Recent Encounters of Aircraft with Volcanic Ash Clouds

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Outline

- Motivation
- Compilation of Encounters from 2010 onwards
- Severity Index for Volcanic Ash Encounter
- Encounter Analysis 2010-2014
- Summary and Outlook

Motivation

- Volcanic ash crises in 2010 and 2011 with restrictions in air traffic
- Initiation of DLR internal project VolcATS (Volcanic Ash Impact on the Air Transport System) with the DLR institutes of
  - Atmospheric Physics, Flight Guidance, Air Transportation Systems
  - Materials Research, Propulsion Technology, Flight Systems
- Research needs in different areas, such as susceptibility of aircraft systems to volcanic ash
- Flight Systems: Investigation of the effects of volcanic ash on the aircraft, in particular on the navigation and communication systems
- What happens during an encounter of an aircraft with volcanic ash clouds?

→ **Compilation** and **Analysis** of encounters with volcanic ash

Compilation of Encounters from 2010 onwards

- Detailed incident compilation available up to 2009: Encounters of Aircraft with Volcanic Ash Clouds: A Compilation of Known Incidents, 1953–2009, by Marianne Guffanti, Thomas J. Casadevall, and Karin Budding
  - Report and database from the U.S. Geological Survey (USGS) freely available under http://pubs.usgs.gov/ds/545/

- Collaboration with Marianne Guffanti (USGS)
  - Joint compilation of new known incident reports from 2010 onwards
  - Updating the existing database with minor adjustments

Compilation of Encounters from 2010 onwards

- The following sources were cited and evaluated (→ number of reports)
  - EVAIR – EUROCONTROL Voluntary ATM Incident Reporting → 186
  - Volcanic Ash Advisory Center Montreal → 23
  - The Aviation Herald → 2
  - Internet News → 2
  - (confidential) written and oral communication → 3
  - NASA Aviation Safety Reporting System → 0
- Incident reports without real volcanic ash encounter were disregarded, like the following real reports:
  - „flying north of flight path due to eruption“
  - „helicopter entered closed airspace“
- Remaining reports were classified according to an existing **severity index** (Source: ICAO Doc 9691)

Severity Index for Volcanic Ash Encounter

- Severity index was formulated in 1994 by T. Casadevall and K. Budding (in consultation with engine and airframe manufacturers and the Air Line Pilots Association) and endorsed by ICAO (Doc 9691 2nd Edition, Appendix G).

- Minor adjustments by ICAO in 2007. Currently six classes from 0 (lowest) up to 5 (loss of control).

- The encounter compilation showed that no classification criterion is available for some of the reported encounters.

- Review process started (discussion with pilots and technical experts).

Severity Index for Volcanic Ash Encounter

Class	Criteria
0	• Sulfur odor noted in cabin. • Anomalous atmospheric haze observed. • Electrostatic discharge (St. Elmo's fire) on windshield, nose, or engine cowls. • Ash reported or suspected by flight crew but no other effects or damage noted.
1	• Light dust observed in cabin. • Ash deposits on exterior of aircraft. • Fluctuations in exhaust gas temperature with return to normal values.
2	• Heavy cabin dust. • Contamination of air handling and air conditioning systems requiring use of oxygen. • Abrasion damage to exterior surfaces, engine inlet, and compressor fan blades. • Pitting, frosting, or breaking of windscreen or windows. • Minor plugging of pitot-static system, insufficient to affect instrument readings. • Deposition of ash in engine.
3	• Vibration or surging of engine(s). • Plugging of pitot-static system to give erroneous instrument readings. • Contamination of engine oil or hydraulic system fluids. • Damage to electrical or computer systems. • Engine damage.
4	• Temporary engine failure requiring in-flight restart of engine.
5	• Engine failure or other damage leading to crash.

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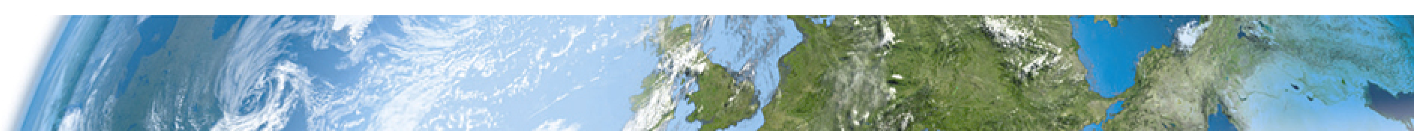

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5	• Engine failure or other damage ~~leading to crash~~ resulting in loss of control / aircraft.

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Severity Index for Volcanic Ash Encounter

- Different general comments received
  - criteria for the classification unclear (potential hazard to the aircraft, mission fulfilment, repair costs, economic impact,…)
  - simultaneous occurrence of system failures not considered
  - multi-scale table
    - impact on the airframe ↔ degree of volcanic ash existence
    - potential hazard to the aircraft ↔ economic impact
    - phenomenon ↔ impact on aircraft ↔ … on humans

Level	Phenomenon	Impact to Aircraft	Impact to Humans
0	Sulfur odor noted in cabin Anomalous atmospheric haze observed Ash reported or suspected by flight crew	Electrostatic discharge on windshield, nose, or engine cowls	Smell sulphur, but no impact on health
1	…	…	…

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Severity Index for Volcanic Ash Encounter

Level	*Descriptor*	*Severity description (customize according to the nature of the product or the service provider's operations)*
1	Insignificant	No significance to aircraft-related operational safety
2	Minor	Degrades or affects normal aircraft operational procedures or performance
3	Moderate	Partial loss of significant/major aircraft systems or results in abnormal application of flight operations procedures
4	Major	Complete failure of significant/major aircraft systems or results in emergency application of flight operations procedures
5	Catastrophic	Loss of aircraft or lives

- Excerpt from ICAO Doc 9859 "Safety Management Manual (SMM)", Third Edition – 2013 (First Edition – 2006)
- Severity table (basic) – alternate version on next slide
- Basis for current volcanic ash encounter severity index?

Severity Index for Volcanic Ash Encounter

Level	Descriptor	Severity description (customize according to the nature of the product or service provider's operations)					
		Safety of aircraft	*Physical injury*	*Damage to assets*	*Potential revenue loss*	*Damage to environment*	*Damage to corporate reputation*
1	Insignificant	No significance to aircraft-related operational safety	No injury	No damage	No revenue loss	No effect	No implication
2	Minor	Degrades or affects normal aircraft operational procedures or performance	Minor injury	Minor damage Less than $__	Minor loss Less than $__	Minor effect	Limited localized implication
3	Moderate	Partial loss of significant/major aircraft systems or results in abnormal flight operations procedure application	Serious injury	Substantial damage Less than $__	Substantial loss Less than $__	Contained effect	Regional Implication
4	Major	Complete failure of significant/major aircraft systems or results in emergency application of flight operations procedures	Single fatality	Major damage Less than $__	Major loss Less than $__	Major effect	National Implication
5	Catastrophic	Aircraft/hull loss	Multiple fatality	Catastrophic damage More than $__	Massive loss More than $__	Massive effect	International implication

Use the highest severity level obtained to derive the overall severity?

Severity Index for Volcanic Ash Encounter

- Five experienced pilots (CL-604, A320/A330/A340, B747 // captain and/or co-pilot // test pilot and examiner) have the missing criteria sorted into the existing severity index.

Interference of navigation or communication systems
Engine failure requiring in-flight permanent shutdown of engine
Reduced engine thrust due to contaminated engine(s)
Health[1] problems of flight crew (e.g. due to sulfur odor/dust)
Complete loss of VHF communication

[1]sickness, restrictions on breathing and speech, dryness of throat

Severity Index for Volcanic Ash Encounter

- Five experienced pilots (CL-604, A320/A330/A340, B747 // captain and/or co-pilot // test pilot and examiner) have the missing criteria sorted into the existing severity index.

	A	B	C	D	E	Ø
Interference of navigation or communication systems	3-4	2	3	3	3	2.9
Engine failure requiring in-flight permanent shutdown of engine	4-5	5	4	4	4-5	4.4
Reduced engine thrust due to contaminated engine(s)	4	4	3	4	4	3.8
Health[1] problems of flight crew (e.g. due to sulfur odor/dust)	4	3	4	5	4-5	4.1
Complete loss of VHF communication	2-3	2	3	3	3	2.7

- Some pilot/expert recommend shifting some of the existing criteria into a more critical severity class

[1]sickness, restrictions on breathing and speech, dryness of throat

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Encounter Analysis 2010-2014

- Examples of interference reports
  - Engine bleed failure
  - Engine fluctuation
  - Abrasion on edges of engine fan blades
  - Blocked drain hole of pitot probe, pitot head replaced
  - Erosion of passenger cabin windows (69 out of 76 replaced)
  - Restriction in breathing and speech, dryness in the throat
  - The co-pilot appeared to be sick due to the smell
  - …

→ Classification according to the existing severity index!

Encounter Analysis 2010-2014

	Severity class				
Aircraft type	**0**	**1**	**2**	**3**	**Σ**
Unknown aircraft type	1	3	1		5
Helicopter (H)					14
Turboprop/-shaft (H_T)	1	6	1		
Unknown		6			
Landplane (L)					94
Piston (L_P)	4	3			
Turboprop/-shaft (L_T)	11	4			
Jet (L_J)	30	13	7	6	
Unknown	12	1	3		
Σ	59	36	12	6	113

aircraft type description according to ICAO Doc 8643

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Encounter Analysis 2010-2014

- Often missing information in the available incident reports
  - Incomplete or missing information of the position/time of the encounter
  - Duration of encounter (exposure time)
  - Usually no detailed damage descriptions available

- No queries possible because (usually) no conclusions on operators, which have in addition restrictive policy

- Key information is volcanic ash dosage / volcanic ash concentration correlated to the damage to the aircraft

- Determination of the key information mostly not possible due to
  - missing or uncertain flight track
  - missing information about volcanic ash clouds and their concentration

Encounter Analysis 2010-2014

- Capability in DLR to analyze incident reports with available flight trajectories and modelled volcanic ash dispersion (zoning model).

Low	0.2 – 2.0 mg/m³	cyan	FL000 – FL200
Medium	2.0 – 4.0 mg/m³	grey	FL200 – FL350
High	> 4.0 mg/m³	red	FL350 – FL550

- Visualization with FATS (Future Air Traffic Simulator) from DLR-Institute of Flight Guidance.

- Combination of **flight trajectories** (EUROCONTROL Demand Data Repository (DDR)) with **modelled volcanic ash dispersion data** from UK Met Office (rerun using a newer version of the NAME model)[1].

- Some selected examples will be shown on the following charts
  - Verification of encounters
  - Identification of flights (to localize encounter)
  - Close of information gaps

[1] see Webster, H. N., et al. (2012),Operational prediction..., *J. Geophys. Res., 117, D00U08, doi:10.1029/2011JD016790*

Case: Multiple Suspected Flights

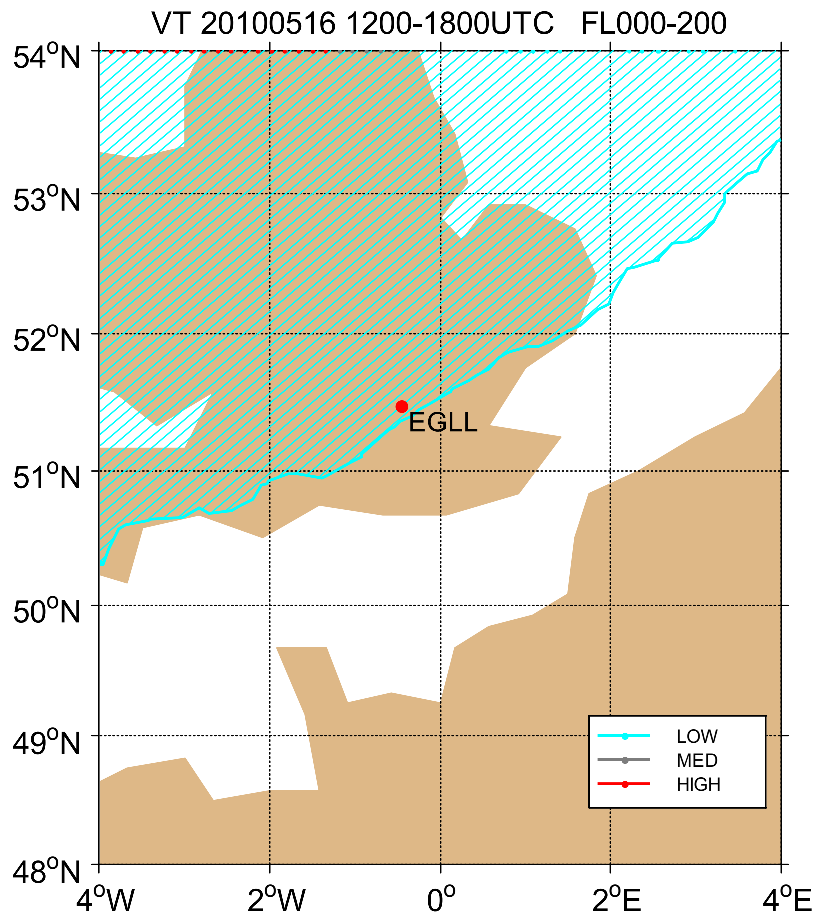
- Crew of a two-engine jet wide-body aircraft operating inbound London-Heathrow airport reported an acrid smell in the flight deck at 6,000 ft.

- Subsequently on taxi-in after landing, the aircrew noticed number 2 engine pressure ratio gauge fluctuations from 1.01 to 1.10, which did not return to normal values. The engine was shut down.

- Severity Index Classification: 3

- <u>Problem</u>: flight, location and time are not known.

Case: Multiple Suspected Flights



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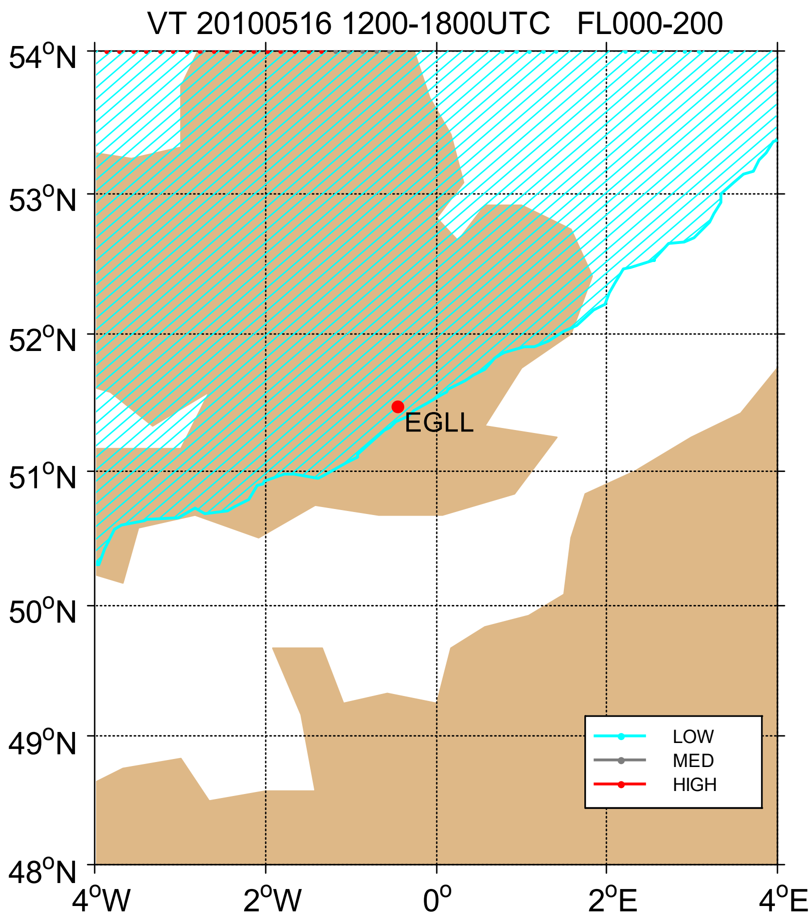

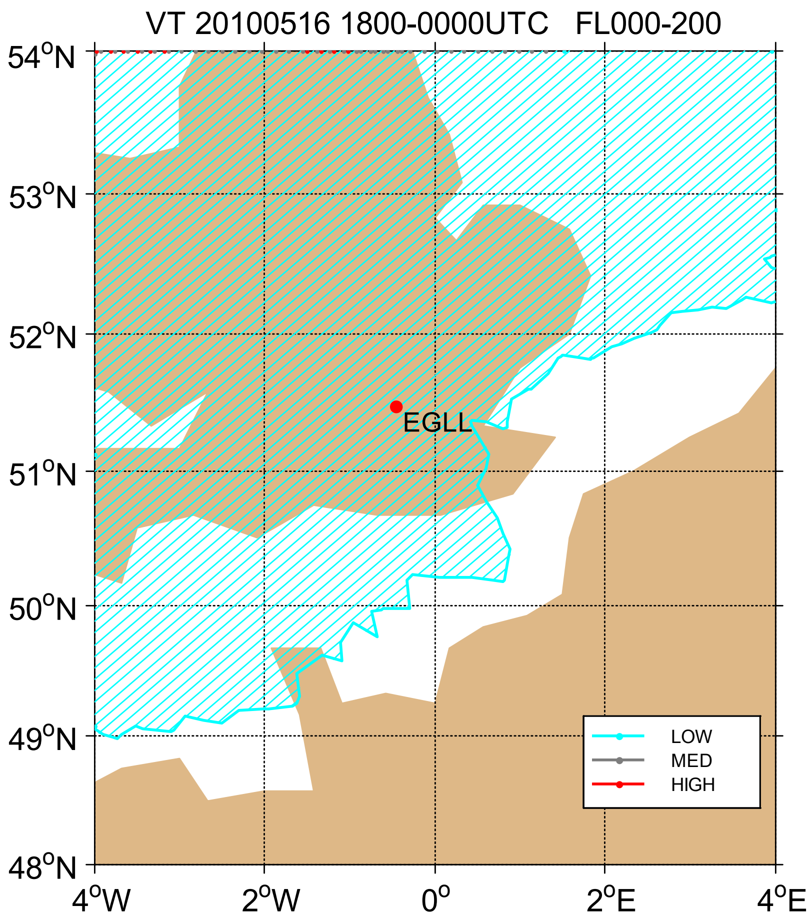

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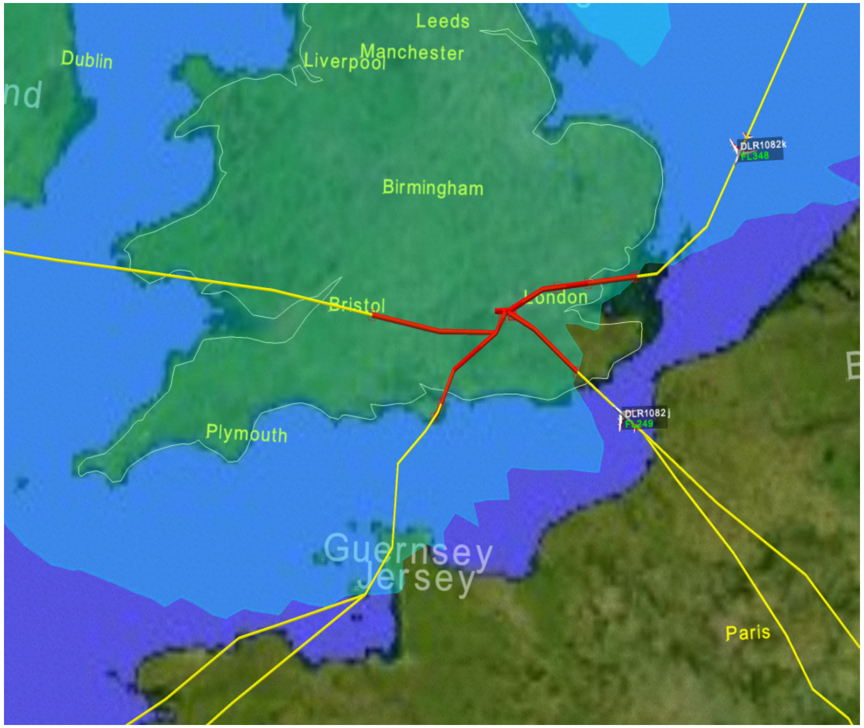
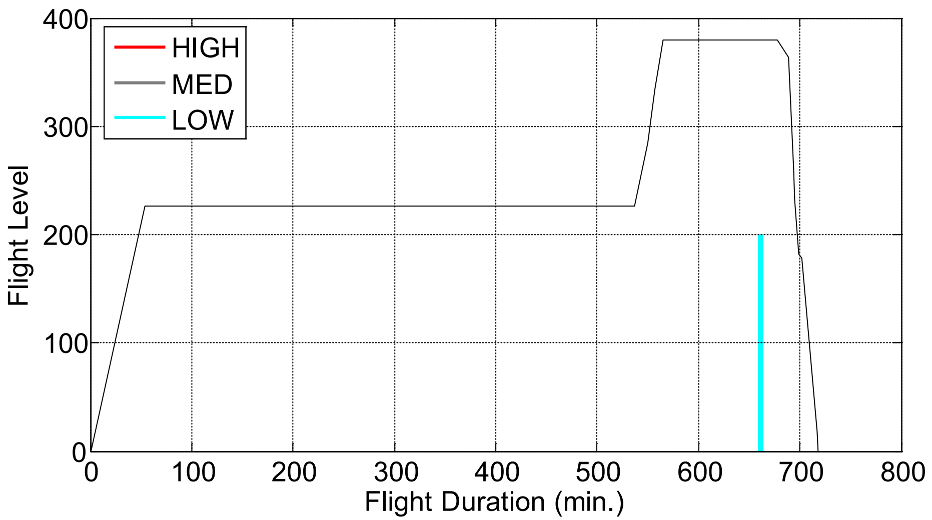
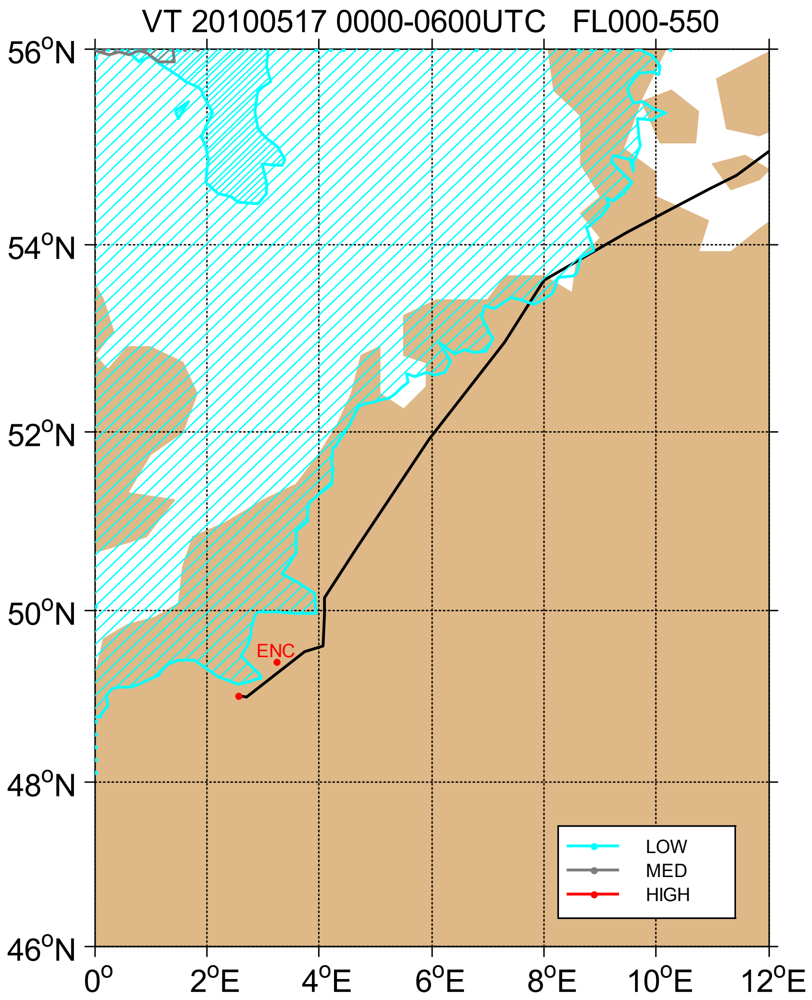


- Landings with aircraft type in question during 12 UTC and 24 UTC
- No outlier noticeable in terms of flight duration in low concentration area (between 3 and 24 minutes)
  - 7 aircraft more than 15 minutes
  - 2 aircraft of them more than 20 minutes
- Additional information needed to identify the affected aircraft for further investigation

Case: Verification of Encounter

- Crew of a four-engine wide-body jet aircraft reported engine fluctuations during the arrival.
- Severity Index Classification: 3





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Summary and Outlook

- The compilation of encounters with volcanic ash clouds has shown that aircraft fly into volcanic ash clouds. However, **not all encounters are reported** and therefore remain unknown.

- The analysis of encounters with volcanic ash clouds provides not only important information about the potential hazard to the aircraft, but also gives a **feedback** to the meteorological services for the optimization of their dispersion model.

- The essential information is often inadequate or non-existent. The establishment of a **global reporting system** can improve the situation and is therefore promoted. Aviation personnel is encouraged to report such encounters, e.g. via a pilot report (PIREP).

- The severity index should be amended and restructured. A **separation between observation and impact on human and machine** seems to be reasonable and favored among the experts.

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Additional Literature

- **Christmann, C., Nunes, R. R. and Schmitt, A. R.** *Recent Encounters of Aircraft with Volcanic Ash Clouds.* Deutsches Zentrum für Luft- und Raumfahrt e.V., Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt - Lilienthal-Oberth e.V., 2015. urn:nbn:de:101:1-201510306387.

- **Nunes, R. R., Christmann, C. and Oertel, H.** *Hazards Caused by Volcanic Ash on Avionic Systems*. Deutsches Zentrum für Luft- und Raumfahrt e.V., Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt - Lilienthal-Oberth e.V., 2015. urn:nbn:de:101:1-201510192231.

- **Schmitt, A.R.**, **Kuenz, A.**, *A reanalysis of aviation effects from volcano eruption of Eyjafjallajökull in 2010*, in Digital Avionics Systems Conference (DASC), 2015 IEEE/AIAA 34th, pp.1B3-1-1B3-7, 13-17 Sept. 2015 doi:10.1109/DASC.2015.7311335.

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Eyjafjallajökull on 17th April 2010

Thank you for your attention!

Any Questions?