Effect of Ashes and Sand on Aviation Safety

Quo vadis

More questions than answers

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Outline

- Introduction
- Some information about volcano’s and the past
- Safety effects on aircraft and engines
- What changed in April 2010?
- What did we learn so far?
- ICAO task force on Volcanic Ash
- Challenges

European Aviation Safety Agency

Ash cloud or cirro / alto cumulus or - stratus?

Any (visible) ash?

European Aviation Safety Agency

First analysis in 1989 KLM Mount Redoubt encounter: volcano cloud: military secret

Legends and Mythology

- The word 'volcano' comes from the little island of Volcano in the Mediterranean Sea off Sicily;
- Romans believed that a volcano was the chimney of the forge of Vulcan, the blacksmith of the gods;
- He hammered out bolts of lightning for Jupiter

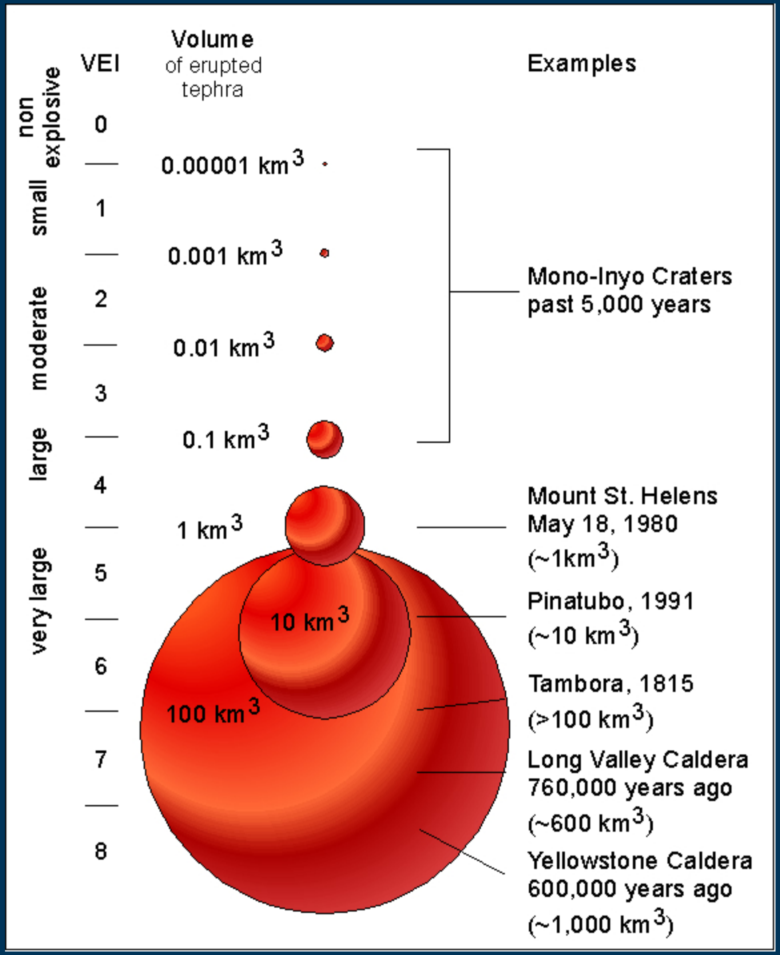
Volcanic Eruption

- **Hot lava, gas and burning ash bursts out of the earth;**
- **An eruption can throw solid rock into the air;**
- **There is usually a warning;**
- **There are around 60 eruptions a year;**
- **Some volcano's erupt 500 times a year (**Sakura-Jima 25 km from airport in Japan**:** are those 500 counted as 1 eruption?**)**

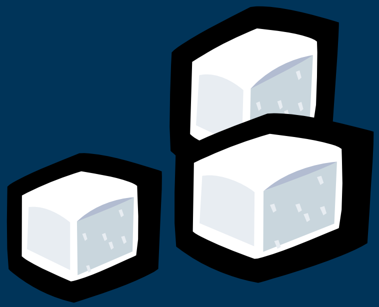
Sakura-jima Japan
25 km's from airport, 500 eruptions / year

Is this an ash cloud…or sand…..or a normal cloud?

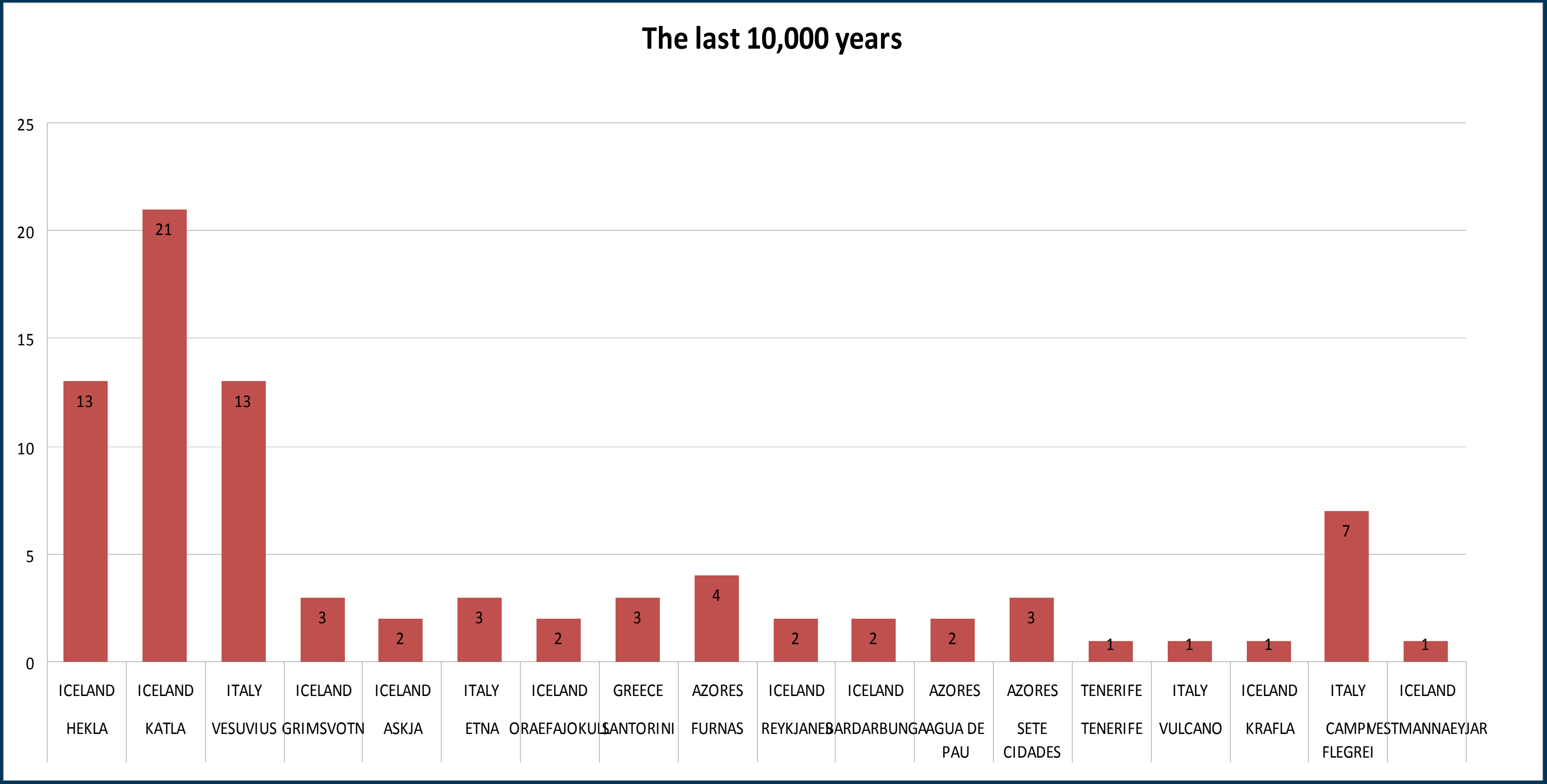
Volcanic Explosivity Index (VEI)



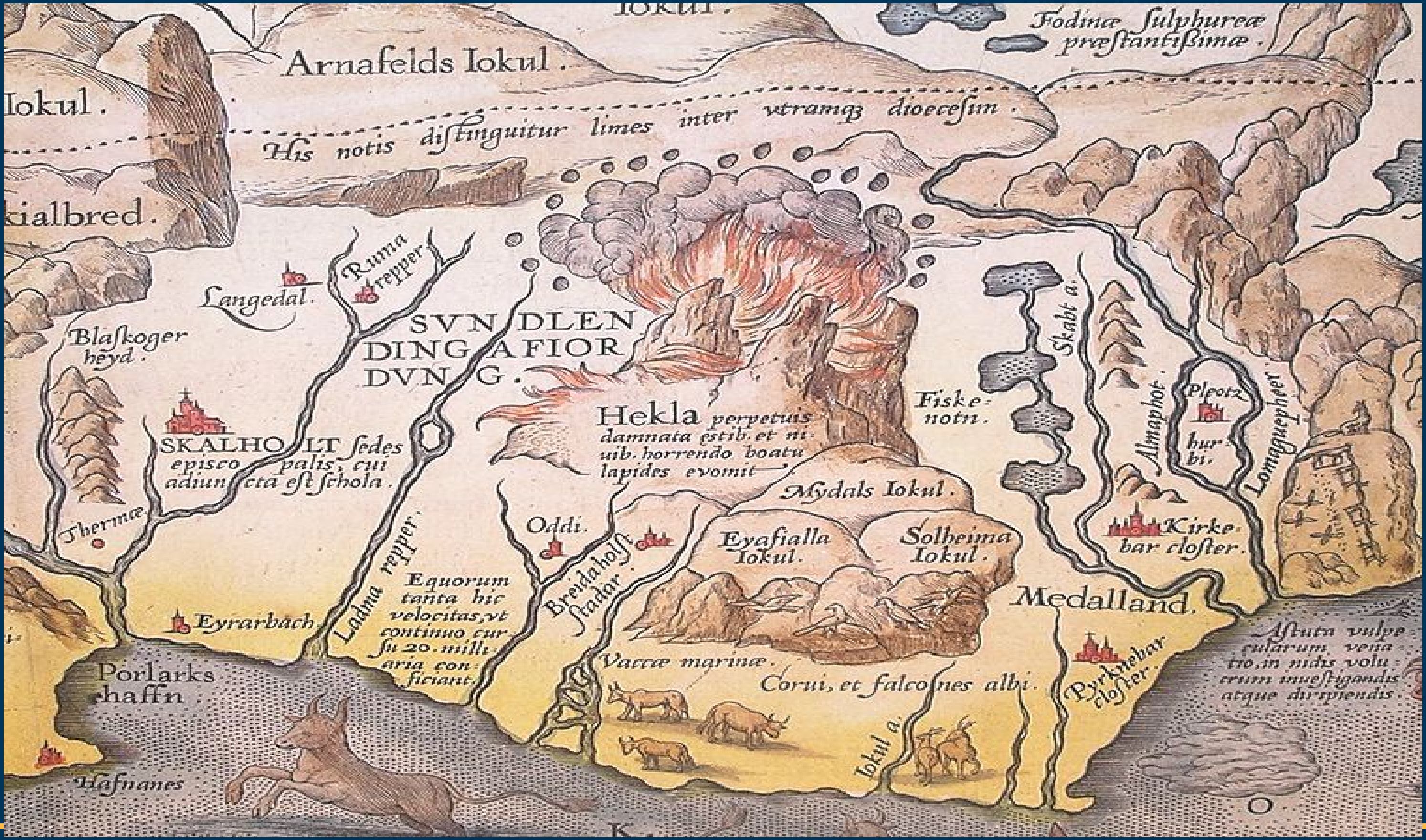
Km^3



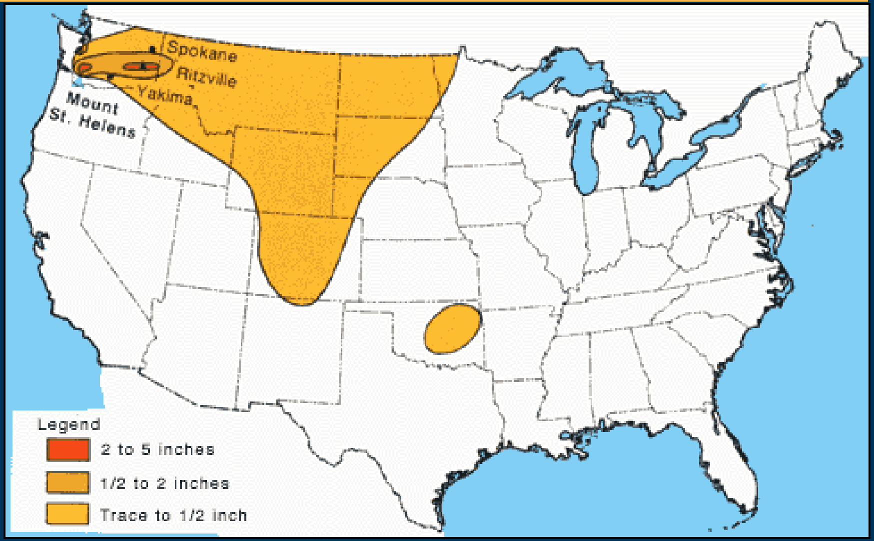
Large-volume Holocene explosive eruptions in Europe (> VEI 4)



1585 map of Iceland showing Hekla in eruption



Mt. St. Helens – VEI 4



- During the 9 hours of vigorous eruptive activity, about 540 million tons of ash fell over an area of more than 22,000 square miles

Pinatubo (VEI 5) long term reported effects in aircraft maintenance

- Window crazing
- SO_2 caused higher than normal corrosion on turbine parts

the facts: volcanic ash / sand in the atmosphere can:

- take an aircraft out of the sky (single cause catastrophic event with hull loss and multiple casualties)
- negatively effect the maintenance cost of your fleet of aircraft
- cause unwanted disruption of the aviation transport system (economic effect)

- All of this is not new information: we very well new that since many years (1982 BA 747 and KLM 1989)

aircraft level safety effects when volcanic ash is encountered:

- Engines: (unrecoverable (multiple) engine power loss: CAT; recoverable would be HAZ)
- Engines: reduced restart capability in flight (HAZ)
- Pitot systems (worst case: loss of or degraded essential inputs for air data systems: MAJ-CAT)
- Environmental control systems (pollution but not necessarely catastrophic)
- Air equipment/computer cooling (loss of computer generated information or protective functions: HAZ-CAT)
- Windows/structure: abrasive effects (MAJ-HAZ), corrosion (ECO)

Engine level effects

- Worst case safety effect: unrecoverable power loss
- After serious encounter and powerloss: reduced in flight restart capabilities (lower altitude) because of significant loss of engine stall and surge margin: see BA and KLM restart 13K ft
- Maybe not all failure modes are known yet (there is focus on gas path, but there may be other failure modes)
- Economic effects: abrasion, corrosion, faster than normal loss of EGT, stall and surge margins, reduced TBO‘s

The last 50 years

- Civil aircraft have not been designed nore certified to cope with effects of flying in airspace contaminated with volcanic ash or sand (or other volcano by products like SO2)
- We have seen no civil Hull losses, no casualties related to sand or volcanic ash encounters, however, we came close with KLM (1989) and BA (1982)
- we have seen substantial economic damage
- Conclusion: good world wide safety record, and we would be happy the next 50 years to keep it like that
- Military may have more or other experience

After the KLM 1989 Anchorage and 1982 BA B747 incidents

- The airworthiness of the aircraft was not questioned, however,
- Some trials were done after 1989 with engines to know more about the effects from ashes on aircraft engines
- In the following 20 years after 1989 no further progress was made in the ICAO Volcanic Ash working groups w.r.t. aircraft and engine tolerance to volcanic ash (question: why?)

What changed since April 2010?

- ‘OUR‘ perception of the situation: we were confronted with how the aviation transport system and its interdependencies in the technical, institutional and operational domain in Europe responded to the airspace contamination with volcanic ash
- airworthiness aspects became an important (maybe essential) part of the discussion
- Positive: Public confidence in aviation safety was not lost: from that perspective: good job!

What questions were asked?

- How much ash can aircraft tolerate, safety not compromised?
- How can prediction of ash concentrations be improved (uncertainties factor at best 2 or 3)?
- Can manufacuturers determine a binding ash safety limit (council of ministers from the EU)?
- What are manufacturers recommendations for flights into low contaminated (not visible ash) airspace (EASA Safety Information Bulletin 2010-17R2)?
- How do we interpret ‘ash level’ on maps and charts? Is it a predicted value, a real value, a peak value, an average value. What are the definitions?
- Is the science behind 2 x 10E-03 grams/m3 ash proven?
- When will EASA write a generic CRI for immediate use?

What questions were asked?

- Should we try to find 'no effect ash level limits'?
- What are the characteristics of volcanic ash: no volcano produces the same ashes: problem is to multidimensional!
- What could be short term wins, and how can we improve on long term?
- What is the probability of having such an eruption again? Have we overreacted? (we may have to wait for VEI 4 a 100 years?)
- What would be the balance of cost of finding aircraft level solutions versus improvements in ash prediction forecasts?
- Is certification of aircraft-engines going to bring us something useful? At what cost? When would we benefit. What would be the benefit?
- Does it make sense to find technical solutions for operational and institutional problems?
- When will EASA start to change the Certification Specifications

The most wanted question at technical level, finding an ‘ash tolerance level’ is justified,

because

- Avoidance of ash is not always possible, even if you theoretically could see it
- We asked the same type of questions in the past for other (multidimensional) atmospheric phenomena with safety challenges that could not be avoided for 100%: such as effects of lightning, icing, turbulence, birds
- Certification concept: show you ‘can cope with the threat’, or determine limitations
- We do not ask airlines to avoid lightning based on a safety case, but make sure a minimum level of robustness of the design was assured

The most wanted question ‘how to improve the accuracy of the ash dispersion prediction model‘ is also justified

- For short term improvement in ‘airspace available‘
- Long term: for more information where we should focus on for improvements in the whole range (for consideration where ‘we‘ invest our money…)

In real life, we do fly in certain levels of sand and ashes

- **Sand from the Sahara (Cape Verde and Canary Islands)**
- **Concentration may go up to 500 u gram/m3 (= 0,5 x 10E-3 gr/m3)**

High altitude (18000-20000 ft top) dust outbreaks are frequent events in Canary Islands and even more in Cape Verde islands during the summer months.

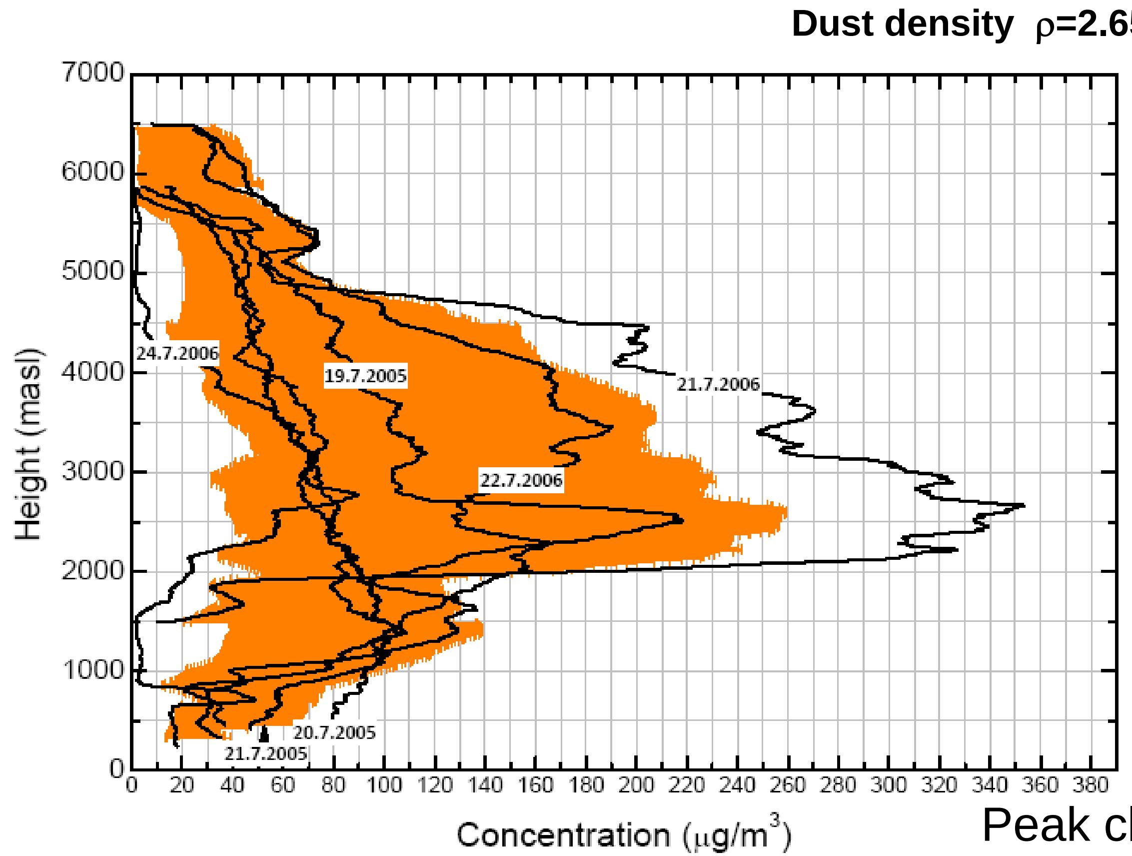
With mass loadings of 100-200 μg, which are frequent during the summer months, and 20-30 minutes of immersion, no care has to be taken apart from reduce the engine oil replacement time

Peaking concentrations of 500 μg and even more can locally be found

Dust profiles during TROMPETA project

Mass concentration in the 0.1-3 µm range (real concentration larger)

Top of the layer between 6000-6500 m



Peak close to 0.4 µg/m3

In orange one standard deviation

Differences in composition between ash and dust

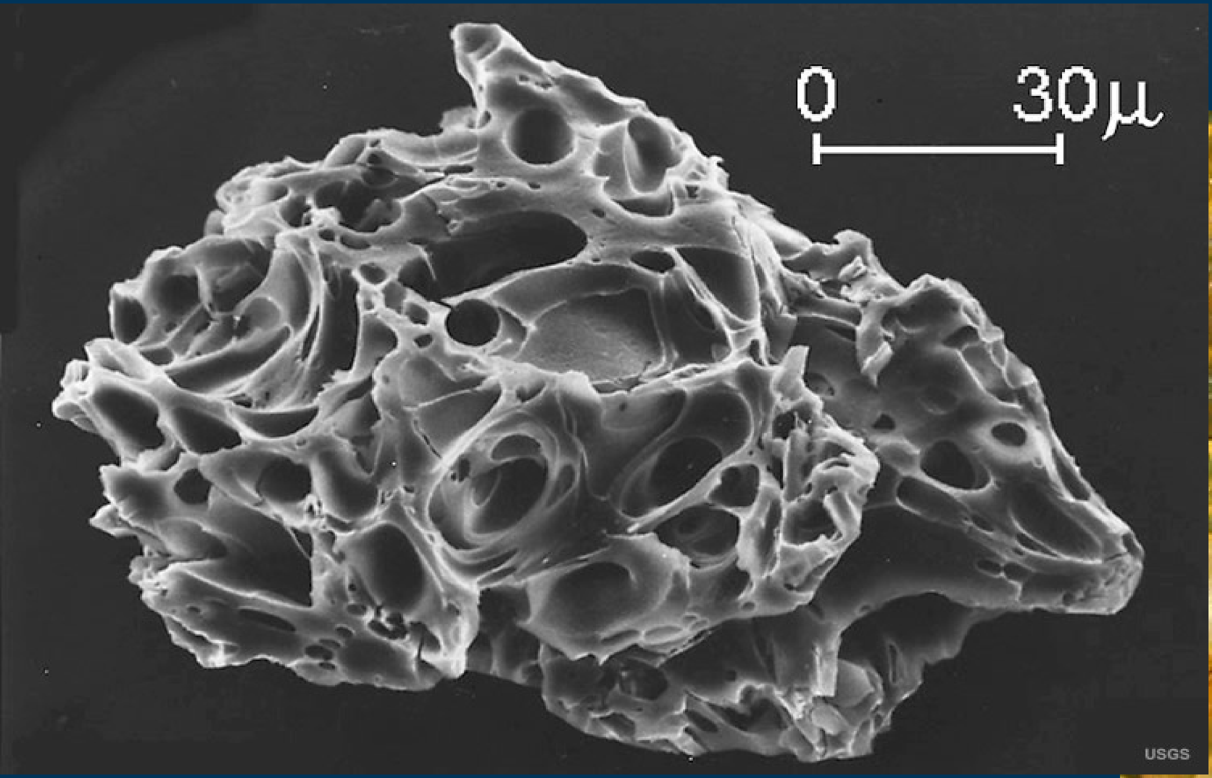
Chemical analysis from 5. May - Níels Óskarsson

Eyjafjallajökull - 5. maí 2010		
Sample	**0505a**	
SiO_2	61,46	
Al_2O_3	13,8	
FeO	8,44	
MnO	0,21	
MgO	2,99	
CaO	4,74	
Na_2O	4,68	
K_2O	1,7	
TiO_2	1,39	
P_2O_5	0,42	

Silicates melting temperature = 1100ºC

	Dust (%)	Ash (%)
	Formenti JGR 2003	IES 2010
Si	16.4	28.7
Al	8.2	7.2
Fe	4.4	6.5
Ca	2.9	3.4
K	1.7	1.4
Mn	1.2	0.2
Na	0.7	3.4
P	0.7	0.2
S	0.5	
Cl	0.5	

Ash –v- Sand



What did we learn so far?

(from aircraft operational and technical perspective)

- The effects of volcanic ash encounters on aircraft and engines are not dramatically changed: avoidance is still the best recommended approach: there may still be unknown failure modes-effects
- Engines remain the most vulnarabe system on the aircraft
- Avoiding visible ash (clouds) as a recommended operational procedure has proven itsself as a good practise, however, it is not under all circumstances a robust method, because:
- Ash cloud may be visible (with the eye or other techniques), but might not be recognised as volcanic ash (KLM 1989) and not easy to avoid
- One may be flying in airspace contaminated with ash which is below visibility thresholds: there can be long term effects

What did we learn so far?
(from aircraft operational and technical perspective)

- engine and aircraft tolerance level to sand and volcanic ash is >> higher than ZERO (even if we stay out of visible ash)
- A combination of operation through predicted ash concentration levels and enhanced aircraft maintenance procedures worked allowing continuation of air traffic in April 2010
- More than 250.000 flights in low contaminated airspace without major findings

What did we learn so far?

(from aircraft operational and technical perspective)

- From the ‘New Orleans‘ initiative (EASA-Manufacturers):
- An ‘single volcanic ash level safety limit‘ as a binding limit is difficult to find for all combinations of engines and aircraft, considering the variety in design and the fact that it is a multi-dimensional issue
- More knowledge about effects on engines and aircraft is a long term issue for which testing may be needed
- Scenario‘s for testing can be developed

EASA action plan

- Mostly for internal use
- Goals, deliverables, co-operation
- ICAO
- Ambition ‘bringing’ together

ICAO Volcanic Ash Task Force

- Montreal 27-30 July 2010: working on a global approach
- Scope: review and issue up to date guidance material
- Airworthiness Sub Group
- Air Traffic Management Sub Group
- Science Sub Group
- Coordination group

ICAO IVATF Airworthiness Sub Group

- define unsafe factors for operations in volcanic ash
- Determine airframe and engine susceptibility
- Develop airworthiness criteria to be used for states to allow operations
- Review flight crew procedures
- Review guidance for maintenance and inspection
- Study potential certification implications
- Prepare for a possible event or possible scenario‘s (OEM support)

Challenges:

- Towards a system with more responsibility for the operator: can that be done? (CDM proces)
- Interdependency in the total system
- ‘risk based approach‘: what are elements of a risk based approach, how can risks be mitigated?
- How did aircraft and engine certification deal in the past with multidimensional certification concepts (lightning? turbulence? Icing?).
- Ash levels – what are they? Ash level predicted or real value, average or peak, safe level or economic level? Need to exactly define what we are discussing. Transparency needed!

Challenges

- To be transparent, convincing to one another, and come to good conclusions?
- to find a 'total systems approach' (and balance cost)
- To explain/substantiate why some solutions may not work: not enough to say 'it cannot be done': explain why

Treat volcanic ash or sand as weather?

- Can we do that in the same way as lightning strike?
- Does that mean we do not require a minimum level of robustness of aircraft for dust/sand (or a 'system' to handle it)?

Definitions of ash levels

(explain why shown)

- <u>Volcanic Ash Concentration Level Predicted Value (kg/m3)</u> **= (VAP) = the predicted amount of volcanic ash in kilograms in 1 m3 of air under standard atmospheric conditions (1015<u>3,25</u> mbar or 10500 <u>1013,25</u> Hectopascal at 15 degrees C);**
- <u>Volcanic Ash Concentration Level Real Value (kg/m3)</u> **= (VAR) = the real amount of volcanic ash in kilograms in 1 m3 of air under standard atmospheric conditions (1015 <u>1013,25</u> mbar or 10500 <u>1013,25</u> Hectopascal at 15 degrees C).**
- **Further refinement could be sought when discussion 'volcanic ash concentration level safety limits': it could be defined as follows:**
- <u>Volcanic Ash Concentration Level Safety Limit (kg/m3) Predicted Value</u> **= (VAPsafe) = the predicted amount of volcanic ash in kilograms in 1 m3 air under standard atmospheric conditions** *<u>above</u>* **which continued safe flight or trouble free operation of a particular engine, aircraft, system or engine/aircraft/system combination is not ensured;**

Definition of ash levels

(explain why shown)

- Volcanic Ash Concentration Level Safety Limit (kg/m3) Real Value **= (VARsafe) = the real amount of volcanic ash in kg/m3 under standard atmospheric conditions** ***above*** **which continued safe flight or trouble free operation of a particular aircraft, engine, system or engine/aircraft/system combination is not ensured.**
- **The following definition could also be used: the FAA proposed 'NO EFFECT' Limit:**
- Volcanic Ash Concentration Level Real Value No Effect Value/Limit (kg/m3) **= (VARne) = the real amount of volcanic ash in kg/m3 under standard atmospheric conditions** ***below*** **which there is no measurable or effect on the operation of an engine, aircraft, system or engine/aircraft/system combination**

Thank you