6.2

ROLE OF THE AVIATION WEATHER SYSTEM IN PROVIDING A REAL-TIME ATC VOLCANIC ASH ADVISORY SYSTEM*

James E. Evans
Melvin L. Stone

Massachusetts Institute of Technology
Lincoln Laboratory
Lexington, Massachusetts 02173-9108

1. INTRODUCTION

Inadvertent engine ingestion of volcanic ash has caused expensive damage to a number of aircraft recently and could have caused accidents in at least two cases.[Casadevall, 1993] Consequently, there is great interest in a real-time air traffic control (ATC) volcanic ash advisory system which could provide timely warnings of operationally significant ash concentrations to planes in flight as well as information for flight planning.

The current system (see figure 1) is characterized by non-automatic determination of ash eruption characteristics (especially altitudes) with trajectory analysis based on the National Meteorological Center (NMC) forecast winds being used to provide warnings of future locations. SIGMETS and Airport Weather Advisories are the principal means of providing information on the ash locations to pilots and controllers.

After one to three days, volcanic ash from Alaska can be transported over major portions of the US aviation system (figure 2) [Heffter, et al. 1990]. The operational use of the ash trajectory predictions which do not provide information on hazard associated with the ash density has resulted in more frequent disruption of air traffic. The most recent example was an incident on 19 September 1992 where a 17 September eruption from Mt. Spurr in Alaska resulted in a significant disruption of air traffic in the Upper Midwest. A workshop in Washington, DC [Machol, 1993] discussed many of these issues associated with the Spurr disruption and the operational response to ash clouds which had been drifting for several days.

2. ROLE OF FUTURE AVIATION WEATHER SYSTEM

This paper discusses how the weather sensors and an aviation-oriented weather information dissemination system currently under development by the Federal Aviation Administration (FAA) and National Weather Service (NWS) [Sankey and Hansen, 1993] could play a key role in generating and disseminating volcanic ash advisory information to the aviation system. Although this aviation weather system has been developed to meet other important ATC needs, its existence and development offers the possibility of a more cost-effective volcanic ash advisory system than would be possible with a stand-alone system. As shown in figure 3, this system is characterized by Aviation Gridded Forecast System (AGFS) algorithms operating on the NMC 4D database of state of atmosphere variables (SAV) (winds, temperature, humidity, pressure) to provide a 4D database of aviation impact variables (AIV) such as icing, turbulence, winds aloft, ceiling and visibility. The Aviation Weather Product Generator (AWPG) will manipulate the AIV database to generate, display and disseminate operationally usable products to controllers, traffic managers, CWSU meteorologists and airlines. In the terminal area, the Integrated Terminal Weather System (ITWS) will use the AGFS database together with data from sensors near the terminal area (e.g., TDWR and NEXRAD) to provide a similar high-resolution database and user-friendly products.

We suggest a system (figure 4) in which volcanic ash is treated as a type of AIV from the viewpoint of information dissemination. Real-time information from ground, aircraft and satellite sensors would be combined with the numerical model predictions of ash transport to provide real-time estimates and predicted 3D locations of various levels of ash concentration. The real-time location estimates would be provided to en route air traffic controllers and pilots to assist in tactical decision making while the predictions would be provided to the traffic management units (TMU) in en route/national centers and to airlines for strategic planning.

3. DETERMINING ASH CONCENTRATION AND LOCATION

A key element of the recommended system is the determination of spatial location of operationally significant ash concentrations (as opposed to the current estimates of an unspecified ash concentration over very large geographical areas). Providing this information will require improvements in the knowledge regarding operationally significant ash concentrations and in the ability to sense and predict ash concentration remotely.

Table 1 summarizes the principal ash surveillance sensor options. Radar appears to be the most attractive ground-based sensor for operation in Alaska and the

---

* This work was sponsored by the Federal Aviation Administration. The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Government.

Northwest (locations of the principal active US volcanoes) due to the high likelihood of rain clouds in these areas. Weather radars have been found to be useful for estimating volcanic ash characteristics of the Mt. St. Helens eruption[Harris and Rose, 1983], and a research radar was deployed near the Alaska volcanoes in the past year[Rose and Kostinski, 1993]. A number of WSR-88D (NEXRAD) radars will be deployed to Alaska and the Pacific Northwest [Stone, 1993]. Volcanic ash particles that drift away from the immediate vicinity of a volcano typically have diameters less than 1 mm and, hence, can be regarded as Rayleigh scatters for both the TDWR and NEXRAD systems.

However, the sensitivity of the radar systems is such that useful information can be obtained only relatively near the volcano. To illustrate, tests on jet engines suggest that an engine ingestion rate of 1 kg/min is enough to produce engine stoppage [Casadevall, 1993]. If we assume that all the ash particles have diameters of 1 mm (corresponding roughly to clouds within 50 km of the volcano [Rose, 1987]), the effective dBZ is approximately +17 dBZ, which is detectable by both NEXRAD and TDWR to 400 km (the NEXRAD clear-air mode would detect such clouds to over 800 km).

Table 1.
Ash Surveillance Sensor Options

	Weather Radar	Laser Radar (LIDAR)	Passive Radiometer	*In situ* Sampling	Visual
Density	fair	good	poor	yes	poor
Sizes	no	perhaps	no	yes	no
Volume Extent	near volcano	yes	fair	fair	fair
Column Height	near volcano	yes	no	no	yes
Motion	yes	yes	fair	fair	fair
Cloud Penetration	yes	poor to none	poor	vehicle dependent	poor to none

However, if all the ash ingested by the engine had diameters of 10 µm (typical of ash clouds that have been drifting for 1-2 days), it would have a -43 dBZ effective reflectivity, which is not practically detectable by TDWR or NEXRAD. Hence, we conclude that the microwave weather radars can be useful for initial ash cloud parameter estimation but would not be practically useful for detecting or validating the ash advection model for ash clouds that had been drifting for over a day.

The best option for monitoring such "old" ash clouds would appear to be *in situ* sensing. There are two potentially cost-effective options. One would be to design a sensor that could be located on commercial aircraft which would determine ash densities and report results via data link (e.g., with ACARS as is done for temperature and winds). This would be useful for identifying the edges of ash clouds and validating propagation models.

Safety considerations and the need to make measurements in areas (e.g., northern Canada) that do not have many air carrier flights suggest the use of an unmanned air vehicle (UAV) such as recently proposed for hurricane monitoring [Langford and Emanuel, 1993]. Such UAVs have sufficient range and time aloft (see figure 5) to be of use for monitoring ash clouds at long distances from a cloud.

4. NEXT STEPS

Significant research work is needed in several directions to provide the capability discussed above:

1. Obtaining a quantitative characterization of the threat ash densities for modern high by-pass engines,
2. Developing and validating models for ash location and concentration,
3. Adapting the NEXRAD scan strategies, display characteristics, and product algorithms for systems near volcanoes to better provide the input needed for the overall volcanic ash advisory system, and
4. Developing a cost-effective system (e.g., the UAV system discussed above) for verification of ash concentrations 1-2 days downwind of a volcanic eruption.

In the near term, the current ash trajectory prediction model needs to be interfaced to the AGFS and suitable products defined for the AWPG.

REFERENCES

Casadevall, T. 1993: Proceedings Volume of the First International Symposium on Volcanic Ash and Aviation Safety, USGS Bulletin 2047.

Harris, D.M. and W. I. Rose, 1983: "Estimating particle sizes, concentrations, and mass of ash in volcanic clouds using weather radar," *Jour. Geophys. Res.*, **88**, 10969-10983.

Heffter, J.L., B.J. Stunder, and G.D. Rolf, 1990: "Long-range forecast trajectories of volcanic ash from Redoubt volcano eruptions," *Bull. of Am. Meteor. Soc.*, **71**, 1731-1738.

Langford, J. and K. Emanuel, 1993: "An unmannned aircraft for drop windsonde deployment and hurricane reconnaissance," *Bull. Amer. Meteor. Soc.*, **74**, 367-375.

Machol, R. 1993: Federal Aviation Administration Workshop on Old Volcanic Ash Clouds, Washington, DC. April 22-23, 1993.

Rose, W., 1987: "Interaction of aircraft and explosive eruption clouds: a volcanologist's perspective," *AIAA Journal*, 25, 52-58.

Rose, W. and A. Kostinski, 1993: Near real time radar observations of 1992 eruption clouds from Crater Peak/Spurr Volcano, Alaska, submitted for USGS Bulletin (Spurr) ed. by T. Keith

Sankey, D. and A. Hansen, 1993: FAA's work in improving aviation weather, Presentation at Am. Meteor. Soc. 9th Intl. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology IIPS), Anaheim, CA.

Stone, M., 1993: Application of contemporary ground-based and airborne radar for the observation of volcanic ash, Proceedings Volume of the First International Symposium on Volcanic Ash and Aviation Safety, USGS Bulletin 2047.

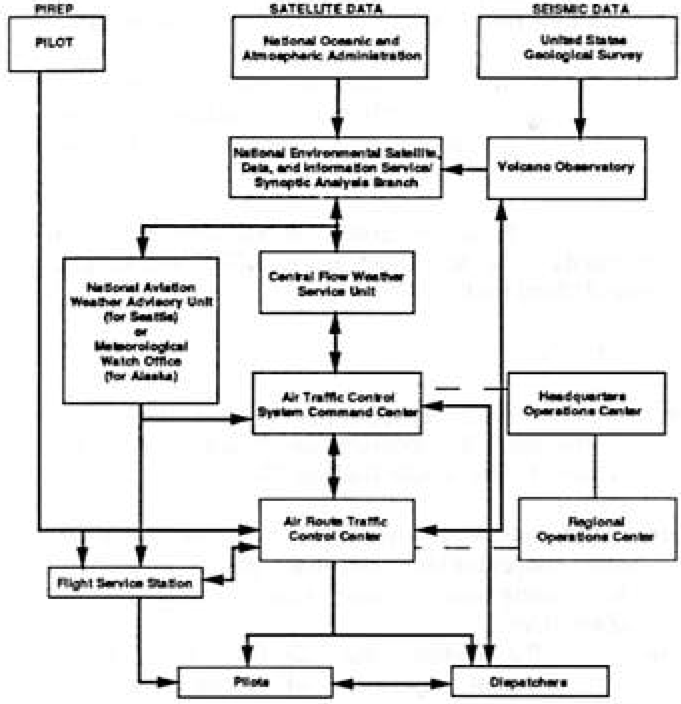

Figure 1. Current information flow following volcanic eruption.

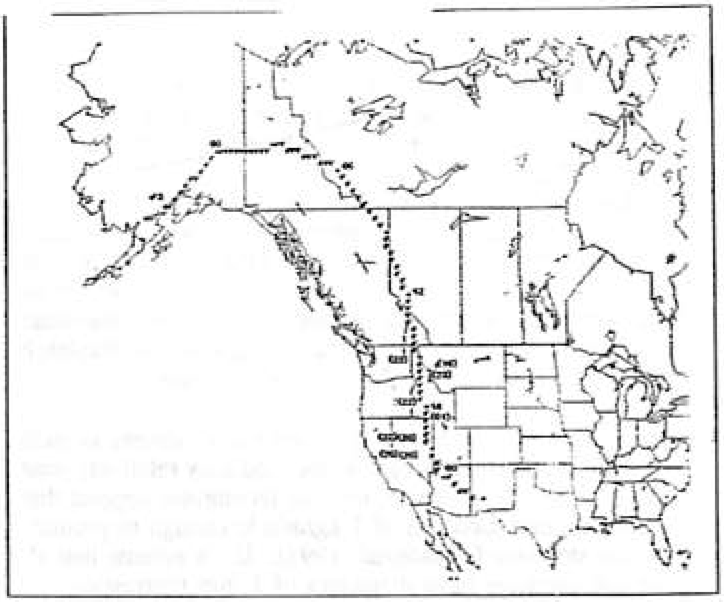

Figure 2. Comparison of 300 mb forecast trajectory for eruption 2 from Mt. Redoubt at 19 UTC on 15 December 1990. Ash sighting locations, appropriate at the 300 mb level, are given by parenthetical pairs with the UTC time of the sighting within parentheses. Sightings are on 16 December with the exception of (01) on 17 December. Note that the ash trajectory intersects the bulk of the U.S. air carrier routes to and from the West coast. [from Heffter, 1990].

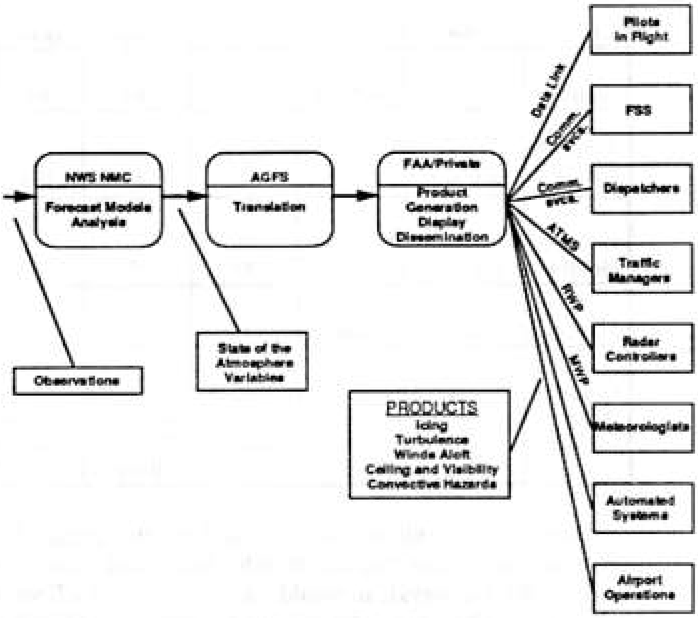

Figure 3. Future en route aviation weather system.

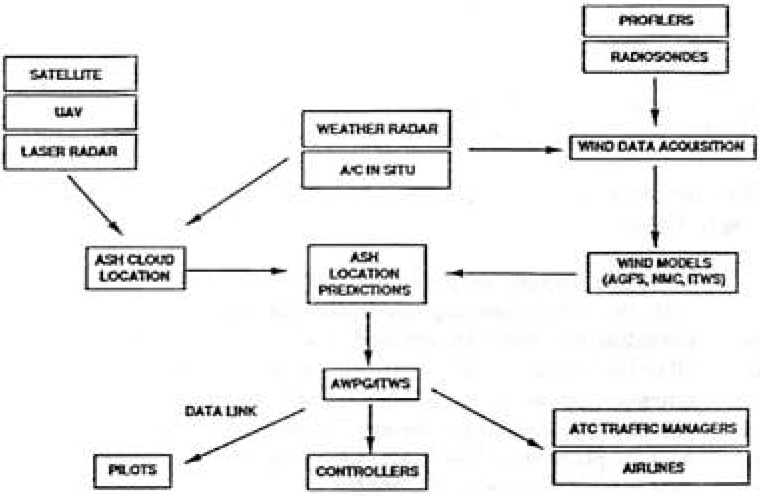

Figure 4. Major elements of recommended volcanic ash advisory system for aviation. Gridded wind forecasts are combined with ash locations measured near and downwind of the volcano to generate 4D predicted locations of ash clouds. Distribution of the 4D ash locations are accomplished by the FAA/NWS weather information systems.

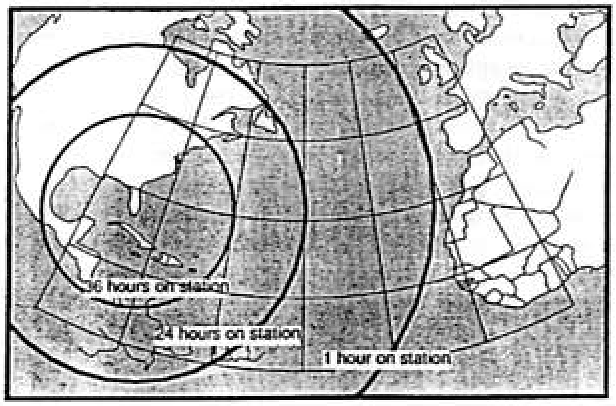

Figure 5. Projected range of Perseus B UAV [Langford and Emanuel, 1993].