# A jet aircraft manufacturer's perspective of volcanic ash

## DRAFT Icelandic Eyjafjallajökull Volcanic Ash Conference Paper, September 15-16, 2010

## White Paper

**September 15, 2010**


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**Editor:**

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# 1. ABSTRACT

This paper presents Boeing's perspective of the best way to address flight in areas of volcanic ash. Boeing considers that avoiding flight in ash addresses the safety concern of such situations more appropriately than developing specific regulatory requirements for a volcanic ash threshold.

## 2. INTRODUCTION

In mid-April and May of this year, the Icelandic volcano Eyjafjallajökull erupted, spewing an ash plume that drifted eastward, reaching as far as the United Kingdom and parts of Western Europe. This created a significant situation for aviation because the ash cloud reached some areas of very high air traffic volume, and was initially forecast to affect a larger geographic region than it actually did.

## 3. DATA AND INFORMATION

In the previous decades, there have been several significant jet-powered commercial airplane encounters with volcanic ash that have resulted in significant damage to the aircraft. Some of the most notable of these events are:

**Mt. St. Helens, United States, 1980**

A Boeing 727 and a DC-8 encountered separate ash clouds during this major eruption. Both airplanes experienced damage to their windshields and to several systems, but both landed safely despite the windshield damage.

*Source: http://en.wikipedia.org/wiki*

**Galunggung volcano, Indonesia, 1982**

Several Boeing 747 airplanes encountered ash from this eruption. One airplane lost thrust from all four engines and descended from 36,000 ft to 12,500 ft before all four engines were restarted. That airplane, on a flight from Kuala Lumpur, Malaysia, to Perth, Australia, diverted to Jakarta and landed safely despite major engine damage. The airplane subsequently had all four engines replaced before returning to service.

*Source: http://en.wikipedia.org/wiki*

**Mt. Redoubt, United States, 1989**

On a flight from Amsterdam to Anchorage, Alaska, a new Boeing 747-400 (only three months old, with approximately 900 hours total flying time) encountered an ash cloud from the erupting Mt. Redoubt near Anchorage. All four engines ingested ash and subsequently flamed out. The crew successfully restarted the engines and landed safely at Anchorage. All four engines were replaced and many airplane systems also had to be repaired or replaced before the airplane was returned to service.

*Source: http://en.wikipedia.org/wiki*

**Mt. Pinatubo, Philippines, 1991**

More than 20 volcanic ash encounters occurred after the Mt. Pinatubo eruption, which was one of the largest volcanic eruptions of the past 50 years. The ability to predict where ash was to be found was challenging because of the enormous extent of the ash cloud. Commercial flights and various military operations were affected; one U.S. operator grounded its airplanes in Manila for several days.

*Source: http://en.wikipedia.org/wiki*

Although some information about volcanic eruptions had been available at the time of each of these eruptions, the aviation community recognized that it was inadequate. Industry then collaborated with the volcanological and meteorological communities to begin a joint effort to find ways to avoid future volcanic ash encounters.

The International Civil Aviation Organization (ICAO) has laid much of the foundation for the volcanic ash issue through its Volcanic Ash Warnings Study Group (VAWSG). ICAO also formed the International Airways Volcano Watch (IAVW) in 1987. These ICAO-sponsored teams formalized the international arrangements for monitoring and providing warnings to the aviation community about volcanic ash in the atmosphere. ICAO's Annex III and the World Meteorological Organization's (WMO) Technical Regulation C.3.1 introduced a standard to disseminate information about volcanic ash to the aviation community in the form of Significant Meteorological Information (SIGMET) and Notices to Airmen (NOTAM).

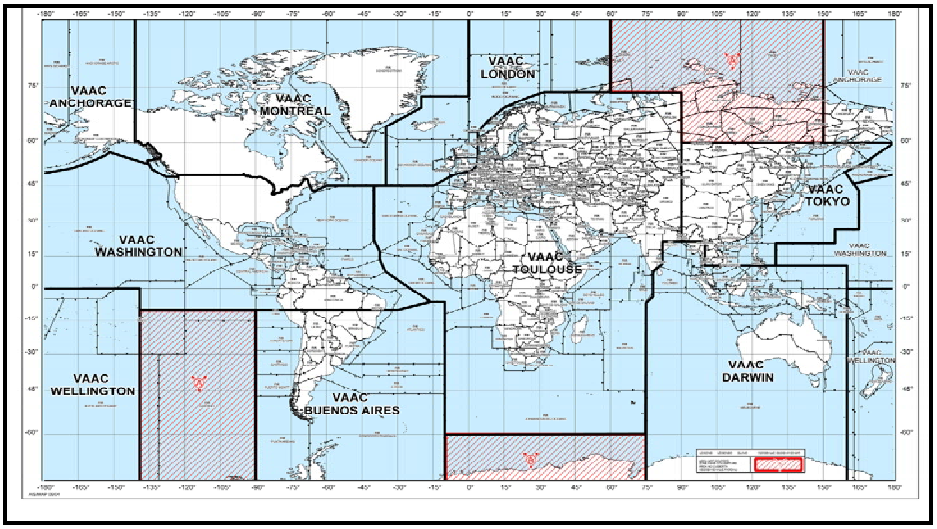


**Figure 2: 9 Worldwide Volcanic Ash Advisory Centers (VAAC)**
*Source: http://en.wikipedia.org/wiki/File:VAAC_Coverage.jpg*

One of the outcomes of these ICAO efforts is the establishment of today's Volcanic Ash Advisory Centers (VAAC). The VAACs provide an important link among volcano observatories, meteorological agencies, air traffic control centers, pilots, and operators. A total of nine VAACs observe and report on a particular region of the world.

```
FVAK23 PAWU 230825
VAAAK3
VA ADVISORY

DTG: 20090323/0820Z

VAAC: ANCHORAGE

VOLCANO: REDOUBT 1103-03

PSN: N6029 W15245

AREA: SOUTH CENTRAL ALASKA

SUMMIT ELEV: 10198 FT/3109 M

ADVISORY NR: 2009-1

INFO SOURCE: GOES/AVO/PILOT REPORT/RADAR/

AVIATION COLOUR CODE: RED

ERUPTION DETAILS: EXPLOSIVE ERUPTION OF MT REDOUBT BEGAN AT APPROX
0638 UTC WITH SUBSEQUENT INTERMITTENT ACTIVITY CONTINUING.

OBS VA DTG: 23/0800 UTC

OBS VA CLOUD: SFC/FL500 N6107 W15322 - N6105 W15136 - N6007 W15207 -
N6013 W15328 - N6107 W15322 MOVING N 65 KNOTS.

FCST VA CLOUD +6 HR: 23/1415Z SFC/FL400 N6251 W15346 - N6147 W15024 -
N5956 W14954 - N6047 W15552 - N6251 W15346

FCST VA CLOUD +12 HR: 23/2015Z SFC/FL400 N6340 W14902 - N6150 W14529
- N5957 W15103 - N6107 W15504 - N6340 W14902

FCST VA CLOUD +18 HR: 24/0215Z SFC/FL400 N6459 W14709 - N6311 W14108
- N6007 W15112 - N6135 W15535 - N6459 W14709

REMARKS: RADAR INDICATES VA TO FL500.  PIREPS VERIFED ABV FL400.

NXT ADVISORY: 20090323/1415Z

TRENZ MAR 2009
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**Figure 3: Examples of output from the Anchorage (Alaska) VAAC for the recent 2009 Mt. Redoubt eruption**
*Source: Anchorage VAAC*

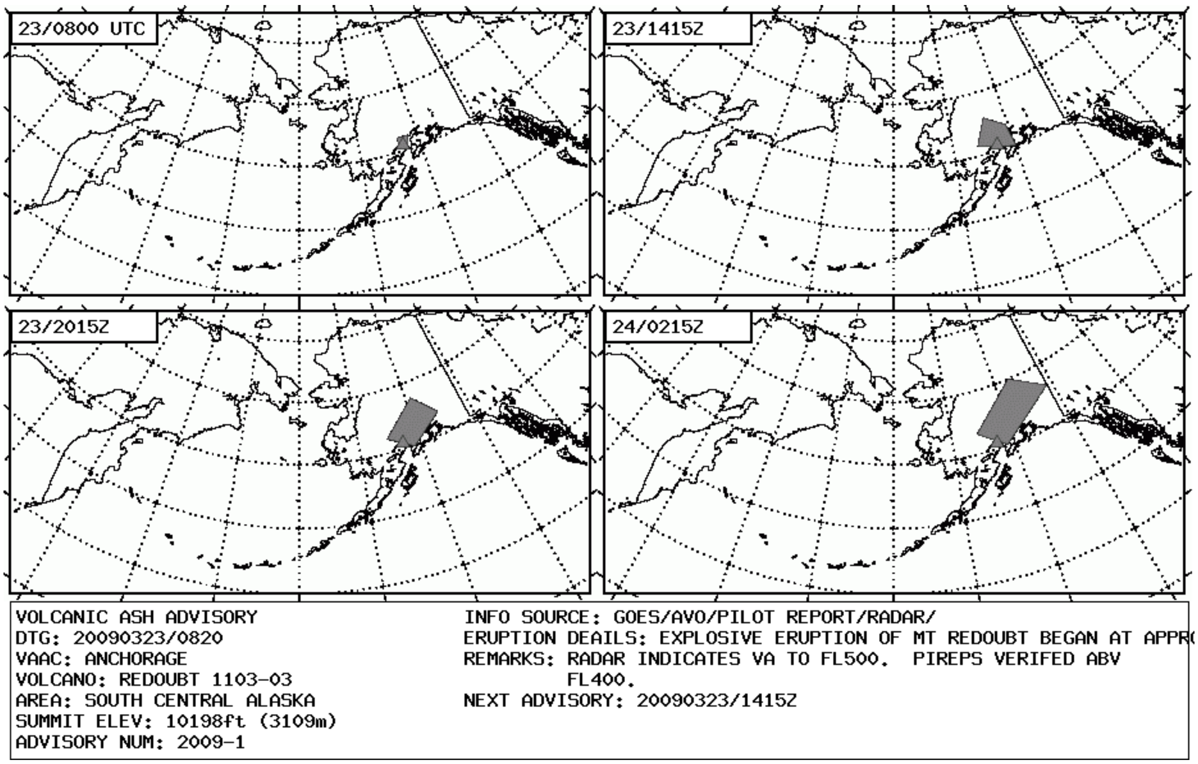



**Figure 4: Examples of output from the Anchorage (Alaska) VAAC for the recent 2009 Mt. Redoubt eruption**
***Source: Anchorage VAAC***

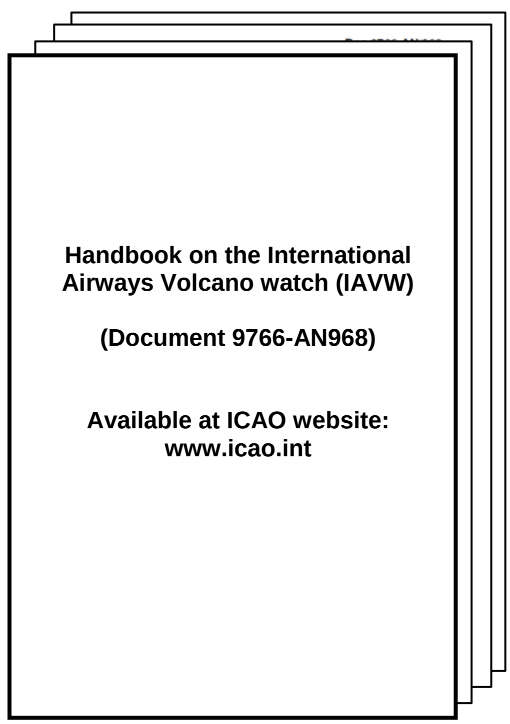



**Figure 5**: **ICAO Handbook Doc 9766**

ICAO has published Handbook Doc 9766, which provides operational procedures both for the dissemination of information on volcanic eruptions and associated volcanic ash clouds in areas that could affect routes used by international flights, and for implementing the necessary pre-eruption arrangements.

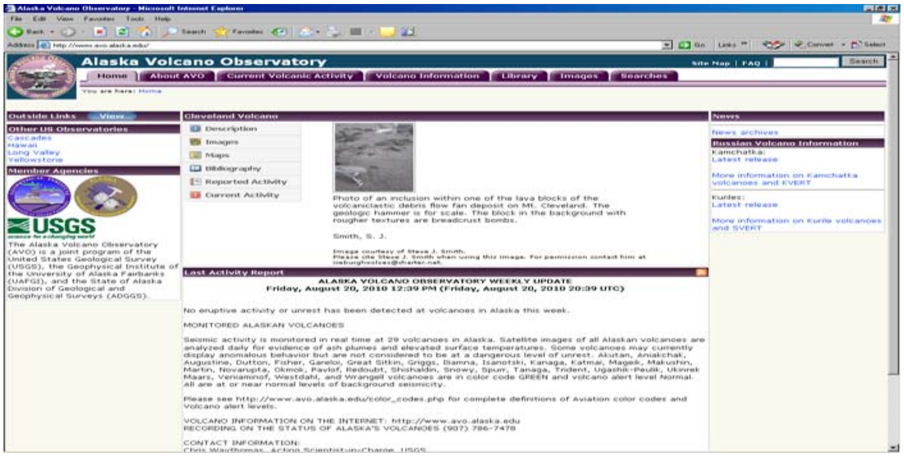



**Figure 6: Alaska Volcano Observatory in Anchorage Weekly Bulletin**
***Source: Anchorage VAAC***

Many operators maintain direct contact with volcano observatories within their flight domains. For instance, the Alaska Volcano Observatory in Anchorage issues a weekly bulletin by e-mail and fax detailing the activity of key volcanoes. (Seismic activity is monitored in real time at 29 volcanoes in Alaska. Satellite images of all Alaskan volcanoes are analyzed daily for evidence of ash plumes and elevated surface temperatures.)

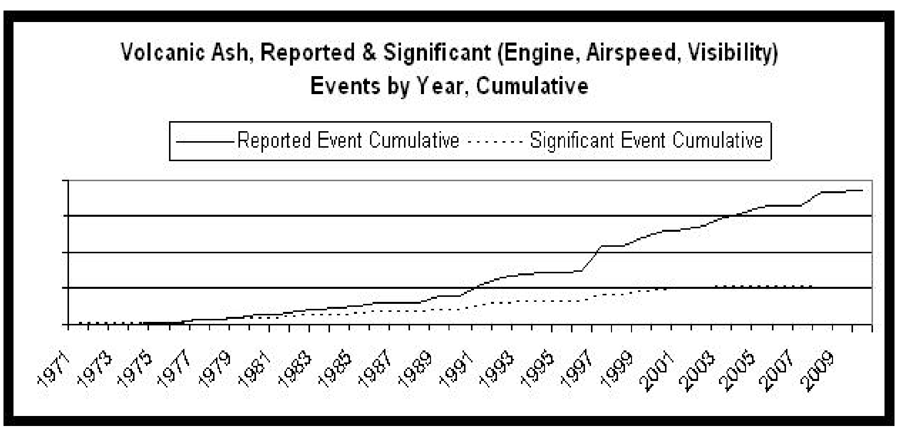



**Figure 7: Volcanic Ash, Reported & Significant Inflight Events**

Since the introduction of the VAACs and the communication channels between them, the WMO, and the aviation community, the number of significant inflight volcanic ash encounters has diminished dramatically, even though the number of volcanic ash events has increased over the years.

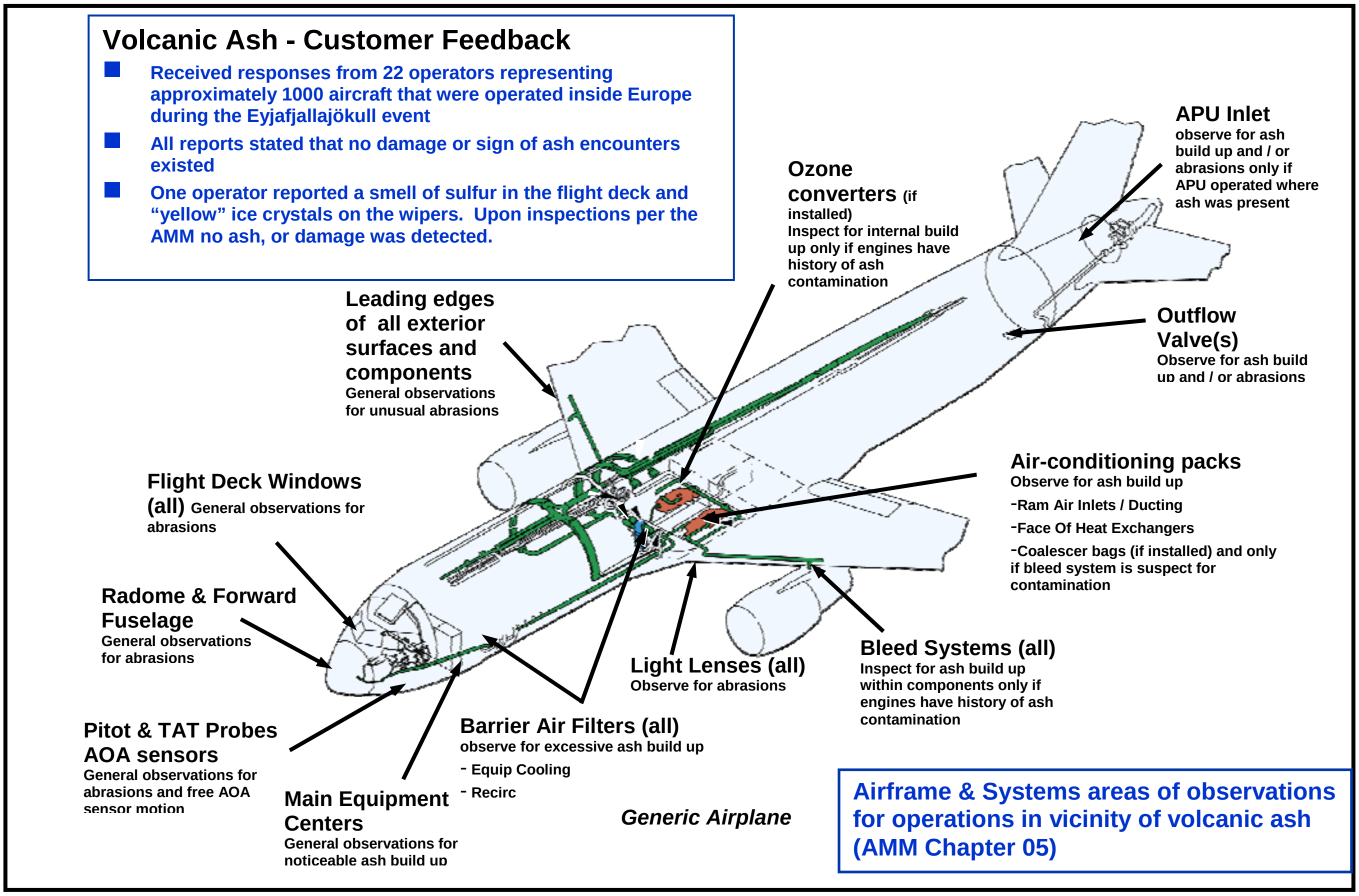



**Figure 8: Volcanic Ash Conditional Inspections**

With regard to the recent Eyjafjallajökull eruption, Boeing requested feedback from airline operators who operated inside Europe during this event. Boeing received responses from 22 operators representing approximately 1,000 aircraft. All reports stated that no damage or sign of ash encounters existed. One operator reported a smell of sulfur in the flight deck and "yellow" ice crystals on the wipers; however, inspections per the Airplane Maintenance Manual (AMM) revealed there was no ash or damage to the airplane.

Based on operator feedback and an internal review of the previous format of the AMM chapter 05, Volcanic Ash Conditional Inspections, Boeing has restructured the inspections to a phased approach. This approach will allow the inspections to be ceased if no signs of damage, or ash, exists at certain points. Airframe and systems areas of particular interest for operations in areas contaminated with volcanic ash are described in Figure 8.

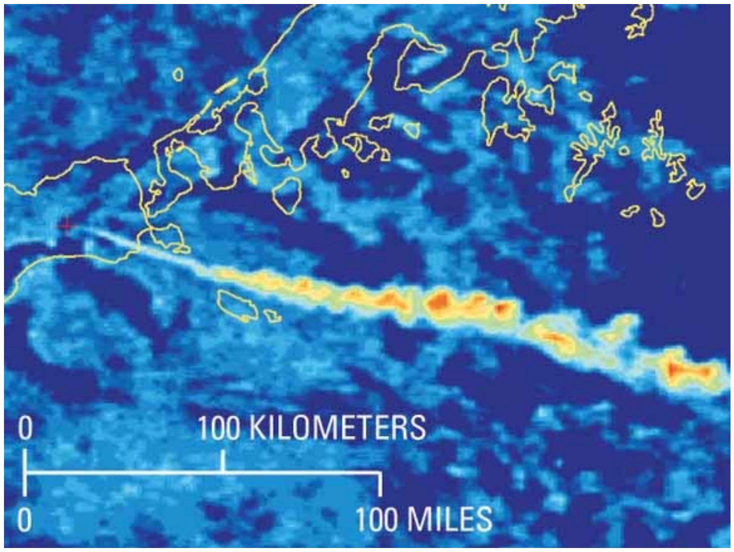



**Figure 9: Discernable Volcanic Ash Clouds**
***Source: USGA website: http://pubs.usgs.gov/fs/2004/3084/***

With regard to flight operations in volcanic ash contaminated airspace, Boeing's position is to avoid operations in discernable ash. "Discernable" in this case means by satellite imagery, ground observers, flight crew, pilot reports (PIREPS), etc., and/or augmented by forecasting model predictions, as required.

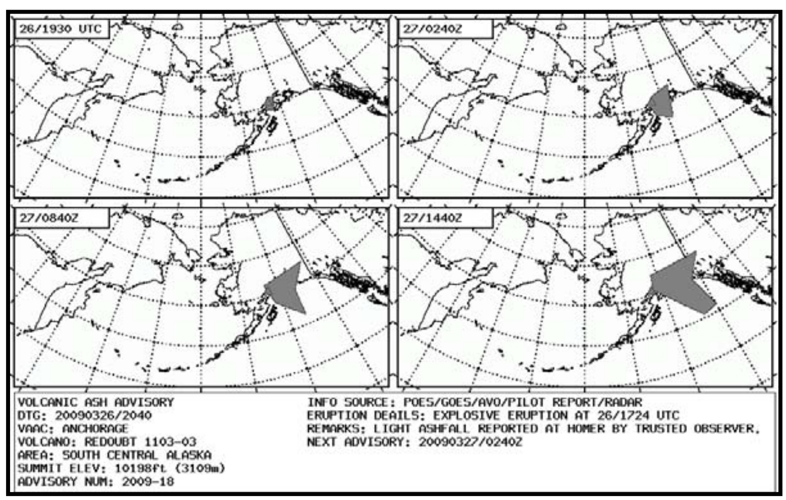
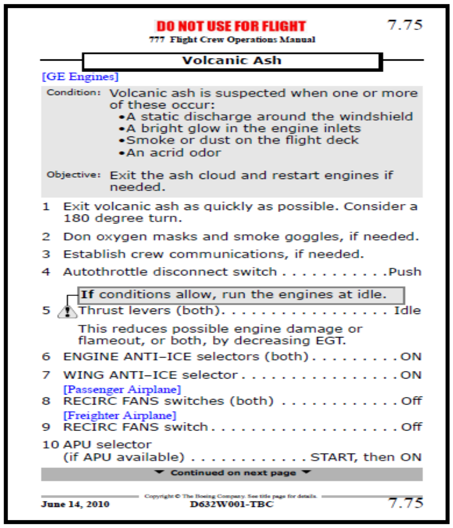



**Figure 10: Mt Redoubt – March 2009 SIGMET Advisory Based on All Available Information**
***Source: Anchorage VAAC***

Operations in the vicinity of a volcanic ash cloud need to be rerouted to ensure that the aircraft do not encounter the ash cloud. An example of a SIGMET from the 2009 Mt. Redoubt eruption using satellite imagery, ground observers, flight crew, pilot reports (PIREPS), and forecasting models is shown in Figure 10.

## 4. INSIDE BOEING AND OTHER MANUFACTURER



7.75

DO NOT USE FOR FLIGHT

777 Flight Crew Operations Manual

**Volcanic Ash**

[GE Engines]

Condition: Volcanic ash is suspected when one or more of these occur:
- A static discharge around the windshield
- A bright glow in the engine inlets
- Smoke or dust on the flight deck
- An acrid odor

Objective: Exit the ash cloud and restart engines if needed.

1 Exit volcanic ash as quickly as possible. Consider a 180 degree turn.

2 Don oxygen masks and smoke goggles, if needed.

3 Establish crew communications, if needed.

4 Autothrottle disconnect switch . . . . . . . . . . . .Push

**If** conditions allow, run the engines at idle.

5 Thrust levers (both). . . . . . . . . . . . . . . . . . Idle

This reduces possible engine damage or flameout, or both, by decreasing EGT.

6 ENGINE ANTI–ICE selectors (both) . . . . . . . . . .ON

7 WING ANTI–ICE selector . . . . . . . . . . . . . . . . .ON

[Passenger Airplane]

8 RECIRC FANS switches (both) . . . . . . . . . . . . .Off

[Freighter Airplane]

9 RECIRC FANS switch . . . . . . . . . . . . . . . . . . . . .Off

10 APU selector (if APU available) . . . . . . . . . . . . .START, then ON

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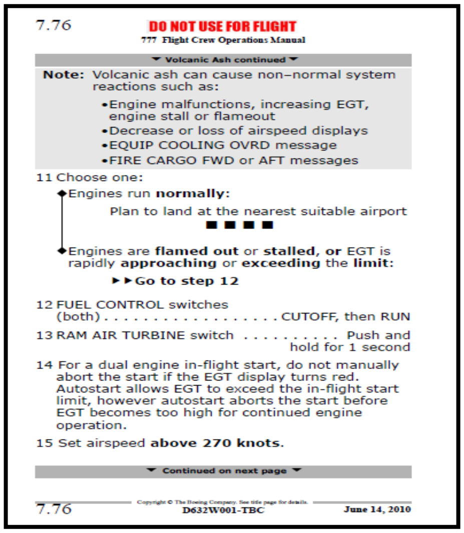
June 14, 2010 D632W001-TBC 7.75



7.76

DO NOT USE FOR FLIGHT

777 Flight Crew Operations Manual

Volcanic Ash continued

**Note:** Volcanic ash can cause non–normal system reactions such as:
- Engine malfunctions, increasing EGT, engine stall or flameout
- Decrease or loss of airspeed displays
- EQUIP COOLING OVRD message
- FIRE CARGO FWD or AFT messages

11 Choose one:

◆Engines run **normally:**

Plan to land at the nearest suitable airport

■ ■ ■ ■

◆Engines are **flamed out** or **stalled, or** EGT is rapidly **approaching** or **exceeding** the **limit:**

►►**Go to step 12**

12 FUEL CONTROL switches (both) . . . . . . . . . . . . . . . . . . .CUTOFF, then RUN

13 RAM AIR TURBINE switch . . . . . . . . . . Push and hold for 1 second

14 For a dual engine in-flight start, do not manually abort the start if the EGT display turns red. Autostart allows EGT to exceed the in-flight start limit, however autostart aborts the start before EGT becomes too high for continued engine operation.

15 Set airspeed **above 270 knots**.

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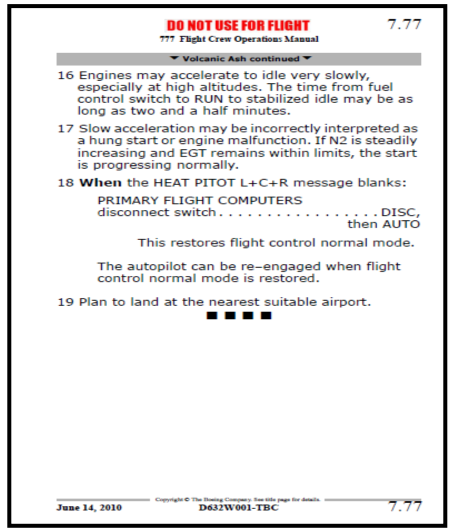

7.77

DO NOT USE FOR FLIGHT

777 Flight Crew Operations Manual

Volcanic Ash continued

16 Engines may accelerate to idle very slowly, especially at high altitudes. The time from fuel control switch to RUN to stabilized idle may be as long as two and a half minutes.

17 Slow acceleration may be incorrectly interpreted as a hung start or engine malfunction. If N2 is steadily increasing and EGT remains within limits, the start is progressing normally.

18 **When** the HEAT PITOT L+C+R message blanks:

PRIMARY FLIGHT COMPUTERS disconnect switch . . . . . . . . . . . . . . . . . .DISC, then AUTO

This restores flight control normal mode.

The autopilot can be re–engaged when flight control normal mode is restored.

19 Plan to land at the nearest suitable airport.

■ ■ ■ ■

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**Figure 11: Airplane Manufacturers Provide Training and Instructions for Detecting and Exiting a Volcanic Ash Encounter**

Boeing, as well as other aircraft manufacturers, provides training and instructions for flight crews to perform when there is an indication that an airplane has inadvertently entered an ash cloud. Discernable indicators that an airplane is penetrating volcanic ash include odor, haze, changing engine conditions, airspeed, pressurization, and static discharges.

**Odor**.
When encountering a volcanic ash cloud, flight crews usually notice a smoky or acrid odor that can smell like electrical smoke, burned dust, or sulfur.

**Static discharges**.
An electrostatic phenomenon similar to St. Elmo's fire or glow can occur. In these instances, blue-colored sparks can appear to flow up the outside of the windshield or a white glow can appear at the leading edges of the wings or at the front of the engine inlets.

**Changing engine conditions**.
Surging, torching from the tailpipe, and flameouts can occur. Engine temperatures can change unexpectedly, and a white glow can appear at the engine inlet.

**Haze**.
Most flight crews, as well as cabin crew or passengers, see a haze develop within the airplane. Dust can settle on surfaces.

**Airspeed**.
If volcanic ash fouls Pitot tubes, the indicated airspeed can decrease or fluctuate erratically, with associated effects on airplane systems.

**Pressurization**.
Cabin pressure can change, including possible loss of cabin pressurization.

If an airplane does encounter a volcanic ash cloud, Boeing, as well as other aircraft manufacturers, provides flight crew procedures for dealing with the situation. The following are general recommendations (each operator's flight operations manuals will include more specific directions):

1. Flight conditions permitting, reduce thrust to idle immediately.
2. Turn the autothrottles off.
3. Exit the ash cloud as quickly as possible. A 180-degree turn out of the ash cloud, using a descending turn, is the quickest exit strategy.
4. Turn on engine and wing anti-ice devices and all air-conditioning packs.
5. If possible, start the auxiliary power unit (APU).
6. If volcanic dust fills the flight deck, the crew may need to use oxygen.
7. Turn on the continuous ignition.
8. Monitor engine exhaust gas temperature (EGT).
9. Fly the airplane by monitoring airspeed and pitch attitude.

Following these procedures appropriately will ensure the highest possible level of flight safety. While this information has been available for several years, flight crews need to continue to be vigilant of the signs of volcanic ash and to be familiar with the proper procedures to prevent serious incidents.

Following a volcanic ash encounter a Volcanic Ash Conditional Inspection should be performed as detailed in the AMM Chapter 05.

There is extensive experience from around the world in dealing with airspace control in the presence of volcanic ash.

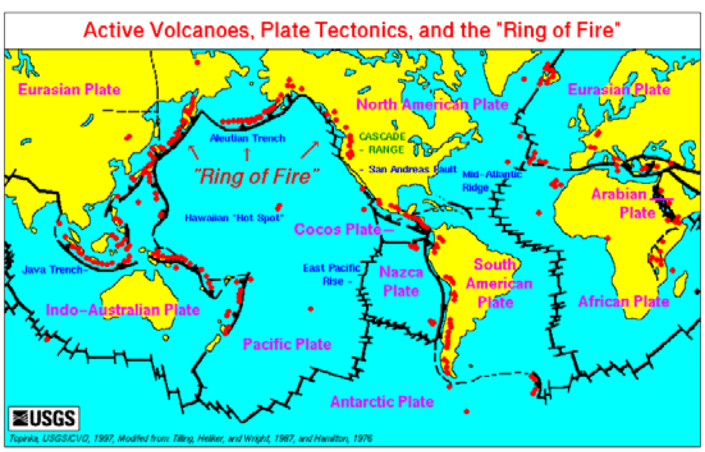



**Figure 12: Ring of Fire**
*Source: USGA website: http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/Maps/map_plate_tectonics_world.html*

The Pacific "Ring of Fire," a 25,000-mile horseshoe-shaped area surrounding most of the Pacific Ocean, has 452 volcanoes and is home to over 75% of the world's active and dormant volcanoes. Regulatory authorities, operators, and pilots in this region have extensive experience working together to safely avoid volcanic ash encounters. In support of the ICAO Annex III standards and the Volcano Watch Handbook procedures, the U.S. government has created an inter-agency plan for volcanic ash events.

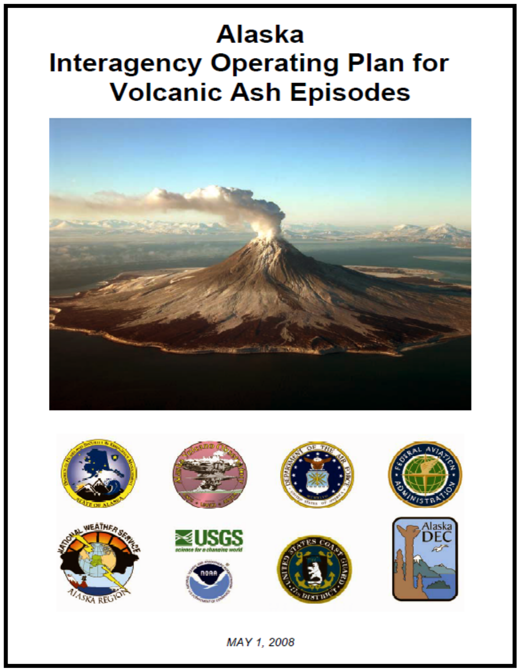
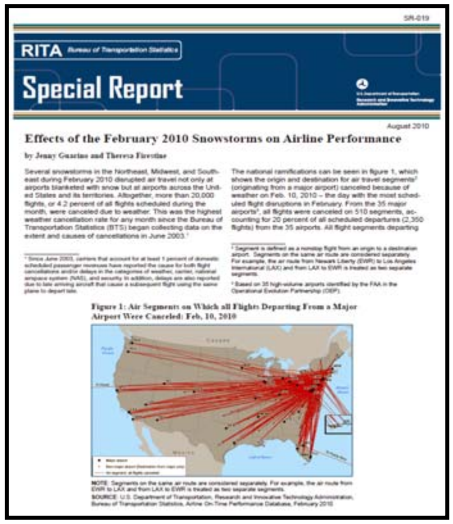



**Figure 13: U.S. Government Inter-agency Plan Coordinates Activities to Facilitate Safe and Efficient Aviation Operations during Volcanic Ash Events**

*Source: USGA website: http://www.ofcm.gov/p35-nvaopa/regional_plans/AK%20IA%20plan_2008.pdf*

The plan coordinates the operations of the Alaska Volcano Observatory (AVO), Federal Aviation Administration (FAA), and National Weather Service (NWS), among others. The NWS includes the Alaska Aviation Weather Unit (AAWU), which is the only ICAO Meteorological office in the world that is both a Volcanic Ash Advisory Center (VAAC) and a Meteorological Watch Office (MWO). The AAWU, as an International MWO, issues volcanic eruption and volcanic ash SIGMETs. In an ash event, the AAWU, acting as the Anchorage VAAC, issues a Volcanic Ash Advisory (VAA), which serves as a guidance product to the aviation, meteorological, and volcanological community. The FAA disseminates this information in PIREPs and NOTAMs. The AAWU runs its applicable models to produce forecasts of where the volcanic ash cloud is expected to go. These predictions nominally forecast where discernable ash will be. The forecasts are "calibrated" against satellite imagery, pilot reports, ground observation, and spotter aircraft. This approach of providing advisory information to operators is similar to how other significant meteorological events are handled, such as hurricanes.

This collaborative approach worked very effectively during the recent 2009 Mt. Redoubt eruption. For example, Alaska Airlines did not have any significant inflight volcanic ash encounters.  This is not to say, however, that they did not have numerous schedule disruptions as a result of the Mt. Redoubt volcanic ash cloud.  The U.S. has its share of airline schedule disruptions from meteorological events.  The U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, Airline On-Time Performance Database, shows that more than 20,000 flights were canceled in February 2010 due to one such meteorological event – a snow storm that blanketed the eastern coast of the U.S.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RITA Bureau of Transportation Statistics

Special Report

August 2010

Effects of the February 2010 Snowstorms on Airline Performance

by Jenny Guarino and Theresa Firestine

Several snowstorms in the Northeast, Midwest, and Southeast during February 2010 disrupted air travel not only at airports blanketed with snow but at airports across the United States and its territories. Altogether, more than 20,000 flights, or 4.2 percent of all flights scheduled during the month, were canceled due to weather. This was the highest weather cancellation rate for any month since the Bureau of Transportation Statistics (BTS) began collecting data on the extent and causes of cancellations in June 2003.[1]

The national ramifications can be seen in figure 1, which shows the origin and destination for air travel segments[2] (originating from a major airport) canceled because of weather on Feb. 10, 2010 – the day with the most scheduled flight disruptions in February. From the 35 major airports[3], all flights were canceled on 510 segments, accounting for 20 percent of all scheduled departures (2,350 flights) from the 35 airports. All flight segments departing

[1] Since June 2003, carriers that account for at least 1 percent of domestic scheduled passenger revenues have reported the cause for both flight cancellations and/or delays in the categories of weather, carrier, national airspace system (NAS), and security. In addition, delays are also reported due to late arriving aircraft that cause a subsequent flight using the same plane to depart late.

[2] Segment is defined as a nonstop flight from an origin to a destination airport. Segments on the same air route are considered separately. For example, the air route from Newark Liberty (EWR) to Los Angeles International (LAX) and from LAX to EWR is treated as two separate segments.

[3] Based on 35 high-volume airports identified by the FAA in the Operational Evolution Partnership (OEP).

Figure 1: Air Segments on Which all Flights Departing From a Major Airport Were Canceled: Feb. 10, 2010

**Figure 14:  U.S. Air Traffic Disruptions Due to February 2010 Snow Storm**
***Source:  U.S. Department of Transportation***

As a result of the Icelandic Eyjafjallajökull volcano eruption and the concerns regarding the airspace control procedures used in that situation, ICAO's European and North Atlantic (EUR/NAT) Office initiated a Volcanic Ash Task Force.  This Task Force very quickly developed an airspace control proposal similar to the approach used by the State of Alaska and other airspace control authorities:  after the initial eruption, the volcanic ash cloud is treated like a meteorological event, and advisory and SIGMET information is provided to operators to allow them to determine how best to avoid operations in discernable ash.


**Figure 15:  ICAO's European and North Atlantic Volcanic Ash Contingency Plan Proposal**

Boeing supports the EUR/NAT proposal, except for the need to define specific "*Areas of Low/Medium/High Concentration*" that are tied to specific concentration (grams per meter$^3$) values. The values proposed assume some consistency from one volcanic eruption to the next. However, data from the U.S. Geological Survey website (*[http://volcanoes.usgs.gov/ash/properties.html](http://volcanoes.usgs.gov/ash/properties.html)*) indicate that each volcanic eruption has unique characteristics (e.g., ash chemical composition and ash particle size), depending on the volcanic eruption and the distance from the eruption. That is, the characteristics of a volcanic ash cloud cannot be defined by a simple concentration value.

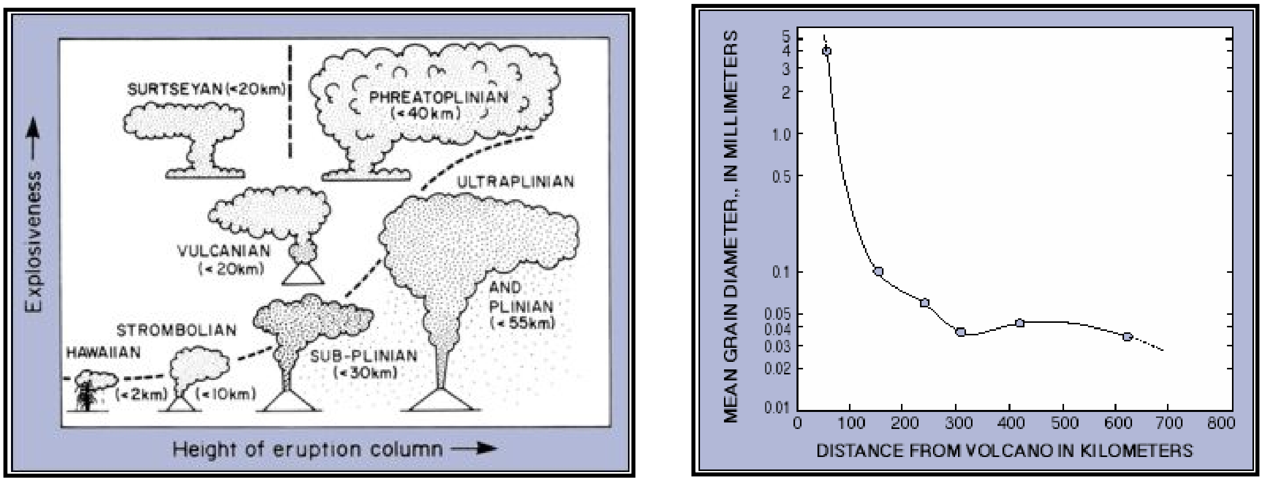


**Figure 16: Volcanic Ash Clouds are Not Consistent**
***Source: USGA website: http://volcanoes.usgs.gov/ash/properties.html***

Additionally, the ash concentration values produced by these forecasting models are a strong function of the input values to the models (e.g., the total amount, composition, and particle size of ash being ejected from the volcano).

**Figure 17: Eyjafjallajökull Eruption April 2010**
*Source: http://en.wikipedia.org/wiki/File:Eyjafjallajokull_volcano_plume_2010_04_18.JPG September 8, 2010*

The inaccuracies associated with these estimated values are then combined with state-of-the-art meteorological forecasting models to predict where the ash is expected to go. Even these state-of-the-art meteorological forecasting models have limitations, as is routinely experienced in the U.S. when it comes to forecasting the movement of hurricanes and snowstorms. Conversely, in the Alaska procedures, the satellite imagery, pilot reports, ground observation, and spotter aircraft are used to "calibrate" the forecast models and provide better advice regarding forecasted areas of discernable ash concentration. For the April/May 2010 Eyjafjallajökull event, the areas where high ash concentration was forecasted appear to correlate roughly to areas of discernable ash for that particular event

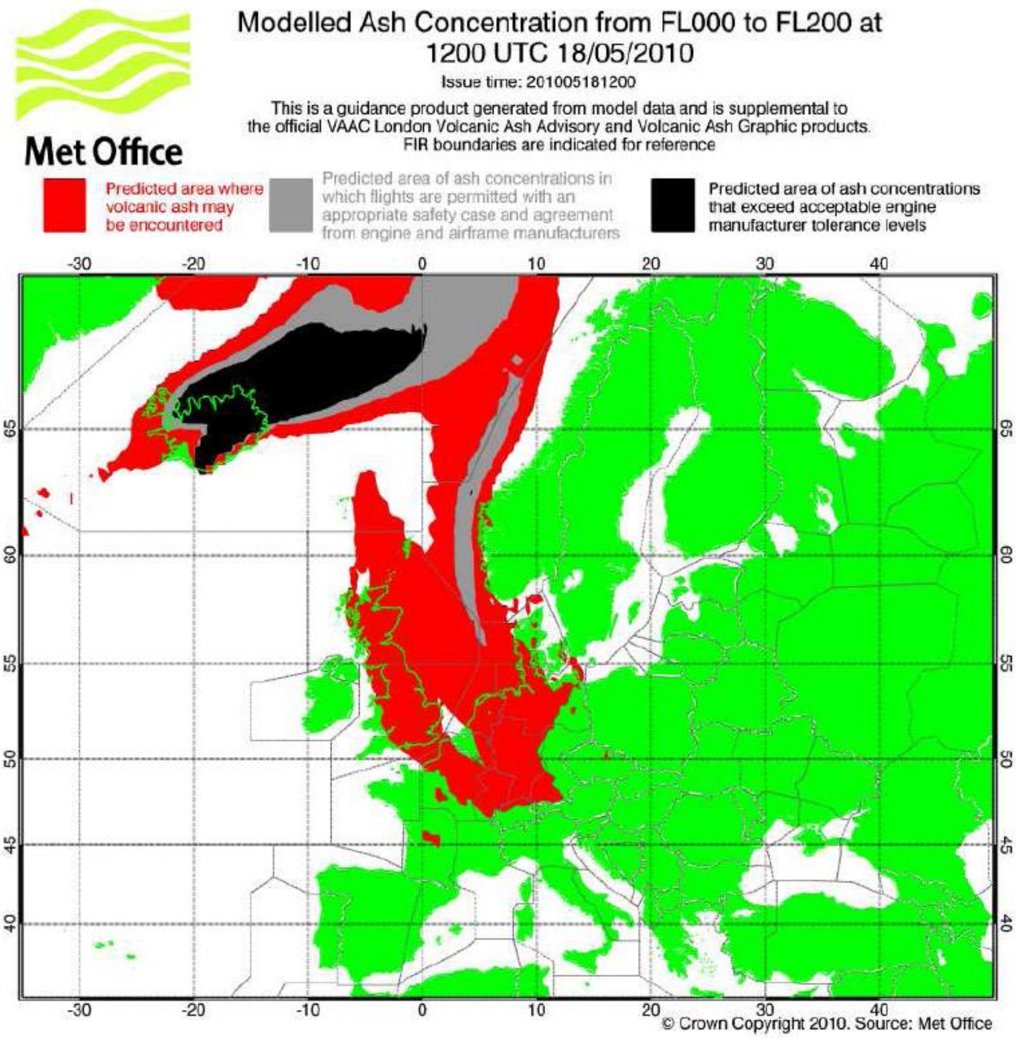


**Figure 18: UK CAA MET Office Ash Concentration Forecast for FL000 to FL200, May 18, 2010**
*Source: © British Crown Copyright 2010, The Met Office*

This does not guarantee, however, that the EUR/NAT's proposed "*Area of High Concentration*" will correlate well to the areas of discernable volcanic ash for the next volcanic eruption that affects European airspace.

Table showing concentrations of leachable constituents in ashfall from historic eruptions (all concentrations in mg/kg).

| | Fuego, Costa Rica | | Pacaya, Guatemala | | Santiaguito, Guatemala | | Mt. St. Helens, USA | | Ruapehu, New Zealand | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | Mean | Max | Mean | Max | Mean | Max | Mean | Max | Median | Max |
| **Al** | 5.2 | 26.8 | 12.8 | 21.2 | 5.2 | 19.6 | - | - | 42.8 | 1160 |
| **B** | 0.088 | 0.044 | 0.06 | 0.108 | 1.08 | 3.92 | - | - | - | - |
| **Ba** | 0.296 | 1 | 0.68 | 1.12 | 0.132 | 0.348 | 0.152 | 0.24 | - | - |
| **Br** | - | - | - | - | - | - | - | - | 1.6 | 13.6 |
| **Ca** | 400 | 1040 | 196 | 304 | 600 | 2240 | 440 | 800 | 1890 | 6760 |
| **Cd** | 0.008 | 0.04 | 0.056 | 0.128 | 0.056 | 0.256 | 0.0052 | 0.0252 | - | - |
| **Cl** | 124 | 232 | 204 | 840 | 440 | 1400 | 392 | 668 | 248 | 2020 |
| **Co** | 0.0036 | 0.0328 | 0.0072 | 0.024 | 0.132 | 0.6 | 0.0196 | 0.072 | - | - |
| **Cu** | 0.324 | 2.52 | 1.24 | 2.36 | 1.56 | 2.8 | 0.164 | 0.48 | - | - |
| **F** | 21.2 | 88 | 28.8 | 44 | 14.4 | 23.2 | 7.2 | 12 | 25.8 | 95.6 |
| **Fe** | 2.08 | 22.4 | 2.8 | 9.2 | 1.56 | 3.6 | 0.376 | 0.48 | 5.74 | 92.8 |
| **K** | - | - | - | - | - | - | - | - | 36.1 | 253 |
| **Li** | 0.044 | 0.116 | 0.0036 | 0.064 | 0.4 | 1.88 | 0.208 | 0.52 | 0.5 | 1.45 |
| **Mg** | 22 | 44 | 19.6 | 52 | 96 | 400 | 48 | 84 | 235 | 1200 |
| **Mn** | 1.48 | 3.12 | 1 | 2.88 | 19.6 | 92 | 7.6 | 13.2 | - | - |
| **Na** | 128 | 184 | 156 | 440 | 400 | 1760 | 264 | 440 | 292 | 1150 |
| **Pb** | 0.104 | 0.96 | 0.014 | 0.044 | 0.0096 | 0.048 | 0.0092 | 0.072 | - | - |
| **Si** | 7.2 | 12.4 | 9.2 | 15.2 | 7.6 | 11.2 | 40 | 56 | - | - |
| **Sr** | 2 | 5.2 | 1.64 | 2.6 | 1.48 | 4.4 | 1.76 | 2.88 | - | - |
| **U** | 0.00108 | 0.0028 | 0.00008 | 0.00048 | 0.0012 | 0.006 | 0 | 0 | - | - |
| **V** | 0.06 | 0.128 | 0.0248 | 0.068 | 0.0364 | 0.08 | 0.0012 | 0.0264 | - | - |
| **Zn** | 0.144 | 0.56 | 5.6 | 18.8 | 2.04 | 8.4 | 2.04 | 26.8 | - | - |
| **Nitrate** | | | | | | | | | 21.9 | 88.9 |
| **Sulphate** | | | | | | | 1000 | 1800 | 5190 | 24530 |

**Figure 19: Composition of volcanic ash constituents from historic eruptions**
***Source: USGA website: http://volcanoes.usgs.gov/ash/properties.html***

Because of the unique characteristics of each volcanic eruption and the ensuing ash cloud, as noted before, it is not practical to define a single ash concentration threshold for aircraft or jet engines. If a threshold is defined, it most likely will not provide any additional safety enhancement, but will likely result in operational inefficiencies over the successful approaches that are currently used around the world.

Boeing supports efforts to continue to understand the susceptibility of aircraft and jet engines to volcanic ash clouds. Such an undertaking is consistent with an industry desire to continuously enhance aviation safety.

**Figure 20: ICAO International Volcanic Ash Task Force Inaugural Meeting July 27-30, 2010**

Boeing applauds ICAO leadership in initiating the International Volcanic Ash Task Force (IVATF) to consulate the world's best practices for addressing airspace control during a volcanic eruption, and in updating their volcanic ash handbook to encourage a coordinated, consistent global approach. Boeing is actively participating in ICAO's International Volcanic Ash Task Force (IVATF).


**Figure 21: Volcanic Ash Detector Technology**


Boeing is also following the development of aircraft-mounted ash detection systems that are currently under study to better understand their capabilities and operational characteristics. Included in those reviews will be an assessment of the technology maturity, compatibility with existing airplane systems, and overall benefit.

## 5. SUMMARY

Commercial jet aviation has been operating safely for many years since the hazards associated with operations in discernable volcanic ash have been identified and airspace and flight operational procedures have been put in place. Boeing supports efforts by ICAO and the industry to accumulate and review the world's best practices for addressing airspace control during a volcanic eruption, and to produce a consistent global approach that accommodates all situations.

However, Boeing does not consider controlling airspace in the presence of volcanic ash based solely on ash dispersion model forecasts of ash concentration is a pragmatic approach. Boeing is convinced that operations in the presence of volcanic ash can be conducted safely by avoiding operations in discernable ash. A volcanic ash event should be treated like a meteorological event such as a sever weather condition. Operators should be provided advisory information based on the best available information used, in conjunction with dispersion forecasts. This provides the best information regarding the location of an ash cloud for operators to use in determining the most appropriate action to take (e.g., reroute flights, divert flights to alternate airports, or cancel flights). This approach leaves the decision to fly, and where to fly, with the operators.

## Bibliography and References

## Acronyms

| | |
|---|---|
| **AAWU** | Alaska Aviation Weather Unit |
| **AMM** | Airplane Maintenance Manual |
| **AVO** | Alaska Volcano Observatory |
| **EUR** | European |
| **FAA** | Federal Aviation Administration |
| **IAVW** | International Airways Volcano Watch |
| **ICAO** | International Civil Aviation Organization |
| **IVATF** | International Volcanic Ash Task Force |
| **NAT** | North Atlantic |
| **NOTAM** | Notices to Airmen |
| **NWS** | National Weather Service |
| **PIREPS** | Pilot Reports |
| **SIGMET** | Significant Meteorological Information |
| **VAAC** | Volcanic Ash Advisory Centers |
| **VAWSG** | Volcanic Ash Warnings Study Group |
| **WMO** | World Meteorological Organizations |