Volcanic Hazards and Aviation Safety: Lessons of the Past Decade

Avoiding the ash-laden cloud from a volcano is the only way to guarantee that an aircraft is not damaged by the cloud's dangerous particles, which can destroy an aircraft engine and threaten flight safety. Nature remains the ultimate force.

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Modern jet airplanes and their engines are designed to operate in environments that are free from dust and corrosive gases.

Explosive volcanic eruptions, such as the 1991 eruptions of Mount Pinatubo Volcano in the Philippines, inject large amounts of very small rock fragments, known as volcanic ash, and corrosive gases into the upper troposphere and lower stratosphere. Unfortunately, this is also the normal cruising altitude for jet airplane traffic.

Such explosive eruptions have occurred somewhere on earth about 10 times per year during the past decade. Many of these explosive volcanoes occur around the Pacific "ring of fire" and have a direct impact on air routes around the Pacific basin. [The ring of fire refers to the chain of volcanoes located northward from Panama along the western coast of the United States, westward across the Aleutian Islands, southward along the various island chains bordering the Asian coast, through the islands in Malaysia and then eastward back into the Pacific Ocean.]

In the past 12 years, more than 60 modern jet airplanes, mostly jumbo jets, have been damaged by drifting clouds of volcanic ash that have contaminated air routes and airport facilities.
Seven of these encounters are known to have caused in-flight loss of engine power to jumbo jets carrying a total of more than 2,000 passengers. The repair and replacement costs associated with airplane-ash cloud encounters are also high. The repair of the Boeing 747-400 damaged by an ash cloud from Redoubt Volcano, Alaska, U.S., in December 1989 was estimated to cost in excess of US$ 80 million.
Compounding the problem is the fact that volcanic ash clouds are not detectable by the present generation of radar instrumentation aboard aircraft. Complete avoidance of volcanic ash clouds is the only procedure that guarantees flight safety.

Ash Cloud Encounters In Early 1980s Spurred Study Of Safety Issues

The threat of volcanic hazards to aviation safety first received public attention when several commercial jet aircraft were damaged after flying through volcanic ash clouds from the May 1980 eruptions of Mount St. Helens in Washington, U.S. Interest in the aviation safety issue grew rapidly in the early 1980s after several jumbo jets encountered ash clouds that had travelled several hundred miles from their sources. Eruptions of Galunggung Volcano in Indonesia in 1982, Redoubt Volcano in Alaska, U.S., in 1989 and 1990, and Mount Pinatubo Volcano in 1991 caused significant damage to aircraft, including engine failures, and severely disrupted regional air operations. Ash clouds from eruptions in Colombia, Italy, Japan, the United States and Zaire have also damaged aircraft.

Ash Clouds Vary in Type and Severity

Active volcanoes emit several types of plumes and clouds. Quiescent plumes consist of water vapor and gases with few or no rock particles. They seldom rise above 20,000 feet (6,060 meters) and usually disperse within tens of miles of the volcano. Quiescent plumes are not a significant threat to aviation safety.

Eruption columns are the violent, cauliflower-shaped pillars of ash and gas generated above a volcanic vent during an explosive eruption. Within tens of minutes some clouds columns can rise to altitudes of 40,000 feet (12,121 meters) to 100,000 feet (30,303 meters). They typically contain blocks of volcanic rock up to several inches in diameter, plus dense concentrations of ash and gas. Eruption columns seldom last for more than a few hours and only affect an area within a few miles of the volcanic vent, so they pose a relatively small threat to aviation safety. However, because eruption columns contain large blocks of rock, they must be avoided by aircraft.

Drifting ash clouds consist of finely broken rock fragments and gas that are carried away by winds from a violent eruption column. Large volcanic eruptions produce clouds that enter the stratosphere and may be carried by the jet-stream for thousands of miles.

Drifting ash clouds pose the greatest threat to aircraft.

Although these ash clouds can circle the globe in a matter of weeks, they usually deposit most of their ash within a few hours to a few days. Drifting ash clouds pose the greatest threat to aircraft.

Mitigating the ash hazard is complex because ash clouds are difficult to detect by conventional weather radar or visually from an airplane. Ash clouds are very difficult to detect at night, and they may be obscured by weather clouds. Ash clouds must be tracked by relying on volcano-logical observers on the ground, pilot reports (PIREPS), satellite observations and meteorological forecasts of ash-cloud movements. Immediate communication from ground observers and meteorologists to aircraft dispatchers and controllers, and to pilots, is essential.

Three Eruptions Affected Aircraft Operations Significantly

Three eruptions of the past decade have greatly helped to focus attention on the problem of volcanic hazards and aviation safety. Each of these eruptions included multiple encounters between aircraft and drifting volcanic ash clouds.

In 1982, two Boeing 747-200 passenger jets encountered ash at night from separate eruptions of Galunggung Volcano in Java, Indonesia. In each case, pilots observed St. Elmo's fire, noted the acrid smell of sulphur gas, observed fine dust quickly filling the cabin and experienced moderate turbulence while in the ash cloud. In both cases, volcanic ash entered the jets' engines and caused surging, flameout and immediate thrust loss of all four engines. After powerless descents of nearly 25,000 feet, the pilots of both aircraft eventually restarted all engines and landed safely at Jakarta. Both aircraft suffered extensive damage to engines and exterior surfaces.

The December 1989 to April 1990 eruption period of Redoubt Volcano widely affected commercial and military airplane operations near Anchorage. These affects included rerouting and cancellation of flight operations for some time, which significantly affected the Anchorage economy.

From December through February, ash clouds from Redoubt damaged five commercial jet liners. The most serious incident occurred on December 15, 1989, when a new Boeing 747-400 encountered a drifting ash cloud while descending to land at Anchorage. On entering the cloud at 25,000 feet (7,576 meters), about 150 miles (242 kilometers) northeast of Redoubt, the pilot tried to fly out of the ash cloud and had climbed nearly 3,000 feet (909 meters) before all four engines failed. The aircraft descended 13,000 feet (3,939 meters) without power before the engines were restarted and flight resumed to Anchorage. No passengers were injured, but the aircraft's engines, avionics and exterior were damaged extensively. Repair costs were estimated to exceed $80 million.

Other damaging encounters between jet aircraft and ash clouds from Redoubt were reported on December 15 and 16, 1989, and February 21, 1990. Fortunately, these aircraft did not experience engine failures. Following the eruptions and encounters on December 15 and 16, Anchorage International Airport remained open. Most air carriers, however, cancelled operations for up to several days, and some international carriers cancelled or curtailed operations through January 1990. These curtailments reduced revenues at Anchorage International Airport by approximately $2.6 million.

The June 15, 1991, eruption of Mount Pinatubo was the largest of the past 60 years. The eruption produced a huge ash cloud that moved rapidly to the west over the South China Sea, Borneo and Indochina Peninsula (Figure 1), disrupting aircraft operations over a broad area of the Philippines and Southeast Asia. Five airports in the Philippines, including Manila International Airport and military airfields at Basa, Clark, Sangley and Cubi Point, were damaged by ash-fall, which occurred during a major typhoon and covered airfields at Basa, Clark and Cubi Point with up to six inches of ash. The wet ash and constant ground shaking on June 15 led to the collapse of numerous aircraft hangars and maintenance facilities at several airfields. Manila International Airport was closed from June 15 to 19 and did not resume normal operations until July 4. Clark and Basa remain closed.

At least 20 commercial jet airplanes were damaged by volcanic ash. Most damage was because of in-flight encounters with ash clouds from Pinatubo. These in-flight encounters involved 10 Boeing 747s, five DC-1Os, one L-1011, and one Boeing 737. Because of ash ingestion, a total of 10 engines, including four engines on a single Boeing 747, were badly damaged and had to be replaced. Several other airplanes were damaged on the ground by ash loading and improper removal of ash from cockpit windows.

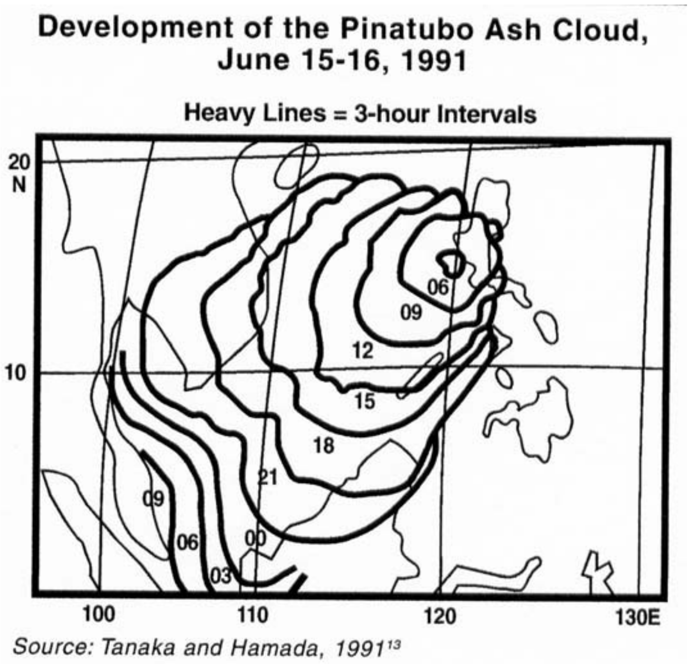


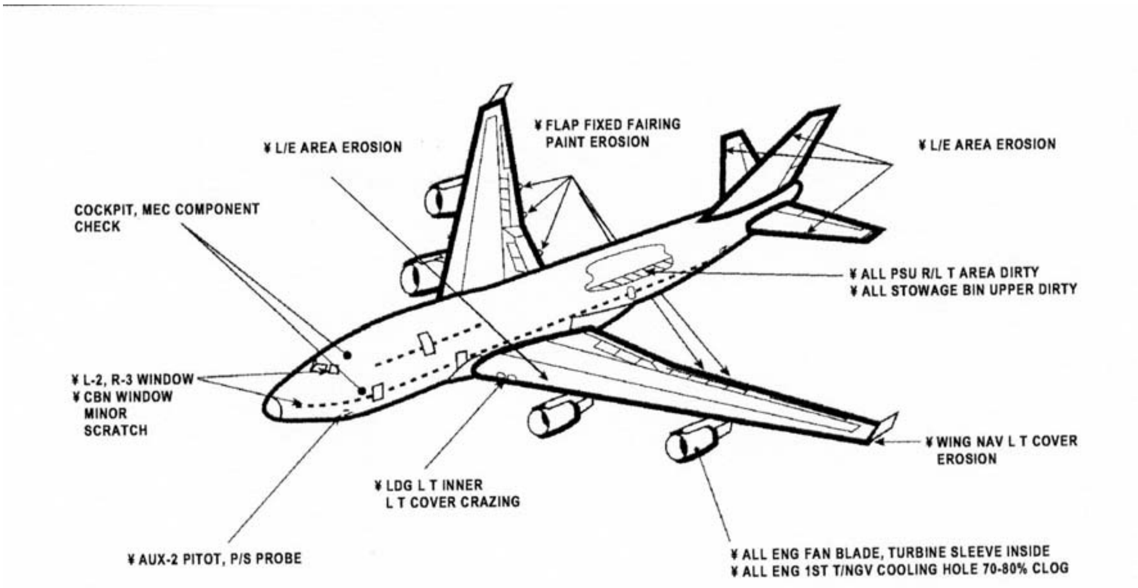
Figure 1

Unlike encounters at Galunggung and Redoubt, which caused multiple engine failures and occurred within 150 miles (242 kilometers) of the erupting volcano, the majority of Pinatubo encounters were at distances of more than 600 miles (967 kilometers) from Pinatubo. Only two encounters occurred during landing approaches to Manila. All other encounters were to the west in the Singapore, Ho Chi Minh and Hong Kong Flight Information Regions. This large number of encounters reflected a major breakdown in the ways that information about the ash-cloud hazard was communicated. In the Philippines, volcanologists of the Pinatubo Volcano Observatory were aware of the eruptions at the time they occurred. With access to real-time satellite information, meteorologists and volcanologists in the United States were also aware of the volcano's activity, including the speed and direction of the ash cloud's movement. The key problem was one of timely communication of this information to the proper agencies in the aviation community.

Aircraft Damage Can be Immediate and Long-term

A range of damage may occur to an airplane that has flown through a volcanic ash cloud (Figure 2). Effects may be apparent immediately or they may take longer to manifest themselves. Immediate effects are easy to identify and, in some cases, easily repaired. Medium-term and long-term effects are considerably more difficult to identify and are primarily related to the gaseous components in the volcanic cloud, especially the acid gas sulphur dioxide.

When a modern jet aircraft, travelling at high speed/encounters a drifting cloud of sand-size rock fragments, a wide variety of damage will occur and the consequences are usually evident immediately. Volcanic ash is typically composed of a mixture of sharp, angular fragments of rapidly quenched volcanic glass, as well as mineral and rock fragments that range in size from fine powder to fragments up to an eighth of an inch in diameter. Fragments typically include the minerals feldspar, quartz and pyroxene. The ash is hard and can easily scratch and abrade glass, plastic and metals. Any forward-facing surface of the airplane, such as windows, landing light covers, leading edges of the wings and the fuselage, will be damaged (Figure 2). Because of its small size, ash also can enter very small openings in the aircraft exterior, including the air supplies for flight instruments such as the pitot static system.



Source: Thomas J. Casadevall

Figure 2
Diagram of Boeing 747-400 Aircraft showing exterior damage from ash cloud

The ingestion of volcanic ash by jet engines may cause serious deterioration of engine performance or even engine failure (Figure 3). Since 1980, at least seven encounters between jet-powered aircraft and volcanic ash clouds have resulted in temporary engine failures. 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 in the engine. Erosion of compressor blades reduces the compression efficiency of the engine but has not been proven to cause engine failure. Ash deposits in the hot sections of the engines, including the fuel nozzles, the combustor and the 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.

Air that enters the airplane cabin is taken from the engine. This air powers generators and pneumatic systems through-out the aircraft and provides breathing air for passengers. The air passes through an environmental control system and is carried through ducts to appropriate parts of the aircraft.

Ash particles may abrade completely through the duct system as well as clog filter systems designed to remove moisture from the air.

Flying an airplane through an ash cloud causes damage that is immediately evident. More difficult to evaluate is the damage that occurs by repeated long-term exposure to the clouds of mostly gas and gas-derived particles that remain in the stratosphere. For large eruptions, such as Mexico's El Chichon in 1982, and Pinatubo in 1991, these gases may remain suspended in the stratosphere for years after the solid rock particles have settled. The sulphur dioxide in the clouds absorbs water vapor and is converted to droplets of sulphuric acid. When aircraft fly in a stratosphere polluted with volcanic aerosols, these acid droplets adhere to aircraft skins and windows and may penetrate micro-cracks in those surfaces. This is most easily observed in acrylic windows where the clouding and crazing of acid-attacked windows prompts their replacement.

Other corrosion damage to plastics and rubber used in seals and lubricants and metal components used in the airframe is not as easily identified. Identifying corrosion damage to these components may require long-term programs of inspection and maintenance.
Even then, corrosion by volcanic pollution may be impossible to distinguish from other environmental pollution such as salt in sea spray and acid gases in polluted urban atmosphere.

Because engines are typically inspected and rebuilt more frequently than the rest of the airplane, the problems of engine corrosion by volcanic gas may be more easily identified and addressed during regular maintenance.

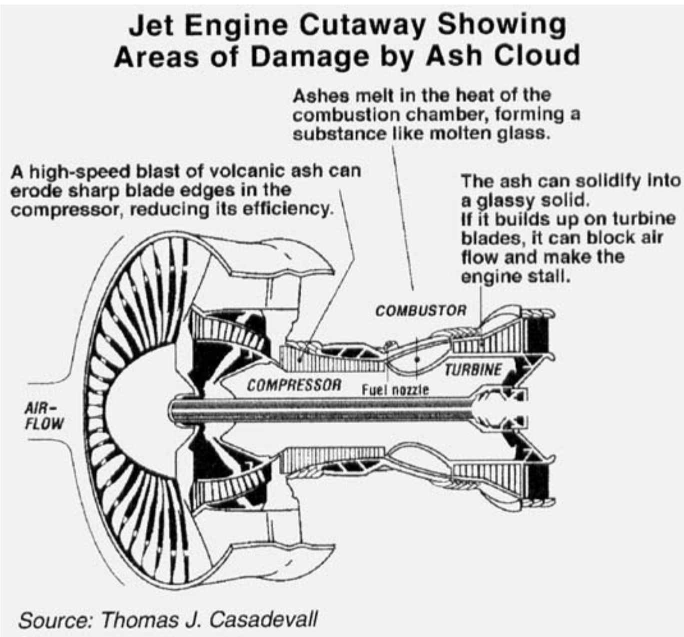


Figure 3

Nevertheless, the airframe and skin are most susceptible to long-term influence from repeated exposure to volcanic clouds. Scientists and engineers have not yet assessed the long-term effect of corrosion by acid components in volcanic clouds.

Aircraft Also Face On-ground Ash Hazards

It is easy to appreciate the nature of damage that occurs during an in-flight encounter with an ash cloud. However, a host of additional problems face an airplane sitting or taxiing on the ground. For example, ash-fall of more than several inches will place a considerable load on an aircraft, especially if the ash falls wet with rain. Some aircraft may respond to loading by settling back on their tail sections. Ash loading also may cause hangars to collapse, especially if ash falls wet and if ground shaking caused by volcanic earthquakes is strong and prolonged, as it was during the Pinatubo eruption.
Ash covering airport runways and taxiways is easily resuspended for days to weeks by wind and by ground movement of aircraft for takeoffs, landings and taxiing. Ingestion of resuspended ash by jet engines, especially during full-power takeoff, may be just as damaging as ash encountered while in flight. When wet, ash becomes slippery because of its fine grain size. Slippery ash reduces the coefficient of friction between tires and the runway surface, thus affecting the braking and turning performance of aircraft.

Removing ash from an airplane and its engines must be done with care. Simply washing fine ash from an airplane's exterior must be avoided because water added to ash produces a slurry that may penetrate openings in the skin surface. Subsequent removal is costly and may require disassembling the airplane. A simple three-step procedure is recommended for removing ash from the surface of an airplane parked on the ground: (1) sweep ash away with a broom; (2) vacuum remaining ash with an industrial vacuum; and (3) wash away remaining fine ash, being careful to wash away from openings in the airplane surface.

Only a few airports have had to deal with volcanic ash-fall. One facility where carriers and managers have experience is Kagoshima Airport in Japan, which receives frequent ash-fall from nearby Sakurajima Volcano. While there are some common elements in the cleanup efforts at each airport, airport managers and ground crews have typically relied on local solutions for their cleanup efforts. The type of cleanup effort will usually depend on the amount of ashfall.

Avoiding an ash cloud is the only way to guarantee that an aircraft is not damaged.

Ashfalls less than 0.25 inch (6.2 millimeters) can usually be handled by thoroughly washing airport surfaces, if adequate water and drainage capacity is available. For thicker ashfalls, initial washing is discouraged because ash is likely to fill and block drainage lines. Instead, experience shows that accumulating the ash into mounds large ling an enough to remove with earthmoving equipment is the best first step. This may be followed by washing. If ash is moved to the edges of runways and taxiways, it should be removed or stabilized with quick-growing grass or emulsified asphalt to avoid resuspension of ash by aircraft movement or wind. This method was used successfully at Manila International Airport and Cubi Point Naval Air Station after the 1991 eruptions of Pinatubo.

Research and Experience Have Yielded Valuable Lessons

At considerable expense during the past decade, some important lessons have been learned about the threats that volcanic ash poses to aviation safety in the air or on the ground. An aircraft cannot fly through an ash cloud without sustaining some damage. Avoiding an ash cloud is the only way to guarantee that an aircraft is not damaged.

As existing instruments aboard aircraft simply cannot detect or locate an ash cloud, the most important lesson is that immediate communication to a pilot about a potential volcanic threat is essential to successful avoidance. Three essential sources of information about volcanic activity and ash clouds include observations from ground-based observers to alert and verify an eruption; from pilots, through pilot reports about eruptive activity and ash clouds; and from satellite observations to detect and track ash clouds.

No single source of information is completely reliable and feedback between these three sources is essential for complete and accurate communication. National and international organizations have initiated efforts to improve communications between volcanologists, meteorologists, air traffic controllers and pilots. Yet, the improvements cannot substitute for increased pilot awareness about what to do when an ash cloud is entered inadvertently.

Aircraft must avoid flying into volcanic ash clouds. Avoiding an ash cloud may be difficult or even impossible for an airplane in flight, especially at night. Although such an encounter will almost surely result in some damage to the airplane, depending on the ash content of the cloud and the duration of the encounter, the aircrew can minimize the damage by reducing engine power and reversing course to escape the ash cloud. Such actions require that pilots be well informed about the nature of ash clouds and that they be trained in procedures to minimize damage.

If the aircraft experiences engine failure, pilots must be aware that engine parameters such as temperature and turbine speed for engine starts at high altitude differ from normal starts made on the ground. Analysis of incidents where engines failed because of ash ingestion indicates that in some cases initial restart attempts would probably have been adequate had pilots been aware of the characteristics of high-altitude engine restarts.

For aircraft on the ground or en route toward a potentially hazardous ash cloud, communications between controllers, dispatchers and pilots can usually lead to successful avoidance. This will typically mean carrying additional fuel or planning alternate routes to avoid the contaminated airspace.

The United States has 56 volcanoes that have erupted during the past 200 years. Forty-four of these volcanoes are located in Alaska, including 30 in the 1,000-mile-long (1,613 kilometers) Aleutian Island chain. The U.S. Geological Survey (USGS) is responsible for assessing volcanic hazards and monitoring restless volcanoes in the United States. Only 19 of the 56 U.S. volcanoes are monitored by the USGS from volcano observatories located in Hawaii, Washington and Alaska. Presently, only one of the 30 historically active Aleutian Island volcanoes is monitored. This gap in monitoring coverage is especially critical in view of the large number of commercial and military aircraft that use the great circle routes.

While the USGS efforts focus on ground-based studies, the U.S. National Oceanic and Atmospheric Administration (NOAA) and the U.S. Federal Aviation Administration (FAA) monitor and track volcanic ash clouds in the United States with satellite imagery and pilot reports. In 1989, NOAA and the FAA initiated a joint effort to track volcanic ash clouds and to warn pilots via notices to airmen (NOTAMs). Based on experience gained from the 1989 to 1990 Redoubt eruptions and the 1991 Pinatubo eruption, the NOAA-FAA effort will also formally link the USGS into the process of informing pilots about the threat of volcanic ash clouds.

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In cooperation with the International Civil Aviation Organization (ICAO) and the Air Line Pilots Association (ALPA), the USGS continues to seek ways to inform and educate the aviation community about volcanic hazards and what steps can be taken to mitigate and minimize an ash-airplane encounter — in the air and on the ground — in ways that promote the safety of air travel.

The growing number of ash encounters during the past decade has prompted several international efforts to evaluate and address the problem of volcanic hazards to aviation safety. In 1982, a Volcanic Ash Warnings group was organized under leadership of ICAO. Also in 1982, the Australian Department of Aviation created an Airways Volcano Watch.

A May 1985 encounter between a Boeing 747-200 and an ash cloud from Soputan Volcano in Sulawesi, Indonesia, prompted the Indonesian and Australian governments to form a liaison committee to improve communications about volcanic eruptions in the Indonesian region.

In 1988, ICAO member states adopted amendments for an International Airways Volcano Watch to provide alerts about eruptive activity worldwide. These efforts included development of a special form for pilots to report volcanic events.

Communicating past experiences and practical solutions to pilots and the airlines is key to solving the ash-aircraft problem. The efforts of a wide variety of agencies, both public and private, led to the First International Symposium on Volcanic Ash and Aviation Safety, held in Seattle, Washington, U.S., in July 1991. The symposium sought to encourage improvements in the detection, tracking and warning of volcanic ash hazard so that aircraft may avoid ash clouds; and to review the effects of volcanic ash on aircraft so that pilots who encounter ash might respond appropriately. More than 200 participants from 23 countries attended the symposium.

The manufacturers' principal trade association, the Aerospace Industries Association of America (AIAA), formed a Volcanic Ash Study Committee in February 1991 and presented its recommendations at the international symposium. In connection with the Seattle symposium, ALPA, the Air Transport Association of America (ATA) and the Flight Safety Foundation have actively communicated about the volcanic ash problem to their members and constituents, both nationally and internationally.

Volcanic Ash Threat Will Remain in Coming Years

During the past decade, we have learned some hard lessons about the threat that volcanic ash presents to the modern jet airplane and its engines. This threat is not likely to disappear in coming years. The best solution to the problem is to avoid areas contaminated by ash. Avoidance requires the coordinated efforts of a broad group of technical specialists including volcanologists, meteorologists, dispatchers, pilots and controllers, all working together to detect and track volcanic ash clouds and to provide warnings about volcanic hazards to aviation safety. The goal of these efforts is to avoid an area or airspace that has been contaminated by volcanic ash and corrosive volcanic gas.

Changes to the technical design of airplanes and powerplants have been considered and rejected as being too costly or impractical. Development, particularly in Australia, of sensors carried on the airplane is in the early stages and is a future hope to assist pilots to avoid ash clouds, especially for air routes over remote regions where volcanoes are largely unmonitored.

Because ash clouds often drift over national boundaries and between flight information regions, regional air traffic facilities and carriers must be informed about potential volcanic threats, not just in their local flight region, but in adjacent regions as well. The hazards posed by volcanic clouds have a global scope that requires both local and global approaches to ensure a successful solution.

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Thomas J. Casadevall is the project chief for Volcanic Hazards and Aviation Safety at the U.S. Geological Survey (USGS). He coordinates USGS activities with other federal agencies and with nongovernmental groups in the area of aviation safety. He has worked with the USGS Volcano Hazards Program since 1978 and has been a member of numerous research teams working at active volcano sites around the world. He holds an M.A. in geology and a Ph.D. in geochemistry.

FSF-urged Communication Link Allowed Warning of Volcanic Eruption

The eruption of the 10,560-feet (3200-meters) high Mt. Shivelutch Volcano on the Kamchatka Peninsula, on April 17,1993, is only one of the most recent volcanic eruptions that underscored the importance of the international seminar "Volcanic Activity and Problems Related to Aviation Safety," conducted Sept. 8-12, 1992, on the Siberian peninsula of Kamchatka in the Russian Far East. [Flight Safety Foundation News, October/November/December 1992, "Volcanic Hazards to Flight Highlight Russian Conference, Signals Further Opening of CIS"].

One important outcome of the seminar was that Flight Safety Foundation-Commonwealth of Independent States (CIS) communicated FSF's recommendation by John H. Enders, FSF vice chairman, to the CIS Minister of Communications that a direct communications link be established between the Kamchatka Region and the West. A telephone link to Japan was established after FSF's recommendation, but that link is still subject to various problems in the Russian telephone system.

The timely warning of the Mt. Shivelutch eruption was the first time, for instance, that Japanese aviation authorities had received notice directly from the authorities in the Kamchatka Region of a volcanic eruption, a fairly frequent geological event in that part of the world.
This measurable improvement in communications between CIS-volcanologists and the worldwide aviation community is a direct result of the seminar.

Nevertheless, goodwill, such as that shown by the personnel involved in this timely warning, cannot be a long-term substitute for a routine, reliable and timely communications system. More work must be done to improve the speed and accuracy of information about volcanic eruptions that may create hazardous conditions for aviation operations across the northern Pacific Ocean and along newly opened routes across Siberia and the Russian Far East.
FSF and FSF-CIS sponsored the seminar in cooperation with the Kamchatka Regional Administration, Far East Institute of Volcanology. Aeronautical Meteorological Observation Office of Petropavlovsk-Kamchatskii, KamchatAvia Airlines, Kamtchatka

Joint Aviation Group and Alpha Tours. The 60 seminar participants, including volcanologists, geologists and other scientists, and aviation representatives from flight operations, air traffic control and meteorology, reached several important conclusions during the seminar discussions, including the following:

1. The Kamchatka Region produces a wide spectrum of volcanic activity, some of which constitute hazards to safe aircraft flight;

2. The region's volcanic observation-station network appears to be adequate for scientific purposes, but additional resources could improve its effectiveness in alerting the aviation community of volcanic activity, which would allow for rerouting of flights to avoid hazards;

3. The region's scientists are competent and highly trained; and,

4. The region's communications network is the weak link in warning the aviation community of volcanic hazards.

The seminar served its purpose in presenting the actual state of volcanic activity (especially in the CIS) and its relation to aviation safety. The results of the seminar's discussions, which were presented the following week to the International Civil Aviation Organization's (ICAO) "Volcanic Ash Hazards" meeting in Bangkok, Thailand, added up-to-date information to the ICAO meeting.

FSF and FSF-CIS are considering future meetings in Kamchatka that will augment and complement volcano-related activities by ICAO and the U.S. Federal Aviation Administration (FAA).

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