MITIGATING THE IMPACT OF VOLCANIC ASH CLOUDS ON AVIATION: WHAT DO WE NEED TO KNOW?

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

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C O N T E N T S

May 5, 2010

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Appendix: Answers to Post-Hearing Questions

MITIGATING THE IMPACT OF VOLCANIC ASH CLOUDS ON AVIATION: WHAT DO WE NEED TO KNOW?

WEDNESDAY, MAY 5, 2010

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Gabrielle Giffords [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

Mitigating the Impact of Volcanic Ash Clouds on Aviation—What Do We Need to Know?

May 5, 2010
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

WITNESS LIST

Dr. Tony Strazisar
Senior Technical Advisor
Aeronautics Research Mission Directorate
National Aeronautics and Space Administration

Dr. Jack A. Kaye
Earth Science Division
National Aeronautics and Space Administration

Ms. Victoria Cox
Senior VP, NextGen and Operations Planning
Air Traffic Organization
Federal Aviation Administration

Captain Linda M. Orlady
Executive Air Safety Vice Chair
Air Line Pilots Association, International

Mr. Roger Dinius
Flight Safety Director
GE Aviation

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HEARING CHARTER

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Mitigating the Impact of Volcanic Ash Clouds on Aviation– What Do We Need to Know?

MAY 5, 2010
10 A.M.–12 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

I. Purpose

On May 5, 2010 the Subcommittee on Space and Aeronautics will hold a hearing on the research needed to improve our understanding of the impact of volcanic ash clouds on aircraft and aircraft operations and what can be done to mitigate that impact. Last year, when the *Mount Redoubt* volcano erupted southwest of Anchorage, one of the operating airlines grounded its fleet, diverted flights and wrapped the engines of its parked planes in plastic sealant. Most recently, the eruption of Iceland's *Eyjafjallajökull* volcano paralyzed air travel in Europe for six days, is reported to have inconvenienced hundreds of thousands of passengers around the world, and is projected to cause airline revenue losses of at least $1.7 billion. At this hearing, the Subcommittee will examine the role Federal research can play in:

- Characterizing the damage volcanic ash causes to aircraft and aircraft engines;
- Devising ways to minimize the negative effects of volcanic ash on aircraft and aircraft systems such as engines;
- Improving the modeling, detection, and prediction of how volcanic ash clouds propagate and dissipate, particularly through the integrated use of civil space-based assets;
- Informing guidelines and regulations that establish what aircraft should do when encountering volcanic ash clouds and when it is safe to fly in airspace contaminated with volcanic ash; and
- Improving air traffic management procedures, capabilities and features, including those planned for the new NextGen air traffic control system, to efficiently circumvent contaminated airspace.

II. Planned Witnesses:

Dr. Tony Strazisar
Senior Technical Advisor
Aeronautics Research Mission Directorate
National Aeronautics and Space Administration
[Substituting for Associate Administrator Jaiwon Shin]

Dr. Jack A. Kaye
Earth Science Division
National Aeronautics and Space Administration

Ms. Victoria Cox
Senior VP, NextGen and Operations Planning
Air Traffic Organization
Federal Aviation Administration

Captain Linda M. Orlady
Executive Air Safety Vice Chair
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Mr. Roger Dinius
Flight Safety Director
GE Aviation

III. Overview

Following the biggest disruption in air travel since September 11, 2001, there is much discussion in Europe about the response to the volcanic ash cloud emergency created by the *Eyjafjallajökull* volcano. Some of the discussion focuses on whether the closure of European airspace and its duration were necessary in the first place. The controversy in Europe over the United Kingdom's Civil Aviation Authority's (CAA) decision to close British airspace and the authority's subsequent permission to allow resumption of flights in specified areas highlights the challenge aviation regulators face in light of insufficient scientific data to establish (1) the volcanic ash contaminant level below which air travel is safe and permissible; (2) the atmospheric location and concentrations of ash such that safe flying corridors can be determined on a real-time basis; and (3) the damage, both immediate and long-term, that volcanic ash inflicts on aircraft, particularly their engines.

Although the disruption caused by the Icelandic volcano is not the first time air travel has been impacted by volcanic ash, the magnitude of the disruption is the greatest experienced to date. Anecdotal evidence from several incidents where aircraft have previously encountered volcanic ash alerted aviation regulatory bodies on the dangers of flying through such conditions. Several near-catastrophic incidents involving volcanic ash have occurred:

- In 1982, after flying through an ash cloud, a British Airways Boeing 747 near Jakarta, Indonesia lost all four of its engines as they choked on the ash and flamed out. Ash was reported to have filled the cabin through air vents and the cockpit window was severely scratched. Subsequently, the pilots were able to restart three of the four engines and land safely in Jakarta.
- In 1982, one month after the British Airways incident, a Singapore Airlines Boeing 747 lost two of its four engines and was forced to land in Jakarta because of an ash encounter.
- In 1989, a KLM Royal Dutch Airlines Boeing 747 encountered an ash cloud caused by *Mount Redoubt* while descending into Anchorage International Airport. The aircraft lost all four engines and about half of its instruments failed. Pilots were able to restart all four engines and landed safely.

In response to these incidents, and because there were no agreed upon values of ash concentration that constitute a hazard to aircraft engines, the International Civil Aviation Organization (ICAO), a U.N. agency, recommended avoidance of volcanic ash clouds as the preferred course of action. ICAO also created a worldwide monitoring system composed of 9 Volcanic Ash Advisory Centers (VAAC). The Washington VAAC and Anchorage VAAC are operated by the National Oceanic and Atmospheric Administration (NOAA). [Attachment I shows the VAACs and their areas of responsibility]. According to the Federal Aviation Administration (FAA), the problem of ash clouds in the United States generally occurs in Alaska, Hawaii or the Pacific Northwest. In addition, in part to address the hazard posed by airborne volcanic ash in the North Pacific, the U.S. Geological Survey (USGS), in cooperation with the University of Alaska Fairbanks Geophysical Institute and the Alaska Division of Geological and Geophysical Surveys, established the Alaska Volcano Observatory (AVO) with offices in Anchorage and Fairbanks. The AVO provides hazard assessments, updates and warnings of volcanic activity in Alaska.

NASA has first-hand knowledge of the effects of flying through volcanic ash clouds and the delayed effect on jet engine performance. When its scientists were flying in a DC–8 research aircraft en route to Sweden in February 2000, they flew for about 8 minutes through an ash cloud, a fact unknown to the pilots until they were alerted by on-board scientists who had noticed the event using special instrumentation; conventional radar equipment is incapable of discerning volcanic ash clouds. Although the pilots saw no change in performance in the aircraft, either immediately after being told of the encounter or even after 60 hours of flying in Sweden, a borescopic inspection was performed on all four engines following the aircraft's return to the U.S. Results of the analysis caused NASA to send one of the engines for an overhaul. The agency found that ash clogged holes that provide bleed air cooling to turbine blades, and also left deposits on the turbine blades after ash entered the combustion chamber and melted. [See pictures of damage to one of the engines in Attachment II] The maintenance factory told NASA that they had substantially decreased the life of the engines and that they would have noticed a degradation in performance in as little as a hundred flight hours because of overheating of the engine fan blades. All four engines were subsequently overhauled. Dr. Jaiwon Shin, a witness at the hearing, can provide details on NASA's related aeronautics research activities. He will be accompanied by Mr. Thomas Grindle who is familiar with the events associated with the February 2000 flight.

NASA does not have operational responsibility for observation and analysis of volcanic gas and aerosol emissions. However, its fleet of research spacecraft provides data that are directly applicable to understanding the hazards presented by these phenomena. According to NASA, in response to the recent European situation, it is providing near-real-time information on volcanic sulfur dioxide and ash aerosols from the Ozone Monitoring Instrument aboard the Aura satellite for the VAACs in London and Toulouse, in collaboration with NOAA. NASA states that the information provided to the London and Toulouse VAACs had been previously available for sectors covering the Americas and the Pacific (in collaboration with the Anchorage and Washington VAACs). Numerous other NASA spacecraft instruments provide important data relevant to the problem of volcanic ash clouds. One example is data recently acquired by the Multiangle Imaging SpectroRadiometer instrument on the Terra spacecraft that provide not only the horizontal extent of the plume over Iceland but detailed information about its vertical extent as well. In addition to providing measurements and information to aid decision-makers in responding to the volcanic event and its aftermath, these data from NASA's research satellites are being utilized in several ongoing NASA-sponsored scientific studies of solid Earth processes, atmospheric composition and air quality, Earth's radiation balance and aviation forecasting improvement methodologies within NASA's Earth Science Division's Research and Analysis (R&A) and Applied Sciences programs. Dr. Jack Kaye, a witness at the hearing, can provide additional details on the capabilities of NASA's Earth observation satellites.

The Airline Pilots Association (ALPA), the largest airline pilot union in the world, representing nearly 53,000 pilots at 38 U.S. and Canadian airlines, has devoted several years to expanding the database of operationally relevant information on the potential hazard caused by volcanic ash and improving the warning system necessary to reduce unplanned encounters with hazardous ash clouds. ALPA believes its information may be useful towards understanding the hazard; understanding recommended practices for avoidance, if possible; achieving survival in the event of an unexpected encounter; and finally, reporting the experience. Regarding the recent situation in Europe, it warned members to identify alternate routes to avoid ash clouds. Captain Linda Orlady, a witness at the hearing, can provide additional details on ALPA's relevant activities.

When the ban over air travel was lifted in Europe, officials broke the affected areas of airspace into three tiers: normal flight zones where ash no longer poses a risk, no-fly zones where ash remains in high concentrations, and intermediate, potentially hazardous zones where flights can proceed with caution, subject to route restrictions and other limitations. The UK Civil Aviation Authority (UK's equivalent of the FAA) lifted flight restrictions after consulting with many parties, including the FAA and aircraft and engine manufacturers. In a statement, the FAA indicated its support for the decision by the European Commission to resume air traffic in parts of continental Europe. The FAA said, in its press release, that "*This gradual, cautious return of operations is reliant on the track of the volcanic ash cloud which is being monitored closely. The FAA is continuing to work with the European Union and is sharing technical information and guidance based on previous experience managing weather and volcanic events that have affected portions of U.S. airspace. The FAA remains ready to assist both the air carriers and our colleagues in Europe to do whatever is necessary to help stranded passengers and to safely return air service between our continents*." In addition, the FAA released on April 22, 2010 a Special Airworthiness Information Bulletin (SAIB) advising "*owners and operators of aircraft equipped with turbine engines that operate in airspace where volcanic ash may be present, of recently issued communications from engine manufacturers*." SAIB Number NE–10–28 recommends that:

> "*Before flying from the United States to Europe or within Europe, aircraft owners and operators should review the following recommendations*:
>
> - *Although the FAA does not recommend engine operation or flight into a visible volcanic ash cloud, we do recommend that you obtain definitive information on operational limitations around ash clouds, if any, from each of the European National Authority of the State(s), of which you plan flight operations*.
> - *Follow all aircraft and engine manufacturer's operating and maintenance instructions pertaining to operations in airspace where volcanic ash may be near or present*.
> - *Report any inadvertent encounter with volcanic ash or relevant findings, including abnormal engine behavior, to the respective type certificate holders of the aircraft and engines*."

Ms. Victoria Cox, a witness at the hearing, can provide additional details on FAA's collaborative efforts to assist other aviation regulators as well as how similar situations may be managed under the NextGen air traffic control system. In addition, Mr. Roger Dinius, also a witness at the hearing, can provide details on GE Aviation's role in helping European aviation regulators establish conditions for flight resumption.

There is widespread agreement on the need for a better understanding of the effects of volcanic ash on aircraft and how particulates propagate in the atmosphere. Of particular concern is the small amount of research so far on the cumulative impact of flying for extended amounts of time through even low levels of volcanic ash. What knowledge we still lack and how we go about gaining that better understanding—possibly through additional research, data collection and computer modeling—will be discussed during this hearing.

IV. Issues

Aeronautics Research and Information Needs

- *What is known about the impact of aircraft flying through volcanic ash clouds? What are the areas of greatest uncertainty in our knowledge and what research is needed to reduce that uncertainty?*
- *What research is needed to better understand when and under what conditions (e.g., size of particulates, ash concentration, and height of the cloud) it is safe to fly through airspace that has been contaminated with volcanic ash particulates? Is there a way to characterize the risk of flying under different conditions?*
- *What research is needed to develop sensors and instrumentation to warn aircraft operators of volcanic ash conditions?*
- *Can human factors research enhance the training of pilots who might deal with volcanic ash conditions?*
- *What is known about how much damage volcanic ash can inflict on aircraft engines? What research can help engine designers determine the extent to which the safety of aircraft engines could be enhanced on future aircraft that inadvertently fly through volcanic ash conditions?*
- *What is the extent of research on the effects of aircraft flying through volcanic ash clouds by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA)? What has been learned?*
- *What additional research is needed to help establish limits and conditions under which it is safe to fly in contaminated airspace? What level of resources would such research entail?*
- *To what extent are Federal research programs on aircraft flying through volcanic ash coordinated and how easy or difficult is it to share the research results with relevant stakeholders? To what extent are U.S. and international research programs coordinated?*
- *Are there other sources of research (e.g. by the commercial, or private, non-government sectors) on the effects of aircraft flying in volcanic ash conditions?*

Detection, Monitoring and Modeling Activities and Assets

- *What civil Federal capabilities, such as Earth-observation satellites, are used to assist in detecting and monitoring volcanic ash cloud propagation and dispersion? How effective are they?*
- *To what extent will planned Earth observing satellites contribute to the detection, monitoring and understanding of volcanic ash clouds and their composition?*
- *What enhancements to space-based or airborne sensors, technologies, or techniques are needed to further our understanding of volcanic ash clouds and particulate dispersion?*
- *How effective are current modeling techniques in forecasting the propagation of volcanic ash clouds?*
- *How are the scientific results of research and monitoring of volcanic ash clouds coordinated, analyzed, filtered and disseminated to decision makers who are responsible for determining when it is safe to fly, and what, if any, improvements need to be made to ensure the effectiveness of coordinating and disseminating the information?*

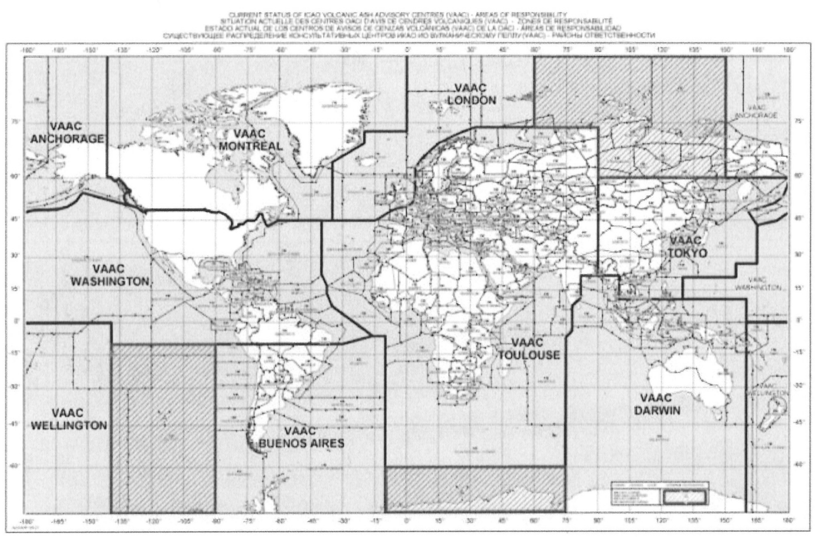
- *What is the extent of collaboration, both nationally and internationally, in the detection and monitoring of atmospheric volcanic ash conditions and dissemination of warnings?*

Air Traffic Management/NextGen and Voluntary Reporting Mechanisms

- *What air traffic regulations are currently in effect to manage aircraft operations in the event of a volcanic ash cloud event, such as those experienced in Alaska? Are there contingency plans for dealing with such events? What information is needed to establish "safe" flight corridors?*
- *What was FAA's role in collaborating with international aviation regulatory bodies to establish safe conditions for resumption of air travel following the eruption of the Eyjafjallajokull volcano?*
- *Can research help inform the establishment of airspace management and air traffic control procedures in the event of a volcanic ash cloud situation? If so, in what areas is research needed and who should conduct such research in the U.S.?*
- *Will the management of aircraft flying in volcanic ash situations be handled differently under NextGen? What information does NextGen need to automatically assign safer air traffic routes? Is that information available today?*
- *Have any of the voluntary safety reporting mechanisms, such as the Aviation Safety Information and Sharing (ASIAS) System, identified issues associated with aircraft flying through volcanic ash clouds?*

ATTACHMENT I

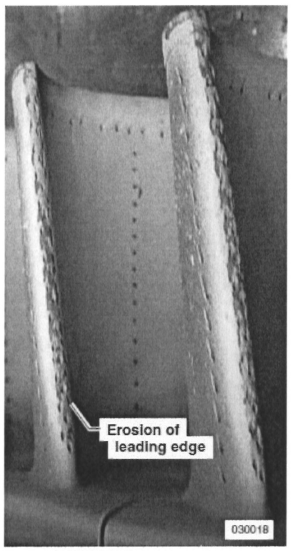
Volcanic Ash Advisory Centers Worldwide



Source: NOAA Satellite and Information Service

ATTACHMENT II

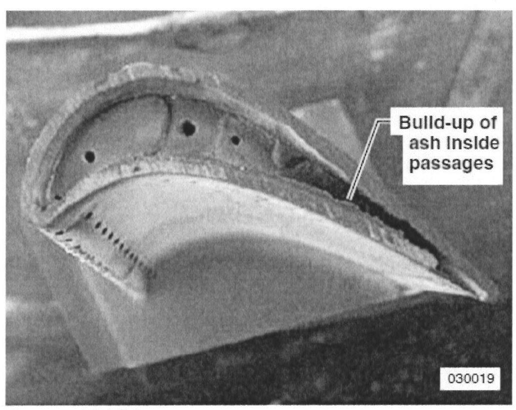
Photographs of Damaged Turbine Blades from Engine number 692632 on NASA DC-8-72 Following Encounter with Volcanic Ash Cloud



Source: NASA

Excerpt from NASA's report (NASA/TM-2003-212030)

"Even though this was a diffuse ash cloud, the exposure was long enough and engine temperatures were high enough that engine hot section blades and vanes were coated and cooling air passages were partially or completely blocked. The uncooled blades still performed aerodynamically but necessitated expensive overhauls. The insidious nature of this encounter and the resulting damage was such that engine trending did not reveal a problem, yet hot section parts may have begun to fail (through blade erosion) if flown another 100 hr."



Source: NASA

Chairwoman GIFFORDS. This hearing will now come to order.

Good morning, everyone. It is with real pleasure that we invite you today to the Subcommittee's hearing. We have an impressive panel of experts, and I am really fortunate to have had a chance to speak, before we started, with some of them. We look forward to having a very good and timely discussion.

As you know, the eruption of the volcano in Iceland forced the closure of European airspace, paralyzing air traffic travel for 6 days. Hundreds of thousands of passengers around the world, including many Americans, in fact, friends and family members I think of all of us, were stranded and airline revenue losses may end up reaching at least $1.7 billion.

While the ink has yet to dry on that episode, one thing is certainly clear: Aviation regulators have insufficient scientific data to establish, one, at what level of volcanic ash contamination air travel is safe; two, where ash clouds are and how concentrated they are on a real-time basis; and three, the extent of damage, both immediate and long-term, that volcanic ash inflicts on aircraft and particularly on their engines.

Moreover, the dangers to aircraft and passengers are not hypothetical, as our witnesses will testify. For example, in 1982, after flying through an ash cloud, a British Airways Boeing 747 near Jakarta, Indonesia, lost all four of its engines as they choked on the ash and flamed out. Ash was reported to have filled the cabin through air vents and the cockpit window was severely scratched. Also in 1982, one month after the British Airways incident, a Singapore Airlines Boeing 747 lost two of its four engines and was forced to land in Jakarta because of an ash encounter. In 1989, a KLM Royal Dutch Airlines Boeing 747 encountered an ash cloud caused by Mount Redoubt while descending into Anchorage International Airport in Alaska. The aircraft lost all four engines and half of its instruments failed as well.

I strongly believe that this Subcommittee should, as one of its primary responsibilities, identify space and aeronautics issues of concern to the Nation and encourage the development of practical solutions if possible. Oftentimes, focused research can help.

While we have been fortunate not to have experienced this type of widespread volcano-induced airspace closure that Europe just experienced, we should view this as a wake-up call for all of us. The reality is that we do have some relevant experience and technologies that can be brought to bear on this problem. As you will hear later, the inadvertent encounter of a volcanic ash cloud by a NASA research aircraft in 2000 showed how much damage volcanic ash can inflict to aircraft engines and the hidden nature of that damage. And NASA was recently called on by our European friends to monitor, using its unique satellite-based instruments, the ash plume as it made its way towards continental Europe.

As our country's aviation regulator, FAA collaborates with other Federal agencies to ensure that our Nation's air traffic safely circumvents any problematic conditions, including volcanic ash situations.

Avoiding volcanic ash clouds certainly is not as easy as it sounds. Conventional radar cannot discern ash particulates. Pilots are keenly aware of this and have been trained on what to do when advised of potential problems.

Finally, as you will hear today, engine manufacturers provided assistance during the decision-making period leading up to the reopening of Europe's skies.

I called today's hearing so that this Subcommittee can help determine what we know and where our knowledge is still lacking. Most importantly, I would like to find out if any additional research can enhance our understanding of the impact of volcanic ash on aviation so that we can ensure that our reaction to future situations is based on sound data and information.

With that, I want to again welcome our witnesses.

[The prepared statement of Ms. Giffords follows:]

PREPARED STATEMENT OF CHAIRWOMAN GABRIELLE GIFFORDS

Good morning, it's a pleasure to welcome you to today's Subcommittee hearing. We have an impressive panel of experts appearing before us this morning, and I look forward to a good discussion.

Today's hearing is timely. As you know, the eruption of the volcano in Iceland forced the closure of European airspace, paralyzing air travel for six days. Hundreds of thousands of passengers around the world—including many Americans—were stranded and airline revenue losses may reach at least $1.7 billion.

While the ink has yet to dry on that episode, one thing is clear:

Aviation regulators have insufficient scientific data to establish (1) at what level of volcanic ash contamination air travel is safe; (2) where ash clouds are and how concentrated they are on a real-time basis; and (3) the extent of damage, both immediate and long-term, that volcanic ash inflicts on aircraft and particularly on their engines.

Moreover, the dangers to aircraft and passengers are not hypothetical—as our witnesses will testify.

For example, in 1982, after flying through an ash cloud, a British Airways Boeing 747 near Jakarta, Indonesia lost all four of its engines as they choked on the ash and flamed out. Ash was reported to have filled the cabin through air vents and the cockpit window was severely scratched.

Also in 1982—one month after the British Airways incident—a Singapore Airlines Boeing 747 lost two of its four engines and was forced to land in Jakarta because of an ash encounter.

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Most importantly, I would like to find out if additional research can enhance our understanding of the impact of volcanic ash on aviation so that we can ensure that our reaction to future situations is based on sound data and information.

With that, I again want to welcome our witnesses, and I now will yield to Mr. Olson for any opening remarks he would care to make.

Chairwoman GIFFORDS. And now I yield to Mr. Olson for any opening remarks that he would like to make.

Mr. OLSON. Madam Chairwoman, thank you for calling this morning's hearing. I greatly appreciate that.

I would like to thank our witnesses for your appearance today. I appreciate your expertise and your willingness to share your perspective with us on this very important issue of how our air traffic management system can best respond to volcanic eruptions and whether any additional research is needed to improve safety and system performance.

The recent volcanic eruption in Iceland was a powerful example of the interconnected world we live in today. Travelers brace for almost anything but delays due to the eruption of an Iceland volcano is not something many would have predicted when they drove to the airport that day.

As a pilot myself, I am very interested to learn what we know of the impact volcanic ash has on aircraft. I am also eager to learn how our air traffic system weighs the known and unknown risks associated with volcanic ash, how our system responds when confronted with such a circumstance, and coupling that knowledge with the desire of thousands of travelers wanting to get to their destinations and airlines eager to get them there.

Post 9/11, the world has been vigilant to prevent the disruption of air travel as we saw on that day, but who could have imagined the second biggest disruption since that day would have been caused by a volcano in Iceland?

That leads to another topic that we need to discuss today: What is the appropriate level of funding we should invest in research and development on events or circumstances that would be classified as rare or highly unlikely? It is easy to imagine that prior to the Iceland volcano erupting, many experts would have likely argued that funding additional research on issues related to the impact of volcanic ash on airplanes, it would be a low priority. Some might even say a waste of money. But events of the previous month may now cause many to reconsider.

Are there other calamities like this that are rare but highly disruptive that we should be researching? These questions are difficult and frankly might be impossible to answer but learning from this situation will help us going forward, and for that I am pleased we are having today's hearing.

Thank you much for coming. I yield back my time, Madam Chairwoman.

[The prepared statement of Mr. Olson follows:]

PREPARED STATEMENT OF REPRESENTATIVE PETE OLSON

Madam Chairwoman, thank you for calling this morning's hearing. I'd like to thank our witnesses for their appearance today. I appreciate your expertise and willingness to share your perspective with us on the very important issue of how our air traffic management system can best respond to volcanic eruptions and whether any additional research is needed to improve safety and system performance.

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Post 9–11, the world has been vigilant to prevent the disruption of air travel as we saw on that day. But who could have imagined the second biggest disruption since that day would have been caused by a volcano in Iceland.

That leads to another topic we need to discuss here today. What is the appropriate level of funding we should invest in research and development on events or circumstances that would be classified as rare or unlikely? It is easy to imagine that prior to the Iceland volcano erupting, many experts would likely have argued that funding additional research on issues related to the impact of volcanic ash on airplanes would be a low priority. Events of the previous month may now cause many to reconsider. Are there other calamities like this that are rare but highly disruptive that we should be researching? These questions are difficult, and frankly might be impossible to answer, but learning from this situation will help us going forward and for that I am pleased we are having today's hearing.

I thank you and yield back the balance of my time.

Chairwoman GIFFORDS. Thank you, Mr. Olson.

If there are members who wish to submit additional opening statements, your statements will be submitted for the record.

At this time I would like to introduce our witnesses. First up, we have Dr. Tony Strazisar, who will be representing Dr. Jaiwon Shin of NASA's Aeronautics Research Mission Directorate. Dr. Shin unfortunately can't be here with us today but we wish him the best. We understand that he is under the weather, but Dr. Strazisar is a senior technical advisor for the Aeronautics Research Mission Directorate at NASA. Welcome. We also have Dr. Jack Kaye, who is a member of the Earth Science Division at NASA. Good morning. Ms. Victoria Cox, who is a Senior Vice President of NextGen and Operations Planning in Air Traffic Organization at FAA. Good morning. Also, Captain Linda Orlady, who is the Executive Air Safety Vice Chair of the Air Line Pilots Association. We are very glad that you are with us this morning, Captain. And finally we have Mr. Roger Dinius, who is the Flight Safety Director at GE Aviation. Again, welcome.

Our witnesses should know that you will each have five minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you have completed all of your spoken testimony, we will begin with our first round of questions, and each member will have five minutes to ask questions. So we are going to begin this morning with Dr. Tony Strazisar.

STATEMENT OF DR. TONY STRAZISAR, SENIOR TECHNICAL ADVISOR, AERONAUTICS RESEARCH MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. STRAZISAR. Madam Chair Giffords, Ranking Member Olson and members of the Subcommittee, thank you for the opportunity to appear before you today. I am here to discuss NASA's past experiences related to the impact of volcanic ash on aircraft systems and operations and some past and current research activities conducted by NASA and the aviation community that could be relevant to the issue.

The International Air Transport Association reported that the recent eruption of Iceland's volcano cost the world's airlines at least $1.7 billion and affected as many as 1.2 million passengers a day. Many Americans were directly or indirectly impacted by this stoppage. Certainly there will be a significant assessment of this issue by the global aviation community in the coming months and years.

Detecting, monitoring and understanding volcanic ash clouds and their composition are critical first steps in addressing this issue, and my colleague, Jack Kaye from NASA's Science Mission Directorate, is discussing this issue with the subcommittee today.

Encounters with volcanic ash are known to have detrimental effects on modern turbine engines. Particulate erosion testing is not a part of commercial engine certification testing. Therefore, today's engines are not certified for volcanic ash ingestion. Engine manufacturers are currently the best source of information regarding the impact of volcanic ash on their engines and various conditions. To be safe, the current established practice is to avoid flight operations in the vicinity of known volcanic debris. As a result, volcanic ash ingestion is not a leading cause of aircraft safety accidents or issues. In fact, they are quite rare. There have been no known or reported aircraft fatalities as a result of flying through volcanic ash. Nonetheless, there are several documented cases of aircraft experiencing engine shutdowns and/or costly damage as a result of unintended encounters.

NASA's understanding of the effects of aircraft flying through volcanic ash clouds comes from its evaluation of an unplanned inflight encounter. Early on the morning of February 28, 2000, a NASA DC–8 airplane, a highly instrumented research platform for conducting atmospheric science research, inadvertently flew through the fringe of a diffuse volcanic ash cloud produced by the Mount Hekla volcano in Iceland. This encounter lasted approximately 7 minutes and occurred in total darkness during a ferry flight from Edwards, California, to Kiruna, Sweden. During this flight, scientists on board the DC–8 monitoring sensitive research instruments reported a sudden increase in sulfur dioxide measurements that indicated the presence of a volcanic ash cloud. Except for the reports from the onboard science team, the DC–8 crew had no indication they were flying through the plume from Mount Hekla. After the airplane returned to Edwards Air Force Base, all four engines were sent to the General Electric Strouther overhaul facility, where they were disassembled and refurbished. Detailed engine inspection revealed that even though this was a brief flight through a diffuse ash cloud, the exposure was long enough and engine temperatures were high enough that engine hot section blades and vanes were coated and cooling air passages were partially or completely blocked.

NASA does not have any ongoing research efforts that are focused on the understanding of the impact of volcanic ash on aircraft engines, mainly because the volcanic ash encounters are very rare events and have been consistently placed at a very low priority for research needs by the aviation community. While NASA aeronautics research has not directly addressed impacts of volcanic ash on aviation, it is possible that some past and current research activities conducted by NASA and the aviation community could be of value to industry and airspace regulators as they seek to better understand the impact of volcanic ash and devise strategies for addressing similar situations in the future.

Making the best possible use of available airports and airspace is critical to sustaining limited service during and recovering from a major disruption such as occurred last month. NASA-developed analysis tools can simulate air traffic scenario, evaluate outcomes and support decisions made by air traffic managers and airline operators.

Past research in dealing with severe weather has shown that even the most daunting scenarios provide limited yet workable operational solutions. Better plume measurements and propagation forecasts and operational procedures together could contribute to air traffic management solutions to the problem of volcanic ash.

Since there are so many factors that contribute to the severity of damage from volcanic ash, it is likely that even a robust research effort will lead to engines that are tolerant of significant amounts of ash ingestion. However, NASA research on integrated propulsion and control systems and robust engine control could have potential applicability in mitigating hazards associated with volcanic ash.

Current research regarding effective interaction or monitoring methods for the crew under degraded engine operating conditions could be applied in instances where those circumstances are due to volcanic ash. NASA aeronautics will continue to make available our expertise and knowledge in these areas to other Federal agencies and the broader aviation community as they assess plans for national and global flight operations in these conditions.

Thank you for your attention.

[The prepared statement of Dr. Strazisar follows:]

PREPARED STATEMENT OF TONY STRAZISAR

Madam Chair Giffords, Ranking member Olson, and Members of the Subcommittee, thank you for the opportunity to appear before you today. I am here to discuss NASA's past experiences related to the impact of volcanic ash on aircraft systems and operations, and some past and current research activities conducted by NASA and the aviation community which could be relevant to this issue.

Airlines thrive on reliability and predictability, as witnessed by their published "on-time departure" metrics. As we have recently learned, volcanic eruptions, and specifically, the dispersal ash clouds are beyond today's predictive capabilities, thus upsetting the reliability of airplane operations. In light of the great uncertainty of the location of volcanic ash, and the extreme hazard it presents to jet aircraft, airlines and air traffic managers take extraordinary precautions to avoid flying into these danger zones. In the case of the recent eruption of Iceland's Eyjafjallajokull volcano, the risk was deemed so great that the only prudent response was to ground all aircraft within the danger zone, which encompassed the United Kingdom and most of northern Europe. The problems associated with the eruption in Iceland were compounded by the fact that many of the impacted flights were the trans-Atlantic oceanic routes, where there is no continuous surveillance (such as radar) and the requirement for proximity to contingency landing sites presents a significant constraint to alternate routes.

The International Air Transport Association reported that the volcanic eruption cost the world's airlines at least $1.7 billion and affected as many as 1.2 million passengers a day. Many Americans were directly or indirectly impacted by this stoppage. Certainly there will be a significant assessment of this issue by the global aviation community in the coming months and years.

Detecting, monitoring and understanding volcanic ash clouds and their composition are critical first steps in addressing this issue. My colleague, Jack Kaye, from the NASA's Science Mission Directorate is discussing this issue with the Subcommittee at this hearing today.

Volcanic Ash and Aircraft

Encounters with volcanic ash are known to have detrimental effects on modern turbine engines. Particulate erosion testing is a part of some engine testing, but these tests are generally focused on abrasive materials such as sand, which have some material properties that have a different impact compared to volcanic ash. Therefore, today's engines are not certified for volcanic ash ingestion.

There has been some notable research on the impact on gas turbine engines of ingesting dust-laden air that was conducted by the Calspan Advanced Technology Center in the late 1980s and early 1990s under sponsorship of the Defense Nuclear Agency. The Calspan team tested several military gas turbine engines using volcanic ash to better understand the impacts of dust-laden air on engine operation. An important research result is that there are a number of factors that significantly impact the effect of a volcanic ash encounter, including engine type, operating conditions, constituents of the ash cloud, and ash concentrations. This research also identified several ways that ash can damage an engine including: melting of ash on components in the engine hot sections, erosion of components, blockage of cooling passages in turbines, and contamination of the oil or bleed air systems. This research also developed and validated various potential recovery strategies for addressing in-flight operational problems, depending upon the engine and conditions encountered.

The signs that an aircraft is in a volcanic ash condition are not always clear. Previous ground tests of engines by Calspan indicate that the warning signs of ash damage vary with engine type and that an ash encounter is often very difficult to discern from existing instrumentation until a serious problem like an engine surge or flame-out occurs.

Engine manufacturers currently are the best source of information regarding the impact of volcanic ash on their engines in various conditions. The Subcommittee will be hearing directly from industry sources about this subject at this hearing, including their experiences recently in facilitating the resumption of commercial operations in European airspace.

To be safe, the current established practice is to avoid flight operations in the vicinity of known volcanic airborne debris. As a result, volcanic ash ingestion is not a leading cause of aircraft safety accidents or issues—in fact they are quite rare. There have been no known or reported aircraft fatalities a result of flying through a volcanic ash cloud. Nonetheless, there are several documented cases of aircraft experiencing engine shutdowns and/or costly damage as a result of an unintended encounter.

NASA DC–8 Volcanic Ash Incident

NASA's understanding of the effects of aircraft flying through volcanic ash clouds comes from its evaluation of one unplanned in-flight encounter. This evaluation was enabled by the presence of an onboard science team and specialized instrumentation for unrelated airborne chemistry research. These findings and lessons were developed from volcanic ash plume and satellite trajectory analysis, analysis of ash particles collected in cabin air heat exchanger filters and removed from engines, and data from onboard instruments and engine conditions.

Early on the morning of February 28, 2000, the NASA DC–8 airplane, a highly instrumented research platform for conducting atmospheric science research, inadvertently flew through the fringe of a diffuse volcanic ash cloud produced by the Mt. Hekla volcano in Iceland. This encounter, which lasted approximately seven minutes, occurred in total darkness (no moonlight) during a ferry flight from Edwards, California to Kiruna, Sweden.

This particular encounter demonstrated the difficulty of predicting the location of the ash plume produced by a volcanic eruption. Thirty five hours after the eruption, the London Volcanic Ash Advisory Center (VAAC), using observatory inputs, satellite pictures, radar imagery and pilot reports, predicted the ash plume would be south of the proposed DC–8 track. However, to provide an additional margin of safety, the DC–8 flight path was adjusted an additional 200 miles north, with the expectation of totally avoiding any possibility of encountering the ash plume.

From this research mission, we have learned that a damaging encounter with volcanic ash can be undetectable, even to an alerted flight crew. During this flight, scientists onboard the DC–8 monitoring sensitive research instruments reported a sudden increase in sulfur dioxide (SO_2) measurements that indicated the presence of a volcanic ash cloud. Except for the reports from the on-board science team, the DC–8 crew had no indication they were flying through the plume from Mt. Hekla. In previous ash plume encounters by aircraft, the events were frequently accompanied by an odor in the cabin air, by changes in engine readings, by the frosting of windows, and at night, by the presence of St. Elmo's fire on forward-facing parts of the aircraft. NASA's DC–8 flight crew noted no change in cockpit readings, no St. Elmo's fire, no odor or smoke, and no change in engine instruments. They did notice that no stars were visible, but this is typical of flight through high cirrus clouds.

Since in-flight performance checks and detailed visual inspections after landing in Sweden revealed no damage to the airplane or engine first-stage fan blades, the research campaign was completed, and the airplane was ferried back to Edwards Air Force Base in California. More complex engine borescope inspections revealed clogged cooling passages and some heat distress in the high temperature section of the engines. One engine appeared to be more heavily damaged.

The DC–8 is powered by four General Electric CFM56–2 high bypass turbofan engines. All four engines were sent to the manufacturer's General Electric Strouther overhaul facility near Arkansas City, Kansas, where they were disassembled and refurbished. Their detailed engine inspection revealed that even though this was a brief flight through a diffuse ash cloud, the exposure was long enough and engine temperatures were high enough that engine hot section blades and vanes were coated and cooling air passages were partially or completely blocked. All engines exhibited a fine white powder coating throughout, leading edge erosion on high-pressure turbine vanes and blades, blocked cooling air holes, blistered coatings, and a buildup of fine ash inside passages. A blade with blocked cooling operates at a sufficiently higher temperature, significantly impacting blade life. Although engine trending did not reveal a problem, hot section parts may have begun to fail (through blade erosion) if flown another 100 hours, in contrast to the normal service life of thousands of hours. The engines were overhauled, at a total cost of $3.2 million.

Research That Could Benefit Future Situations

NASA does not have any ongoing research efforts that are focused on understanding the impact of volcanic ash on aircraft engines, mainly because the volcanic ash encounters are very rare events and have been consistently placed at a very low priority for research needs by the aviation community.

While NASA aeronautics research has not directly addressed impacts of volcanic ash on aviation, it is possible that some past and current research activities conducted by NASA and the aviation community could be of value to industry and airspace regulators as they seek to better understand the impact of volcanic ash and devise strategies for addressing similar situations in the future.

Operational procedures

Making the best possible use of available airports and airspace is critical to sustaining limited service during, and recovering from, a major disruption such as Eyjafjallajokull. NASA-developed analysis tools can simulate air traffic scenarios, evaluate outcomes, and support decisions made by air traffic managers and airline operators. There could be some applicability of these analysis tools to decision support tools for the oceanic flight realm, benefiting routine daily operations as well as recovering from system disruptions such as ash plumes.

Parallels exist between the problems presented by an ash plume and by severe convective weather: both form in an unpredictable manner, present a dynamically changing hazard to aviation, and require coordinated modification of flight routes. The aviation community has made a large, sustained investment in technology development to address convective weather, resulting in sensors, models, and tools that have significantly improved the ability to keep people and aircraft safely moving when subjected to adverse weather conditions. Past research in dealing with severe weather has shown that even the most daunting scenarios provide limited yet workable operational solutions.

Better plume measurements and propagation forecasts and operational procedures together could contribute to air traffic management solutions to the problem of volcanic ash. Tracts of useable airspace could be identified to build routes that can be used to maximize traffic throughput in constrained airspace. Fleet management options could be assessed to quantify the advantages and impacts of different strategies. For example, corridors-in-the-sky that use the available airspace could be developed and dynamically updated based on the prevailing wind and plume conditions. Based on the traffic demands, additional reroutes could be developed as appropriate.

Sharing information about hazards

NASA is developing new display concepts to intuitively convey new information sets available to pilots. One such concept could improve the current Notices to Airmen (NOTAM) system. Current NOTAMs of changes to flight conditions are not instantaneous. Expeditious datalink of NOTAMs with an appropriate display and notification could shorten this to seconds to minutes of when such events occur. NOTAMs related to volcanic ash activity are called ASHTAMs by the International Civil Aviation Organization (ICAO), and are regularly released when such events occur across the globe. However, such information today is very coarse and delayed, and is therefore open to misinterpretation. Improvements in display concepts, while not developed to specifically address the issue of hazardous ash conditions, could enable the provision much more detailed ash information along with real-time updates as they become available through air traffic service providers.

NASA also has available data mining tools that might be of use to industry and regulators to make sense of data resulting from recent operational experiences or future tests.

Engine technologies

Since there are so many factors that contribute to the severity of damage from volcanic ash, it is unlikely that even a robust research effort will lead to engines that are tolerant of significant amounts of ash ingestion. However, some NASA research in novel materials may have an effect of mitigating some of the negative effects from ash ingestion. For example, ceramic matrix composite turbine blades may need fewer cooling channels which would make them less susceptible to degraded cooling performance due to clogging. These materials may also have better damage tolerance qualities. Similarly, research in engine monitoring and instrumentation might also have applicability in this circumstance.

In the 1990s, NASA conducted flight research to examine deteriorated engine operation and performance (the Dryden Performance Seeking Control research project). Extrapolating from that experience, NASA research on integrated propulsion and control systems and robust engine control (i.e. controller design and possible modification of actuators to extend engine operating life) could have some potential applicability in mitigating the hazards associated with volcanic ash. Current research regarding effective interaction or monitoring methods for the crew under degraded engine operating conditions could be applied in instances where those circumstances are due to volcanic ash.

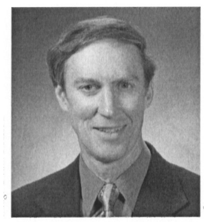
Conclusion

NASA Aeronautics will continue to make available our expertise and knowledge in these areas to other Federal agencies and the broader aviation community as they assess plans for national and global flight operations in these conditions.

BIOGRAPHY FOR TONY STRAZISAR

National Aeronautics and Space Administration

Biography



Dr. Tony Strazisar
Senior Technical Advisor

Strazisar is the senior technical advisor for the Aeronautics Research Mission Directorate. His responsibilities include supporting the associate administrator and aeronautics program leadership in the development of new technologies and programs to meet national needs. He oversees the directorate's Small Business Innovation Research investments and NASA Research Announcements, which provide aeronautics research funding opportunities to industry and academia.

Strazisar is also the chief scientist of the NASA-Glenn Research Center, a position he has held since 2003. In that capacity he advises the center director and senior staff on scientific and basic research issues related to the center's programs and the technical excellence of the staff.

Strazisar joined the staff of the then NASA-Lewis Research Center in 1976. His early work focused on the development and application of laser-based measurement techniques in high-speed rotating components of jet aircraft engines. Measurements acquired by research teams organized by Strazisar have been used throughout the world to improve the accuracy of computer-based design systems for aircraft engine components. From 1994-2004 his work focused on methods of improving the efficiency and the safe operating range of aircraft gas turbine engines. He has written 35 technical papers.

He is a fellow of the American Society of Mechanical Engineers. Honors and awards include the American Institute of Aeronautics and Astronautics' Airbreathing Propulsion Award, the Presidential Rank Awards of Meritorious Career Executive and Distinguished Career Executive, and the NASA Engineering Achievement Medal.

Strazisar holds bachelor's, master's and doctor of engineering degrees from Case Western University.

Chairwoman GIFFORDS. Thank you, Dr. Strazisar.

Dr. Kaye, please.

STATEMENT OF DR. JACK A. KAYE, EARTH SCIENCE DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. KAYE. Good morning, Chairwoman Giffords, Ranking Member Olson and members of the Subcommittee. I appreciate having the opportunity to appear before you today to discuss NASA's earth science-related activities to observe and carry out scientific research of volcanic ash clouds.

The recent eruption of Eyjafjallajökull highlights the different types of contributions that NASA's Earth Science program makes to the study of and response to such events. Through its fleet of 13 major earth-observing missions, NASA is able to rapidly generate and broadly disseminate imagery and data products on the locations, heights and densities of ash plumes and related hazards. These data products fuel a range of research investigations which enhance our knowledge of solid earth processes, atmospheric transporting composition and the impacts that volcanic eruption have on the earth system. NASA is also able to, and did, provide critical data streams from these research satellites to the National Oceanic and Atmospheric Administration to support that agency's operational prediction of ash plumes.

Although NASA does not have operational responsibility for observation and analysis of volcanic gas and aerosol emissions, its fleet of research spacecraft provides data that are directly applicable to the societal hazards presented by these phenomena. NASA has been using its research satellites to study volcanic eruptions, especially their atmospheric impact, for more than 3 decades.

Several of the research satellite missions that NASA is currently developing will be able to provide new and advanced insights into volcanic ash cloud properties. Missions that will be able to study the presence of aerosols in the atmosphere include Glory, scheduled for launch later this year, NPP, scheduled for launch in 2011, and tier 2 missions from the decadal survey, GEO–CAPE and ACE. NPP will help to track volcanic ash clouds using sulfur dioxide observations. Two other decadal survey missions will also support this effort. The DESDynI mission will improve the determination of the likelihood of volcanic eruptions and document posteruption changes while the HyspIRI mission will be able to detect volcanic eruptions and determine the ash content of volcanic plumes.

In addition to providing measurements and information to aid decision makers in responding to the volcanic events and its aftermath, these data from NASA's research satellites are being utilized in several ongoing NASA-sponsored scientific studies of solid earth processes, atmospheric composition and air quality, earth's radiation balance and aviation forecasting improvement methodologies within both NASA's Earth Science Division's Research and Analysis program and its Applied Sciences program. For example, over the past several years the project competitively funded through the Applied Sciences program demonstrated reliable and accurate detection of volcanic ash clouds using observations of sulfur dioxide from the ozone monitoring instrument on board NASA's Aura satellite.

Since volcanic eruptions are essentially the only variable sources of SO_2 large enough to be observed by satellites, false alarms are nonexistent. Satellite observations of sulfur dioxide thus assist operational agencies in identifying and locating volcanic ash clouds, in particular during the first few days after an eruption.

NASA, in collaboration with NOAA, provides near real-time information on volcanic sulfur dioxide and ash aerosols from the OMI instrument. NOAA provides this information to its U.S.-based volcanic ash advisory centers. The international network of these centers is charged with gathering information on the presence and motion of volcanic clouds and assessing any hazards to aviation. In April, NASA products were provided for the first time to the European volcanic ash advisory centers to assist in their decision making.

From a research perspective, NASA-developed global models can be used to simulate the emission of volcanic ash and sulfur dioxide into the atmosphere and to track its subsequent transport and dispersion on regional and global scales. NASA also routinely uses air particle trajectory modeling to estimate the source regions of features seen in satellite data that are suspected to have a volcanic origin. However, such model runs are generally undertaken after an eruption has taken place in order to advance scientific understanding, leading to improvements in the accuracy of the models.

At present, our understanding of solid earth processes and our ability to obtain adequate global measurements to initiate the models are both insufficient for generating routine, accurate predictions of volcanic ash plume range and composition. However, NASA efforts to improve observations will yield new and more refined data on various aspects of the plume including area, height, aerosol properties and associated sulfur dioxide which can be used to help critically evaluate current models and drive the improvement of such models in the future.

Thank you again for the opportunity to testify before you today. I look forward to answering your questions.

[The prepared statement of Mr. Kaye follows:]

PREPARED STATEMENT OF JACK KAYE

Good morning Chairwoman Giffords, Ranking Member Olson and Members of the Subcommittee. I appreciate the opportunity to appear before you today to discuss the National Aeronautics and Space Administration's (NASA's) Earth Science-related activities to monitor and study volcanic ash clouds. The recent eruption of Eyjafjallajökull highlights the different types of contributions that NASA Earth Science makes to the study of, and response to, such events. Through its fleet of satellite assets, NASA is able to rapidly generate and broadly disseminate imagery and data products on the location, heights, and densities of ash plumes and related hazards. These data products fuel a range of research investigations which enhance our knowledge of solid Earth processes, atmospheric transport and composition, and the impacts that volcanic eruptions have on the Earth system. NASA is also able to—and did—provide critical data streams from these research satellites to the National Oceanic and Atmospheric Administration (NOAA) to support that agency's operational prediction of dust plumes. In response to the intense public interest in this event, NASA has conducted focused public outreach activities regarding our research capabilities and science activities in the areas of volcano research and hazard prediction. Although NASA does not have operational responsibility for observation and analysis of volcanic gas and aerosol emissions, its fleet of research spacecraft provides data that are directly applicable to the societal hazards presented by these phenomena.

NASA has been using research satellites to study volcanic eruptions, especially their atmospheric impact, for more than three decades. NASA pioneered such activities using the Total Ozone Mapping Spectrometer (TOMS) instrument flying aboard the Nimbus 7 satellite launched in 1978. The record for the Nimbus 7 TOMS and the flight of successor TOMS instruments on other missions covers the years 1978–2003 and includes observations of a total of 274 eruptive events from 70 different volcanoes (see *http://toms.umbc.edu/*). Starting in 2004 and extending to the present, key successor measurements are provided by the Ozone Monitoring Instrument (OMI) flying aboard NASA's Aura spacecraft.

Information on atmospheric composition in the TOMS/OMI data is based on measurements of ultraviolet radiation; however, this is only one of the ways in which NASA uses its satellites to study the atmospheric impact of volcanic eruptions. NASA's currently operating fleet of 13 satellite missions is being used to generate several data products which provide complementary information on volcanic effects on the atmosphere through measurements obtained from different wavelength regions, viewing geometries, and employing a variety of remote sensing technologies. These products provide information not only on the location of ash clouds and sulfur dioxide (SO_2) injected into the atmosphere, but on the height, size, and composition of the particles. Such data are critically important for the initialization and evaluation of the models that are used to predict the evolution of the gas and ash plumes associated with volcanic eruptions, as well as for direct guidance as to the location and severity of ash plumes.

Monitoring Eyjafjallajökull Using NASA Assets

NASA's satellites have observed the ash plume since the eruption of Eyjafjallajökull, providing essential data on the size and composition of the plume as it expanded and moved over Europe. For example, data acquired by the Multi-angle Imaging SpectroRadiometer (MISR), one of the instruments on NASA's TERRA spacecraft (launched in 1999) provided information on both the horizontal and vertical extents of the plume. The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the Terra and Aqua (launched in 2002) satellites captured images of the eruption; the multiple wavelength measurements provided by the MODIS instruments aid researchers in separating ash plumes from clouds in the imagery. Information on the height of the ash plume was also provided by MODIS. NASA was able to validate the Terra and Aqua ash plume height observations using data from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite, launched in 2006. CALIPSO's active remote sensing (lidar) approach not only detects aerosols (small particles such as dust, smoke and pollution) and thin clouds that are often invisible to radar, but determines their heights and vertical concentration profiles. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument, also onboard Terra, is able to detect and track lava flows, as well as ash and gas plumes, with high spatial resolution. For the Eyjafjallajökull eruption, additional thermal and visible images of the plume were captured using the Atmospheric Infrared Sounder (AIRS) instrument on Aqua and the Hyperion instrument on Earth Observing-1 (EO–I), launched in 2000. The data and images are archived and available from the NASA Earth Observing System Distributed Active Archive Center. Select imagery can be accessed at: *http://earthobservatory.nasa.gov/NaturalHazards/event.php?id=43253*.

In addition to providing measurements and information to aid decision-makers in responding to the volcanic event and its aftermath, these data from NASA's research satellites are being utilized in several ongoing NASA-sponsored scientific studies of solid Earth processes, atmospheric composition and air quality, Earth's radiation balance, and aviation forecasting improvement methodologies within NASA's Earth Science Division's Research and Analysis (R&A) and Applied Sciences programs.

For example, over the past several years a project competitively funded through NASA's Applied Sciences Program demonstrated reliable and accurate detection of volcanic ash clouds using observations of sulfur dioxide (SO_2) from the Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite. SO_2 is a reliable marker for fresh ash clouds from explosive magmatic eruptions as it provides a clear discrimination between volcanic plume and ordinary clouds. Since volcanic eruptions are essentially the only large sources of stratospheric SO_2, false alarms are non-existent. Satellite observations of SO_2 thus assist operational agencies to identify and locate volcanic ash clouds, in particular during the first few days after an eruption. In general the ash in a volcanic plume will drop due to gravity effects faster than the SO_2, so that some distance away from the volcano the ash and SO_2 clouds may be separated. Details of how this Applied Sciences work is now being used in an operational regime are presented in the next section.

Collaboration with U.S. and International Organization to Monitor Volcanic Ash Plumes

NASA works with other agencies to ensure that data from NASA's research satellites can be used to meet operational needs. For example, NASA, in collaboration with NOAA, provides information on volcanic sulfur dioxide (SO2) and ash aerosols from OMI aboard the Aura satellite every three hours after the data is acquired. This information is used to supplement data from NOAA's Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellite (POES) fleets. NOAA distributes these data on-line to its Volcanic Ash Advisory Centers (VAACs) at: *http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html*. Nine VAACs were founded in 1995 as a part of an international system set up by the International Civil Aviation Organization (ICAO) called the International Airways Volcano Watch (IAVW). The VAACs are charged with gathering information on the presence and motion of volcanic clouds and assessing any hazards to aviation. They issue advisories and alerts to airline and air traffic control organizations on the possible danger of volcanic clouds. VAACs assist the aviation community to utilize satellite data, pilot reports, and other sources of information to detect and track ash clouds, and to use trajectory and dispersion models to forecast the motion of ash plumes.

At the time of the latest eruption, SO_2 information was being made routinely available for sectors covering the Americas and the Pacific, through the Anchorage and Washington Volcanic Ash Advisory Centers (VAACs). However, beginning on April 19, 2010, NASA began to provide this information for sectors covering Iceland and Northwest Europe to the VAAC in London. This information is now being utilized in the formulation and validation of Volcanic Ash Advisories over Europe.

As an additional response to the eruption, the Support to Aviation Control Service (SACS), a support center for the European VAACs, is now directly linking to the Aura/OMI near-real time products (*http://sacs.aeronomie.be/*). The SACS SO_2 data and alert service delivers near-real time data derived from satellite measurements regarding SO_2 emissions possibly related to volcanic eruptions, and in case of exceptional SO_2 concentrations ("SO_2 events") can use the data to send out alerts by email to interested parties. When volcanic activity poses a hazard to aviation, the VAACs issue alerts to air traffic control and airline organizations to help them decide whether to reroute planes away from volcanic clouds. In the case of the Eyjafjallajökull eruption, the satellite measurements and products were also directly shared with Schiphol Airport (Amsterdam) and the Netherlands Ministry of Traffic Affairs through the OMI Principal Investigator at the Royal Netherlands Meteorological Institute.

Future NASA Assets With Volcanic Ash Monitoring Applications

Several of the research satellite missions that NASA is currently developing will be able to provide new and advanced insights into volcanic ash cloud properties.

Later this year, NASA will launch the Glory mission to study the Earth's energy budget and the presence of aerosols in the atmosphere. Glory will be able to distinguish various species of aerosols, information which will advance the study of volcanic effluent composition.

In 2011, NASA is scheduled to launch the NPOESS Preparatory Project (NPP). The Visible/Infrared Imager Radiometer Suite (VIIRS) instrument on NPP is designed as an operational follow-on to the research-grade MODIS instrument on Terra and Aqua. The Ozone Mapping and Profiler Suite (OMPS) on NPP will provide data that to continue support for the detection of volcanic ash clouds using SO_2 observations, currently performed by Aura/OMI. Operational availability of VIIRS data will continue on the Joint Polar Satellite System, scheduled for launch in 2015.

The 2007 National Research Council (NRC) Decadal Survey recommended several missions that promise to advance future volcano research. The **Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI)** mission, a Tier 1 mission, has as a key mission objective to improve the determination of the likelihood of earthquakes, volcanic eruptions, and landslides. This will enhance our ability to anticipate future eruptions, whereas the response to the Eyjafjallajökull eruption was reactive. Likewise, the Tier 2 **Hyperspectral Infrared Imager (HyspIRI)** mission would include measurements over a range of optical and infrared wavelengths useful for detecting volcanic eruptions, determining the ash content of volcanic plumes, and identifying the occurrence and effects of associated landslides. The **Geostationary Coastal and Air Pollution Events (GEO–CAPE)** mission, also a Tier 2 mission, would measure aerosols and allow the tracking of pollutants being transported in the atmosphere. Similarly, data from the Tier 2 **Aerosol-Cloud-Ecosystems (ACE)** mission would be able to distinguish volcanic aerosols from other aerosol types and clouds, and will track the dispersion of volcanic plumes in three dimensions on a global basis.

Improvements to Volcanic Ash Plume Modeling

NASA-developed global models can be used to simulate the emission of volcanic ash and SO_2 into the atmosphere, and to track its subsequent transport and dispersion on regional and global scales. NASA also routinely uses air parcel trajectory modeling to estimate the source regions of features seen in satellite data that are suspected to have a volcanic origin. However, such model runs are generally undertaken after an eruption has taken place in order to advance scientific understanding, leading to improvements in the accuracy of the models. At present, our understanding of solid Earth processes and our ability to obtain adequate global measurements to initiate the models are both insufficient for generating routine, accurate predictions.

The mandate of NASA's Earth Science program is to increase scientific understanding of Earth processes as an integrated system. NASA thus does not produce routine, operational predictions of volcanic ash and SO_2 cloud transports and evolution. Because there is a lack of immediately available information on the quantity and characteristics of emissions from any particular volcano, any forecasts of ash and SO_2 emission and propagation are relatively crude. With the present "state of the art," estimates of SO_2 cloud transport and characteristics are based heavily on estimates of emitted SO_2, and while model results usually match well with observed cloud dispersion and distribution, they do not produce reliable estimates of SO_2 concentrations. At this time, air parcel trajectory models, in which columns of air parcels are initialized over erupting volcanoes at the time of the eruption and then tracked as the parcels are transported away from the volcano location by forecast wind fields, estimate the evolution of the ash cloud but do not consider important loss processes such as fallout, rainout, and washout, precluding a reliable forecast of ash cloud mass loading.

The Global Modeling and Assimilation Office at NASA Goddard Space Flight Center generates weather forecasts for the NASA research community, using the Goddard Earth Observing System—Version 5 (GEOS–5) Data Assimilation System. This system includes an aerosol model, Goddard Chemistry Aerosol Radiation and Transport (GOCART), as part of its routine twice-daily weather forecast. GOCART must be forced with appropriate emissions and produces 3-dimensional distributions of aerosols during the forecast period. At present, the GEOS–5 system includes an inventory of continuously outgassing volcanoes, but episodic volcanic eruptions are not included.

Routine forecasts of the propagation of volcanic ash and SO_2 clouds following an eruption using the GEOS–5 system would be possible given some modifications. More detailed observations of the constituents of the ejecta and their vertical distribution are required. Observations need to include information about the timing and duration of the eruptions, the injection altitudes as a function of time, and the particular characteristics of the emissions (amount, size, type). The information would need to be made available or converted to machine-readable data files with time of eruption, location, plume height and strength of the emission in terms of SO_2 and ash. The GOCART aerosol model would need to be modified explicitly to include a volcanic ash constituent. A third area of improvement is the development of statistical models of uncertainty useful to decision makers. For this, an ensemble forecasting technique would be necessary, spanning likely scenarios of ejecta and their vertical distribution as well as weather forecast uncertainty.

The London VAAC runs a version of the Numerical Atmospheric-dispersion Modeling Environment (NAME) model (*http://www.metoffice.gov.uk/aviation/vaac/eruption_detection.html*). The London VAAC has used the OMI aerosol index (AI) to validate their dispersion model output, although their main source of satellite data has been the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) infrared instrument on the European geostationary Meteosat Second Generation (MSG) satellite, which has better temporal resolution than the polar-orbiting OMI. However, their automatic system based on SEVIRI detects only about 2/3 of the eruptions. Using near real time ultraviolet data, such as OMI Aerosol Index and SO_2 (as an ash proxy) in addition to thermal infrared data could improve early (thick) volcanic plume detection, not visible in the infrared.

NASA recently began providing OMI near real time SO_2 and AI data to Operations Department of the European Centre for Medium Range Weather Forecasts (ECMWF) for evaluation in assimilation tests. The goal is to create an advanced operational data assimilation system that will: (1) reasonably model a volcanic plume (given the uncertainties in injection height, and composition of the plume); (2) assimilate available satellite near-real-time data to constrain the model forecast; and (3) provide forecasts for the VAACs.

It is important to note that the North American-Asia air traffic routes overfly the volcanic arcs of the North Pacific from Tokyo, Japan to Anchorage, Alaska. These are among the most violent and active volcanoes on Earth. The Washington and Anchorage VAACs, operated by NOAA, have a stellar record of tracking, monitoring and warning of volcanic ash dispersion. These VAACs run NOAA's HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. They utilize operational NOAA GOES and POES satellite data, NASA research observations, as well as data leveraged from European, Japanese, Indian, and other environmental satellites. The Washington and Anchorage VAACs' areas of responsibility extend from South America through the Caribbean and cover the continental United States, Alaska, and most of the Pacific.

Airborne Assets With Volcano-Monitoring Capabilities

Volcano remote sensing researchers have a strong need for *in situ* sampling of eruption plumes and drifting ash clouds to improve, calibrate and validate ash dispersal models. Airborne assets are uniquely qualified to measure the gas and ash content of volcanic plumes at altitude. However, sampling a volcanic plume is also a hazardous procedure given the dangers that volcanic-ash contamination poses to aircraft engines.

The United States maintains both research and operational airborne assets that could be used to monitor future eruptions. However, NASA's research aircraft and unmanned aerial vehicles are typically engaged in coordinated field campaigns investigating other science research questions, but could be diverted to a hotspot on an emergency basis. Such a decision would constitute an interruption to the baseline mission profile and would require at least a one week lead time in order to position the aircraft, instruments, and crew.

One such asset is NASA's ER–2 aircraft, which could be instrumented with the Cloud Physics Lidar (CPL) and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) in order to study atmospheric particles. In the future, NASA's new high-altitude, long-endurance, heavy-lift Global Hawk unmanned aerial system might also be utilized for volcanic plume monitoring. The Global Hawk is still in its development phase, so rapid response use will be limited for the next few years as NASA gains operational experience with the Global Hawk and integrates new instruments onto the platform.

Conclusion

As the Eyjafjallajökull eruption has shown, volcanic eruptions have a significant impact on the Earth's atmosphere and the planes that travel through that airspace. Although NASA does not have an operational requirement to monitor and predict volcanic ash plumes, existing and planned NASA assets provide essential data on volcanic emissions that can be used by operational agencies around the world to determine if there are hazards to aircraft. NASA's satellites and associated research programs have added significantly to our ability to observe not just the position of volcanic ash plumes, but to understand their composition, height, and properties. Through the NASA Applied Sciences Program, we can facilitate the use of the data collected by NASA's research satellites in operational regimes. NASA researchers are developing and improving models that can be used to predict how volcanic ash plumes will propagate. While there are still areas for improvement, NASA's Earth Science Division supports this work through new instruments and satellites and continued work in its Applied Sciences and Research Programs.

BIOGRAPHY FOR JACK KAYE

Jack Kaye currently serves as Associate Director for Research of the Earth Science Division (ESD) within NASA's Science Mission Directorate (SMD). He has been a member of the Senior Executive Service since August, 1999, managing NASA's Earth Science Research Program. Earlier positions in his more than 26 year career at NASA include being a Space Scientist at the Goddard Space Flight Center and Manager of the Atmospheric Chemistry Modeling and Analysis Program at NASA HQ. In addition, he has held temporary acting positions as Deputy Director of ESD and Deputy Chief Scientist for Earth Science within SMD. His academic training is in chemistry (B.S. Adelphi University, 1976; Ph.D., California Institute of Technology, 1982). He also held a post-doctoral research associateship at the U.S. Naval Research Laboratory. As Associate Director for Research, Dr. Kaye is responsible for the research and data analysis programs for Earth System Science, covering the broad spectrum of scientific disciplines that constitute it.

He represents NASA in many interagency and international activities and has been an active participant in the U.S. Global Change Research Program (USGCRP) in which he has served for several years as NASA principal and Vice Chair of the Subcommittee on Global Change Research (since Jan. 20, 2009 he has served as the Acting Chair for these activities). He also serves as NASA's representative to the Senior Users' Advisory Group for the National Polar Orbiting Operational Environmental Satellite System and to the Joint Subcommittee on Ocean Science and Technology. He is a member of the Steering Committee for the Global Climate Observing System and is an ex officio member of the National Research Council's Roundtable on Science and Technology for Sustainability. He has received numerous NASA awards (most recently, the Outstanding Leadership Medal in 2009), as well as been recognized as a Meritorious Executive in the Senior Executive Service in 2004. He was elected to serve as co-secretary of the Atmospheric Sciences Section of the American Geophysical Union (AGU) for 1998–2000 and earlier served on the AGU Publications Committee. The AGU has recognized him on two occasions with a Citation for Excellence in Refereeing. He has published more than 50 refereed papers, contributed to numerous reports, books, and encyclopedias, and edited the book *Isotope Effects in Gas-Phase Chemistry* for the American Chemical Society. In addition, he has attended the Leadership for Democratic Society program at the Federal Executive Institute and the Harvard Senior Managers in Government Program a the John F. Kennedy School of Government at Harvard University.

Chairwoman GIFFORDS. Thank you, Dr. Kaye. We appreciate your testimony. The volcano who normally goes unnamed, I appreciate your courage in attempting to pronounce the name correctly. I appreciate that. Welcome.

Ms. Cox, please.

STATEMENT OF VICTORIA COX, SENIOR VICE PRESIDENT, NEXTGEN AND OPERATIONS PLANNING, AIR TRAFFIC ORGANIZATION, FEDERAL AVIATION ADMINISTRATION

Ms. COX. Thank you, Chairwoman Giffords, Ranking Member Olson, members of the Subcommittee. Thank you for inviting me to testify today on mitigating the impact of volcanic ash clouds on aviation.

The FAA has dealt with the issue of volcanic ash clouds before, both from a research and an operational perspective, and we are happy to share this information with the Subcommittee.

Volcanic eruptions are not unusual. In fact, there is almost always an eruption somewhere in the world that may pose a hazard to international air navigation. What is rare are accidents and incidents resulting from encounters with volcanic ash. FAA's voluntary reporting databases show only five encounters and 20 complications due to volcanic ash since 2007. When compared to the thousands of aviation operations taking place in the national airspace system every day, this is indeed a small number.

The FAA's primary method of dealing with volcanic ash events is operator avoidance. Since the geographical location of areas that may be affected by volcanic ash is weather dependent, our model of managing air traffic when confronted with volcanic ash is to treat it much like a major weather event. That is, we gather the information from the reporting agencies and disseminate that information to the operators of aircraft. In turn, the operator makes the decision of go or no go. If the operator chooses to fly, then our air traffic controllers will direct the operator around volcanic ash to the best of our abilities.

Our past participation in volcanic ash research reflects this. Because the FAA is essentially a consumer of weather services that can help tell us where the volcanic ash will disperse, we have worked with the weather reporting agencies to develop weather products specifically for aviation use.

The European response to last month's volcanic eruption in Iceland was generally to close the airspace where volcanic ash could pose a threat to aviation safety. This may have been due to the constrained airspace over Europe that limited the possibility of reroutes as well as the need to coordinate the actions of the multiple civil aviation authorities in the various countries of the European Commission.

After the shutdown of airspace, European regulators were faced with the challenge of reopening their airspace, and the FAA was able to lend its expertise to our counterparts in Europe. FAA air traffic personnel also participated in daily telephone conferences with the United Kingdom's Civil Aviation Authority and the interdisciplinary group that they assembled. While we primarily offered information on our operator avoidance practices, we also helped to brainstorm operational solutions for reopening European airspace such as developing a collaborative volcanic ash forecasting process and developing pathfinder test flight traffic patterns between cities with low ash impact.

I know that this Committee is interested in how the Next Generation Air Transportation System, NextGen, may affect our current model of operator avoidance when confronted with volcanic ash. Because the issue is really based upon receiving the best information, NextGen will enable an improved information-sharing process. NextGen focuses on how to best put information in a format that can be used by pilots, controllers and dispatchers, and integrated into decision support tools.

Volcanic ash information is treated like significant weather information. Under NextGen, the NextGen Network Enabled Weather product enables the publication of the same weather information to all airspace users. The role of NOAA, the National Oceanic and Atmospheric Administration, is to provide quality data to all its users including data that meets the FAA's air traffic control requirements. The FAA integrates the information provided by NOAA into tools expressly for air traffic management. NextGen will help improve the quality and delivery of information to the FAA and aviation users, enabling all of us to make better informed operational decisions when confronted with adverse conditions such as volcanic ash.

Madam Chairwoman, Ranking Member Olson, members of the Subcommittee, this concludes my prepared remarks. Thank you again for inviting me here today to discuss the impact of volcanic ash on aviation operations. I would be happy to answer any questions you may have.

[The prepared statement of Ms. Cox follows:]

PREPARED STATEMENT OF VICTORIA COX

Chairwoman Giffords, Ranking Member Olson, Members of the Subcommittee: Thank you for inviting me to testify before you today on mitigating the impact of volcanic ash clouds on aviation. The Federal Aviation Administration (FAA) has dealt with the issue of volcanic ash clouds before, both from a research and an operational perspective, and we are happy to share this information with this Subcommittee.

Effects of Volcanic Ash on Aircraft

Volcanic ash is extremely damaging to aircraft. Should an aircraft encounter volcanic ash during flight, it could ingest the ash into the engines. If the volcanic ash passes through the turbine engines of an aircraft, the burner section can melt the ash, which then can deposit on the turbine's nozzles as a hard glaze. This can negatively affect the engine's operation and can result in a loss of power or total shutdown of the engine. When an engine loses power or shuts down due to turbine nozzle glazing, it will cool down rapidly. This can result in the fracturing of the volcanic ash glaze. Once the glazing breaks up and falls away, the engine may be able to resume normal operation.

There are additional negative effects of volcanic ash on an aircraft turbine engine. These may include erosion of compressor blades and rotor-path components as well as turbine cooling passages, contamination of the oil system and bleed air system, and plugging of the engine's inlet pitot static probes. These effects can cause severe and costly damage to an aircraft and its components.

FAA Volcanic Ash Response

While the severe impact of a major volcanic event such as we saw in Europe last month is extremely unusual, volcanic eruptions are not unusual. There is almost always an eruption somewhere in the world that may pose a concern to international air navigation. In certain parts of the United States, such as Alaska, volcanic eruptions are enough of a possibility that the FAA has developed an operational response.

FAA Orders 7900.5B and 7110.65T and JO 7930.2M Notice to Airmen (NOTAM) provide operational information regarding volcanic ash. The FAA's primary method of dealing with volcanic ash events is operator avoidance. Since the geographical location of areas that may be affected by volcanic ash is weather-dependent, our model of managing air traffic when confronted with volcanic ash is to treat it much like a major weather event. That is, we gather the information from the reporting agencies and disseminate that information to the operators of aircraft. In turn, the operator makes the decision to fly or not. If the operator chooses to fly, then our air traffic controllers will direct the operator around the volcanic ash to the best of our abilities.

As an additional safety precaution, on April 22, 2010, the FAA issued a Special Airworthiness Information Bulletin, NE–10–28, regarding turbine engine operation in volcanic ash airspace. The FAA noted that before flying from the United States to Europe or within Europe, aircraft owners and operators should review the following recommendations:

- Although the FAA does not recommend engine operation or flight into a visible volcanic ash cloud, we do recommend that aircraft owners and operators obtain definitive information on operational limitations around ash clouds, if any, from each of the European National Authority of the State(s), over which they plan flight operations.
- Follow all aircraft and engine manufacturer's operating and maintenance instructions pertaining to operations in airspace where volcanic ash may be near or present.
- Report any inadvertent encounter with volcanic ash or relevant findings, including abnormal engine behavior, to the respective type certificate holders of the aircraft and engines.

FAA Past Volcanic Ash Research Efforts

In the 1990s, the International Civil Aviation Organization (ICAO) established Volcanic Ash Advisory Centers (VAAC) that disseminate information worldwide on atmospheric volcanic ash clouds that may endanger aviation. There are nine VAACs located around the world run by local weather forecasting organizations. In the United States, the National Oceanic and Atmospheric Administration (NOAA) runs VAACs in Anchorage, Alaska and Washington, D.C.

In the past, the FAA has participated with other Federal agencies on developing a national plan for dealing with volcanic ash with regard to aviation operations. Under the auspices of the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), led by NOAA, the FAA helped develop the *National Volcanic Ash Operations Plan for Aviation*.

Because the FAA is essentially a consumer of weather services, we work with the weather-reporting agencies to develop weather products specifically for aviation use. Our role in that partnership is to set the requirements of what the weather products must provide in order to be useful for aviation users, whether they are air traffic controllers or pilots. Accordingly, our participation in the OFCM project was primarily to set the requirements for the development of volcanic ash information products for the FAA and aviation operators to use.

Aviation operations in volcanic ash situations rely on information based on detection and monitoring, alerting, modeling, and post event assessments. The U.S. Geological Survey (USGS) provides seismic monitoring for early detection and passes the information directly to the FAA to provide early warnings when an eruption is imminent or has occurred, which is especially important for en route aircraft. NOAA uses satellite monitoring as a core element in detection, tracking, and monitoring eruptions, and the resultant ash plume. Pilots also make observations, and the FAA disseminates pilot reports or PIREPS along with NOTAMs and Significant Meteorological Information (SIGMETs). SIGMETS originate from NOAA's National Weather Service.

Much of the capability to predict dispersion of volcanic ash clouds is based on mathematical modeling. The HY–SPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is the current model in use by NOAA and Australia's Bureau of Meteorology and its Darwin VAAC. Other, similar, models are used by other VAACs. Post assessment is carried out by the USGS, NOAA and the Smithsonian to determine how we can improve the services provided to industry and the FAA's air traffic management.

FAA Assistance in Response to Eyjafjallajokull Eruption

The European response to last month's volcanic eruption in Iceland was generally to close the airspace where volcanic ash could pose a threat to aviation safety. This was due in part to the constrained airspace over Europe and the need to coordinate the actions of the multiple civil aviation authorities of the various countries of the European Commission.

After the shutdown of airspace, European regulators were faced with the challenge of reopening their airspace, and the FAA was able to lend its expertise to our counterparts in Europe. FAA air traffic personnel also participated in a daily telephone conference with the United Kingdom's Civil Aviation Authority and the interdisciplinary group they assembled. While we primarily offered information on our operator avoidance practices, we also helped to brainstorm operational solutions for reopening European airspace such as developing a collaborative volcanic ash forecasting process and developing "pathfinder" test flight traffic patterns between cities with a low ash impact.

NextGen and Volcanic Ash

I know that this Committee is interested in how the Next Generation Air Transportation System (NextGen) may affect our current model of operator avoidance when confronted with volcanic ash. Because the issue is really based upon receiving the best information, NextGen will enable an improved information sharing process. NextGen focuses on how to best put information in a format that can be used by pilots, controllers, and dispatchers and integrated into decision support tools.

Volcanic ash information is treated like significant weather information. Under NextGen, the NextGen Network Enabled Weather (NNEW) product will enable the publication of the same weather information to all airspace users. NOAA's role will be to provide quality data to all its users including data that meets the FAA's air traffic control requirements. The FAA will integrate the information provided by NOAA into tools expressly for air traffic management. NextGen will help improve the quality and delivery of information to the FAA and aviation users, enabling all of us to make better informed operational decisions when confronted with adverse conditions such as volcanic ash.

Madame Chairwoman, Ranking Member Olson, Members of the Subcommittee, this concludes my prepared remarks. Thank you again for inviting me here today to discuss the impact of volcanic ash on aviation operations. I would be happy to answer any questions that you may have.

BIOGRAPHY FOR VICTORIA COX

As the Air Traffic Organization's Senior Vice President for NextGen and Operations Planning, Vicki Cox provides increased focus on the transformation of the nation's air traffic control system by providing systems engineering, research and technology development, and test and evaluation expertise. She is also responsible for the NextGen portfolio and its integration and implementation.

Within the FAA, Cox has served as the Director of the ATO's Operations Planning International Office, the Director of Flight Services Finance and Planning and the Program Director of the Aviation Research Division.

Prior to joining the FAA, Cox was Director of International Technology Programs in the Office of the Director of Defense Research and Engineering in the Office of the Secretary of Defense. She has an extensive research and development and program management background, having supported the Deputy Undersecretary of Defense for Science and Technology as the DOD Laboratory Liaison. She also worked as a Program Manager for a number of ballistic missile defense technology programs for the U.S. Air Force. A physicist, Cox served as Chief of Physics and Scientific Director of the European Office of Aerospace Research and Development in London. She also worked as a scientist responsible for thermal vacuum conditioning and testing of the Hubble Telescope for NASA.

Cox graduated from Converse College and received a Master's degree from East Carolina University. She has a certificate in U.S. National Security Policy from Georgetown University and is a DOD Level III Certified Acquisition Professional in Systems Planning, Research, Development and Engineering. She also earned her private pilot's license in 1985.

Chairwoman GIFFORDS. Thank you, Ms. Cox. We are glad you are here with us.

Captain Orlady.

STATEMENT OF CAPTAIN LINDA M. ORLADY, EXECUTIVE AIR SAFETY VICE CHAIR, AIR LINE PILOTS ASSOCIATION, INTERNATIONAL

Ms. ORLADY. Madam Chair, Ranking Member Olson, members of the Subcommittee, I am Captain Linda Orlady, Executive Air Safety Vice Chair of the Air Line Pilots Association International representing the safety interests of more than 53,000 professional pilots in the United States and Canada. On behalf of our members, I thank you for this opportunity to testify on volcanic ash and the risks it poses to aviation.

Fifty-five to 60 volcanic eruptions annually worldwide and resulting ash and gases reach altitudes routinely traveled by the airlines. As vividly demonstrated during the recent Icelandic eruption, ash cloud can drift for days, weeks, contaminate large areas of airspace. Flying in volcanic ash and gases poses a significant but little understood threat to the integrity of aircraft, its engines and to the health of its occupants.

Although no fatal airline accidents have been attributed to volcanic ash, damage to aircraft, potential damage to passengers and crew have been well documented. Two notable involved a British Airways 747 flight over Indonesia in 1982 and a KLM 747 flying over Alaska in 1989. Both of these aircraft lost power to all four engines during an inadvertent volcanic ash encounter. In each case, the pilots struggled to restart engines, handle other malfunctions and managed to safely land badly damaged aircraft. The encounters caused extensive damage to the engines, windshields and other aircraft systems. Documented volcanic ash encounters have revealed these vulnerabilities. Further study is required to fully understand our susceptibilities to volcanic ash and gas cloud contamination.

Additionally, volcanic gases pose serious health hazards to aircraft crew and passengers including breathing difficulties, headaches, itchy eyes. Volcanic gases can produce an acrid odor which may mislead a flight crew into thinking they have an electrical problem or might mask the presence of an actual electrical problem. Volcanic ash cloud gases are not displayed on cockpit radar nor on radar at air traffic control. They are extremely difficult to detect at night. Pilots must rely on information from dispatchers, other pilots to determine the location of these hazards. Coordinating and standardizing this information is further complicated by the number of different entities who supply it.

The recent Icelandic eruption demonstrated a lack of standardization between the various forecasts available to flight crews and dispatchers. As operations resumed in Europe, we received reports from pilots at different airlines who were given conflicting information in their dispatch release documents. In some cases, pilots had one depiction showing extensive air coverage while others showed nothing at all. While we have made progress in predicting where and when an eruption may occur, work must be done to improve forecasting and standardizing information about where and how an ash cloud will spread.

The recent air travel disruption demonstrated the benefit of having data to reliably and objectively define a specific hazard area, potentially allowing flights into some regions. However, we did not have scientifically reliable data to make that determination. Arrays of potential hazards cannot currently be defined in terms that flight crews can use for dispatching while airborne.

ALPA is encouraged the Senate version of the FAA reauthorization bill supports research on volcanic ash hazards. We urge Congress to enact this legislation. Without such research to improve the understanding of the hazards and ways to mitigate them, ALPA continues to advocate that the only safe course of action for flight crews is to avoid any encounter with volcanic ash. We need to determine if scientifically validated threshold levels developed with stakeholder participation can define an acceptable ash encounter. This determination must be based on rigorous, structured testing and produce reliable, scientifically quantifiable results. It will never be acceptable to hope for the best as we see how close we can fly to an ash cloud.

To continue operating in areas where there is a risk of flight into volcanic ash, ALPA believes we need several improvements. First, onboard systems to detect ash clouds concentrated volcanic gases which allow pilots enough time to identify potential hazards and sufficient time to provide for safe navigation around them. Secondly, more vigorous aircraft certification standards. Thirdly, new procedures and training programs for flight crews, dispatchers, mechanics and air traffic controllers.

As a rare but positive example, Alaska Airlines has developed volcanic ash training scenarios. They provide tools, techniques for both avoidance and recovery from inadvertent entry into volcanic ash and gas cloud conditions. Unfortunately, this type of comprehensive training is not universal for airlines operating in the vicinity of potential volcanic activity.

Thank you for the opportunity to testify on this important topic.

[The prepared statement of Captain Orlady follows:]

PREPARED STATEMENT OF LINDA ORLADY

Ms. Chairwoman and members of the Subcommittee, I am Captain Linda Orlady, Executive Air Safety Vice-Chair of the Air Line Pilots Association, International ("ALPA") which represents the safety interest of over 53,000 professional pilots at 38 airlines in the United States and Canada. On behalf of our members, I thank you for this opportunity to testify before you on the issue of volcanic ash and the risk it poses to aviation.

There are 1,500 known volcanoes around the world, and 600 (40%) of them are currently listed as active. Collectively, there are 55 to 60 volcanic eruptions annually, and the ash and gases propelled from these eruptions reach altitudes that are routinely traveled by the airlines. Flying in the presence of volcanic ash and gases poses a significant, but unfortunately little understood threat to the integrity of an aircraft, its engines, and to the health of all occupants onboard. Adding to these threats is the disturbing fact that volcanic ash clouds and gases are not displayed on either radar installed in the aircraft or on radar used by air traffic controllers. Furthermore, volcanic ash and gas conditions are extremely difficult to identify at night. When trying to avoid drifting ash clouds or gases, pilots must rely on forecasts from dispatchers, reports from air traffic controllers, or feedback from other pilots flying in the area to determine the location of these potential hazards. The coordination and standardization of this information is further complicated by the number of different entities who supply information to airlines and their crews.

The recent Icelandic eruption demonstrated quite clearly that there is a lack of standardization between the various forecasts available to flight crews and dispatchers. As operations resumed in Europe last week, we received several reports from crews at different airlines who were given conflicting information in their dispatch release documents. In some cases, crews had one depiction showing extensive ash coverage and yet another which showed nothing at all.

Although there have been no fatal commercial airline accidents attributed to volcanic ash, the occurrence of damage to aircraft and potential dangers to the passengers and crew have been well documented. The two most notable incidents involved a British Airways 747–200 flight over Indonesia in 1982 and a KLM 747–400 flying over Alaska in 1989. Both of these aircraft lost power to all four engines during an inadvertent volcanic ash encounter. In the case of the British Airways incident, all four engines lost power when the flight, operating in darkness, encountered a volcanic ash cloud invisible to them or the aircraft's weather radar. The crew declared an emergency as the airplane descended to about 12,000 ft where they were beneath the ash cloud but near mountainous terrain. They were able to restart three of the four engines but lost power to one of the three remaining engines when they again encountered ash while attempting to remain clear of the mountains! The crew was finally able to safely land the crippled airplane with only two of the four engines operating and with badly scratched windshields that impaired their visibility. Similarly, in the case of the KLM incident, the crew was able to restart the engines and safely land a crippled airplane, averting the loss of human life and a catastrophic aviation event. In both cases, there was extensive damage to the airplane engines, windshields, and environmental control systems. Documented volcanic ash encounters such as these have revealed the known vulnerabilities in current aircraft systems; however, as aircraft are constructed and equipped with newer technologies such as sophisticated electronic systems, we will need to study and understand those susceptibilities to volcanic ash contamination.

The flight safety risk associated with operations in the vicinity of volcanic ash clouds is not limited to just the vulnerability of the aircraft, engines, and the onboard systems. There is also a potential health hazard from the volcanic gases such as Sulfur Dioxide (SO_2) or Hydrogen Sulfide (H_2S). For example, SO_2 can cause breathing difficulties if inhaled at significantly high concentration levels. H_2S may cause headaches and itchy eyes. Indications that volcanic gases are present include an acrid odor similar to electrical smoke, which may mislead the crew into thinking they have an electrical problem and cause further distractions or, worse yet, mask the presence of an actual serious electrical problem. Prolonged exposure to H_2S may dull the sense of smell causing the flight crew to believe erroneously that they are clear of the gaseous environment.

Since the occurrence of the two near catastrophic events cited above, there has been an increased awareness in the airline community of the potential hazards of ash encounters. The improved availability of satellites coupled with technologies to transform satellite data into useful information along with improved coordination among international volcano monitoring facilities has helped to reduce the number of volcanic ash encounters worldwide. To date, ALPA along with the aviation industry has advocated for continued improvements in forecasting capabilities and dissemination of information to enable crews to safely avoid areas where there is a potential for a volcanic ash encounter. One outcome of this advocacy has been the creation of the Volcanic Ash Advisory Centers (VAAC), which is a network of nine facilities located worldwide. Each VAAC monitors the status of the active volcanoes within their assigned areas and disseminates information as needed to enable aircraft to safely avoid flying in hazardous volcanic ash conditions. ALPA continues to advocate for improved monitoring and forecasting capabilities but currently maintains the position, as is stated in the FAA Aeronautical Information Manual, to avoid any encounter with volcanic ash.

As vividly demonstrated during the recent eruption of the Eyjafjallajökull Volcano in Iceland, an ash cloud can drift for several days, travel thousands of miles, and envelop large areas of airspace. And while we have made progress in predicting where and when an eruption may occur, as previously stated, there is still work needed in forecasting and standardizing the information on where and how the resulting ash cloud will spread. The seismic activities and events leading up to the Eyjafjallajökull eruption were well monitored by the London-based VAAC, and as a consequence, flight crews had ample awareness of the imminent hazard and the possible need to re-route their flights accordingly. Unfortunately, the resulting ash cloud was so widespread that re-routing flights around European airspace to avoid potentially hazardous areas was not a viable option. European regulators, to their credit, recognized that in the absence of data demonstrating that safe flight was possible, the prudent course of action was to cease operations in the interest of safety. The disruption in air travel service cost billions of dollars to the industry and extreme inconvenience to the traveling public. The conservative approach taken by authorities—to put safety ahead of economic considerations—ensured that no lives were lost. However, the extent of the impact on worldwide operations demonstrated clearly that the strategy of circumventing an area of ash and gas is not necessarily a practical solution. Just as clearly, the situation demonstrated the benefit of having data to make it possible to reliably and objectively define a specific hazard area, potentially making it possible for flights to operate in some regions. The dilemma is that currently we do not have scientifically reliable and valid data which tells us how that might be accomplished. The areas of potential hazard cannot currently be defined in terms that are useable to flight crews both for dispatch and for use while airborne. Furthermore, the nature of potential damage to airframes and engines is not well understood. ALPA agrees that action is warranted to address future disruptions in service, however, as the economic impacts are assessed and mitigation strategies considered, the safety risk of flight operations in the vicinity of volcanic ash clouds cannot be compromised. ALPA is encouraged that the Senate version of the current FAA reauthorization bill contains language supporting the importance of research into volcanic ash hazards as well as other weather phenomena, and we urge the Congress to continue efforts to enact this legislation. Without such research to improve understanding of the hazards and ways to mitigate them, ALPA continues to advocate that the only safe course of action is for flight crews to avoid any encounter with volcanic ash.

If in the future, flight crews are allowed to fly in areas where there is a potential to encounter volcanic ash or gas concentrations, then any acceptable threshold established for safe operations within this environment must be based upon credible scientific data, analysis, and sound verification processes. New technologies will be needed to ensure all associated hazards within the allowable pre-established threshold are anticipated for and can be detected, measured, and safely mitigated by the flight crew prior to any encounter.

Anticipate the hazard: Better forecasting methods and information dissemination will be needed to enable crews to plan for and to implement, if necessary, safe exit strategies in the event of a volcanic ash encounter that exceeds the pre-determined limits of the airplane. As noted earlier, the current products available to flight crews vary widely in their interpretation of available data. These products must be standardized so that flight crews operating in an area, dispatchers on the ground, and air traffic controllers have a common understanding of where the threats areas may be and what mitigations may be possible. In addition, flight crew training programs must accommodate scenarios designed to help crews understand when volcanic effects are a potential hazard, how to recognize and cope with those effects, and how to develop effective exit strategies. This challenge is particularly true for carriers whose typical route structure involves flight in areas of known volcanic activity. Alaska Airlines, for example, has developed extensive classroom and scenario-based simulator training that provides crews with effective tools and techniques that can be used in the event of inadvertent airborne ash cloud exposure. In this training, pilots face a full range of hazards, both to the aircraft and to its occupants, and develop strategies for successfully recovering from such an emergency. More importantly, awareness of and simulated exposure to ash and gas clouds underscores the need for avoidance of these hazards. This type of comprehensive training, however, is not universal for airlines that may operate in the vicinity of volcanic activity. Detailed study of the effects of ash and gas on aircrews and airplanes must be undertaken and this information must be incorporated in training programs for crews operating in potential threat areas.

Detect & Measure the hazard: Currently, ATC and aircraft radars do not distinguish ash clouds from other weather related clouds. Crews may not realize they have entered a hazardous volcanic ash situation until they are already in it. By that time damage may have already occurred to the airplane engines and/or other flight systems. Forward looking systems are needed to detect an ash cloud and gases ahead of the airplane at sufficient distances to allow adequate time for the crew to safely divert around an unacceptable hazard. The forward looking system will also need to measure vital characteristics of the volcanic cloud, such as density and hazardous gas levels, to enable the crews to evaluate the hazard relative to pre-determined threshold levels and decide if it safe to proceed through an area of concern or to divert. Aircraft certification requirements will need to be updated to provide for more ruggedized aircraft health monitoring systems and management processes. Both flight and maintenance crews will need to know and act accordingly if an aircraft engine or other vital component has been damaged or has deteriorated at an accelerated rate that would compromise the continued safety of flight. Finally, we need to understand if any encounter with ash might be considered acceptable. This understanding must be based on rigorous, structured testing and produce reliable and scientifically quantifiable results. It will never be acceptable to simply see how close to an ash cloud we can fly and hope for the best.

Mitigate the hazard: Regarding the establishment of an acceptable threshold for flight near or into known volcanic ash or gaseous conditions, there are important and applicable lessons learned from the regulatory and operational experiences that have enabled allowable flight into known icing conditions. Extensive wind tunnel research, studies, and flight testing has been done over many years to assess and certify the safety of flight into icing. Though flight into known icing conditions is allowed and can be safely conducted under certain conditions and with specific aircraft anti-icing and de-icing equipment and appropriately trained crews, icing-related accidents and incidents still remain an important flight safety issue in the airline community. As we have learned with icing, mitigating the risk of flight into acceptable volcanic cloud conditions will not be a quick process but evolutionary as we learn more about the nature of the hazards. As testing, research, and development mature enough to establish initial acceptable threshold levels and to identify the required equipment changes, new procedures will also be needed.

Government and industry must work together to develop consistent regulatory and operational guidance and training plans to ensure the new technologies and information is properly transitioned to the primary users such as airline dispatchers, air traffic controllers, mechanics, and pilots.

In conclusion, we have made good progress over the past several years in monitoring worldwide volcanic activity and alerting the affected aviation community of an imminent eruption. However once an eruption has occurred, there is still work needed to better forecast and standardize information so that hazards associated with drifting volcanic ash clouds and gases can be safely avoided in flight. ALPA currently maintains that flights into volcanic ash environments are to be completely avoided. There is a significant amount of research and coordination needed to fully understand the hazards, vulnerabilities, and mitigation strategies to ensure safety is not compromised before we would support the dispatch and operation of aircraft into areas of known volcanic ash, even with a pre-determined threshold level considered to be safe.

Thank you again, for the opportunity to testify on this important subject.

Biography for Linda Orlady

Captain Linda Orlady presently holds two positions for the Air Line Pilots Association, International (ALPA). She was appointed as the Executive Air Safety Vice-Chair in January, 2009 and serves as the Safety Management System (SMS) Project Director. Captain Orlady is a member of the FAA SMS Focus Group and the Joint Planning and Development Office (JPDO) Safety Working Group. She was appointed by the FAA to serve as one of the tri-chairs for the FAA's SMS ARC (aviation rule-making committee).

Captain Orlady has been involved in aviation and human factors for thirty years as author, researcher, instructor and lecturer. She helped organize the first International Symposium on Aviation Psychology in 1981 and later served as Technical Chair. She has been a NASA-sponsored researcher for Yale and Harvard University on a research project investigating crew complement, procedures and automation. With her late father, Harry Orlady, Linda co-authored a 600-page book, Human Factors in Multi-Crew Flight Operations, published by Ashgate Publications in 1999.

Captain Orlady is a third-generation pilot. She received her initial flight training at the Ohio State University while completing a Masters in Business Administration with concentration in organizational behavior and human factors. She flew for several corporations and for Henson and Comair Airlines in the early '80s. She was hired by United Airlines as a line pilot in 1985 and has flown the Airbus A–319, A320, Boeing B–737, and B–747–400. Captain Orlady also worked in United's Crew Resource Management Department and was the program manager. She presently flies domestic and international routes on the Boeing B–757 and B–767 out of Washington, DC. She also holds a commercial rotorcraft rating.

Captain Orlady is the Chair of the Flight Safety Foundation Icarus Committee and serves on the Board of Governors for the Foundation. She also serves as a Trustee for the Vaughn College of Aeronautics and Technology in New York.

Captain Orlady resides in Lothian, Maryland with her husband, John Cirino, and four dogs.

Chairwoman GIFFORDS. Thank you, Captain.

Mr. Dinius.

STATEMENT OF ROGER DINIUS, FLIGHT SAFETY DIRECTOR, GE AVIATION

Mr. DINIUS. Madam Chair, members of the Subcommittee, I am Roger Dinius, Flight Safety Director for GE Aviation. Thank you for providing the opportunity to share these observations of the impact of volcanic ash on engines.

In 1989, we supported the NTSB investigation of a KLM 747 which experienced multi-engine power loss as a result of a severe volcanic ash encounter over Alaska. In this event, approximately one minute after the aircraft entered the dense volcanic ash cloud, power loss occurred. After exiting the volcanic ash cloud, the engines started and the aircraft landed safely.

Volcanic ash impacts the engine in three significant ways. One is corrosion of the compressor blades plugging cooling holes. It also accumulates on hot parts, deposits on hot parts. This last failure mode is the least understood and the most impactful on engine operation. Ash melts as it passes through the combustor and deposits on turbine nozzles, which can lead to stalls and subsequent power losses. This is the KLM event. In the KLM event, ash accumulation on high-pressure turbines' nozzles led to the engine stall and power loss. The rate of accumulation from a specific threat is unknown but likely a function of local volcanic ash concentrations, ash chemistry, engine design and engine power setting. Compressor erosion and plugged cooling nozzles or cooling holes are longer-term deterioration, leading to failure.

In the days following the volcanic eruption in Iceland, GE issued communications to airlines, the procedures to inspect and maintain engines post-exposure to volcanic ash. GE participated in a series of international phone calls dealing with the volcanic ash crisis. We researched records, relevant data of the past. We freely shared this information on the safety matter with agencies, airframers and other engine companies. The three large engine manufacturers reached consensus with the FAA and CAA that a no-fly zone would be established based on a model that predicted volcanic ash concentration and visible volcanic ash. In addition, a volcanic ash advisory area with a lower predicted concentration was established. Operations in this advisory area outside the no-fly zone would be monitored to determine the impact to engine operation. We reached this consensus based on industry experience and engineering judgment.

One quick example. A core engine on a 737-sized aircraft on hold at 20,000-feet altitude will ingest approximately one pack of Sweet and Low per minute. This seems like a low amount but this amount can accumulate as debris and cause engine failure, leading to premature engine failure. Industry practices have been to avoid volcanic ash. Such avoidance is made possible by worldwide weather services, air traffic control and proper flight planning.

Volcanic ash is a flight safety hazard and can impact multiple engines on a given flight. Ash has caused failures within minutes after encounter. GE recommends avoiding flight into visible ash. If industry is not satisfied with avoidance as a solution, additional research into two areas is recommended to reduce risk. The first is volcanic ash prediction, validation of the models, and the second is to quantify the impact ash damage has on commercial engines through controlled experimentation.

Thank you for the opportunity to discuss this with you.

[The prepared statement of Mr. Dinius follows:]

PREPARED STATEMENT OF ROGER DINIUS

Madame Chair, Members of the Committee, I am Roger Dinius, Director, Aviation Safety for GE Aviation. Thank you for providing us this opportunity to present our views and observations to the Subcommittee today.

GE aircraft engines and CFM International engines fly approximately 50 million flight hours per year worldwide. Every two seconds, a GE or CFM-powered airplane is taking off somewhere in the world. At any given moment, more than 2,200 of these aircraft are in flight, carrying between 50 and 300 passengers. That's more than 300,000 people, right now, who are depending on our engines.

In order to appreciate the potential hazard posed by volcanic ash on commercial aviation, and in particular on aviation gas turbine engines powering these aircraft, one has to have a basic understanding of how these engines operate. The modern turbofan engines that power today's commercial airliners are complex machines that contain more than 10,000 individual parts. In today's commercial aviation operations, the engine is expected to remain on the wing for 20,000 hours, or about five years. Therefore, the engines have to be very reliable while being capable of operating in all kinds of environments.

Each commercial engine is certified to 14 CFR part 33. This regulation requires specific design characteristic, design analysis, and testing be completed and approved by the FAA prior to being certified for installation on a commercial aircraft. There are currently ingestion requirements for birds, ice, rain and hail, but no requirement for volcanic ash ingestion. Sand ingestion is no longer a certification requirement, since effects of sand ingestion are more of a longer-term maintenance issue and not a flight safety issue typically. Volcanic ash ingestion is not a certification requirement for commercial engines. Historically, engines have not been required to meet a specific volcanic ash threat as a result of the relatively infrequent encounters.

Before I discuss GE Aviation's experience with volcanic ash ingestion, a short lesson on engine technology is needed. A gas turbine engine is comprised of five basic sections: the fan, compressor, combustor, high-pressure turbine and low-pressure turbines.

The fan brings in a large amount of air from the outside and pressurizes it. This is either exhausted directly to product thrust, the force that pushes an airplane through the air, or passes it to the compressor. The fan is typically made up of a single row of blades (airfoils—wings) to pressurize the air.

The compressor takes the air from the fan and pressurizes it further. This compressed air is passed to the combustor. The compressor is typically made up of 9 to 14 rows of blades (airfoils) to pressurize the air. Each one of these blade rows contains between 30–76 blades (airfoils). These compressor blades are aerodynamically shaped for efficient air pressurization. Additionally the compressor provides air for cooling hot metal parts in the turbine stages of the engine, enabling long reliable life.

The combustor takes the air, mixes a portion of it with fuel and then burns it to increase the temperature of the air stream. Since the fire in the combustor is so hot, the remainder of the compressors supplied air is typically used to cool the metal liner of the combustor and first stage turbine nozzle and blades. Without this cooling the combustor liner would crack and subsequently lead to a rupture failure, and engine shutdown.

The high-pressure turbine takes the hot high-pressure air from the combustor and takes work out of the air stream to drive the compressor. The high-pressure turbine is comprised of two main components: the turbine nozzles and turbine blades. The turbine nozzles set the area behind the combustor to maintain the pressure and turn the air to efficiently interact with the rotating turbine blades. The turbine nozzle section is a row of stationary vanes (airfoils). The turbine blades are typically one or two rows of airfoils that receive the discharged hot high-pressure air from the turbine nozzles and convert it to rotational force to turn the compressor. The turbine is like a waterwheel in operating concept, or a windmill. The high-pressure turbine operates at very high temperatures, in excess of 2500 degrees Fahrenheit. At these temperatures the base materials lose their strength properties, so in order to survive under these conditions and provide long reliable life, the blades and nozzles are cooled with un-burned compressor discharge air.

The low-pressure turbine receives the air exhausted from the high-pressure turbine and takes work out of the air stream to drive the fan. The low-pressure turbine is comprised of both nozzles and blades similar to the high-pressure turbine, except the low-pressure turbine is typically not cooled or cooling is limited to structural frames and nozzles.

For a jet engine to operate properly and produce continuous thrust, it is imperative that the air continuously flows from the fan section and proceed to exit the low-pressure turbine. When this continuous flow of air is disrupted in the compressor, the engine is said to "stall". To maintain the continuous flow of air it is important that the airfoils, both stationary and rotating, maintain their shape.

With this understanding of the engine, we can now look at how and why volcanic ash poses a hazard to aviation. Volcanic ash can hazard an aircraft if the encounter is of high enough concentration and long enough duration. There have been a number of engine temporary power losses due to volcanic ash cloud encounters. GE's first experience with volcanic ash came in 1989 when we supported the investigation after a KLM 747–400 experienced a multi-engine power loss while encountering severe volcanic ash. In this event, approximately a minute after the aircraft entered a dense volcanic ash cloud, a multi-engine power loss occurred. After exiting the volcanic ash cloud, the engines restarted and the aircraft landed safely. The volcanic ash damaged the engines, causing power loss as well as a permanent performance loss from the engines. It should be noted that while this is an extreme case, there are many cases of minor volcanic ash encounters that go unnoticed by the crew, but contribute to reduced engine on-wing life.

Industry wide experience with the volcanic ash threat has been acceptable because when aircraft avoid volcanic ash clouds, the airborne hazards are mitigated. This is a result of worldwide weather services, Air Traffic Control, and proper flight planning. Volcanic ash advisories occur across the globe on a weekly basis. Operators respond to these advisories by avoiding the troublesome area.

Volcanic ash damages engines and can lead to engine failure. The volcanic ash impacts the engine in at least three significant ways: erosion of compressor blades, plugging of cooling circuits, and accumulation on turbine nozzles.

Of these three failure modes, the volcanic ash deposits on turbine nozzles is the least understood and most impactful on engine operation as a result of high concentrations of volcanic ash. Volcanic ash can melt as it passes though the combustor and is then deposited on turbine nozzles, leading to a reduction in flow area, making the compressor work harder and resulting in subsequent engine stall (loss of airflow and thrust). This failure mode was likely the most operationally disruptive on the KLM 747/CF6 event for which GE has detailed data. In this event, the ash accumulated on the high-pressure turbine nozzles in approximately one minute, which led to the engine stall. The rate of ash accumulation on turbine nozzles in a specified volcanic ash environment (estimated to be 2 grams per cubic meter in this event) is unknown and likely a function of volcanic ash density in the atmosphere, volcanic ash chemical make-up, engine design, and engine power setting.

The next most impactful failure mode is airfoils erosion. Volcanic ash, like sand, erodes compressor blades, changing their shape. This change in shape reduces the efficiency of the airfoil and reduces its aerodynamic capability to maintain the airflow. Taken to the engines limit, erosion will lead to an engine stall (loss of airflow and thrust). Depending on the volcanic ash density in the environment and particle size of the volcanic ash encountered this can be more severe, from an erosion stand point, than a sand storm.

The last of the most impactful failure modes is the disruption in airflow in the hot section cooling circuits. Long life of the turbine hardware is predicated on maintaining the temperatures within design limits. As volcanic ash passes through an engine it will find its way into the cooling circuits and deposit, which results in limiting, or loss of, cooling flow. This loss of cooling will lead to premature combustor, turbine blade and/or turbine nozzle failure.

Additionally, volcanic ash contaminates oil systems, air conditioning systems, erodes flowpath hardware and piping, and deposits ash in the combustor. While these failure modes are real, and impact engine operation, they're not typically the most significant failure modes from a time to failure standpoint when exposed to significant volcanic ash density. These are expected to be longer-term failure modes resulting from light to moderate levels of volcanic ash exposure.

The week following the eruption of the Eyjafjallajokull volcano, GE provided support to our customers to minimize disruptions in service, and supported U.S. agencies and European agencies to establish safe guidelines for the resumption of operations in European airspace while volcanic ash may be present.

On April 14, following the eruption of Eyjafjallajokull volcano, GE initiated efforts to ensure airlines had information to continue operations with a volcanic ash threat. The following day, we issued an update to all operators to inform airlines of procedures to inspect and maintain engines post-exposure to volcanic ash. Also on that day, the UK Civil Aviation Authority (CAA) suspended flight operation, due to volcanic ash in the environment.

On April 16, we received an invitation from the FAA New England Regional Office to participate in an international teleconference to deal with the European volcanic ash issue. GE initiated efforts to understand past volcanic ash events with engines. On April 17 and 18, we supported additional international phone calls hosted by the UK CAA.

Actual ash concentration predicted based on the UK National Weather Service (MET) office model for volcanic ash concentration was discussed and the group worked to establish an appropriate level to prevent a hazardous environment for civil flights. GE freely shared our knowledge, observations and experience on this potential safety matter with agencies, airframers and other engine companies (Pratt & Whitney, & Rolls-Royce). We researched records to gather relevant data on past volcanic ash encounters with engines. The UK CAA was acting on guidance within the International Civil Aviation Organization (ICAO) "Manual on Volcanic Ash, Radioactive Material, and Toxic Chemical Clouds" DOC 9691, which states in paragraph 3.4.8: ". . . the recommended procedure in the case of volcanic ash is . . . . regardless of ash concentration—AVOID AVOID AVOID".

The group worked to understand the UK MET office model and its validation. The UK MET office initiated flights to support model validation. On April 19th, there were further phone calls to establish consensus on the concentration level of volcanic ash an engine could tolerate without causing a safety hazard.

On April 20th, engine manufacturers (RR, P&W, & GE) reached consensus with FAA NE office that flights in volcanic ash would be acceptable up to volcanic ash concentration levels of up to 2milligrams per cubic meter and in absence of visible volcanic ash. Additionally the London Volcano Area Advisory Center IVAAC) would issue volcanic ash advisories for predicted concentration in excess of 0.2 milligrams per cubic meter. Operation in volcanic ash concentrations between 0.2 and 2 milligrams per cubic meter and clear of visible volcanic ash would be monitored to determine the long-term impact on engine operation. This consensus was based on industry experience and engineering judgment.

GE continues to support regulating agencies and airlines with volcanic ash inquires, and mature sampling plans. In addition, GE issued All Operator Wires and Service Bulletins to socialize the agreement above and to provide guidance for operators on sampling plans to access longer-term engine impact. In summary, government and industry working together determined that the Volcanic Ash threat can be mitigated as long as aircraft avoid visible volcanic ash.

Volcanic ash can pose a threat to safe aviation flights. It has caused engine failure within minutes of the encounter in severe volcanic ash cloud environments. Much work still needs to be done to understand the effects on aircraft gas turbine engines. The quantitative flight safety risk due to volcanic ash is dependent on a number of factors, some known and some unknown. These unknowns make establishing a quantitative limit on volcanic ash a challenge. GE provided and continues to provide support to our customers and regulatory agencies to maintain safe operation in light of the recent volcanic ash threat. The current best practice for abating the volcanic ash hazard is to avoid visible volcanic ash. GE supports further research to better define the volcanic ash threat and to establish working limits, that maintain safe environment for flight and provide meteorologists a metric to establish a forecast volcanic ash area to allow ATC and flight crews a known area to avoid.

Thank you again for the opportunity to discuss this issue with you.

Chairwoman GIFFORDS. Thank you, Mr. Dinius, and thank you to all of our witnesses today. I honestly don't think we could have assembled a more senior expertise and really diverse group of witnesses to an issue that is very important. And of course, what strikes me is, as Mr. Olson said in his opening comments, that really not since 9/11 have we had such a large disruption in air traffic. We have yet to have any fatalities or catastrophic incidents associated with volcanic ash but the possibility is great and our job here on the Subcommittee is to make sure that we are doing everything we can so that we have the research and the information to keep air travelers safe, to keep airlines running and to make sure that we can have the information also to explain it to passengers and to the general public as well.

CHARACTERIZING THE RISK

We are going to begin our first round of questions, and the Chair will recognize herself for five minutes.

I would like to begin with Captain Orlady. Speaking of expertise, she is a third-generation pilot, which is tremendous, and as I said when we had a chance to meet before the hearing, those of us who commute here to Washington every week feel like we have a very close relationship with all the pilots and we have a lot of trust in the FAA and other organizations that of course keep us safe as well as obviously the general public. But Captain, you indicated in your written statement that the dilemma is that currently we do not have scientifically reliable and valid data which tells us how we might—how that might be accomplished in terms of the need for research and development. So I was hoping that you could and then the other members as well, if you could talk about the research that you feel is needed to better understand when it is safe to fly through airspace that has been contaminated with volcanic ash and is there a way to characterize the risk of flying under such conditions?

Ms. ORLADY. Thank you very much, Madam Chair, and I appreciate your business and the confidence you have in the air transportation system because we work hard and it is a process to keep working with that.

There is not an acceptable level of contamination right now. Part of the dilemma I think is twofold. One, we don't get—we do not receive, rather, good real-time data. There is data that is collected, and these folks, my fellow panel members can talk much more precisely about it than I can, but there are models that are interpreted. There are different models that are used. Even if they are using the same model, there are different interpretations that are used, and in fact, my husband made, I think, a good analogy last night when we were talking about this as I was driving through some DC. traffic and looking at a display. He said well, that is not real-time data so just go ahead and plow through even though it is red. We can't do that up in the air. You know, if you don't like it on the beltway, you pull over and park or something else perhaps but you can't do that airborne. We cannot afford to take that risk so we don't get good real-time data as well we don't have a high level of confidence. It has gotten much better but in terms of the forecasting methods, in terms of are we all talking on the same terms, with agreement on the same terms and understanding as to what they mean.

So I don't mean to seem a little bit skeptical with that but at this point there is no acceptable level of contamination that we think we know enough about to accept. I wish we did, given how the economic problems that we had with, as my partner here suggested with the big E volcano because it was quite disastrous.

Chairwoman GIFFORDS. And in terms of characterizing the risk of this, can you put it in layperson's terms of—I mean, we have heard a lot of information, but as a pilot, with all of us in the cabin, I mean, how do you quantify that?

Ms. ORLADY. This would not be that difficult. So you have your power plants, your engines. They potentially stop working. You become a glider. Your windshield can be very quickly eroded. In fact, one of the procedures I have seen from one of our member airlines mentions specifically if the windshields are eroded, consider diverting to an airport where an auto land can be made. This does not exactly make your day. Then you have what sort of things are you breathing, you know, in terms of this and how much do we really know about it in terms of the itchy eyes, in terms of breathing difficulties. There is nothing about this that sounds appealing. If it was just one item, one factor, maybe we would do that. Maybe we will have engines that will be able to withstand some of this. That would power plants, that would be good, but we have so many other issues and aircraft systems that are affected that we really do not understand. I think of all of the ramifications. We have a learning to do. But mostly for passengers and certainly for pilots, no interest in kind of going there. There are just too many things that kind of go wrong, and heaven forbid not being able to see out the windshield to land.

Chairwoman GIFFORDS. Thank you.

Would others care to comment?

Mr. KAYE. I will just comment briefly then. In terms of one of the real challenges is both having the observations and the models. For NASA as a research organization, the satellites can overfly a particular volcano at a regular time based on durable mechanics. There are other satellites that NOAA as an operational agency and particularly has used geostationary satellites that do get enhanced temporal coverage, but you can only—for most of the satellites that we have, we can only overfly them in a certain time period but we can use models to help. We can initialize models and the data can help evaluate them and improve them for the future.

Chairwoman GIFFORDS. Thank you.

Mr. Olson.

THE EUROPEAN RESPONSE

Mr. OLSON. Thank you, Madam Chairwoman. I don't know if you all had an opportunity this morning to see there was an article in the Wall Street Journal this morning, and let me read the headline: "E.U. ministers to speed up talks on aviation rules," and there was just one little paragraph here that I thought was pretty appropriate for what we are taking about today. "The 27 ministers also agreed that there is a need to urgently come up with limits as to how much ash is dangerous for the airplane engines," and so sort of taking up on that and following up on some of the comments you made, Mrs. Cox, in your opening statement, how would you characterize—this is a question for all of you but how would you characterize the European Civil Aviation Authority's response to the Icelandic volcano? I mean, was the breadth and duration of the shutdown a sensible approach based on sound science? Was it kind of a play-it-safe reaction because of a lack of scientific knowledge? And also, just sort of want comments on what was the impact of a balkanized air traffic control system here?

Ms. COX. So I don't want to second-guess the Europeans' decision to close the airspace not having been there with the actual data that they were looking at. I will say that certainly the geographic layout of Europe probably contributed to their decision. In the United States, we largely handle volcanic ash by routing around it. Their particular situation probably prohibited their ability to do that. So that was a contribution. But certainly there is no known level of volcanic ash that is known to be safe to fly through.

And as I mentioned in my testimony, the fact that there were 27 civil aviation authorities who had to contribute to the decision probably contributed to the difficulty in once the decision was made in deciding what to do about resuming flight.

Mr. OLSON. Captain Orlady, any comments?

Ms. ORLADY. I agree with Ms. Cox. I am not sure—Europe has some different challenges that I think they handled very, very well most of the time but we handle things a little bit differently. We have a little bit more airspace here so it is difficult, you know, when one is going to the other and you want to be safe, but basically I agree with everything Ms. Cox has just said.

Mr. OLSON. Any other panel members want to comment on that issue? Okay. We will take that as a big no.

COORDINATING RESEARCH AMONG AGENCIES

All right. Dr. Kaye, the next question is for you then. This is about coordinating research among the Federal agencies. It appears that other operational agencies are heavily reliant on NASA-provided data to enable their own capabilities to characterize, measure and forecast volcanic ash cloud movements. To what degree are research efforts being coordinated among Federal agencies to develop future sensor and modeling products?

Mr. KAYE. Well, there is an interagency coordinating effort carried out under the auspices of the Office of the Federal Coordinator for Meteorological Services and Supporting Research, so I think that deals with some of these kinds of things on a regular basis. In the longer term, there is any of a number of ways in which we will work together to help develop plans. Some of the things that we are trying to do at NASA, especially as we look towards the future and some of the future missions, those that have been identified by NRC and the decadal survey is to bring the users into the mix as early as possible so, for instance, one thing that we did this past February was hosted, we call it essentially an applications workshop between our Applied Science program and our Flight program so that we could have a way for those who would be potential users of the data that we would be able to provide with the next generation of satellites talking with us so we better understand what their needs are and the relationship between what we can provide and what they do need. So those kinds of conversations, especially for NASA, bringing people, potential users in at an early stage helps us understand and potentially tailor things where it makes sense. For instance, one of the—the HyspIRI mission, which is a SO_2 decadal survey mission, some of the wavelength bands are specifically chosen to provide information on volcanic SO_2.

Mr. OLSON. Thank you very much. Just in closing, I would like to make a statement. I mean, it is pretty clear to me that we need to develop onboard equipment and a thorough communication network, so as Captain Orlady said, the pilots on board the traffic can get real-time information about any volcanic ash activity. I mean, the only thing that is going to be 100 percent safe is avoidance, and I was in the Navy, a P–3 pilot. As a young patrol plane commander, I made a mistake and we are coming home after an 8-hour mission about 4:00 in the morning, had some get-home-itis and we had a radar on board that wasn't weather certified but guys kind of made guesses and they said we have got a thunderstorm here in front of us, Mr. Olson, it is about 10 miles wide. I am big and bad, I am a new patrol plane commander, all-weather aircraft, we will just punch it through, guys, rather than spend another 45 minutes going around it. We punched it through. We got through fine. The lightning bounced off the aircraft. That is very uncomfortable. You know you have gotten yourself in a position you shouldn't be in, and, you know, I threw the people around on the aircraft for a good three, four minutes and that was completely unnecessary. And of course, when I got back to the ground and had to deal with 11 crew members walking around, "Oh, Mr. Olson, my back, it's so sore."

The point of it is, is we got to get them the information. If I had had the information and seen how dense that cloud was when we punched through it, I would have never done it. I would have gone around it and we would have been 100 percent safe. Same thing with volcanic ash. If we avoid it, if we get the air crews the information they need to that aircraft, they will make the right decision every time.

Thank you, Madam Chairwoman.

Chairwoman GIFFORDS. Thank you, Mr. Olson.

We are going to hear now from Ms. Kosmas.

THE USE OF SIMULATIONS FOR TRAINING

Ms. KOSMAS. Thank you, and thank you all for being here today. I happen to represent the central Florida area which has the National Center For Modeling and Simulation, which is in Orlando, and that develops the simulator tools that are used to increase skills, mostly in my area for the military at this current time but of course all of that information leads to simulation that helps us in nearly every scientific endeavor that we are working on these days.

Captain Orlady, you had discussed the use of simulators by American Airlines in training their crews to provide them with advanced training in the event of ash cloud exposure, and so I was curious whether you or any of the other members could discuss the use of simulators for advanced training for crews in this type of situation and whether it can or should be incorporated into crew training universally?

Ms. ORLADY. Thank you very much, and just for the record, it is Alaska Airlines rather than American that——

Ms. KOSMAS. Oh, I am sorry.

Ms. ORLADY. —that had that, and as you might imagine, because they have the chance to—their exposure rate is quite a bit higher. I have talked to in fact a captain 2 days ago who had just been through some recurrent training, and recurrent training at the airlines, as you may know, will have different things every year. Wouldn't you know this year they have some scenario for volcanic ash and inadvertent entry? Obviously this was planned well before Iceland decided to kind of get active so the timing is quite curious. It can be very effective in terms of putting you through the scenario and the checklists that we have and seeing how it works, and I am reminded from talking with him and your question, one of the symptoms also that I did not mention or potential consequences, all the avionics we have in today's aircraft, the radios, navigation radios and particularly with the newer generation aircraft, they needed to be cooled just like our computers at home. They don't get the cooling of the airports if you will, our cooling ports are blocked. They do not-desirable things. They blank and they just kind of disappear. So that isn't very helpful.

So it is very good with training scenarios. The high-fidelity simulators that we have do allow a high degree of realism. It is helpful to do it and it is good to go through it and I think it certainly sends home the message quite loudly that you do not want to be in this air and don't try be a P–3 trying to get home kind of quickly so you can be done with it. It is just, you know, not worth it. So the simulations can be very good although the message at least for us right now is, you don't want to get in this, it reinforces. Thank you.

Ms. KOSMAS. Thank you. I appreciate that.

Does anyone wish to comment on that particular question? Obviously the desire is not to be there but should the occasion come up where someone is, the ability to be prepared and to make the right kinds of decisions is helped, I think, by early training and simulation training.

Thank you very much.

Chairwoman GIFFORDS. Thank you, Ms. Kosmas.

Mr. Rohrabacher.

ENGINE DESIGN

Mr. ROHRABACHER. Thank you very much, and thank you, Madam Chairman, for calling this hearing. It is obviously of great interest to the overall public and to those of who travel every week on jet airplanes. I flew in last night. I would like to identify myself with the statement by Ranking Member Olson, who put this in perspective in terms of threats. What we have here is a threat that rarely is confronted, but when we do confront it, it becomes something of utmost importance because it could result in a tragic loss of life, and we hear this argument a lot on Near-Earth Objects. I mean, the chance of a meteorite hitting the earth, what is that. But of course if it does, it could kill hundreds of thousands if not millions of people, so these are the threats that we need to pay attention to. Unfortunately, and how that relates to our committee, is that research is skewed or at least directed towards threats that are a little bit more frequent than these threats that don't happen very often, but when they do happen, they pose a great danger.

Let me ask, is there any—first of all, Mr. Dinius, your Sweet and Low package, you are saying that that much debris in a jet engine could actually bring down a plane?

Mr. DINIUS. Okay, so to clarify. No, sir, it will not.

Mr. ROHRABACHER. Okay.

Mr. DINIUS. That was just a particular example for a one-minute time. If that same kind of concentration were to be taken, for instance, from London to Paris and back on five trips a day, you are talking multiple pounds of contaminant that can get in the engine to either deposit on turbine blades, plug cooling holes and potentially lead to failure.

Mr. ROHRABACHER. And right now is there any research efforts going on that would—with your company or that you know of in the Federal Government that is taking this threat into consideration in terms of jet engine design or is this something that is just not being addressed now?

Mr. DINIUS. Sir, from a very obvious standpoint, contaminants in the engine and the small cooling holes in these parts, the reality is, we have to keep those clean for long life. We expect these engines to stay on wing for 20,000 hours, five years. Flying through this type of debris shortens the life of the engine, could lead to failure. It is a cumulative thing. You know, you fly through it——

Mr. ROHRABACHER. Do you know of any efforts or is there anyone looking at this and saying here would be an engine design that would be less susceptible to that?

Mr. DINIUS. Not that I know of, sir.

Mr. ROHRABACHER. Anybody else know of any research like that? Again, this might be one of those instances where because the threat is not frequent, that we are paying attention to other threats rather than this and it may be worthy of us looking into that.

Mr. Olson's experience in terms of cloud density, let me just ask, when we are talking about cloud density, Mr. Olson, that turbulence that you experienced, did that affect the engines of the plane or is it just the other dynamics of the plane?

Mr. OLSON. It did not affect the engines on the aircraft. I mean, the big problem that I encountered that I didn't appreciate was the fact that the equipment on board my aircraft wasn't weather radar and it was an operator who could make guesses, and I took that as something, okay, we can punch through this and decided to punch it through, but it was not anything that damaged the aircraft.

Mr. ROHRABACHER. So the research that we are talking about might—if there is a research and a scientific solution or something that would help might take in, for example, research into radar and that would then—or methodology of determining density of what people are flying into, the density of the air, the clouds, et cetera. What about materials research? Mr. Dinius or anyone else who would have this, is there something that we could do in terms of the materials that engines are made out of or is this simply the design of those engines?

Mr. DINIUS. I am not aware of any material work that could be done to avoid this at this point.

Mr. ROHRABACHER. Any other thought on that? This is a materials issue then, it is an actual design issue. Well, thank you very much for your testimony.

Madam Chairman, again, thank you for putting together an expert panel for us to enlighten us on this issue, and I have gotten a lot out of this. Thank you.

Chairwoman GIFFORDS. Thank you, Mr. Rohrabacher.

Now we are going to hear from Ms. Edwards.

EUROPEAN CONSULTATIONS

Ms. EDWARDS. Thank you, Madam Chairwoman, and I will tell you, for weeks I have been dying to say, what is it, Eyjafjallajökull or something.

My question actually, Mr. Dinius, goes to you. Was GE Aviation consulted by the Europeans before resuming flights, and was NASA's DC–8 experience taken into consideration in that consultation?

Mr. DINIUS. So yes, we were invited to participate in a series of teleconferences with the FAA and the CAA over the weekend that followed the eruption in Iceland. We took into consideration the data we knew of, the DC–8 NASA, we knew of that one. There are other events that we have data from. It should be pointed out that the DC–8 event NASA had was not an engine failure, it was an economic impact but not an engine failure.

DETECTING CONTAMINANTS

Ms. EDWARDS. And I guess I am curious, on the ground like in testing engines, because you have to do some kind of cost-benefit analysis, I mean, it is not as though aircraft are flying through volcanic ash all the time, although it is significant. How do you actually—how would you design and test an engine for whatever level of volcanic ash would be acceptable?

Mr. DINIUS. Ma'am, there is no certification requirements today for sand and dust or volcanic ash. However, you could run engineering tests or you can control the level of contaminants that are put in the engine and then see how the engine responds as well as look at the engine afterwards to see its condition, its health.

Ms. EDWARDS. And over time, you could have a number of given contaminants that might impact an engine or other aircraft parts so you might know on a first run, for example, on one flight it might be sand, depending on where that flight is going. On another flight it might be volcanic ash. I think what the discussion hasn't come to is, what combination of those things, even if it is not one or the other, is there a combination of those kind of environmental materials that really could contribute to engine failure and measuring one and not the combination might not tell you very much about whether the aircraft could travel safely?

Mr. DINIUS. So the chemical constituents inside the volcanic ash make a difference on the failure modes. The melting point of the contaminant, the volcanic ash, make a difference. If it doesn't melt, it is not going to stick to the turbine blades. It may erode them but it won't stick to them. So that is a different failure mode than your classic sand and dust. We have good history with sand and dust. We understand how blades erode. With volcanic ash, the data is fairly sparse.

HUMAN FACTOR

Ms. EDWARDS. And Captain Orlady, one of the things that you pointed to was the fact that, you know, so for example, with volcanic ash, for one pilot it might result in itchy eyes, for another it might result in not being able to see out of a windshield where some other pilot actually might be able to see out of that windshield but wouldn't have itchy eyes, so there are a whole number of human factors that one couldn't possibly account for. I guess what I am getting to is that when the question becomes do you shut down an entire system or not, I think it is very hard to measure the point of your testimony that you get to which is do you really want to take that chance. I mean, it is a huge economic cost but it may be better to shut down the system because you could never really account for the factor or other human or mechanical that could contribute to a failed flight.

Ms. ORLADY. I think that is an accurate perception. It really is a multi-pronged problem. The questions that were asked of Mr. Dinius about the engine, perhaps——

Chairwoman GIFFORDS. Captain, your microphone.

Ms. ORLADY. I pushed it. We will put it closer. But it is a multi-prolonged problem because let us say we determine something with the engines and maybe we do—but that just doesn't solve the avionics that still need to be cooled. It still doesn't solve the windshield that if I can't see out of, even if I don't have breathing difficulties and itchy eyes, if I can't see out of it, then it doesn't make much difference. So I wish I was more optimistic but I think your description is correct in terms of looking at the severity, potential severity and consequences. We don't have much choice until we get better data at this point.

Ms. EDWARDS. Thank you, Madam Chairwoman.

Chairwoman GIFFORDS. Thank you, Ms. Edwards.

We are going to have a second round. We have got a couple of follow-up questions that would like the panel to answer. Following up on Mrs. Edwards' point about the DC–8, with us in the audience we have Mr. Thomas Grindle, who is a propulsion engineer, and I was hoping that he could come up to answer a couple of questions. Thank you, Mr. Grindle.

NASA DC–8 EXPERIENCE

A report that you wrote indicates the pilots did not notice anything out of the ordinary after flying through volcanic ash clouds. After landing, could you talk about what parts of the aircraft that you did look at and did any other aircraft besides yours go through the same areas and did they also reach similar no-problem conclusions?

Mr. GRINDLE. Thank you, Madam Chairwoman. Yes, once we—the scientists on board were the ones that alerted the flight crew that we were currently flying a diffuse ash cloud from the Hekla volcano. The pilots noticed no onboard indications whatsoever. Engine parameters were normal. No smells in the cockpit. Because it was night, we looked for the St. Elmo's fire. No indications whatsoever. The scientists were the only ones because of their instrumentation on board to notice that we were flying through the cloud. The incident lasted for about seven minutes, and the aircraft continued on to Sweden.

Once there, they contacted us back at NASA Dryden and asked about, you know, what they should and we recommended to do a complete visual inspection on all the leading surfaces of the airplane, the windshield, the leading edges, to look at the engine fan blades, engine cowls, anything that could have had any abrasive damage or anything. They performed those inspections, found no damage whatsoever. Our recommendation from Edwards was to then replace the air conditioning filters and the engine oil on all four engines and hold samples for us for once they returned back to NASA Dryden. They flew for about 68 hours in Sweden doing other atmospheric research missions and returned back to Dryden where we were able to do a complete engine borescope on all four engines and there we noticed some clogged cooling holes and abraded leading edges on the turbine section. We removed one of the engines, which was getting close to an overhaul maintenance requirement, and sent it to the engine manufacturer in Strother, Kansas. They tore it down and found more damage inside. We then removed the other three engines and sent them to the same manufacturer as well, and upon those teardowns they found more of the same contaminations inside and the same damage listed in all four engines.

Chairwoman GIFFORDS. Mr. Grindle, can you talk about the lessons learned from this experience? What are the key take-aways for us that we should be focusing on, and in your view, from all the knowledge and information that you have gathered, are these lessons actually being applied today?

Mr. GRINDLE. I can only speak about the DC–8 incident which we had, and prior to us leaving Edwards we knew about the eruption and so we purposely made our course as far north as possible, and in fact on the way over we added another 200 miles, so I think our total distance from the volcano was almost 800 miles, and at the altitude and the latest information we had gotten from the London Volcanic Ash Advisory Center, we were well north of any kind of ash cloud whatsoever, and upon the engine teardown and the scientific data evaluation, some of the particles we flew through were less than one micron in diameter, and even at those limits, we didn't experience any engine parameter failures or any indications whatsoever but the engine manufacturer who did the work specified that we probably would have started seeing performance degradation in some of the engines in as little as 100 flight-hours because of the loss of cooling and other things.

And as far as I know, we were the only aircraft to fly in that area through the ash cloud, and once we did realize we were in it, we updated the London center and told them that we had experienced it in that area and they were able to update their predictions in those areas as well.

Chairwoman GIFFORDS. Thank you.

Mr. GRINDLE. Thank you.

DETECTION SYSTEMS

Chairwoman GIFFORDS. I have a follow-up question for either Dr. Strazisar or Dr. Kaye, and this builds on Mr. Olson's comments about having an onboard display. How far away are we technologically speaking or even from an implementation standpoint from a cost perspective for an onboard volcanic ash-type detection system that ALPA was talking about in terms of really giving the pilots the information that they need? I am curious, I mean, do we know how to build them and do we know when we will have them?

Mr. STRAZISAR. We are in our aviation safety program working constantly on instrumentation that is forward looking, primarily to provide better indications of weather because convective weather is actually on a probability basis a much greater problem than volcanic eruptions. Some of those forward-looking systems have the potential to detect ash but that is not their primary purpose. So we are continuing to do research on constantly improved instrumentation. We will keep our eyes open in the future for any technologies that would have a side benefit of being able to also detect ash, but we are not working currently on any system specifically to detect ash.

Chairwoman GIFFORDS. Ms. Cox or Mr. Dinius or Dr. Kaye, any additional—because Captain Orlady is looking a little nervous, so maybe wants some reassurance that we are working on this technology.

Ms. COX. I can comment on some of the work the FAA is investing in with our NextGen research and our NextGen programs. While we are not focusing on onboard sensors on aircraft, we are focusing on delivering better information to the pilot, to the controllers, to the airline dispatchers so that they would all have the same information in real time that they could use to make better decisions collaboratively about how to proceed in these conditions. Reports—there was a very good report done by NOAA after the Mount Redoubt eruption in 2009. It was just published this January, actually. And they published best practices and findings and recommendations. Overall, one of the best practices was web-based communications that they had during the Mount Redoubt eruption. Findings and recommendations focused in large part around better communication and better collaboration, so this is where our focus is.

Chairwoman GIFFORDS. Anyone else?

Mr. KAYE. I think what I will have to do is to take an action to try to get additional information and report back, especially as to what precisely the sensors were that were aboard the DC–8. I don't know if we know exactly what they were doing that provided us some information, whether they were in situ measurements that actually made air sampling in the vicinity of the aircraft or remote sensing kinds of things. It is an answerable question. I just don't have that. If it is in situ, of course, then that becomes an issue because then you essential have to have a detector which if that involves cutting a hole in the plane, that is a whole separate set of issues for that, and if it is a remote sensing thing, then you have to find out, you know, radar is—for very small aerosol particles, radars typically don't work. That is the way we do a lot of optical wavelengths and LIDARs, but I will have to get back to our people and find out specifically what the instrumentation was that detected that and then see whether that is something that potentially would be applicable or not.

Chairwoman GIFFORDS. We would appreciate that, Dr. Kaye, if you could report back to the Subcommittee. Obviously we are interested. This is a timely hearing, and you know, the general public is also very interested. You know, we hadn't focused on this for many years but with this eruption certainly it was all on our radar screens.

Mr. Olson, do you have any follow-up questions?

Mr. OLSON. Two more questions. Home stretch.

FUTURE REMOTE SENSING

The first one is for you, Dr. Kaye. You outlined a number of instruments found on orbital NASA research satellites that have been key towards helping understand the composition physics of volcanic plumes. What is the future of doing these kinds of capabilities from space related to what is the likelihood that NOAA or the USGS will be able to absorb these capabilities into their own operational systems?

Mr. KAYE. A number of the sensors that we have and the satellites that we have are past their—what we call their prime life period. They are in extended operations. But thanks to good engineering, we can nurture these things for quite a while, the satellites, for a very long period of time. There is some evolution that is planned, future satellites that we have planned, the Glory satellite, which is specifically designed to measure aerosols using polar metric technique, so that will add significantly to our body of knowledge because those observations will help provide information not just about aerosol presence, where something is, but what something is, which is very important as well, especially for initializing models.

For including a lot of the optical infrared observations that are done through our modus instrument, the NPP mission, we will do the launch in 2011, we will continue those, and that is a precursor to the Joint Polar Satellite System, which will provide enhanced operational capability into the future.

There are some other things that we do that there is no sort of near-term plans but people look at in the long term. We use multiangle viewing with the MISR instrument that looks in nine different directions and helps provide information about altitude, composition. One of our decadal survey missions, the ACE mission would use multiple-angle techniques but that one is further out into the future, and one of the neat things that we have right now is the Calypso. It is a LIDAR-based measurement which can get very accurate and very precise information about thin layers. It looks straight down but it is an optical equivalent of radar so you can see very thin layers and know precisely what altitude they are at. That has been flying since 2006, and we don't have—the next LIDAR I think that we will be looking at for aerosol purposes would be also the ACE mission, which is one of the DOD decadal survey missions.

One thing I can say is that for a lot of these things we don't have to go it alone. There is a good record of data sharing with our international partners to the extent that the Europeans will do things or the Japanese will do something, the Europeans in particular I think are looking at LIDAR missions. So we will have some opportunities there.

You mentioned U.S. Geological Survey. I haven't talked about them. They have the primary responsibility for surface-based measurements, especially about what is going on and at the surface of volcanoes, so that is a different kind of thing than what we normally do. We work with them on land cover observations as well and that is a good relationship.

PRIORITIES

Mr. OLSON. Thank you very much. One last question, and I don't mean to put words in your mouth but given the constrained spending environment we are dealing with up here, if we had to prioritize our efforts going forward, what do you believe makes the most sense? And I think the group, if I could summarize, and if you disagree with this, please hit the button and chime in. But I think the first priority should be developing technology both on board and within the aircraft tracking system, get real-time information to the pilots as these volcanic plumes developed. The second priority should be develop a better understanding of engine performance and degradation, and the third priority should be trying to harden the engines and make them where they can fly through things that they probably can't fly through now. And again, to me that seems to be the consensus here of our priorities going forward with our limited dollars. If anybody has a disagreement with that, I would certainly like to hear it. All right. Amen. Thank you very much.

Chairwoman GIFFORDS. Thank you, Mr. Olson. Before we bring this hearing to a close, I want to thank all of our witnesses for being here. We have just scratched the surface today. The Subcommittee hearing is timely. Obviously your expertise is an asset and a real value to the Congress, to the American people and to the international community as well. So we look forward to any additional information that you would have for us, updates of course we would welcome, and thank you for taking time out of your busy schedules to be here, and Mr. Grindle as well, thank you for coming in from California. We very much appreciate all that you do to keep our skies safe. We sincerely appreciate it. And again, as mentioned many times, this is an unusual incident but the potential of catastrophic loss of life and risk to the airline industry is great, so we appreciate particularly Captain Orlady. Again, I think because all of us commute so much, we really feel like we have a personal relationship with all of our pilots, so appreciate everything you do on behalf of all of our airline pilots and of course all the flight attendants and everyone who we, you know, spend a lot of our time with as well.

The record will remain open for two weeks, so if there are any additional statements from members and any answers to any of the questions that we would like our witnesses to follow up on, please submit that for the record.

The witnesses are excused and the hearing is now adjourned. Thank you again.

[Whereupon, at 11:23 a.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Tony Strazisar, Senior Technical Advisor, Aeronautics Research Mission Directorate, National Aeronautics and Space Administration

Questions submitted by Chairwoman Gabrielle Giffords

Q1. It is clear that from the difficulties European aviation regulators experienced while deciding when to reopen airspace, some fundamental data was missing. Yet, the negative impact of flying into volcanic ash clouds has been demonstrated. And, thanks to NASA, we have been warned that engines may not show signs of damage until after 100 flying hours. So why do you think there hasn't been greater focus on this area by the world's aeronautics research community? What research needs to be performed?

A1. We believe there has not been greater focus on the issue of commercial aircraft operations in and around volcanic ash clouds because an event such as the recent eruption in Iceland is rare. Hazardous weather conditions such as convective weather (thunderstorms) and icing pose daily disruptions to commercial air traffic around the world. As a result, the aviation community has focused research and development efforts on the development of capabilities such as airborne and ground weather radar, air traffic re-routing procedures, and aircraft icing protection systems. Satellite assets are capable of detecting volcanic ash clouds, but the dispersion of the cloud and the concentration of ash are difficult to accurately predict with current weather modeling capability. Research leading to improved prediction of ash cloud extent and ash concentration within the cloud would enable more accurate air traffic re-routing to avoid flying into airspace in which ash concentrations are unacceptable.

Q2. What technology is needed such that aircraft can have onboard warning of volcanic ash conditions? What research is needed to develop and demonstrate that technology? Who should perform such research?

A2. Technologies capable of detecting small-diameter particles suspended in the atmosphere are required if onboard indication of volcanic ash conditions is desired. Although techniques such as Cloud Physics Lidar and Visible Infrared Imaging Spectrometry are available for NASA research aircraft, it would be prohibitively expensive to equip the commercial aircraft fleet with such capability. NASA continues to develop capability for airborne forward-looking sensing of atmospheric hazards. This research is looking across a suite of state-of-the-art sensing technologies that have potential to detect various hazards types, which could include volcanic ash. Improvements in technologies such as LiDAR (Light Detection and Ranging), FLI (Forward-Looking Interferometry), and X-band radar hold potential for detecting volcanic ash and aiding pilots to determine the safety of flight through volcanic ash areas. Current NASA aviation safety research on LiDAR seeks, encourages, and emphasizes the ability to detect multiple hazards (which to date have primarily included icing, wake turbulence, and limited visibility). Some current research, such as the forward-looking interferometer research, has looked at volcanic ash detection capability. NASA will continue to support the development of sensing technology capable of detecting multiple hazards, including volcanic ash. This month EasyJet airlines announced plans to test a system consisting of two infrared sensors carried in a plane's tail fin *http://www.guardian.co.uk/world/2010/jun/04/easyjet-volcanic-ash-radar*. The system, developed by the Norwegian Institute for Air Research, has the potential to detect volcanic ash particles up to 62 miles ahead of a plane's flight path.

As an alternative to onboard ash detection, research leading to improved forecasting of plume location and ash concentration would be beneficial. Improved plume prediction models would enable the Volcanic Ash Advisory Centers (VAAC) to pass more accurate information through the aviation advisory capability of the aeronautical fixed services operated by the Federal Aviation Administration so that plume location information could be used for flight planning for plume avoidance. The NASA Science Mission Directorate testimony outlined several improved modeling activities.

Q3. It is probably impractical and uneconomical to design a jet engine that can withstand all volcanic ash conditions. From what we know about aircraft engines, aviation safety, and the economics of the airline industry, what is the best that we can expect from future engine technology improvements?

A3. The most immediate effect on a modern aircraft engine of ingesting volcanic ash is the melting of the ash in the hot section of the engine. The ash then forms glassy deposits that alter the airflow through the turbine blades downstream of the combustor. Continued buildup of these deposits can restrict airflow through the engine and cause the engine to stall. In several well-publicized incidents, engine stall has occurred in a matter of minutes after passing through severe concentrations of ash. In addition, volcanic ash can clog the cooling holes and damage the thermal barrier coatings which are used to protect the turbine blades from combustor exhaust temperatures that exceed the melting point of an unprotected blade. This reduced thermal protection can over a longer period of time reduce the remaining safe life of the turbine components. To increase cycle efficiency and reduce fuel bum, future engine technology is pushing toward ever-increasing combustor exit temperatures, which will only exacerbate the problems caused by melting ash and reduced cooling system performance. There is current research on adaptive engine technology being performed under the DOD Versatile Affordable Advanced Turbine Engine (VAATE) initiative. This research is developing technology to enable gas turbine engines to alter their operating mode to adapt to varying mission requirements. Once these technologies are demonstrated for military applications they may find their way into commercial applications and could enable an engine to re-configure its operating conditions in response to the accumulation of ash deposits and a reduction of cooling flows to turbine components. This technology is several years away from reaching a maturity level at which it could be included in new commercial aircraft engine designs.

Q4. Captain Orlady indicated in her statement that Alaskan Airlines has developed extensive classroom and scenario-based simulator training that provides crews with effective tools and techniques that can be used in the event of inadvertent airborne ash cloud exposure. Considering NASA's unique expertise in human factors in aviation, is there value in more focused research on developing technologies that can simulate volcanic ash conditions to pilots and crew?

A4. There is value in educating pilots and crew in proper procedures to follow in the event that an unintended encounter with a volcanic ash cloud impacts engine performance. However, it is not clear that any additional research on simulating ash conditions is required. In the late 1980s and early 1990s, research on the effects of dust ingestion on gas turbine engine performance was led by Dr. Michael Dunn at the Caispan Corporation in Buffalo, N.Y. Dr. Dunn is currently at Ohio State University. Dr. Dunn used volcanic ash as a source of dust during those investigations. In the course of that research, Dr. Dunn discovered that glassy deposits of volcanic ash that accumulated on the surface of turbine blades could be cleared by reducing engine power to idle and then returning to a cruise throttle setting. During the brief return to idle the turbine blades cooled and shrank slightly, causing the glassy ash deposits to break off. This finding was incorporated in a flight crew briefing video created by the Boeing Company in 1992, *Volcanic ash avoidance—flight crew briefing*: Boeing Commercial Airplane Group, Customer Training and Flight Operations Support, which is available as Video 4V703 from the International Civil Aviation Organization (ICAO). The video discusses what pilots and airline dispatchers can do to avoid volcanic eruption clouds, and the recommended steps a pilot should take in the event of an unexpected encounter. This training video also shows how volcanic ash can affect jet aircraft and provides a pilot's first-hand account of an incident in which a Boeing 747 encountered an eruption cloud and temporarily lost power in all four engines. ICAO provides translations of the video into French, Russian, and Spanish. Presently, neither that video nor other volcanic-ash information developed by airframe and engine manufacturers is mandated for inclusion in training material for pilots. *http://volcanoes.usgs.gov/ash/trans/aviation_threat.html*

Q5. To what extent are Federal research programs on aircraft flying though volcanic ash coordinated, and how easy or difficult is it to share the research results with relevant stakeholders? What about coordination with non-U.S. research programs?

A5. Federal agencies including the Federal Aviation Administration (FAA), NASA, the National Oceanic and Atmospheric Administration, the National Weather Service, and the National Satellite, Data, and Information Service are working to improve the state-of-the-art of the global transport models needed to accurately predict volcanic ash plume location and dispersion.

Information has been shared through two international forums to date—one in Seattle, Washington in 1991 and a second in Alexandria, Virginia in 2004.

The International Civil Aviation Organization (ICAO) continues to advocate increased scientific understanding of ash cloud dynamics. In May 2010 ICAO called for establishment of the International Volcanic Ash Task Force (IVATF) to develop during the next year a global safety risk management framework that will make it possible to determine the safe levels of operation in airspace contaminated by volcanic ash. The IVATF will closely coordinate with ICAO's International Airways Volcanic Watch Operational Procedures Study Group and ICAO's European and North Atlantic Volcanic Ash Task Force. Mr. Steve Albersheim of the FAA has been nominated to represent the United States on the IAVTF and will coordinate U.S. participation in the task force activities.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Jack A. Kaye, Earth Science Division, National Aeronautics and Space Administration

Questions submitted by Chairwoman Gabrielle Giffords

Q1. I understand that NASA's MODIS instrument that is flying aboard the Terra satellite has collected data that provided information on the horizontal as well as the vertical extent of the volcanic ash plume over Iceland. To what extent will future planned instruments be capable of maintaining these types of observations?

A1. The Terra platform, launched in 1999, has two instruments that provide information about atmospheric particulates: the Moderate Resolution Imaging Spectroradiometer (MODIS) (*http://modis.gsfc.nasa.gov/*) and the Multi-Angle Imaging SpectroRadiometer (MISR) instrument (*http://www-misr.ipl.nasa.gov/*). The MODIS instrument on Terra and its twin on the Aqua satellite provide information about the horizontal and temporal variability of aerosols, but do not provide information about their vertical location. However, the MISR instrument, which is unique to Terra, has demonstrated global stereoscopic measurement of the heights of many volcanic plumes, including Eyjafjallajökull. MISR makes height estimates by taking measurements at nine different viewing angles, ranging from 70.5 degrees in front of the spacecraft to 70.5 degrees behind it. The multi-angle and multispectral capability of MISR also allows additional information to be acquired such as wind speed in the plumes and particle properties such as size and shape.

The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument will continue the MODIS observations of the horizontal extent of volcanic ash clouds. The Ozone Mapping and Profiling Suite (OMPS) will continue the Ozone Monitoring Instrument's (OMI) measurements of volcanic ash and volcanic sulfur dioxide. Both instruments, VIIRS & OMPS will fly first on NASA's NPOESS Preparatory Project (NPP) mission in late 2011 and then on subsequent Joint Polar Satellite System (JPSS) missions.

The next NASA mission that might produce a data set using both multispectral (like MODIS) and multi-angle (like MISR) approaches is the Aerosol/Cloud/Ecosystems (ACE) Mission (*http://dsm.gsfc.nasa.gov/ace/index.html*), described by the National Research Council in its 2007 Decadal Survey (*Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*). The ACE mission is one of the Survey's "Tier 2" missions, and no launch date is currently scheduled. NASA is currently investing in technology through its Earth Science Technology Office in order to advance the techniques and instrumentation that will ultimately be part of the ACE mission (see ACE-related links in *http://esto.nasa.gov/about_esto_documents.html*). Infrared observations from current (e.g. the AIRS instrument on NASA's AQUA satellite) and future research (e.g. the CRIS instrument aboard NPP) as well as operational (e.g. the IASI instrument aboard MetOp) instruments also contribute to our knowledge of volcanic gases and ash.

Q2. How challenging is it to fuse data from weather satellites, volcano observatories on the ground and science instruments in orbit? Is it mostly a technical issue or are there organizational considerations?

A2. The fusion of data from different types of instruments and platforms for scientific and/or operational uses certainly constitutes a technical challenge and can constitute an organizational one as well. Scientifically, the fusion of very different data types is best done within the context of a data assimilation system. The more different the data type, the greater the challenge in the assimilation process simply because they measure different aspects of the environment. These challenges include addressing differences in data formats, spatial resolution, measurement uncertainties, and temporal coverage among the data sources, along with subtle differences in the actual quantities being measured. Scientists at NASA and other Federal agencies, most notably the National Oceanic and Atmospheric Administration (NOAA), have significant capability in data assimilation. At NASA, most data assimilation expertise resides within the Global Modeling and Assimilation Office at the Goddard Space Flight Center—see *http://gmao.gsfc.nasa.gov/*. Most of NASA's efforts in data assimilation have emphasized atmospheric (meteorology, i.e., temperature, moisture, winds, and non-volcanic aerosols) and also oceanic and land surface data; assimilation of atmospheric aerosols is currently under development.

While satellite measurements are important for constraining the aerosol composition of the atmosphere on a global scale, much information about the timing and intensity of the volcanic emissions (most notably ash and sulphur dioxide) can be obtained from ground-based volcanic observatory data. The improved information of a volcanic event afforded by accurate surface emissions greatly enhances our ability to utilize the satellite-based measurements. Although volcanic emissions have been incorporated in retrospective data assimilation of the climate record, global multi-agency coordination is still necessary for this information to be utilized in near real time applications. In order for NASA's observation and model results to be most useful for operational purposes, continuing and enhanced cooperation between NASA personnel and the those of the Volcanic Ash Advisory Centers (VAACs), building on current successes, will be necessary.

Substantial organizational challenges do not exist, in part owing to long-time investments in comprehensive data systems, format standards, and multi-agency science centers such as the Joint Center for Satellite Data Assimilation and Short-term Prediction Research and Transition Center (SPoRT).

Q3. It has been reported that Europe needs better models to predict the path of volcanic ash and that this had been done in other parts of the world. I understand that more accurate models would allow us to be surgical in what airspace to close down and what to keep open. So how does one make a model "better"? Is more empirical data what is needed to verify the model's accuracy? What is the most effective way to collect such empirical data?

A3. There are several approaches which can be used to improve forecast models. The first step is to improve the initial conditions for such models so that they start off from conditions as close to reality as possible. For the volcanic ash case, that means knowledge about the spatial distribution of particulates and gas phase molecules ejected by the volcano, as well as the underlying meteorology (temperature, moisture, clouds) in near-real time. For particulates, it is important to know not only where they occur, but also their properties (size, chemical composition, radiative properties). The discrimination of ash from condensate clouds both horizontally, and especially vertically, is also important. Other improvements in models can come from sustained use of observations and advances in theory and modeling approaches in order to improve the representation of atmospheric processes and quantitative evaluation of models. Frequently, it is through detailed comparison of observations with models that modelers best understand the shortcomings of the models and can focus their energies on their improvement. The availability of such data is particularly important when there are only a limited number of case studies for comparison, which is the case when dealing with major volcanic clouds. These data are obtained from diverse sources: geosynchronous satellite imagers, multi-spectral techniques, polar-orbiting satellite instruments, and high-altitude airborne lidar, creating data fusion challenges. Model improvement can also come from the ability to resolve more fully the processes represented in them and the spatial scales at which they operate. Achieving enhanced resolution in these areas is dependent on the availability of adequate computational resources, without which approximations that may degrade model quality are required. The development, improvement, and utilization of forecast models is a labor-intensive effort that requires sustained effort by a multi-disciplinary team able to harness the power of observations, theory, and computation to provide results for real-time use.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Ms. Victoria Cox, Senior Vice President, Nextgen and Operations Planning, Air Traffic Organization, Federal Aviation Administration

Questions submitted by Chairwoman Gabrielle Giffords

Q1. The FAA Administrator was reported to have suggested that Europe take the lead in establishing a standard for future volcano situations but offered FAA's technical assistance. What type of technical assistance was he referring to and why does he believe Europe should be taking the lead in establishing a standard?

A1. The FAA will provide assistance to the European community in establishing a standard for situations related to volcanic eruptions. This assistance involves many different levels of expertise. The FAA has already established a team of experts who will be supporting the FAA on the International Civil Aviation Organization (ICAO) Volcanic Ash Task Force. The FAA will work in a collaborative decision making process through the ICAO on the establishment of any global standards for volcanic ash in support of aviation. Specifically, the FAA in consultation with the NOAA/NWS/NESDIS will examine the current state-of the-art of global transport models and define the operational performance requirements for these models for decision support tools for operators. In addition, the FAA will work collaboratively with the United States Geological Survey on the development of good scientific practices for any proposed international standards that support modeling.

Q2. What was the extent of FAA's consultation with international aviation regulatory agencies and aircraft manufacturers in developing the Special Airworthiness Information Bulletin on volcanic ash operations FAA released on April 22, 2010?

A2. The FAA participated in a series of international volcanic ash teleconferences that started on April 17, 2010. On April 22, the FAA issued Special Airworthiness Information Bulletin (SAIB) NE–10–28 after close consultation with European and Canadian regulatory agencies and aviation industry. The FAA worked closely with the European Aviation Safety Agency as each authority shared their draft safety bulletins with each other. The regulatory agencies and industry reached consensus prior to final issuance of our respective bulletins. In addition, the FAA held separate teleconferences with engine manufacturers to assure a coordinated industry/regulator response. The FAA also requested each of the manufacturers to issue immediate guidance to the airlines on inspections after an ash encounter.

Q3. To what extent are Federal research programs on aircraft flying through volcanic ash coordinated, and how easy or difficult is it to share the research results with relevant stakeholders? What about coordination with non-U.S. research programs?

A3. The FAA does not sponsor any specific Federal research program that addresses aircraft flying through volcanic ash. There is research supported by other Federal agencies that examines the state-of-the-art in modeling, forecasting, and using remote sensing to provide greater accuracy on the location of ash clouds. These combined programs result in a body of knowledge that supports the issuance of warning messages to avoid or mitigate ash encounters. Similar to our work in forecasting convective weather, this research is focused on ash avoidance—not on engine tolerance. The International Civil Aviation Organization, the World Meteorological Organization, and the International Union Geodesy and Geophysics work collaboratively to promote scientific understanding of volcanic eruptions and subsequent ash clouds that affect aviation. The information is shared at international fora and through peer review of published papers. All information garnered from these fora are shared with all interested stakeholders.

Q4. As you know, the National Weather Service's (NWS) Volcanic Ash Advisory Centers (VAAC) and Meteorological Watch Offices (MWO) provide warnings and advisories to the aviation industry regarding volcanic ash hazards. Such weather products area a vital component of FAA's air traffic control system.

a. During recent volcanic ash incidents, how would you characterize the role of the NWS and the working relationship between FAA and NWS?

A4a. The FAA and NWS work collaboratively in a positive manner on detecting and reporting volcanic ash that can pose a hazard to aviation. As you have noted, the NWS provides advisories and warning messages from VAAC and the MWO respectively. The FAA's responsibility is to disseminate the information to flight crews and airline operation centers. The FAA operates and maintains the aeronautical fixed services (AFS) that disseminate all ICAO-compliant messages to stakeholders. These messages receive high priority distribution over the AFS and are immediately integrated into support decision tools for flight planning purposes.

With regard to the eruption of Mount Eyjafjallajokull, the NWS had no direct involvement because the ash cloud did not affect a U.S. Flight Information Region under the responsibility of a NWS VAAC. The role of the Washington VAAC was to advise users to check the London VAAC for information on the ash cloud. The FAA also worked collaboratively with National Air Traffic Services on contingency plans for the overseas tracks that were available to avoid the ash cloud.

b. How did the NWS work products mitigate the impact these incidents had on aviation?

A4b. Although the ash cloud that resulted from the eruption of Mount Eyjafjallajokull did not affect a U.S. Flight Information Region, the Washington VAAC, if requested by the FAA, would provide any pertinent information in support of traffic flow management as to how the ash cloud might affect operations.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Captain Linda M. Orlady, Executive Air Safety Vice Chair, Air Line Pilots Association, International

Questions submitted by Chairwoman Gabrielle Giffords

Q1. A Wall Street Journal *article reported the following:*

> *Meanwhile, commercial pilot groups remain concerned about the safety implications of the current situation. For instance, the Air Line Pilots Association, the largest pilot union in North America, on Friday warned members to identify alternate or escape routes to avoid ash clouds. Descending and turning around is recommended by the union, rather than climbing through such clouds. Upon encountering volcanic debris, ALPA recommends that pilots reduce engine thrust to idle and don oxygen masks. And the union's update stressed that if an engine shuts down, it may take longer and be harder to restart than normal.*

Is such a warning from ALPA unusual? What has been the feedback from your members?

A1. Safety guidance provided by ALPA to its member pilots is not unusual. When ALPA becomes aware of a safety concern such as a potential volcanic eruption which could have an immediate impact to a broad spectrum of our members, the applicable information is then distributed to our members via ALPA Safety Alerts and/or Operational Bulletins. For example, since 2005 ALPA has issued 64 Safety Alerts and Operational Bulletins, four of which have been related to volcanic activity. In the case of potential volcanic ash encounters, the guidance provided by ALPA is considered by its members as useful backup information which is complementary and consistent with guidance from operators, aircraft manufactures and the FAA. The feedback received from our membership is that these Safety Alerts and Operational Bulletins are quite helpful and are often shared with the management of their airline for further dissemination.

Q2. In your statement, you raised an issue that has been seldom mentioned by the media following the Icelandic volcano eruption, namely that volcanic gases such as Sulfur Dioxide (SO_2) or Hydrogen Sulfide (H_2S) could pose potential health hazards to passengers and crews. Who do you believe should be conducting research in the health effects of volcanic ash on aircraft passengers and crews?

A2. ALPA believes the FAA should take the lead in sponsoring and conducting research on the effects of volcanic gases on aircraft occupants, and in particular the FAA Civil Aerospace Medical Institute (CAMI) located in Oklahoma City. CAMI is the medical certification, research, education, and occupational health wing of the FAA's Office of Aerospace Medicine. The goal of CAMI is to enhance aviation safety.

Q3. At the hearing, we discussed the need for onboard warning of volcanic ash conditions. How high a priority is it for pilots that we have such an airborne capability?

A3. Currently aircraft weather radar systems cannot detect volcanic ash clouds. Consequently, at night or in low visibility conditions, pilots have no way of knowing where the potential danger areas are other than by weather forecast or reports from other pilots who have encountered the ash cloud. Forecast information is by its nature an estimation rather than a direct observation of actual conditions. Even reports from other pilots do not necessarily reflect what may be occurring immediately around another aircraft. If in the future, pilots are expected to consider operations in some scientifically pre-determined acceptable levels of volcanic ash concentration, then there must be some onboard sensing and warning capability to enable the pilot to remain clear of the danger areas. Until such capabilities are available to the pilots, flight into known volcanic ash areas of any concentration level is to be avoided.

Questions submitted by Representative Pete Olson

Q1. Your statement emphasized the importance of developing standardized data products for use by flight crews, dispatchers and air traffic controllers to track volcanic clouds. Presumably, your peers at other carriers here and abroad would similarly benefit from a common set of standards and definitions. What organization, in your view, should lead this effort, and why hasn't this type of standardized data format already been implemented?

A1. In our view, the FAA would be the lead organization within the U.S. for coordinating the development of standardized data products to track and detect volcanic ash clouds. And to effectively achieve a global standardization of definitions and products, the International Civil Aviation Organization (ICAO) would lead with the FAA participating. The FAA can better answer the status of any such activity and why products, if available, have not already been implemented.

Q2. Following resumption of air operations in Europe, including flights into or near airspace containing volcanic ash, what has been the anecdotal experience of operators and flight crews? Are they seeing any surprises with respect to engine damage, abrasion, or degradation of other aircraft systems? Have air service authorities become more adept at coordinating traffic? Have the volcanic could models proved reliable?

A2. Since the resumption of air operations in Europe we have seen a heightened awareness by the aircrews concerning the potential dangers of volcanic ash encounters. There has also been significant activity among the European aviation regulators and industry to determine if an acceptable concentration level of volcanic ash can be established for safe flight. But until any new policy or technology is provided, we have advised our membership to stay fully cognizant of and to abide by their particular airline's policy for flight in the vicinity of volcanic ash. To the best of our knowledge the U.S. air carriers and the FAA, although looking into the matter, have not changed their previous policies that flight into known volcanic ash conditions is to be avoided. Consequently, we have not seen a rise in the amount of damage to aircraft due to inadvertent volcanic ash encounters. We are not aware if there has been any change in the difficulty of coordination of air traffic with respect to volcanic activity or if the forecast models have been updated. However, we are concerned that flight safety would be compromised if new policies are implemented where pilots are expected to enter into known areas of volcanic ash concentration, yet are not equipped with the means to measure if the concentration levels are within pre-determined acceptable thresholds.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Roger Dinius, Flight Safety Director, GE Aviation

Questions submitted by Chairwoman Gabrielle Giffords

Q1. It is probably impractical and uneconomical to design a jet engine that can withstand all volcanic ash conditions. From what we know about aircraft engines, aviation safety, and the economics of the airline industry, what is the best that we can expect from future engine technology improvements?

A1. Today GE & our partners have approximately 25,000 engines operating world wide in commercial service. It is expected to be economically impractical for all engines in the fleet to be retrofitted if a "volcanic ash kit" were identified.

It is not anticipated that significant technology advances will be made to "harden" modern commercial turbojet engines to volcanic ash exposure. There is not an anticipated commercial market for an engine robust to volcanic ash, if it costs any more than today's engines. Technologies would be required to: 1) eliminate the need for hot section cooling, 2) an "ash-phobic" coating would be required on all hot section components, and 3) advances would be required in anti-erosion materials. Additionally, oil system components would need to be designed to be robust to ash contamination.

Q2. Captain Orlady indicated in her statement that aircraft certification requirements will need to be updated to provide for more ruggedized aircraft health monitoring systems and management processes. Recognizing that GE aircraft engines are part of the aircraft's overall system, what are your views on Captain Orlady's suggestion?

A2. If the industry elects intentionally fly into volcanic ash, a "history record" will likely be required to keep track of the volcanic ash exposure. This "history record" will likely involve a volcanic ash exposure record that will likely be a function of power setting of engine, engine operability margin available, local ash concentration and exposure time. Today, technology does not support a sensor that can determine the local ash concentration on-board commercial aircraft. This is not expected to be operationally economical, and it will likely degrade overall aviation safety. GE does not recommend flight into visible volcanic ash.

Q3. I understand that engine manufacturers and international aviation regulators had been in discussion for a few years on trying to establish the concentration level of volcanic ash an engine could tolerate without causing a safety hazard. Six days after the closure of European airspace, consensus was reached. Why was consensus so difficult to achieve and what finally precipitated an agreement?

A3. GE was not involved in establishing an engine tolerance level for volcanic ash over the past few years, until April 16, 2010. The difficulty in establishing a tolerable level of volcanic ash centers on the assumption that a concentration level is all that is important to understand engine damage. Actually it is only one of several factors critical to assess the impact. It is anticipated to understand engine tolerance requires knowledge of exposure time, engine condition prior to encounter, particle size distribution, and ash chemistry. The airspace closure over Europe brought engine manufacturers and government agencies together to assess available data to establish the current interim ash concentration limits. Long-term engine impacts of operations in these levels of volcanic are unknown. GE continues to recommend against flight in visual volcanic ash.

Questions submitted by Representative Pete Olson

Q1. Your written statement noted that it is 'acceptable' for jets to fly through volcanic clouds having ash equal to or less than 2 milligrams per cubic meter. What do you mean by using the term 'acceptable'? Are modem turbojet engines capable of operating in such an environment without enduring any lasting, long-term damage? Would operators be at risk of having to overhaul their engines on a shorter cycle because of this level of exposure?

A1. "Acceptable" here referred to a qualitative engine impact assessment where engines impacts are limited to economic impacts and not operational safety impacts. If engines are operated in volcanic ash environments, up to 2 milligrams per cubic meter, cumulative engine damage is anticipated which will drive engines off wing early and require a shop level overhaul to restore engine performance. GE does not recommend flight into visible volcanic ash.

Q2. Following resumption of air operations in Europe, including flights into or near airspace containing volcanic ash, what has been the anecdotal experience of operators and flight crews? Are they seeing any surprises with respect to engine damage, abrasion, or degradation of other aircraft systems? Have air service authorities become more adept at coordinating traffic?

A2. No unserviceable conditions have been observed to date from volcanic ash exposure following the April 2010 Icelandic volcanic activity, to my knowledge. No flight crew reports of volcanic ash encounters impacting engine operation have been reported, to my knowledge. Based on inspection results to date engines accumulated ash, but not to a point of being unserviceable. I don't have an expertise in air traffic or the air service authorities capabilities, so can't comment on their past or current capabilities.

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