health monitoring system. • Lacks operational flexibility.
Option 3: New CS	Pros	• Creates a benchmark standard and level playing field for industry. • Provides additional operational flexibility.
	Cons	• The challenge will be in developing new Certification Specifications that establish airworthiness limits for flight into known volcanic ash contaminated airspace, that are both safe and cost-effective to industry. • The quantitative effects of ash on engines are dependent on many parameters and would be difficult to comprehensively map. • If the standard allowed flight into visible volcanic ash would it be used? • Airframe guidance would have to be consistent with the engine guidance. • Research necessary to identify a test specification.
Option 4: Generic module testing	Pros	• Creates a benchmark standard and level playing field for industry. • Provides additional operational flexibility. • Pooling of resources and expertise.
	Cons	• The challenge will be in developing new Certification Specifications that establish airworthiness limits for flight into known volcanic ash contaminated airspace, that are both safe and cost-effective to industry. • The quantitative effects of ash on engines are dependent on many parameters and would be difficult to comprehensively map. • If the standard allowed flight into visible volcanic ash would it be used? • Airframe guidance would have to be consistent with the Engine guidance.

		• Research necessary to identify a test specification. • Requires cooperation between industrial competitors. • Modelling results required to be validated by engine and rig testing specific to individual types/models. • Large safety factors may have to be applied potentially not allowing for significant improvement beyond today's situation.
Option 5: Business Case	Pros	• Creates a benchmark standard and level playing field for industry. • Will potentially provide maximum operational flexibility. • It is likely that some engines could run with a level of ash exposure beyond the current guidance with an acceptable risk of in-flight shutdown.
	Cons	• The challenge will be in developing new Certification Specifications that establish airworthiness limits for flight into known volcanic ash contaminated airspace that are both safe and cost effective to industry. • The quantitative effects of ash on engines are dependent on many parameters and would be difficult to comprehensively map. • Airframe guidance would have to be consistent with the engine guidance. • Research necessary to identify a test specification. • Clearance to higher levels would come with an additional maintenance burden which might preclude economic operation.

Question 13

What option(s) do you consider to be most appropriate and why?
Add others if none of the above.

Question 14

What is needed to move towards establishing engine ingestion limits?

Question 15

In the absence of a Certification Specification for ash ingestion capability, how will volcanic ash tolerance be ensured for future engines?

Question 16

Can you quantify expected costs and other impacts for the various options?