Alice's Adventures in Volcano Land: The Use and Abuse of Expert Knowledge in Safety Regulation

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As a volcano refugee in Frankfurt, it was rather interesting to see a slow motion regulatory science disaster taking place. On April 14 2010 the Icelandic volcano Eyjafjallajökull erupted sending millions of tons of ash into the upper atmosphere. The ash cloud, blown by the prevailing winds, moved down over northern Europe. European air traffic authorities, following well established and widely published safety protocols, began shutting down the air transport system due to the well known hazard of volcano ash. The shutdown lasted 6 days and soon became an unequal political contest between airline money on the one side and regulatory science on the other. In a classic case of shooting the messenger bringing bad news the responsible airline parties tried to shift the blame for shutdown to the regulators, while nervous governments quailed before the bullying of the airline executives. Demands for compensation and accusations of regulatory incompetence filled the media. Despite their 25 years of pointing out the hazards of volcanic ash and its implications for air travel, volcano scientists and the air traffic system that relied on them were steamrollered into political oblivion and public humiliation by the combined financial and political clout of ambitious airline executives, their trade association (IATA) and cowardly politicians. Practically overnight the fundamental regulatory system, based on avoiding volcanic ash was jettisoned for what was declared to be a previously unknown "safe" level of ash. While the ultimate dénouement of this débâcle will not be known for some times, a taxpayer bailout for the airlines that refused to prepare for a natural disaster is certainly being pushed. The implications for science-based safety regulation are also ominous.

Airplanes and volcanic ash

Volcanic ash is a severe threat to aircraft. Ash is actually a misnomer, since it implies a combustion process, rather than the explosive melting typical of volcanoes. Volcanic ash is a gritty mix of hard razor sharp particles of various sizes and composition. Volcanic eruptions vary widely in the type and volume of ash they produce. In an explosive eruption, ash can be projected high into the atmosphere and carried on winds around the world. Ash clouds also vary widely in their density and composition. There have been over 80 documented instances of aircraft being damaged by flying through volcanic ash. In at least one case a 747 Jumbo jet had all four engines shut down. In the hot combustion chamber of a jet engine the volcanic ash can melt and condense on the turbine blades, in the worst case shutting the engine down. The scientific consensus is clearly stated in comprehensive recent documents:

"The risk to aviation from airborne volcanic ash is known and includes degraded engine performance (including flameout), loss of visibility, failure of critical navigational and operational instruments, and, in the worse case, loss of life."[1]

Volcanic ash is a special aviation hazard since it can cause rapid simultaneous failure of multiple aircraft engines. Transatlantic flights (especially those with two engine aircraft) are operated based on both the high reliability of individual jet turbines and a belief in the lack of a routine source of simultaneous engine failure. However volcanic ash can cause exactly

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1 US Government Department of Commerce, "National Volcanic Ash Operations Plan for Aviation FCM-P35-2007".

such a simultaneous failure. In terms of engines, volcanic ash has both acute and long term effects. The ash can not only shut down an engine in the short term, it can cause concealed damage that can only be cured by replacement or total overhaul of the affected engine. Such damage can often only be discovered by a full overhaul of the engine. So until every engine exposed to ash is overhauled, the safety problem from flying through an ash cloud can continue.

It is also well known that an aircraft can suffer engine damage in an ash cloud that is not detectable by the pilots. In 1999 a NASA DC-8 aircraft on a routine flight flew inadvertently through an Icelandic volcanic ash cloud. The pilots saw nothing and had no idea they were in volcanic ash but sensitive instruments on board detected the ash. When the engines were examined they had suffered damage requiring the engines to be removed, refurbished and replaced.[2] Certainly any airborne event that can cause undetected latent simultaneous damage to engines demands the highest level of regulatory attention. ICAO, the United Nations organization charged with international air traffic safety issued a Manual in 2007 that was unequivocal on the danger and the fundamental policy of avoiding ash:

3.4.8 "Unfortunately, at present there are no agreed values of ash concentration which constitute a hazard to jet aircraft engines. This matter is discussed in detail in Chapter 4, but it is worth noting at this stage that the exposure time of the engines to the ash and the thrust settings at the time of the encounter both have a direct bearing on the threshold value of ash concentration that constitutes a hazard. 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."

5.4.1.2 "... In fact, any interruption in the smooth and carefully planned operation of scheduled air services can lead to acute problems with serious financial penalties to the operator, and distress and frustration to the passenger."

5.4.1.3 "The first consideration, however, must always be the safety of the aircraft and its occupants. The safety implications of an inadvertent ash encounter are already well documented and are addressed elsewhere in the manual. The aim is to avoid!"[3]

Understanding the ash problem also requires some discussion of a volcanic ash plume. Volcanic eruptions vary widely in their content, altitude and moisture. These all affect both detection and avoidance of ash.[4] In the type of explosive eruption that occurred at Eyjafjallajökull the volcano ejects the ash material into the upper atmosphere. Eyjafjallajökull was a large but not huge eruption with a *volcanic explosivity index* (VEI) of 4. For comparison the 1991 eruption of Mount Pinatubo in the Philippines had a VEI equal to 6.[5] The VEI is a very rough guide to the quantity of ash, but its particle size and distribution can still vary. Measuring and predicting the movement of the ash is very difficult.

Volcanologists estimate the composition of the ash cloud from the eruption based on a variety of measures. Visual, satellite and chemical analysis all assist in characterizing the plume. Using those inputs, meteorologists use conventional atmospheric models to forecast the movement of the plume. Direct sensing by specialized aircraft and ground stations can be used to refine the forecast. But volcanic plumes are not homogenous and they do not have clearly defined edges. The entire process has substantial measurement uncertainty.[6] As a result, precise "detection" of a cloud of airborne volcanic ash in the path of an aircraft is a very complex scientific problem (which has always been severely underfunded). A major workshop on volcanic ash and aircraft, completed less than a month before the eruption, made a specific conclusion:

"Little work has apparently been done to further validate dispersion models, including comparison to observations as well as between models. No science plan exists for this work, although the advent of new unmanned technology such as video sondes may make direct examination of clouds possible."[7]

2 T. J. Grindle and F. W. Burcham, "Engine damage to a NASA DC-8-72 airplane from a high-altitude encounter with a diffuse volcanic ash cloud", *Technical Memorandum NASA/TM-2003-212030*, p. 22.

3 ICAO, "Manual on Volcanic Ash, Radioactive Material 14/12/07".

4 J. J. Simpson; G. Hufford; D. Pieri and J. Berg, "Failures in Detecting Volcanic Ash from a Satellite-Based Technique", 2 *Remote Sensing of Environment*, Volume 72, May 2000, pp. 191–217(27).

5 See <http://www.smithsonianmag.com/science-nature/91838474.html#ixzz0mbkKoOxl>.

6 G. L. Hufford, L. J. Salinas, J. J. Simpson, E. G. Barske and D. C. Pieri, "Operational Implications of Airborne Volcanic Ash", *Bulletin of the American Meteorological Society* (2000), 81: 745–755.

7 "5th International Workshop on Volcanic Ash Report", Santiago (Chile), 22–26 March 2010, available on the Internet at <http://www2.icao.int/en/anb/met-aim/met/iavwopsg/Meeting%20Documents/IAVWOPSG%20Workshop%20No.%205/Workshop%20No.%205%20Report.pdf>.

It should be emphasized that even knowing the average density and rough location of a plume may not help in plotting a path for an aircraft through the plume. Plumes can vary enormously in ash density so averages may be meaningless in terms of ash risk. Detecting high and low levels of concentration is especially difficult. In effect each flight through the plume is a "sample" of the plume, with all its highs and lows. Commercial aircraft do not carry ash detectors and serious ash may not be visible to pilots, so the suggestion of relying on pilots for ash avoidance has no scientific basis. When pilots recognize they are in an ash cloud the instructions are peremptory and demand emergency action:

"If volcanic ash is encountered, the following should be accomplished
- *Immediately reduce thrust to idle.*
- *Autothrottles off (if throttles engaged).*
- *Exit volcanic ash cloud as quickly as possible.*
- *The shortest distance out of the ash may require a 180° turn.*
- *Land at the nearest suitable airport."*[8]

The scientific and engineering literature describes the engine/ash problem in great detail. The problem has been known since 1982 and the current published technical advice is straightforward:

"Two processes deteriorate engine performance: erosion of moving engine parts, such as compressor and turbine blades, and accumulation of partially melted ash in hot zones of the engine .... Ash deposits in the hot sections of the engines, including fuel nozzles, the combustor and turbine reduce the efficiency of fuel mixing and restrict air passing through the engine. This causes surging, flame out and immediate loss of engine thrust. This loss is the principal cause of engine failure."

According to all published scientific technical information there is currently no published safe ash level for allowing flying through a volcanic plume. The technical reasons deal with the nature of such plumes, the problems of measurement and movement and a lack of data on the effect on engines.

"There continues to remain no definition of a 'safe concentration' of ash for different aircraft, engine types or power settings. In order to give a reliable and justifiable 'all clear' once a plume has dispersed enough to be undetectable, clear limits of ash content are required from both the manufacturers and aviation licensing authorities."[9]

The 2010 conference went into further detail:

7. "No progress was made in the 2007–2010 period on defining a 'safe concentration' of ash for different aircraft, engine types or power settings. ... Referring to the need to have established alert thresholds, Airbus was then asked what is the safe particle size and concentration of ash that is sustainable by aircraft. Similarly, the same question relating to Sulphurous gas was also asked. Airbus could not provide an answer to either question because this information is not readily available."

As part of that meeting Airbus agreed to cooperate by asking engine manufacturers for input:

"Airbus agreed to write to the engine manufacturers asking if an answer is available on the question of safe particle size and concentration of ash that is sustainable by engines on its aircraft. Airbus will respond to IATA who will in turn inform the workshop ..."

This summary reflects the state of the art in March 2010, just before the eruption. The standard response of the engine manufacturers has always been to avoid all ash. A recent web interview of the top GE engine safety specialist explains details for such cautions[10].

There had even been a comprehensive drill in 2008 on the effects of an eruption in Iceland:

"In February 2008 officials from air-traffic-control services across Europe, as well as representatives of weather services and airlines, ran an exercise that simulated a strikingly similar eruption. The volcano they chose was not Eyjafjallajokull, but its neighbour, Katla; the weather conditions were not quite the same. But the procedures were."[11]

Prior to the 2010 eruption the risk of flying in ash was barely on the radar of manufacturers and the airline industry. They did not even bother to participate in the relevant workshops:

8 See <http://www.guardian.co.uk/world/2010/apr/25/volcanic-ash-air-industry-warned>.

9 "5th International Workshop on Volcanic Ash Report", *supra* note 7.

10 Available on the Internet at <http://www.ge.com/audio_video/ge/innovation/leslie_mcvey_on_volcanic_ash_and_jet_engines.html>.

11 See <http://www.economist.com/displayStory.cfm?story_id=15952464>.

"IATA informed the group about the strong efforts made in order to get representation from the industry at the workshop but unfortunately these efforts had not been successful."

"As it had proven difficult to get formal aviation representation at science-focused WMO workshops."[12]

As of March 2010 the regulatory system tracked the state of the art and industry practice. The required response to volcanic ash, as it is with icebergs and in-flight icing is "detect and avoid". There was never any suggestion made by any airline that safe levels of volcanic ash existed. Minutes of the Volcano Watch group's annual meeting, held in New Zealand in 2007, note:
"There is no definition of a safe concentration of ash for different aircraft ... In order to give a reliable and justifiable all-clear, once a plume has dispersed enough to be undetectable, clear limits of ash content are required from both the manufacturers and aviation licensing authorities."[13]

A 2008 meeting additionally added a clear caution:
"This refers to an indisputably difficult and longstanding problem; that there is no defined lower limit on ash concentration. As remote sensing techniques improve, it is likely that the aggregate areas where ash is sensed or inferred will increase, possibly leading to over-warning for ash and cost-blowouts for airlines."[14]

Regulating the airline business and the science of hazards

Commercial aircraft safety is a very complex problem and numerous commentators have mentioned the complex jurisdictional issues in Europe. However the problem is even worse into the area of volcanic ash since most of the major "stakeholders" in the problem do not routinely talk directly to the others. The volcano warning system is literally "patched together" and shows many of the effects of being a late entry to the world of aircraft operational control. It is possible to visualize the stakeholders concerned about volcanic ash in a chain where each talks to its neighbor but not to the other end of the chain:

Engine manufacturers
⇅
Aircraft manufacturers
⇅
Airlines
⇅
IATA
⇅
ICAO
⇅
national regulators
⇅
Meteorologists
⇅
Volcanologists

Naturally this chain omits important stakeholders such as Pilots, passengers and shippers, but for moment it will do. Lines should also be drawn directly between the national regulators and the airlines. The problem is this chain does not clearly define an effective decision making structure capable of responding to the problem. In particular the critical expert stakeholders, vulcanologists and engine manufacturers, are the ones furthest from the decision makers. Neither group would routinely participate in operational decisions such as that required by the Icelandic eruption. The entire process lacks an integrated risk analysis policy making body.

In all technical regulation there is a difference between the purely "technical" issues and fundamental "policy" issues. The fundamental level of safety expected is clearly a policy issue while defining the specific hazard in a specific case is clearly a technical issue. The policy made by the cobbled together system described above was very clear. In the case of volcanic ash in April 2010 the policy was *detect and avoid*. This was the position of the ICAO and no one had ever seriously suggested any alternative plan.

The airlines fully understood this policy and also knew that there was no mechanism in place to rapidly change this policy. There was also no technical basis for a "fly through the ash" policy. There was also very limited ability to determine the precise extent and density of ash clouds. While it is possible that aircraft can withstand some ash under some

12 Fourth Meeting of the International Airways Volcano Watch Operations Group (IAVWOPSG), Paris (France), 15–19 September 2008.

13 World Meteorological Organization, 4th International Workshop on Volcanic Ash, Rotorua (New Zealand), 26–30 March 2007.

14 Fourth Meeting of the International Airways Volcano Watch Operations Group (IAVWOPSG), *supra* note 12, emphasis added.

circumstances it is clear that engine manufactures have never designed or tested aircraft for flying in volcanic ash.

4.1.3 "Objective measurements (wind tunnel experiments) of the threshold concentration at which volcanic ash becomes a 'significant' threat to engines or other components of aircraft have not been done."[15]

In 2004, Leonard J. Salinas who was the Program Manager for Dispatch, Flight Safety and Operations of United Airlines presented a paper that stated

"Emphasis must be placed on the avoidance of volcanic ash. Avoid flight at night in areas of known volcanic activity or in instrument meteorological conditions (IMC), when volcanic ash may not be visible. Plan the flight to remain well clear of reported activity. If possible, stay upwind of volcanic ash ...

Avoidance requires the coordinated efforts of a broad group of technical specialists. The goal of these efforts is to avoid an area or airspace that has been contaminated by volcanic ash. Avoidance of Volcanic Ash Clouds is the only procedure that guarantees flight safety."[16]

John Eichelberger, a senior US expert on volcano safety, who was also a volcano refugee in Paris was quoted

"'But, says Eichelberger, the weak link in all this is we don't really know how much ash modern jet engines will tolerate, so the policy has been zero tolerance. Also, we don't have a well-established procedure for measuring the ash concentration in clouds.'"[17]

The ash hits the turbo-fan

What no one in the airline industry seems to have actually internalized is that a *detect and avoid* system could result in a catastrophic shutdown of the industry if a major volcano erupted where the nodes on the transport system were downwind of the volcano. They were caught without any kind of plan for such a disruption. Most ash plumes require flight diversions. But if the ash plume covers the airports, as opposed to the flight paths, flights will not be possible at all. Volcanoes in Iceland posed precisely such a risk. Iceland is upwind from Europe. Volcanoes are not secrets, they are mapped and plotted. The volcanic heritage of Iceland is well understood, and the glaciers make the volcanoes even more hazardous to aircraft by affecting the physics and chemistry of the eruption. The zones an Icelandic eruption plume could affect were clearly understood and stretched down over Europe. Airlines run a business, and ash is clearly a natural disaster/business risk. Any hotel owner in a hurricane zone understands the problem. An intelligent sophisticated business faced with a natural disaster risk might:

a) Purchase insurance against the risk;
b) Set aside reserves to deal with the risk;
c) Invest in research to see if the risk can be reduced;
d) Create a contingency plan to deal with the risk.

Faced with a real possibility of an operational disaster, the world's leading airlines did none of these things. With all the self assurance of Captain Smith of the TITANIC (who had never, after all, hit an iceberg before) they ran at full speed into a natural hazard with no preparation, and then unleashed their public relations machines to try to shift the blame to the scientists and regulators.

Airline executives display their newly acquired volcano expertise

Airline chiefs, who had previously played almost no part in the scientific analysis of the hazard, even claimed universal superiority of their quickly acquired volcano "expertise".

"'The analysis we have done so far, alongside that from other airlines' trial flights, provides fresh evidence that the current blanket restrictions on airspace are unnecessary,' said British Airways chief executive Willie Walsh. 'We believe airlines are best positioned to assess all available information and determine what, if any, risk exists to aircraft, crew and passengers.'"[18]

15 R. Servranckx and P. Chen, "Modeling volcanic ash transport and dispersion: expectations and reality", Montréal Volcanic Ash Advisory Centre, Canadian Meteorological Centre, *Meteorological Service of Canada Proc 2004 meeting* (ICVASS), available on the Internet at <http://www.ofcm.gov/ICVAAS/Proceedings2004/pdf/12-session3.pdf>.

16 L. J. Salinas, "Volcanic ash clouds pose a real threat to aircraft safety", *Proceedings of the 2nd International Conference on Volcanic Ash and Aviation Safety 2004*, available on the Internet at <http://www.ofcm.gov/ICVAAS/Proceedings2004/ICVAAS2004-Proceedings.htm> (emphasis added).

17 See <http://www.thenational.ae/apps/pbcs.dll/article?AID=/20100424/WEEKENDER/704239842/1299>.

18 See <http://www.huffingtonpost.com/2010/04/19/eyjafjallajokull-volcano_n_542411.html>.

One recurring theme is that industry never provided the names of its "experts", nor did it provide details of analysis for others to review. But the industry claims were relentless:
"Steve Lott, IATA's North American spokesman, says, 'We have technology today where we can determine what levels are unsafe. It's in all our economic interests to do so.'"[19]

No such technology of course has ever been demonstrated. Claims even got more inflated when dealing with the scientific infrastructure:
"Giovanni Bisignani, director general of the International Air Transport Association (IATA), 'Europe was using a theoretical mathematical approach and this is not what you need. We needed some test flights to go into the atmosphere and assess the level of ashes and take decisions.'"[20]

This particular comment ignores the fundamental problem of measurement and prediction of ash clouds, not to mention implies the concept of a safe "level of ash". It also implies that computer models "overstate" the risk. However, there is at least as much evidence that they understate the risk. The DC 8 damaged by the Hekla eruption in 1999 mentioned above was flying 700 miles away from the plume as predicted by the models[21].

The drumbeat continued
"Yesterday Sir Richard Branson criticized the blanket ban and called for the government to compensate the industry. 'All the experts were telling us there was no danger,' Branson said. 'There were plenty of corridors through which the airlines could have flown which would have been quite safe.' Branson added: 'A blanket ban of the whole of Europe was not the right decision. The first few days the ash was up at 35,000ft, the planes could have flown below 35,000ft. There were plenty of ways of dealing with it. But actually planes have to put up with sandstorms in Africa; the engines are designed to put up with a lot more than existed.'"[22]

It goes without saying that no "experts" were quoted by name, nor were any "experts" asked to explain the difference between sand and ash. Engines are not designed to "put up" with ash.

The UK sets a "legal" level of ash – but is it safe?

Faced with the media firestorm unhappy passengers, an imminent election and airline demands for compensation the UK aviation regulatory authorities hurriedly convened what experts and data they could find and announced an emergency level of ash that would allow airplanes to fly.

Aided by the fact that the volcano had at least temporarily slowed its eruption the UK authorities announced an acceptable level of ash for operations. This level was immediately described by many in the airline industry as a "safe" level despite the total lack of published technical support.
"Many pilots still have doubts about the process. But Juergen Weber, chairman of Lufthansa's supervisory board, told the company's annual general assembly last week that any doubts about the carrier's safety standards were 'scandalous' and should be 'rejected.'"[23]

In the same article airline executives were again quoted as describing the closure as unnecessary:
"Low-fare carrier Ryanair, for instance, after only begrudgingly agreeing to comply with the law, says it will seek ' full recovery from the Irish government of all refunds to passengers, both of air fares and any reasonable receipted expenses, during the recent unnecessary seven-day closure of EU airspace by EU governments.'"[24]

The level was set as a concentration of ash in the atmosphere by cubic meter. This is a typical way of stating a "legal" definition which may or may not have anything to do with the average or highest level

19 See <http://www2.macleans.ca/2010/04/26/the-volcano-that-choked-a-continent/>.

20 See <http://www.reuters.com/article/idUSTRE63I4S420100419>.

21 D. Pieri, C. Ma, J. J. Simpson, G. Hufford, T. Grindle and C. Grove, "Analyses of in-situ airborne volcanic ash from the February 2000 eruption of Hekla Volcano, Iceland", 16 *Geophysical Research Letters*, Volume 29, 10.1029/2001GL013688, 2002, p. 1767.

22 See <http://www.guardian.co.uk/world/2010/apr/25/volcanic-ash-air-industry-warned>.

23 See <http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/awst/2010/05/03/AW_05_03_2010_p46-223035.xml&headline=European Authorities Working To Expedite Air Traffic Reform>.

24 See <http://www.irishtimes.com/newspaper/world/2010/0428/1224269220876.html>.

of ash encountered by an airplane, and is set without regard to the different types of aircraft in the sky. There was no explanation of how this precise data in terms of flight plans would be generated. Such precise measurements are also difficult.

"*Simply put, the remote sensing instruments and tools currently available are not capable of producing an accurate quantitative measurement of the 3D space and time structure of airborne volcanic ash.*"[25]

As of the date of this writing none of the technical information justifying the regulatory level has been released for peer review. On their website at least one engine maker Pratt and Whitney Canada does not seem to agree with the "safe" level:

"P&WC does not recommend operation in conditions where volcanic ash is present. Let us explain why. Volcanic ash may clog air filters of turbine engines, block cooling air passages, erode the gas path components, and erode the protective paint on casings. Volcanic ash entering the engine can also melt in the combustor and then re-solidify on the static turbine vanes, potentially choking the turbine airflow and leading to surging and an in-flight shut-down. It is also noted that there is a high level of acidity associated with volcanic ash, and this may also lead to deterioration of engine components."[26]

Perhaps the situation is best summed up by one reaction from an unnamed pilot

"The unease was summed up by a pilot from Manchester. 'Let the great experiment begin,' he wrote. 'The simple fact is that a 20-year-old, worldwide safety regime was overthrown at a two-hour meeting packed with British politicians and airline executives ... tens of thousands of passengers will be used as guinea pigs to prove as self-evident the safety of airline profitability and political power ...'"[27]

Volcanic ash and planning for a natural hazard

Volcanic Ash is a threat to aircraft safety. Active volcanoes are not evenly distributed around the world. Many are far from active air traffic lanes, but Iceland's mass of volcanoes lies directly in the heavily traveled North Atlantic corridor and is not far from the UK and the continent of Europe. The prevailing winds would take volcanic ash directly across Europe from Iceland. All of this has been known for a long time. The volcano fight safety regulatory process was developed after numerous meetings by technical experts and operational regulators. Participation by the airline industry was encouraged and desired but was very limited. International policies were created and published.

When the Iceland volcano erupted the guidance was followed by the technical regulators, and chaos and recrimination quickly ensued. Eventually the UK regulators claimed they reexamined the issue in a few days and came to a dramatically different technical conclusion. The UK authorities issued a standard which may or may not represent good science. But what was clearly lacking all along was a strong voice for both good science and an orderly regulatory process. Perhaps if the regulatory authority had pointed out that for twenty years the airlines had been invited to participate in the regulatory process, and present their claimed expertise for peer review, but had constantly declined, it would have muted some of the more egregious comments. It might also be suggested that the general European practice of relying on rules and coordination rather than a strong executive authority tends to break down in widespread disasters, and that better emergency regulatory processes are needed.

25 Servranckx and Chen, *supra* note 13.

26 See <http://www.pwc.ca/en/service-support/engine-operation-in-volcanic-ash>.

27 *Supra* note 23.