DEPARTMENT OF THE AIR FORCE
Headquarters Aeronautical Systems Center (AFMC)
Engineering Directorate
Wright-Patterson AFB OH 45433-7101

AA-10-03
19 July 2010

AIRWORTHINESS ADVISORY

USAF AIRCRAFT OPERATIONS IN VOLCANIC ASH ENVIRONMENTS

PURPOSE:

This airworthiness advisory addresses operational risk assessment requirements, flight operations and inspection and maintenance actions associated with USAF aircraft operations in volcanic ash environments.

SCOPE:

This airworthiness advisory applies to all USAF aircraft, manned and unmanned, including those operated by the Air National Guard and the USAF Reserve.

REFERENCED DOCUMENTS:

1. Airworthiness Advisory AA-10-01, Volcanic Ash Effects on Aircraft and Procedures for Addressing Exposure, dated 28 April 2010

2. United Kingdom (UK) Civil Aviation Authority (CAA), Rationale for the Introduction of a 'Time Limited Zone' for Operations in Volumes of Airspace Forecast to contain Levels of Volcanic Ash, V1.0, dated 17 May 2010

3. MIL-STD-882D, Department of Defense, Standard Practice for System Safety, 10 February 2000

4. Air Force Instruction 91-202, Air Force Material Command Supplement, Incorporating Change 1 dated 10 February 2009, Safety, The US Air Force Mishap Prevention Program

5. Air Force Instruction 91-202, Incorporating Change 1 dated 18 February 2010, Safety, The US Air Force Mishap Prevention Program

6. Cleaning and Corrosion Prevention and Control, Aerospace and Non-Aerospace Equipment, Technical Order (T.O.) 1-1-691, dated 19 October 2007

7. Maintenance Assistance, T.O. 00-25-107, dated 31 May 1999

8. Federal Aviation Administration, Aeronautical Information Manual, Official Guide to Basic Flight Information and ATC Procedures, Appendix 2 Volcanic Activity Reporting Form, February 11, 2010 [http://www.faa.gov/air_traffic/publications/atpubs/aim/]

DISTRIBUTION STATEMENT A. Approved for public release, distribution is unlimited.

APPENDICES:

Appendix 1: Risk Assessment Methodology for USAF Aircraft Exposure to Volcanic Ash
Appendix 2: Aircraft Volcanic Ash Encounter Mitigation Guidance
Appendix 3: Supplemental Inspection/Maintenance Guidance for Volcanic Ash Encounters

BACKGROUND:

The information presented in this section is intended to provide a common understanding of worldwide volcanic activity, standardized volcanic ash cloud reporting resources and the unique ash concentration standards utilized in Europe for aircraft operations affected by the eruption of the Icelandic Volcano, Eyjafjallajökull. Reference 1 was issued in response to that volcanic activity and provided general guidance on USAF aircraft flight operations and maintenance for volcanic ash contamination. This document augments information presented in the prior advisory by providing additional guidance for addressing volcanic ash exposure.

1. Presently, meteorological observation, sampling techniques and reporting methodologies are not optimum for supporting time-dependent mission critical aviation operations. Volcanic ash particulate density, composition and dispersion forecasting techniques have not been standardized and regional weather service ash cloud concentration and dispersion models have not been validated for their accuracy and are not available for worldwide application.

2. The Global Volcanism Program (http://www.volcano.si.edu/reports/usgs/) reported 16 active volcanoes for the week of 30 June 2010. It is generally accepted that this level of volcanic activity is normal. This fact highlights the need for addressing volcanic activity in planning and executing USAF flight operations.

3. Tracking, reporting and issuing advisories on volcanic activity worldwide is the responsibility of nine Volcanic Ash Advisory Centers (VAACs). These centers are part of an international system called the International Airways Volcano Watch (IAVW) established by the International Civil Aviation Organization (ICAO). Each VAAC is hosted (and administered) by a regional national weather service provider. The Anchorage VAAC (for example) is responsible for Alaska and a large area of Northeast Russia and is administered by the National Oceanic and Atmospheric Administration National Weather Service; the London VAAC covering the United Kingdom and the North Atlantic is administered by the MET Office (the UK National Weather Service). The VAACs utilize standardized volcanic activity warning codes and publish Volcanic Ash Graphics (VAGs) and Volcanic Ash Advisories (VAAs). In addition, VAAC websites publish critical aviation information on volcanic activity and ash cloud threat information in Significant Meteorological Information (SIGMETs) and Notices to Airmen (NOTAMS). VAGs are published multiple times each day (depending on volcanic activity level) and provide standardized, graphical information on ash cloud elevation and area (depicted in figure 1 below). These graphics do not report ash concentration levels.

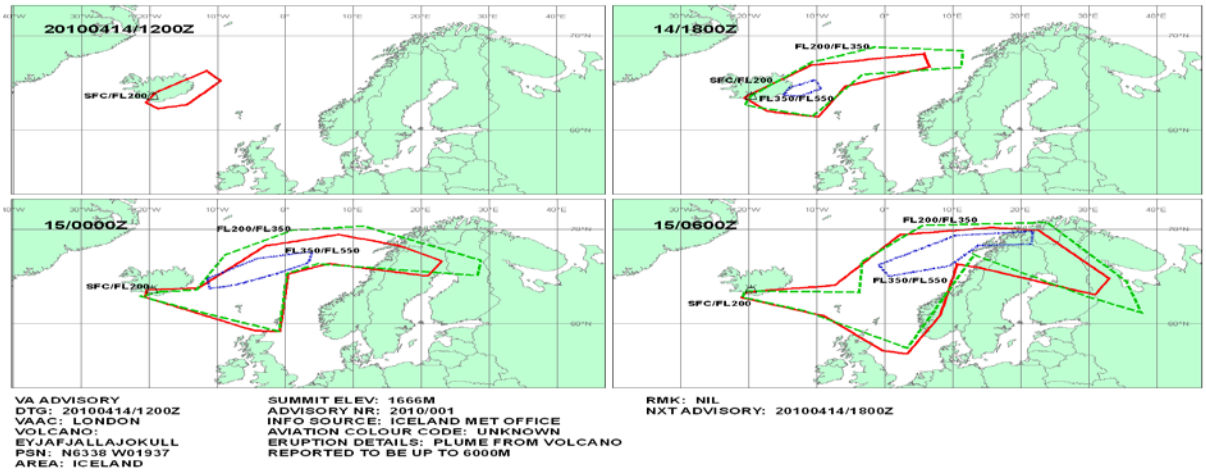


FIGURE 1
Sample of London VAAC Volcanic Ash Graphic (VAG) Showing Cloud Locations for Standard Altitudes and Times

4. The MET Office (for the London VAAC), has been responsible for tracking the ash cloud produced by Eyjafjallajökull and is unique among the VAACs in publishing ash cloud concentration charts derived from a combination of satellite (and other source) imaging technology and cloud concentration and dispersion modeling. In collaboration with the UK CAA, the MET office developed the ash concentration charts to forecast ash density and dispersion information for use in managing European civil and military aircraft operations. The concentration charts (example depicted in figure 2 below) present volcanic ash density information in color-coded zones which correlate to UK CAA published direction on aircraft operational restrictions and limitations:

a. The black zone identifies ash concentration levels that exceed engine manufacturer limits for safe operation and represent densities greater than 4×10^{-3} g/m^3.

b. The grey zone identifies ash concentration levels that range from 2×10^{-3} g/m^3 to no more than 4×10^{-3} g/m^3.

c. The red zone identifies ash concentration levels that range from 2×10^{-4} g/m^3 to no more than 2×10^{-3} g/m^3. Concentrations below 2×10^{-4} g/m^3 are characterized as having no impact on aviation operations.

5. The UK CAA developed the aviation operational restrictions in collaboration with aerospace industry Original Equipment Manufacturers (OEMs) and airline industry and published them in an advisory (reference 2). The ‘No-Fly’ region corresponds to the MET office ‘black zone’ within which aircraft are prohibited from operating. The ‘Time Limited Zone’ or TLZ corresponds to the ‘grey zone’ within which operations are subject to time limits as established in consultation with specific aircraft OEMs and an ‘Enhanced Procedures’ zone corresponds to

the ‘red zone’ within which flight operations are permitted only in consultation with OEMs for prescribed recurring additional maintenance procedures.

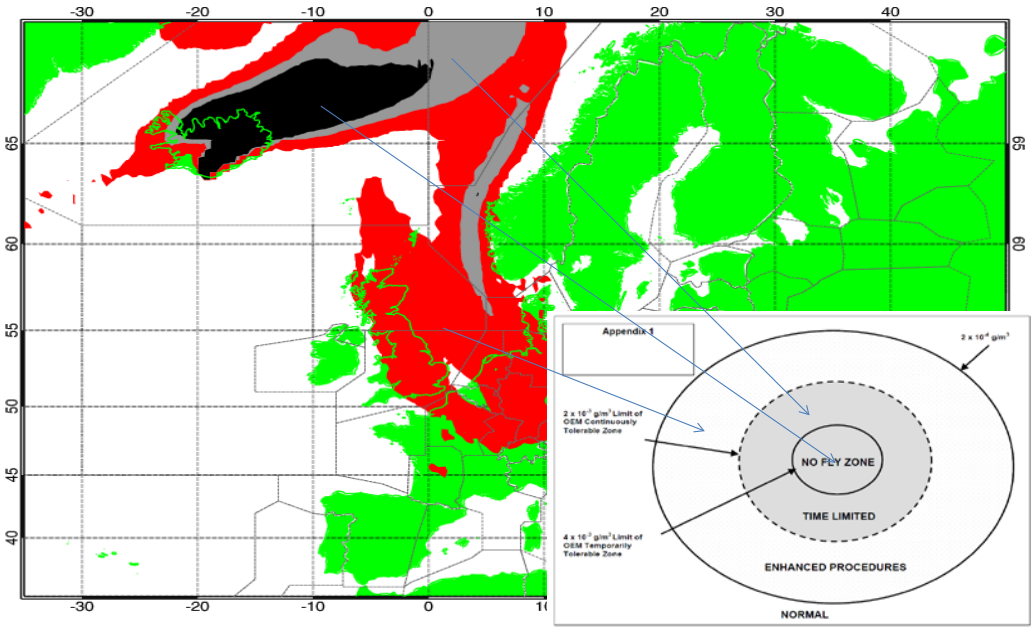


FIGURE 2
MET Office (Sample) Concentration Chart and UK CAA Aviation Flight Limit Zones

6. An early version of the UK CAA flight limits advisory released in April 2010 provided some insight into model predictions of ash concentrations as compared to density values assigned to those concentrations for use in the flight limit zones. That documentation showed that the model forecast ash densities of 1 x 10^{-16} g/m^3 were assigned an ‘expected’ ash density value of 2 x 10^{-3} g/m^3 (the original threshold limit for the no-fly zone). The significant order of magnitude adjustment in predictions used as an expected density level may be an indication of the degree of uncertainty associated with concentration and dispersion predictions.

DISCUSSION:

This advisory treats potential aircraft exposure to volcanic ash as a global threat and provides guidance on assessing volcanic ash environments world-wide. Specifically, this advisory highlights volcanic ash threat considerations for mission planning, documents aircraft functional hazards for use in applying an operational risk assessment methodology, addresses in-flight volcanic ash encounter flight crew mitigation actions and identifies supplemental inspection and maintenance actions.

1. In response to the operational community’s desire to characterize the “risk of operations in the UK CAA defined enhanced procedures zone,” ASC/EN developed the risk assessment methodology presented in appendix 1. The methodology includes a risk matrix accounting for the requirements specified in reference 3 and provides hazard logic diagrams addressing system specific configuration considerations. ASC/EN and AFRL/RZ collaborated in an evaluation of

the UK CAA flight limitations documented in reference 2 and concluded that USAF should not rely on the ash concentration forecasts and should not utilize the flight limitation zones. The collaborative assessment included an extensive evaluation of research material, test data and study literature from a number of agencies, academic institutions, certification authorities and industry aerospace system technical reports. The assessment concluded:

a. The modeling used to forecast the volcanic ash concentration levels and particulate dispersion has not been sufficiently validated for accuracy.

b. The concentration forecasts are currently only provided for ash clouds being tracked through the London regional VAAC and cannot be used for evaluating the volcanic ash threat world-wide.

c. Limited-to-no engineering data exists to characterize the impact of volcanic ash on air vehicle equipment and propulsion systems as a function of concentration levels.

d. Studies and tests have not been performed at the concentration levels addressed in the UK CAA advisory to assess system degradation as a function of ash exposure frequency and duration.

2. Accordingly, the risk assessment methodology employs an alternative set of criteria for assessing volcanic ash exposure (adapted from the Volcanic Ash Encounter Severity Indices developed by T. Casadevall (United States Geological Service) and T. Fox (International Civil Aviation Organization)). A description of the indices (and a discussion of their use) is included in appendix 1. In addition to characterizing the ash threat based on the cueing information provided by the indices, it relies only on the standard VAGs and other advisory products available universally through the VAAC network.

3. In-flight mitigation actions associated with inadvertent volcanic ash encounters and inspection and maintenance actions (supplemental to those specified in general and weapons system specific maintenance and repair technical orders) are components of an overall operational risk assessment methodology. To that end, three (3) appendices are included in this advisory to provide specific information for managing flight operations in volcanic ash environments. A brief overview of each appendix is included below:

a. Appendix 1: A risk assessment methodology and supporting functional hazard logic diagrams are provided for use by operators in assessing operational risk associated with volcanic ash exposure. It is essential that the responsible program office engineering organization (along with the OEM as appropriate) should be involved in the application of the risk assessment methodology to any given weapon system.

b. Appendix 2: Summarizes risk mitigation actions and considerations associated with inadvertent encounters with volcanic ash. The measures outlined in this appendix should be

evaluated for system specific capabilities and used to (supplement) procedures defined in system specific flight manuals.

c. Appendix 3: Provides a summary of additional inspection and maintenance requirements associated with aircraft operational exposure to volcanic ash. The provisions discussed in this appendix are a byproduct of the risk assessment and hazard logic diagrams and are intended as supplemental to general and system specific inspection and maintenance technical order data.

GUIDANCE/RECOMMENDATIONS:

1. Mission planning should utilize the Volcanic Ash Advisory Center (VAAC) for the latest information on volcanic eruptions, alert levels, Volcanic Ash Graphics (VAGs) and Volcanic Ash Advisories (VAAs) for the region(s) through which missions are to be conducted.

2. USAF aircraft should never be operated into VAAC identified ash cloud regions as depicted in VAGs and described in VAAs. Continuing flight operations in volcanic ash (once encountered) must be avoided.

3. Mission planning should account for supplemental information available through the FAA, regional airworthiness authorities and airport, airfield and air traffic control facilities on flight conditions in establishing flight routes. Additional guidance may be available in Notices to Airmen (NOTAMS) and Significant Meteorological Information (SIGMETs) documentation.

4. The risk assessment methodology presented in appendix 1 can be used to assess the risk of flight operations in identified volcanic ash regions. The methodology also serves as a guide to flight crews for assessing an inadvertent volcanic ash encounter threat and outlines post-flight inspection/maintenance activities associated with the severity of any ash encounters.

5. For situations where mission requirements dictate flight operations into identified volcanic ash regions, the responsible weapon system program office engineering organization should be engaged to apply the risk assessment methodology. When used for assessing the risk for intentional flight operations into VAG identified regions of ash, a class 2–5 ash encounter severity level should be assumed. The methodology may be tailored to account for system unique characteristics in consultation with Original Equipment Manufacturers (OEMs). The requirements of reference 3 for assessing hazards and identifying mission decision authority apply. References 4 and 5 should be consulted for instructions on complying with USAF aircraft operational safety policies, as applicable.

6. The adequacy of each weapon system’s -1 Flight Manual for clearly delineating in-flight emergency procedures for inadvertent flight operations into volcanic ash or air-borne contaminants should be reviewed and understood. Supplemental actions and guidance outlined in appendix 2 should be familiar to flight crews operating aircraft in regions of elevated volcanic ash exposure risk.

7. Flight operations checklists should be reviewed to establish that pre-flight and post-flight inspections are adequate for aircraft deployed to locations susceptible to ash fall-out or exposure to excessive airborne dust and abrasive contaminants. System specific technical orders should be reviewed to ensure they adequately outline the general procedures documented in references 6 and 7 for inspection, cleaning and maintenance of systems exposed to volcanic ash while conducting flight operations or subject to ground based exposure. The supplemental inspection and maintenance actions outlined in appendix 3 should be employed when evidence of volcanic ash encounters is confirmed through preliminary inspections. Additional inspection and maintenance procedures might be indicated for specific systems as determined in consultation with the responsible program office engineering organization and system OEMs.

8. Unless specific evidence exists that aircraft have operated in or been exposed to volcanic ash or flight crews have reported ash exposure hazard symptoms, normal operational inspection and maintenance procedures should be followed.

9. Flight crews are encouraged to use the Volcanic Activity Reporting Form (reference 8) to report volcanic ash encounters. Reporting such information will contribute to increased understanding of aircraft operations in volcanic ash environments.

POINTS OF CONTACT:

Contact Mr. Robert Fitzharris (ASC/ENSI, 937-255-7224, DSN 785-7224) to discuss airworthiness related questions/issues and Mr. Timothy Jennewine (ASC/ENF, 937-255-8610, DSN 785-8610) for the technical content of this document. For airworthiness publication issues contact the ASC/AFRL Engineering Standards Group (ASC/ENRS, (937) 904-5476, DSN 674-5476).



JOHN E. WHITE, SES
Director, Engineering

Risk Assessment Methodology
For
USAF Aircraft Flight Operations Subject to Volcanic Ash Exposure

Herein ASC/EN outlines a risk assessment methodology and presents generalized hazard logic diagrams for use in characterizing weapon system operational risks associated with flight operations in volcanic ash environments. ASC/EN does not recommend relying on the ash concentration charts published exclusively through the London VAAC. As explained in the body of this airworthiness advisory, considerable technical uncertainty exists with density forecasting and exposure duration limits. Graphics published universally through all nine VAACs (known as Volcanic Ash Graphics, VAGs) should be consulted for identifying the locations and elevations of ash clouds for regions of flight operations. An explanation of the risk assessment methodology and the associated hazard logic diagrams (along with instructions for use of this information) is provided in the remainder of this appendix.

1. The risk assessment methodology complies with the hazard assessment requirements contained in reference 3. Accordingly, it employs the prescribed hazard risk indices and risk acceptance levels (as shown in figure 3, below). Color codes have been adopted to distinguish the four levels of risk and decision authority. Reference 3 has not been updated to account for current USAF and joint service mishap class dollar values. For evaluation and reporting purposes, the responsible program office should adopt the appropriate dollar values to the hazard categories when tailoring the methodology for application to their specific weapon system.

Hazard Category / Frequency	Catastrophic Fatality > $1 M	Critical Serious Injury $200 K - $1 M	Marginal Injury $10 K - $ 200 K	Negligible Minor $2 K - $ 10 K
Frequent >10^{-1}	1	3	7	13
Probable 10^{-1} - 10^{-2}	2	5	9	16
Occasional 10^{-2} - 10^{-3}	4	6	11	18
Remote 10^{-3} - 10^{-6}	8	10	14	19
Improbable <10^{-6}	12	15	17	20

1 - 5	High	Component Acquisition Executive
6 - 9	Serious	Program Executive Officer
10 - 17	Medium	Program Manager
18 - 20	Low	Program Manager or as Directed

FIGURE 3
MIL-STD-882D Hazard Risk Indices and Reporting Requirements

2. The risk assessment methodology employs a set of ash encounter severity indices (figure 4, below) as the standard for assessing USAF aircraft volcanic ash encounter hazards. The indices encompass three discrete groups representing increasing ash encounter severity. The indices are considered to provide generally accepted, reliable ‘cueing’ information for distinguishing the

degree of ash encounter threat and can be applied for all manned systems for day or night flight operations.

Ash-Encounter Severity Index	
Class	***Criteria***
0	Acrid odor (e. g. sulfur gas) noted in cabin Electrostatic discharge (St. Elmo's fire) on windshield, nose, engine cowls No notable damage to exterior or interior
1	Light dust in cabin; no oxygen used Exhaust Gas Temperature (EGT) fluctuations with return to normal values
2	Heavy cabin dust; "dark as night" in cabin Contamination of air handling and air conditioning systems requiring use of oxygen Minor abrasion damage to exterior surface of aircraft, engine inlet and compressor fan blades Deposition of ash in engine
3	Vibration of engines; surging Frosting or breaking of windows due to impact of ash Minor plugging of pitot-static system; insufficient to affect instrument readings Plugging of pitot-static system to give erroneous instrument readings Contamination of engine oil system Damage to electrical system Engine damage
4	Temporary engine failure requiring in-flight restart of engine
5	Engine failure or other damage with significant potential of flight safety incident

FIGURE 4

Source: Adapted from Volcanic Ash Indices developed by T. Casadevall (United States Geological Survey) and T. Fox (International Civil Aviation Organization) with reference to Casadevall, T.J. (ed.), 1994, Volcanic Ash and Aviation Safety, Proceeding of the First International Symposium on Volcanic Ash and Aviation Safety (Seattle, Washington, July 1991): U.S. Geological Survey Bulletin 2047.

Class 0 is the least threatening index value assigned to a confirmed volcanic ash encounter. Volcanic ash in this class of encounter may not be visible to the flight crew on the exterior of the aircraft in daytime operations. It does encompass cues that can alert flight crews to the presence of ash (day or night) as a result of penetration to the cabin interior.

Class 1 indices encompass an ash encounter that is observable by the flight crew on the interior of the aircraft (day or night). The ash concentration levels may still preclude detection of ash on the exterior of the aircraft in daytime operations. Some additional system performance indicators may provide early indications of ash impact on aircraft systems.

Class 2 – 5 represents the most severe range of ash encounter. Commercial and military aircraft operational experience has shown that once volcanic ash is encountered (visible or not), the potential for a rapid increase in severity exists which could entail significant system performance degradation over a very short period of time.

3. The risk assessment methodology is presented in figures 6 through 11 and includes both a risk matrix and hazard logic diagrams for system specific configuration considerations. The matrix and the hazard diagrams were developed to encompass the widest range of weapon systems and known system capabilities in the USAF fleet. However, the matrix and the logic diagrams may not completely (or adequately) characterize all hazards and account for all system specific capabilities; therefore the matrix and the logic diagrams should be tailored to individual weapon systems. The following overview and guidance is provided for applying the risk assessment methodology to specific weapon systems:

a. The risk assessment matrix accounts for all air vehicle flight systems and avionics functions and identifies a comprehensive list of hazards assigned to each function. As presented, the matrix is populated with hazard descriptions and hazard risk values for each of the defined categories of exposure. The matrix addresses conventional MDS unique functional configuration characteristics and accordingly supports assignment of hazard risk values with select functional hazard logic diagrams for Flight Mechanics and Crew System functions. Significant engineering experience and judgment were applied to develop the risk matrix and logic diagrams and to assign hazard risk indices to three impact categories: flight safety (FS), economic (E) and mission critical (MC).

b. Tailoring of the matrix and the hazard logic diagrams should be performed only by the responsible weapons system program office engineering organization in collaboration with system OEMs (as appropriate).

c. Intentional flight operations into VAAC identified regions of volcanic ash (as defined by VAGs and VAAs) are not recommended. When mission requirements mandate operation in VAAC identified regions of volcanic ash, the default ash encounter severity index is class 2–5. As outlined in the body of this advisory, ash concentration predictions for the region covered by the London VAAC are not considered appropriate for managing USAF flight operations. The cueing information provided by the indices defines the ash threat (and presumably concentration) as increasing from class 0 to class 5. Since it is not possible to forecast the ash encounter severity index that may be associated with a VAG or VAA, it is only appropriate to use the most severe index range (class 2–5) when mission requirements dictate that flight operations must be conducted into identified ash cloud formations. With appropriate tailoring for system specific characteristics (if required), appropriate hazard risk indices can be assigned to critical functions. It is unlikely (even with tailoring) that propulsion systems and fly-by-wire flight control system functions will ever be assigned hazard risk ratings lower than Serious for class 2–5 encounters on

the ash severity index. ASC/EN has assessed the threat in multiple functions for intentional operations into volcanic ash as 'High' risk.

d. Flight crew awareness of the functions, hazards and cueing information provided by the ash encounter severity indices is considered essential when manned flight operations are conducted in proximity to VAAC identified regions of volcanic ash. Inadvertent encounters with volcanic ash (in spite of the best meteorological information and best intentions of flight crews to circumnavigate identified regions) have occurred. For inadvertent ash encounters the cueing information provided over the entire range of the indices, combined with the functional hazard information provided in the risk matrix can be used by the flight crew to assess the severity of the encounter and assess the risk to the system. This information can assist in prioritizing aircrew response and for post-flight assessment of required inspection and maintenance.

e. In those exceptional cases where manned flight operations might intentionally be conducted into identified regions of volcanic ash, the cueing information available in the matrix will serve as an indication of the actual severity of any ash encounter. This information could be used to re-assess actual threat conditions from what may have been identified in planning the mission. Figure 5 highlights the qualifying conditions for applying the ash encounter severity indices in assessing functional hazards depending on whether the assessment is used for a planned mission or for cueing information for inadvertent ash encounters.

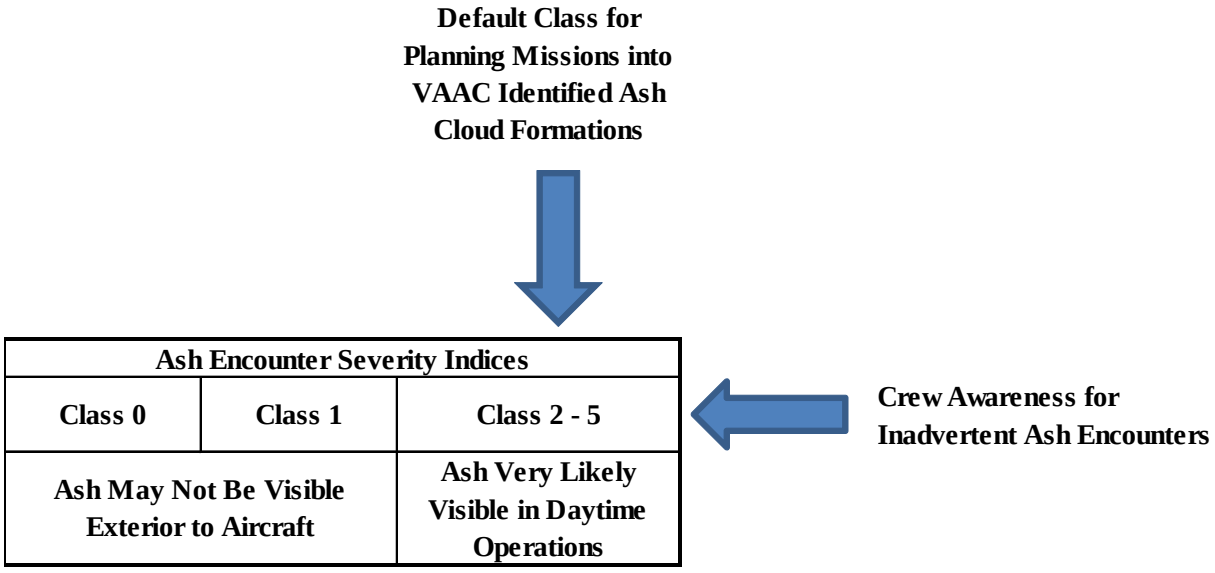


FIGURE 5

f. The risk matrix identifies risk mitigation and additional inspection/maintenance requirements associated with identified functions and hazards. The identified mitigation and inspection/maintenance actions are summarized in appendices 2 and 3, respectively. Those appendices should be consulted for additional details not fully described in the risk matrix. The additional inspection and maintenance actions should be treated as supplemental to specific weapon system maintenance and corrosion protection technical data. System specific technical knowledge may play a role in refining or expanding additional inspection and maintenance procedures associated with a given level of volcanic ash exposure or apparent damage.

				Ash Encounter Severity Indices					
Function	Hazard	MDS Specific Configuration Considerations	Flight Safety (FS), Mission Critical (MC) Economic (E)	Class 0	Class 1	Class 2 - 5	MDS Specific Fault Analysis Applicable	Mitigation	Additional Maintenance
Structures	Structural Abrasion of Forward Facing Airframe Structure	Conventional Material Systems (Non-LO coatings and non-LO structural shapes)	E	11	8	4	No	Mitigate abrasive degradation by minimizing duration and aircraft speed through ash cloud.	Inspect A/C post flight for signs of surface degradation
	Structural Abrasion of Forward Facing Airframe Structure (LO Materials)	LO Coatings/Treatment Material Systems and/or LO Structural Shapes	E, MC	11	8	4	No	Mitigate abrasive degradation by minimizing duration and aircraft speed through ash cloud.	Remove ash post flight by approved sand & dust contamination cleaning procedures; Consult LO expertise to assess the need for signature testing for aircraft exposed to volcanic ash. Request technical assistance per TO 00-25-107 as indicated.
	Structural Corrosion	No	E	14	10	8	No	Chemical composition and corrosive effects of ash are unknown; mitigate with increased frequency of aircraft wash.	Clean aircraft to remove particulate.

FIGURE 6
Airframe Structures Risk Matrix

				Ash Encounter Severity Indices					
Function	Hazard	MDS Specific Configuration Consideration	Flight Safety (FS), Mission Critical (MC) Economic (E)	Class 0	Class 1	Class 2 - 5	MDS Specific Fault Analysis Applicable	Mitigation	Additional Maintenance
Propulsion	Hot Section Thermal Distress	No	FS	8	4	2	No	Reduce thrust to idle immediately. Turn the autothrottles off. Exit the ash cloud as quickly as possible. Turn on engine and wing anti-ice devices and all air-conditioning packs. If possible, start the APU. If ash fills the flight deck, crew may need to use oxygen. Turn on the continuous ignition. Monitor engine exhaust gas temperature. Fly the airplane by monitoring airspeed and pitch attitude. See guidance for additional details.	Perform Visual, Borescope, lube filter inspections, Joint Oil Analysis Program (JOAP). See Guidance for Thresholds.
	Cold Section Erosion	No	E, MC	11	9	5	No		
	Multiple Engine Shutdown (Stability)	No	FS	8	4	2	No		
	Oil System Contamination	No	FS	12	12	8	No		Perform Lube filter inspections, JOAP analysis.

FIGURE 7
Propulsion Systems Risk Matrix

				Ash Encounter Severity Indices					
Function	Hazard	MDS Specific Configuration Considerations	Flight Safety (FS), Mission Critical (MC) Economic (E)	Class 0	Class 1	Class 2 - 5	MDS Specific Fault Analysis Applicable	Mitigation	Additional Maintenance
Flight Mechanics	Air Data System (ADS) Damage/Blockage	Fly-by-Wire (No Mechanical Backup)	FS	8	4	4	See Logic Diagram		Remove, Replace and Retest Sensor Many a/c use external vane/cone probes that have mold line smoothness requirement (i.e., control of where stagnation point is on a cone sensor) that maybe effected by abrasion and/or contamination.
		Fly-by-Wire (With Mechanical Backup & -1 T.O. Emergency Procedure)	FS	12	9	9			
		Fly-by-Wire (With Mechanical Backup & Without -1 T.O. Emergency Procedure)	FS	12	8	4			
		Mechanical system (Non-Flt Critical ADS With -1 T.O. Emergency Procedure)	FS	12	12	9			
		Mechanical system (Non-Flt Critical Without -1 T.O. Emergency Procedure)	FS	12	9	8			
		Mechanical System (Flt Critical ADS)	FS	12	8	4			

FIGURE 8
Flight Mechanics Risk Matrix

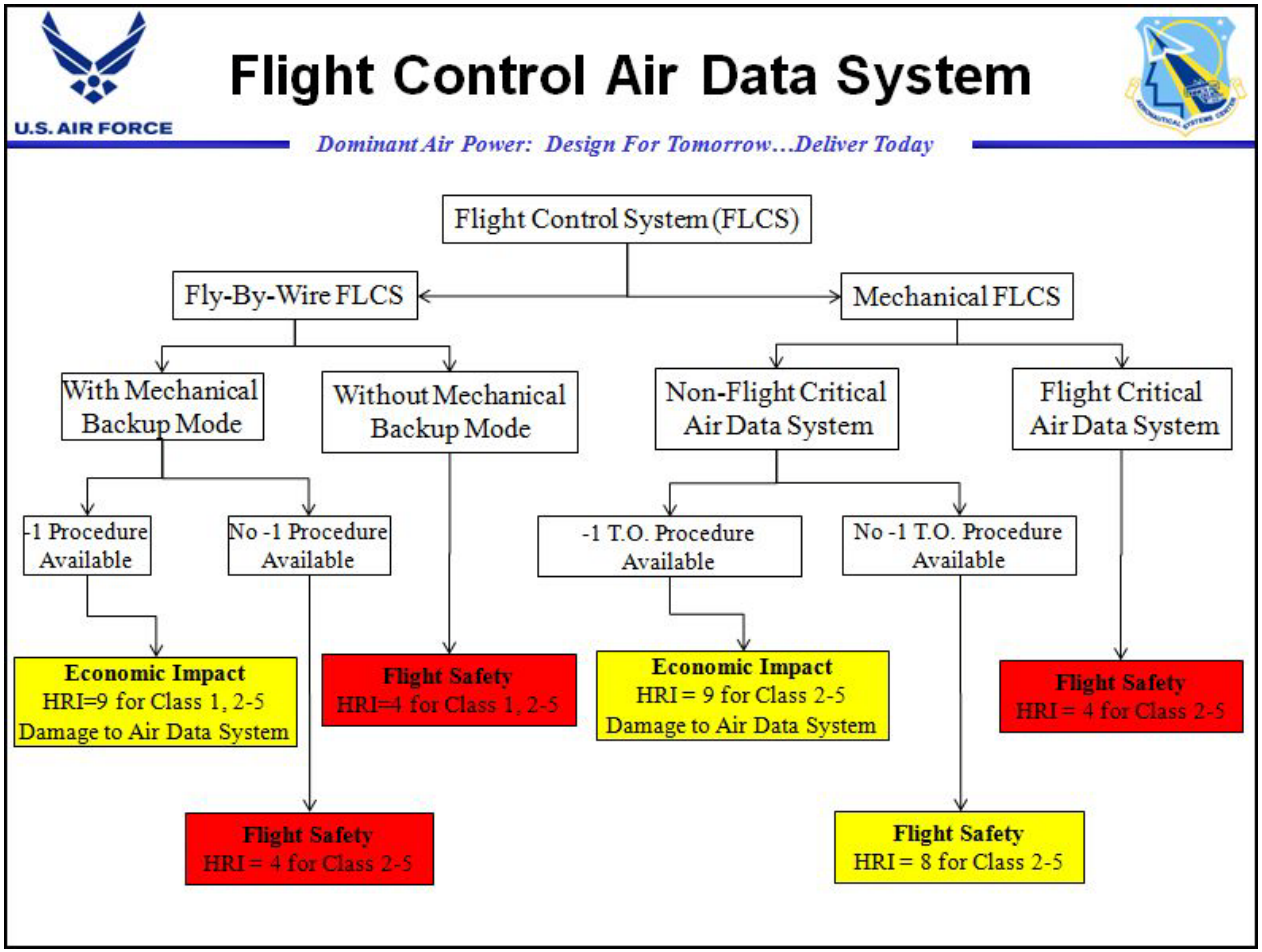


FIGURE 8a
Hazard Logic Diagram for Air Data System

				Ash Encounter Severity Indices					
Function	**Hazard**	**MDS Specific Configuration Considerations**	**Flight Safety (FS), Mission Critical (MC) Economic (E)**	**Class 0**	**Class 1**	**Class 2 - 5**	**MDS Specific Fault Analysis Applicable**	**Mitigation**	**Additional Maintenance**
Crew Systems	**Transparency/ Windscreen Damage**	**IFR capable**	**FS, MC, E**	**11**	**8**	**2**	**See Logic Diagram**	**Avoid Ash Cloud exposure**	**Inspect transparency after each exposure. Remove and replace windscreen as required.**
		Non-IFR Capable	**E**	**17**	**17**	**17**			
	Aircraft Lighting Damage	**Night Operations**	**FS, MC, E**	**18**	**16**	**8**	**See Logic Diagram**	**Avoid Ash Cloud exposure Minimize Formation Flying Minimize Night Flying**	**Inspect lights after each exposure. Remove and replace lens as required.**
		Day-time Operations	**E**	**20**	**20**	**20**			
	G-Valve Contamination	**G-Valve Equipped Aircraft**	**FS, E**	**20**	**17**	**12**	**See Logic Diagram**	**If operated in volcanic ash, the aircraft should be limited to 4Gz during and after the exposure.**	**Remove and replace G-Valve and associated ECS filtering as required.**
	OBOGS Contamination	**OBOGS Equipped Aircraft (Open System)**	**MC**	**19**	**14**	**11**	**See Logic Diagram**	**Select 100% Oxygen for entire mission. If the aircraft has been operated in volcanic ash and receives an OBOGS FAIL ICAW, the pilot should immediately select backup Oxygen and descend to below 10k feet.**	**Inspect, remove, and replace OBOGS inlet filter, ECS filtering, and breathing regulator as required.**
	Oxygen Regulator Contamination	**Open System (Dilution)**	**MC,E**	**19**	**12**	**8**	**See Logic Diagram**	**Select 100% Oxygen for entire mission**	**Inspect, remove, and replace breathing regulator after each exposure.**
		Closed System (Non-Dilution)		**No Elevated Risk Above Normal Operations**					
	Displays Contamination	**No**	**MC**	**17**	**17**	**14**	**No**		

FIGURE 9
Crew Systems Risk Matrix

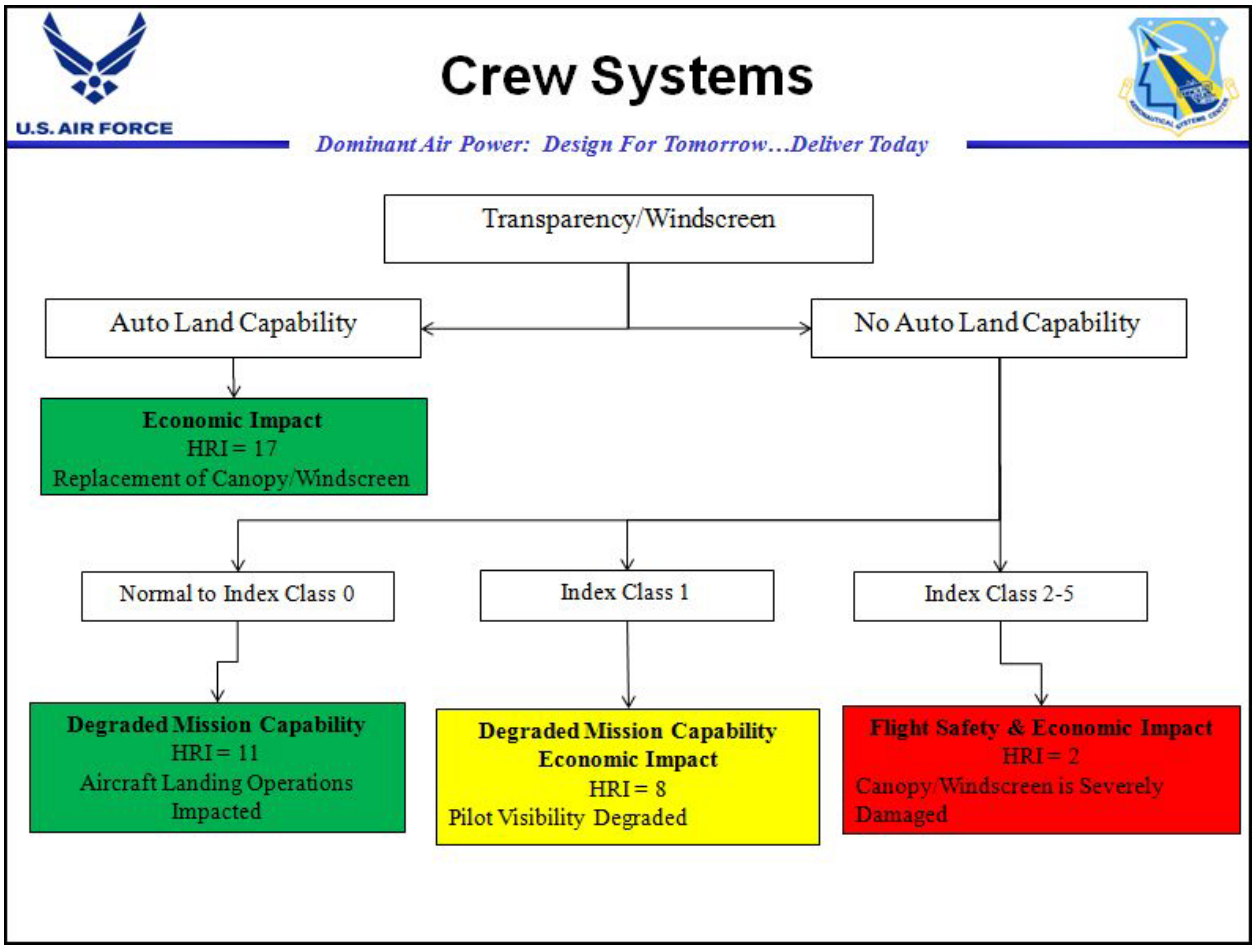


FIGURE 9a
Hazard Logic Diagram for Transparency/Windscreen

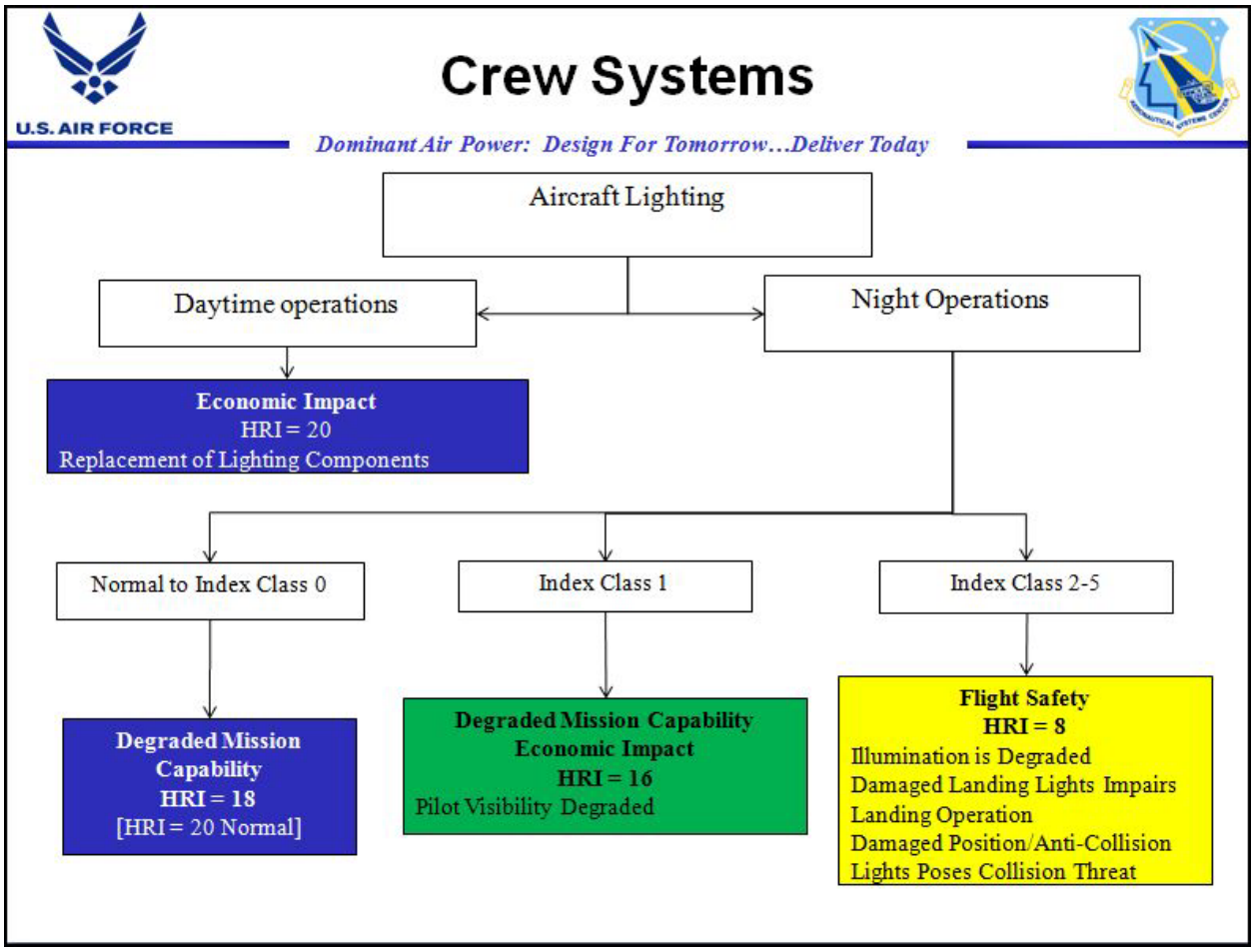


FIGURE 9b
Hazard Logic Diagram for Aircraft Lighting

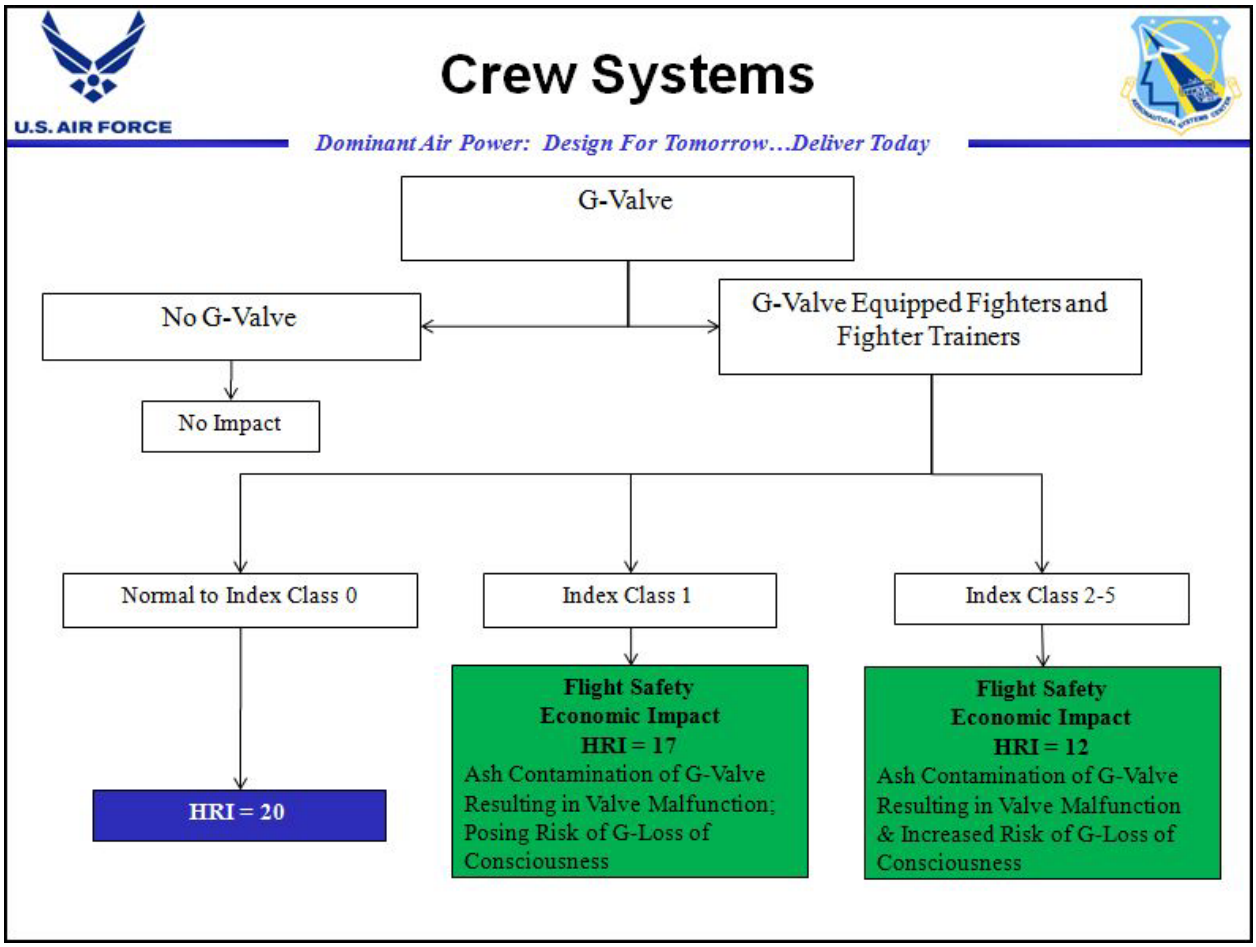


FIGURE 9c
Hazard Logic Diagram for G-Loss of Consciousness Valve

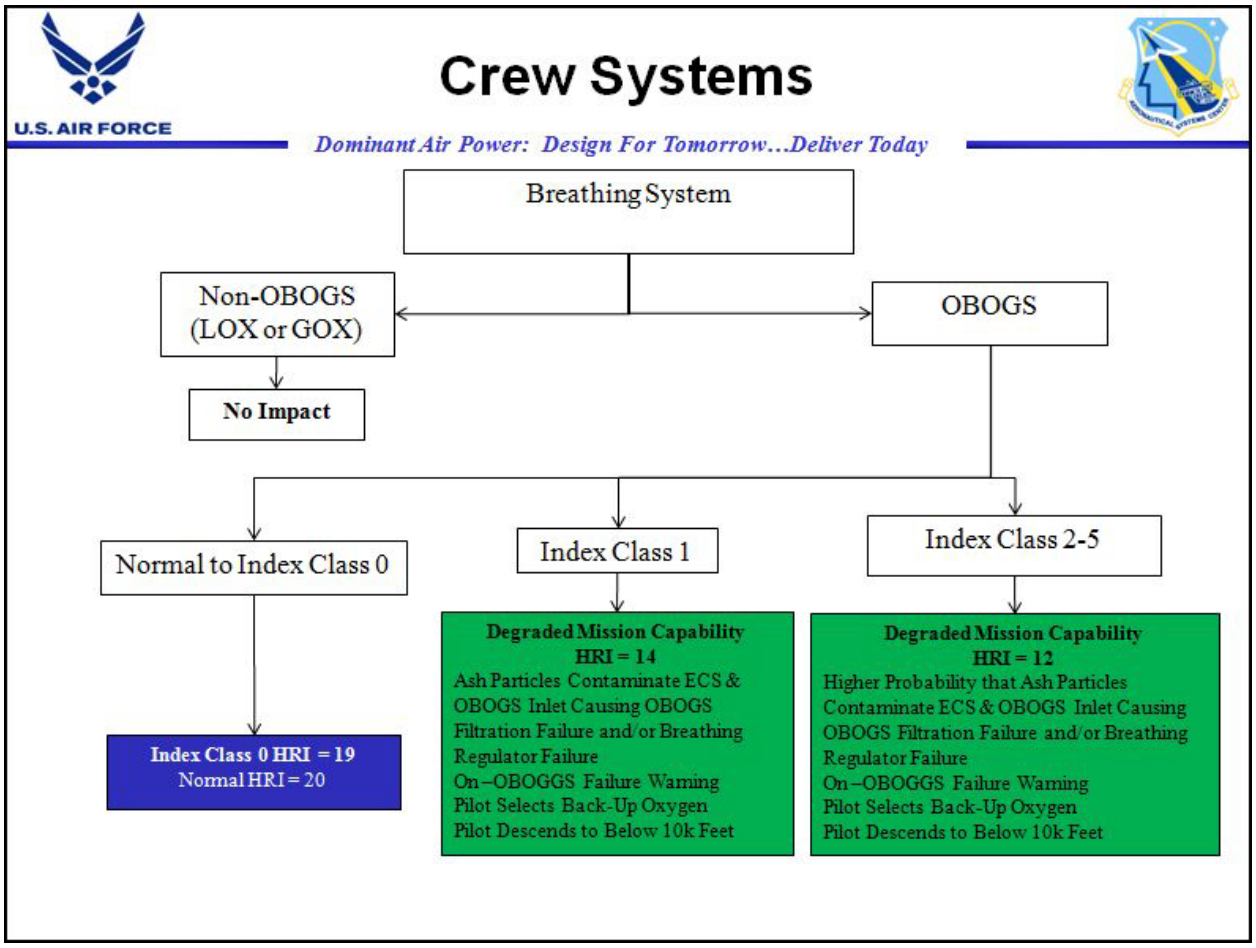


FIGURE 9d
Hazard Logic Diagram for Crew Breathing System

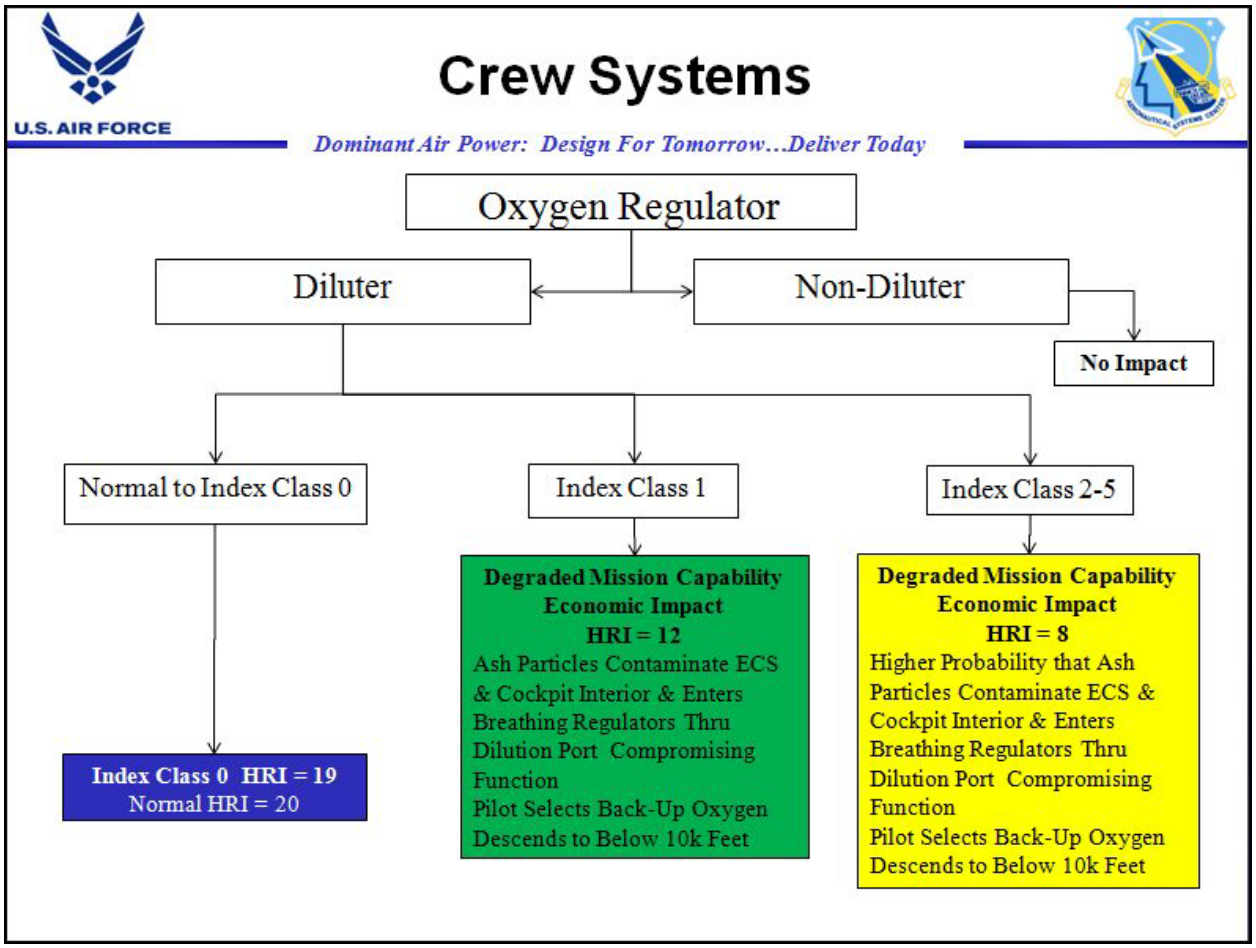


FIGURE 9e
Hazard Logic Diagram for Crew Oxygen Regulator

Function	Hazard	MDS Specific Configuration Considerations	Flight Safety (FS), Mission Critical (MC) Economic (E)	Ash Encounter Severity Indices			MDS Specific Fault Analysis Applicable	Mitigation	Additional Maintenance
				Class 0	Class 1	Class 2 - 5			
Air Vehicle Subsystems	Electrical Power Loss-Shorting/Generator Failure	Air cooled	E and MC	11	9	3	No	Any volcanic ash/dust deposits on power components/connections should be removed	Cleaning task for electric components/connections.
		Oil cooled	E and MC	11	9	9	No	Any volcanic ash/dust deposits on power components/connections should be removed	Cleaning task for electric components/connections.
	Equip. Overheat-Loss of ECS Effectiveness	Closed System (PAO)		No Elevated Risk Above Normal Operations			No		
		Open system (Air cycle)	E	18	16	16	No	Filters, water extractors and/or coalescer socks in the system should be checked and cleaned/changed.	Increased frequency of inspection and cleaning/removal tasks.
	OBIGGS Air Separation Module Damaged	No	E and MC	11	9	9	No	Check inlet filters and air separation module; clean or replace as necessary.	Filter checks/changes.
	APU Shutdown/Damage	No	E, MC and FC	11	9	3	No	Increased frequency of APU inspection. In the "no fly" region, it is assumed the APU is operating (due to risk of engine failure) resulting in high potential for significant damage.	Borescope inspection and potential removal with depot repair if performance is degraded.
	Degraded Subsystems Performance-Fluid Filter Blockage	No	E	18	16	16	No	Increase frequency of filter inspections and shorten replacement intervals.	Filter checks/changes.
	Hydraulic Fluid Leakage-Seal Contamination & Degradation	No	E	11	9	9	No	Increase frequency of reservoir fluid level checks; look for evidence of fluid leakage and actuator seal damage.	Increased inspection activity.
	Loss of Smoke Detectors	No	E	19	18	16	No	Verify smoke detector opening is not blocked.	Smoke detector blockage checks.
	Accelerated Component Wear (i.e.. ash/dust infiltration of static and dynamic mating surfaces causing abrasive wear or corrosion)	No	E	19	18	16	No	Equipment typically is qualified to Sand and Dust requirement in MIL-STD-810 which insures some resistance.	None

FIGURE 10
Air Vehicle Subsystems Risk Matrix

				Ash Encounter Severity Indices					
Function	Hazard	MDS Specific Configuration Considerations	Flight Safety (FS), Mission Critical (MC) Economic (E)	Class 0	Class 1	Class 2 - 5	MDS Specific Fault Analysis Applicable	Mitigation	Additional Maintenance
Avionics Mission Systems	ECS Forced Air Cooled Systems	No	E	19	19	16	No	Operation in volcanic ash will result in increased maintenance (primarily inspections and cleaning) and may impact life of components. Subsystem designs are comparable between both military and commercial aircraft. USAF should monitor results from commercial aircraft operation in volcanic ash environments to determine if additional actions are needed to protect subsystems.	Inspection interval set to ECS inspection interval.
	Ambient Plenum Forced Air Cooled	No	E	19	19	16	No		Inspection interval set by local conditions and documented in unit Tech Order directives.
	Liquid Cooled Systems and Uncooled Sealed Avionics	No	E	No Elevated Risk Above Normal Operations			No	These systems are sealed units.	Maintenance practices in ash conditions should establish methods to reduce infiltration during normal activities with locally established procedures and increased inspection intervals.

FIGURE 11
Avionics Mission Systems Risk Matrix

Aircraft Volcanic Ash Encounter Mitigation Guidance

Ground Operations:
Operation from or to airports and air fields contaminated with volcanic ash should be avoided, if possible. Should volcanic ash exposure be unavoidable, the following recommendations and procedures should be applied:

1. Aircraft parked or stored for any duration at airports and air fields contaminated with volcanic ash should be protected from ash with protective covers. All inlets, intakes, openings or compartments subject to contamination from exposure to falling/blowing ash must be protected with appropriate covers and plugs.

2. Aircraft should be cleaned before departure. Volcanic ash can contaminate lubricated parts, penetrate seals or enter engines gas path, air conditioning system, air data probes and other aircraft orifices. Cleaning procedures must address all possible points of entry for ash.

3. Dry crank engines. Before starting the engines, ventilate them by dry cranking at maximum motoring speed for two minutes.

4. Do not use windshield wipers for ash dust removal.

5. Do not use compressed air in bays containing avionics or subsystem equipment. Forced air cleaning may inadvertently drive ash contamination into interior spaces and equipment, potentially leading to system malfunction.

6. Restrict ground use of Auxiliary Power Unit (APU) to engine starts. Do not use APU for air conditioning and electrical power supply. Use external pneumatic supply for starting the engines, if it is available.

7. Keep bleed air valves closed during ground run and taxiing operations.

8. Taxi with minimum thrust. Advance the levers smoothly to the minimum required for breakaway. Avoid making sharp or high-speed turns. All engines operative taxi is preferred, to minimize thrust level on each engine.

9. Allow ash and dust to settle on runway before starting the takeoff roll.

10. Use the rolling take-off technique if possible.

11. Consider the runway as wet (for dry ash) or contaminated with slush (wet ash) for takeoff/landing performance calculations. Braking efficiency may be degraded by the layer of ash on the runway. Minimize use of thrust reversers to preclude stirring up and ingestion of ash accumulated on taxi/runways.

Flight Operations:
The following procedures are general recommendations. Each system's flight operations manual should be consulted for additional, system specific direction:

1. Reduce thrust to idle immediately. By reducing thrust, engines may incur less buildup of molten ash debris on turbine blades and hot-section components. Idle thrust allows engines to continue producing electrical power, bleed air for pressurization, and hydraulic power for air vehicle control.

2. Turn the autothrottles off. This prevents the engines from increasing thrust above idle. Ash debris in the engine can result in reduced surge margins. Limiting the number of thrust adjustments improves engine recovery capability.

3. Exit the ash cloud as quickly as possible. A 180-deg turn out of the ash cloud using a descending turn is the quickest exit strategy. Ash clouds may extend for hundreds of miles; continuing on the same flight path once an inadvertent ash cloud encounter has occurred may result in lengthy exposure. Climbing out of the ash could result in increased engine debris buildup as the result of increased propulsion system temperatures. The increased engine buildup could lead to total thrust loss.

4. Turn on engine and wing anti-ice devices and all air-conditioning packs. These actions improve the engine stall margins by increasing the flow of bleed air.

5. If possible, start the auxiliary power unit (APU). The APU can power systems in the event of a multiple-engine power loss. It can also be used to restart engines through the use of APU bleed air. Consideration should be given to impact to pilot work load of starting the APU immediately upon exposure to a volcanic ash cloud. If the aircraft has two APUs, consideration should be given to starting only one and holding the other in reserve in the event that ash causes failure of the first APU.

6. If volcanic dust begins to accumulate in the flight deck, it is advisable that the crew immediately begin using oxygen. Use flight deck oxygen at the 100 percent setting and switch to emergency oxygen as required per checklist procedures. Passenger oxygen will deploy automatically if the cabin altitude exceeds 14,000 ft; if dust levels pose a threat to passenger respiratory function, manual activation of passenger oxygen is advised.

7. Turn on the continuous ignition. Confirm that autostart is on, if available. In the event that the engines flame out or stall, use appropriate procedures to restart the engines. During restart, the engines may take longer than normal to reach idle thrust due to the combined effects of altitude and volcanic ash ingestion. If an engine fails to start, try restarting it again immediately. Flight crews must be cognizant that the air vehicle may be outside of the airstart envelope if the ash encounter occurs during cruise phase.

8. Monitor engine Exhaust Gas Temperature (EGT). Because of potential engine debris buildup, the EGT can climb excessively. The flight crew should prevent EGT exceedances. Shut down the engine and restart it if the EGT is approaching limits similar to those encountered with a hung start.

9. Fly the air vehicle by monitoring airspeed and pitch attitude. If necessary, follow the procedure for flight with unreliable airspeed.

Supplemental Inspection/Maintenance Guidance for Volcanic Ash Encounters

The inspection and maintenance considerations outlined below are supplemental to the procedures outlined in references 5 and 6 and system specific inspection, maintenance and repair technical data. These supplemental actions should be implemented in consultation with Original Equipment Manufacturer:

Structures:

1. Inspect airframe structural components (particularly forward facing components) post-flight for abrasion damage.

2. Inspect gaps, steps, seals and access panel/door perimeter boundaries for ash accumulation post-flight. Remove ash by approved sand and dust contamination cleaning procedures.

3. Request technical assistance per T.O. 00-25-107 (reference 7) as indicated.

4. Avoid the use of forced air cleaning of door and access panel gaps as this may push ash into cavities and equipment bays of the aircraft.

5. Consult LO technical resources to determine the need for surface restoration and/or signature testing for aircraft surfaces damaged by volcanic ash.

6. Caution: Volcanic ash contains sulphur, which when combined with water may produce sulphuric acid. Sulphuric acid is caustic and will damage aircraft structural components. Water washing aircraft components should not be performed until accumulated ash has been removed using other approved procedures.

Propulsion Systems:

1. Visually inspect inlet, exhaust and bay for indications of ash accumulation.

2. Visually inspect lube system filters for ash/sludge buildup.

3. Perform a post-flight Joint Oil Analysis Program (JOAP) sample.

4. If no findings or discrepancies are noted and ash encounter is confirmed to be minimal, no further inspections are required and the system is cleared for operation.

5. For engines where ash exposure is determined to be significant (as a result of step 1–3) or by flight crew observation of encounter severity (greater than severity index value 0 on the risk assessment matrix), then additional checks are required as follows:

a. Engines should be placed on 10 hour Code E JOAP trending analysis. Follow T.O. procedures for any JOAP exceedances.

b. Engines possessing a performance trending capability should have their trend data evaluated for not less than three flights.

c. Perform a complete engine borescope inspection. Follow T.O. limits and procedures.

6. Caution: Volcanic ash contains sulphur, which when combined with water can produce sulphuric acid. Sulphuric acid is caustic and will damage engine components. Water washing the engine components should not be performed until accumulated ash has been removed using other approved procedures.

Flight Mechanics (Air Data System):

1. Post-flight, the air data system sensor should be removed, replaced and tested prior to operation.

2. For vane/cone air data probe installations that rely on aircraft mold-line surface smoothness requirements for proper air data system function, the smoothness of ablated surfaces must be restored to specification values.

Crew Systems:

1. Aircraft transparencies, windscreens and lighting lenses should be inspected for abrasion and crazing after each encounter. Replace damaged components as indicated by inspection results.

2. Inspect G-valve and ECS filter components after exposure to ash. If ash contamination is revealed by inspection, remove and replace those components.

3. Inspect OBOGS inlet, ECS filter components and breathing regulator after aircraft exposure to ash. If ash contamination is revealed by inspection, remove and replace those components.

Air Vehicle Subsystems:

1. Electrical power generation and distribution components (to include connectors and conductors) should be inspected for ash contamination. Clean in accordance with technical order data requirements for the system.

2. ECS and OBIGGS air separation filters should be removed and replaced after confirmed exposure to volcanic ash.

3. Perform borescope inspection of APU components after an ash encounter. Severe APU damage after a class 2–5 encounter (in which the APU was operated) is likely and may require system replacement.

4. Inspect exposed mechanical equipment seals for damage from ash; as indicated clean undamaged seals and replace damaged components.

Avionics Mission Systems:

1. Inspection intervals for avionics equipment cooled through ECS forced air systems should be subject to the same inspection and maintenance requirements as the ECS system for exposure conditions.

2. Plenum cooled avionics equipment should be inspected post-flight for contamination for any class of ash exposure.

3. Ash contaminated bays containing avionics equipment should not be cleaned using compressed air. Compressed air may cause ash contamination to penetrate avionics enclosures subjecting the equipment to malfunction.