Volcanic Ash and Gas Turbine Aero Engines - Update

WMO VAAC 'Best Practice' Workshop
5th- 8th May 2015

Rory Clarkson

Engine Environmental Protection

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Introduction

- Engine damage – quantitative understanding
  - Kelut 2014 encounter update
  - Desert sand analogy
  - Clarkson's DEvAC Chart latest
  - Research activities including VIPR-III latest
- Support for flight operations
  - Bardarbunga 2014 experience
- Regulations
  - EASA CS-25 1593 and CS-E 1050

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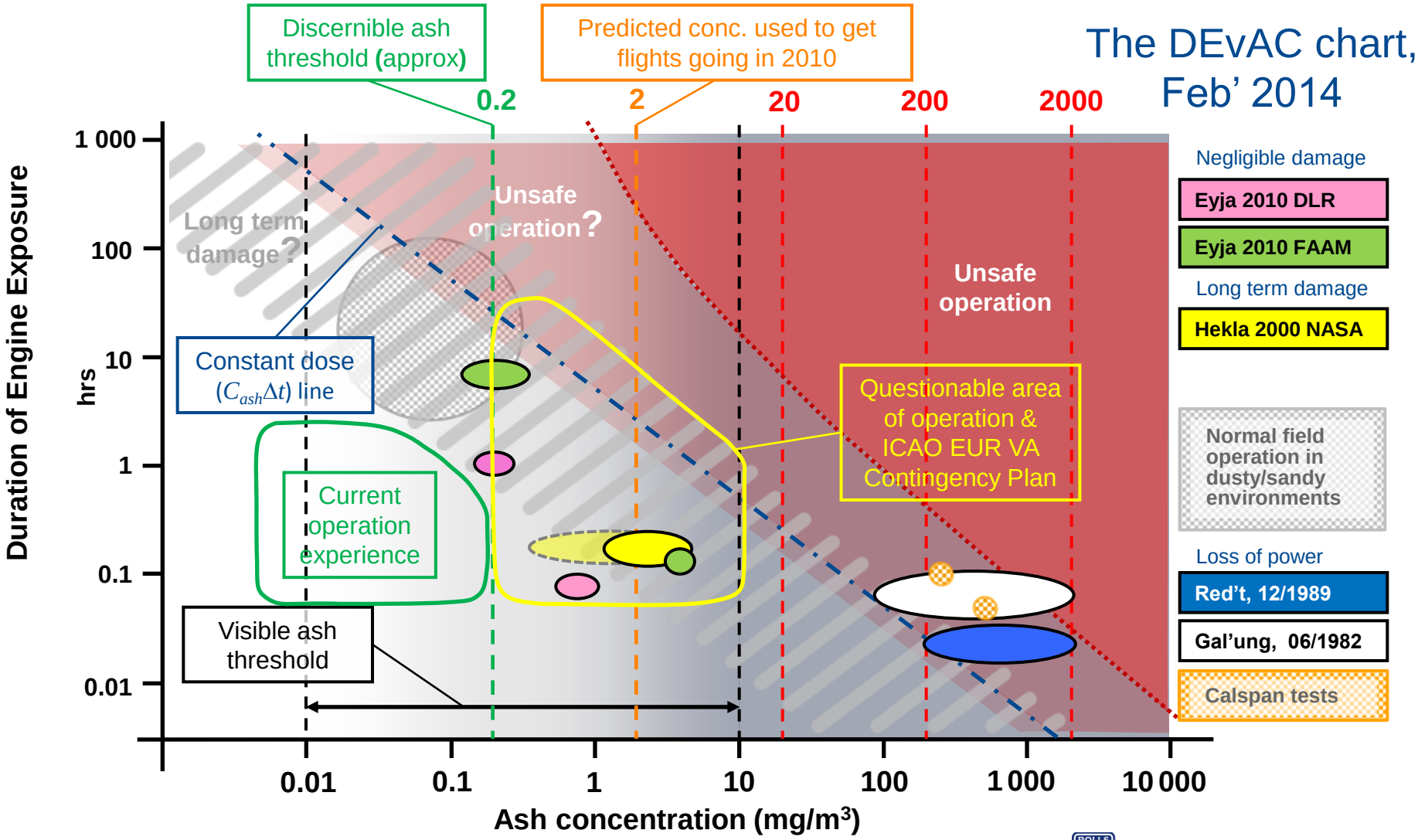
Engine damage – Quantitative Understanding

- BA009, KLM867 & DEvAC chart in IMechE paper soon …



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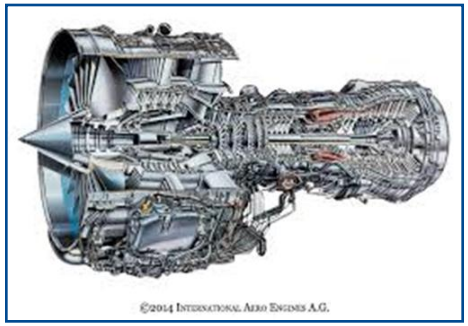
Kelut A320 Encounter 14 February 2014

- Late evening on 13th February 2015 (local time) Kelut erupts
- 2.5 hours later an A320, powered by IAE V2527-A5 engines takes off from Perth, WA, destination Jakarta
- Just over 3 hours later aircraft entered ash cloud 375 km from Kelut



- Followed by safe landing at Jakarta
- Engine inspection
  - Evidence of ash deposit in combustor and HP turbine
  - Engines removed for strip and repair

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Kelut A320 Encounter 14 February 2014

- IAVWOPSG informal ad hoc group submitted questions to A320 flight crew – March 2014
- Response from flight crew:
  - It was just before sunrise when the encounter occurred
  - There was no water cloud about before or during the encounter
  - No ash cloud was visible before or during the encounter – i.e. no change in visibility out the flight deck window; wing tips and engines clearly visible
  - The only evidence of St Elmo's fire was sudden appearance of green sparks coming from the icing rod
  - Wind noise increased ~30 seconds before icing rod sparks started
  - Sulphur smell detected on flight deck as icing rod sparks started
  - Dust noticed in flight deck from the FO's map light and in cabin, but no dust layer left on surfaces once ash cloud exited
  - There were no noticeable changes in flight or engine parameters during the exposure
  - Duration of exposure estimated to be ~6 mins at cruise, ~4 mins at descent

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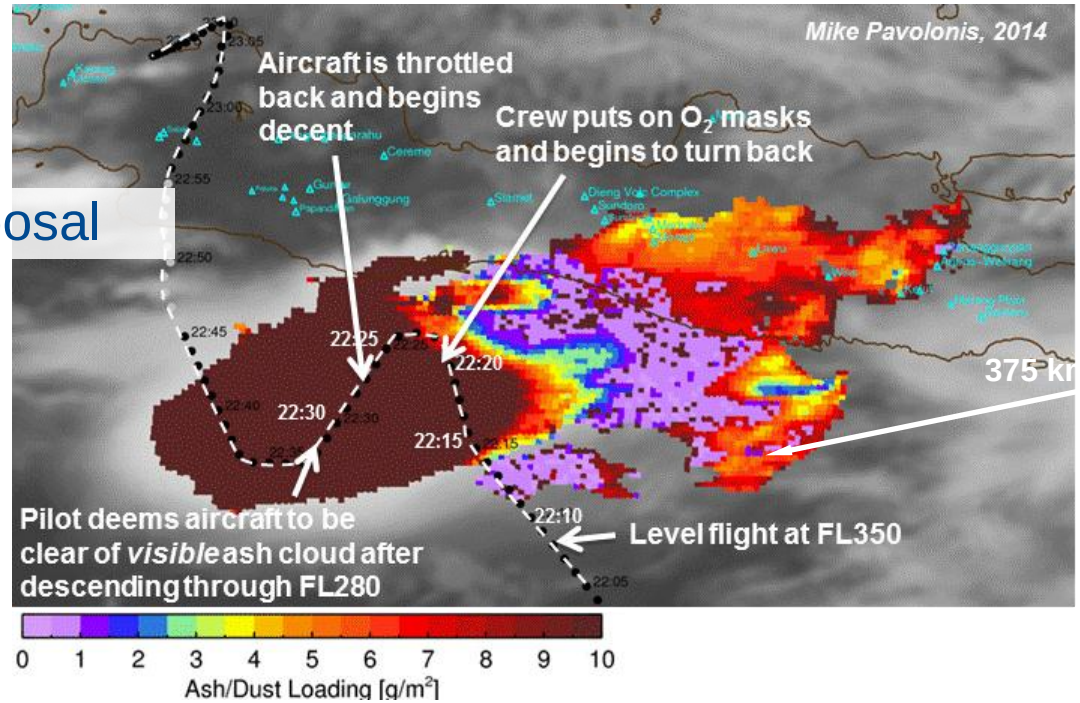
Kelut A320 Encounter 14 February 2014

- Kristiansen, Prata, et al. paper (Geophysical Research Letters)
  - Maximum ash concentrations of 9±3 mg/m^3, mean concentrations of 2±1 mg/m^3 over a period of 10-11 minutes of the flight
- M Pavolonis analysis (Mar' 2014)
  - Aircraft exposed to mean of between 2-10 mg/m^3 for 7-8 minutes at cruise
- ATHAM proposal



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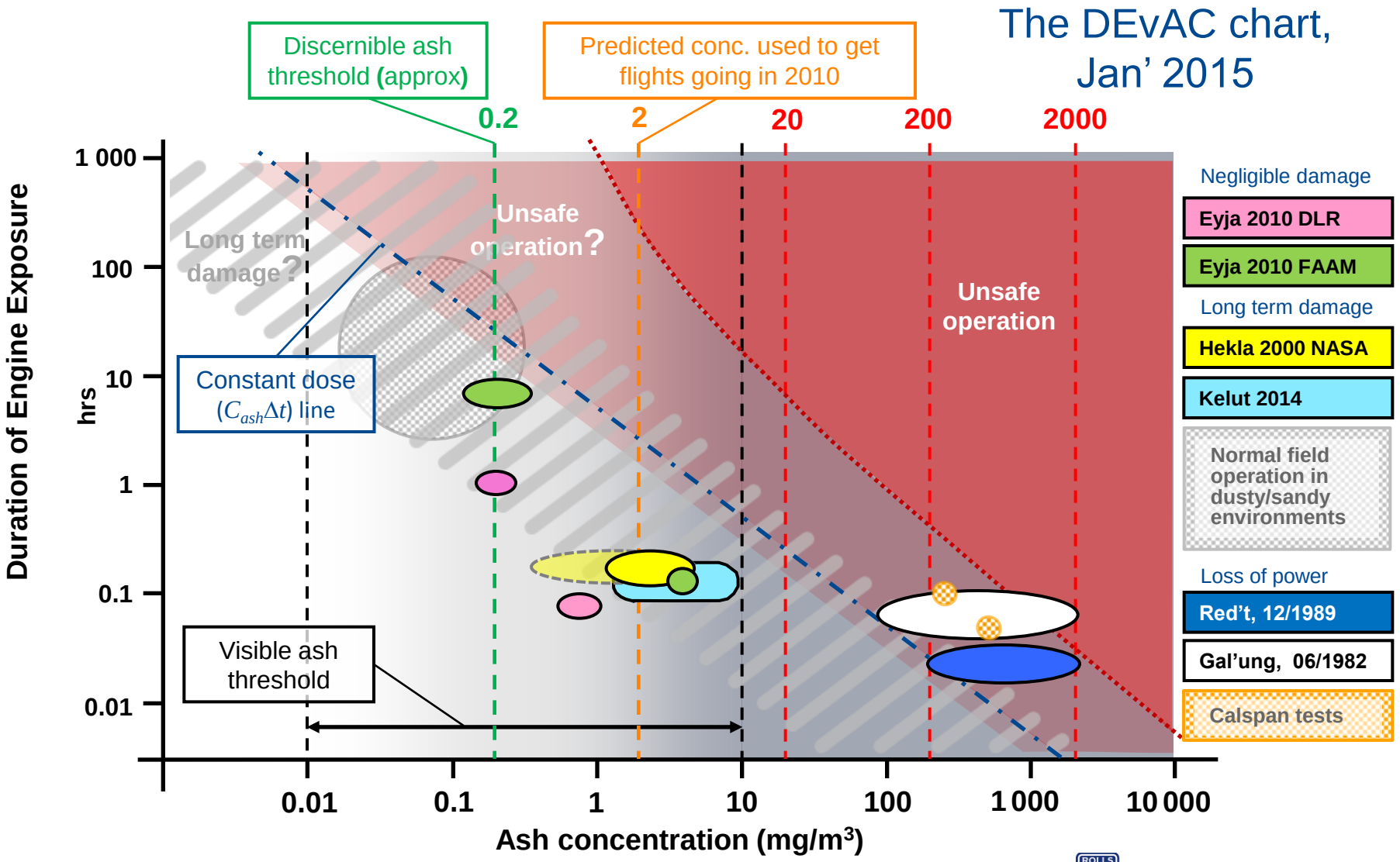
Kelut A320 Encounter 14 February 2014



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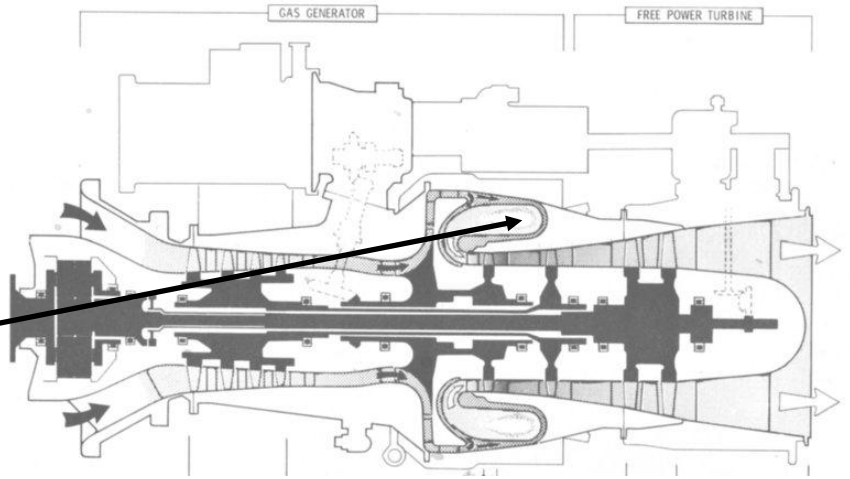
Fogo Cape Verde - 2014

- Early Dec' 2014 a helicopter was exposed to VA cloud

- Flight crew experienced strong sulphur smell – ash not seen
- Estimated ~30 minute exposure
- No impact on engine performance
- Ash found on airframe and some deposit in engine combustors
- Severity index 1 or 2?



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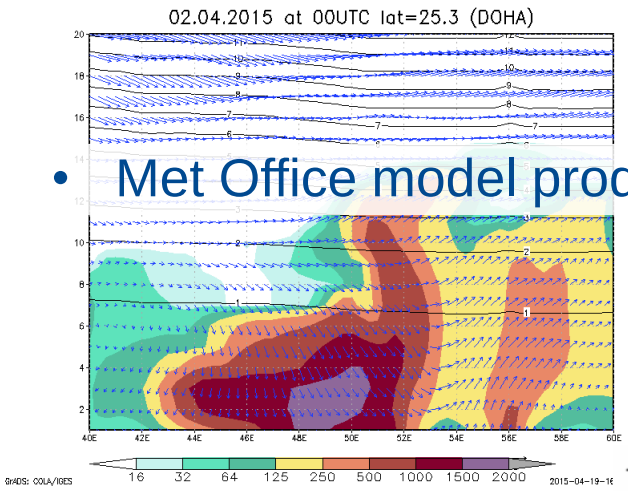
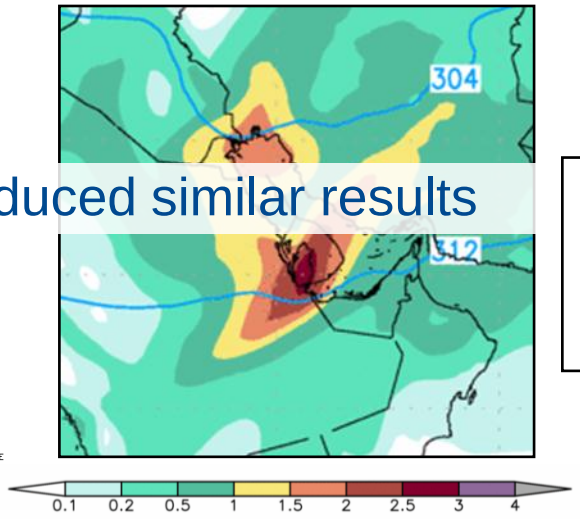
Desert Sand Analogy

- Severe sandstorm in Qatar 1st/2nd April 2015
  - At times visibility in Doha as low as 50 m

- Met Office model produced similar results



Dust conc μg/m3



Dust load g/m2 and 700 hPa geopotential

Dust forecast by Slobodan Nickovic – Dust Regional Atmospheric Model (Nickovic et al, 2001; Vukovic et al, 2014)
Horizontal resolution – 0.25 deg; 28 vertical levels

- Airport remained open – at least 2 aircraft took off during height of storm
  - One of early 2000's vintage
  - The other a very modern design
- Exposure: ~10 mins at 2-8 mg/m3

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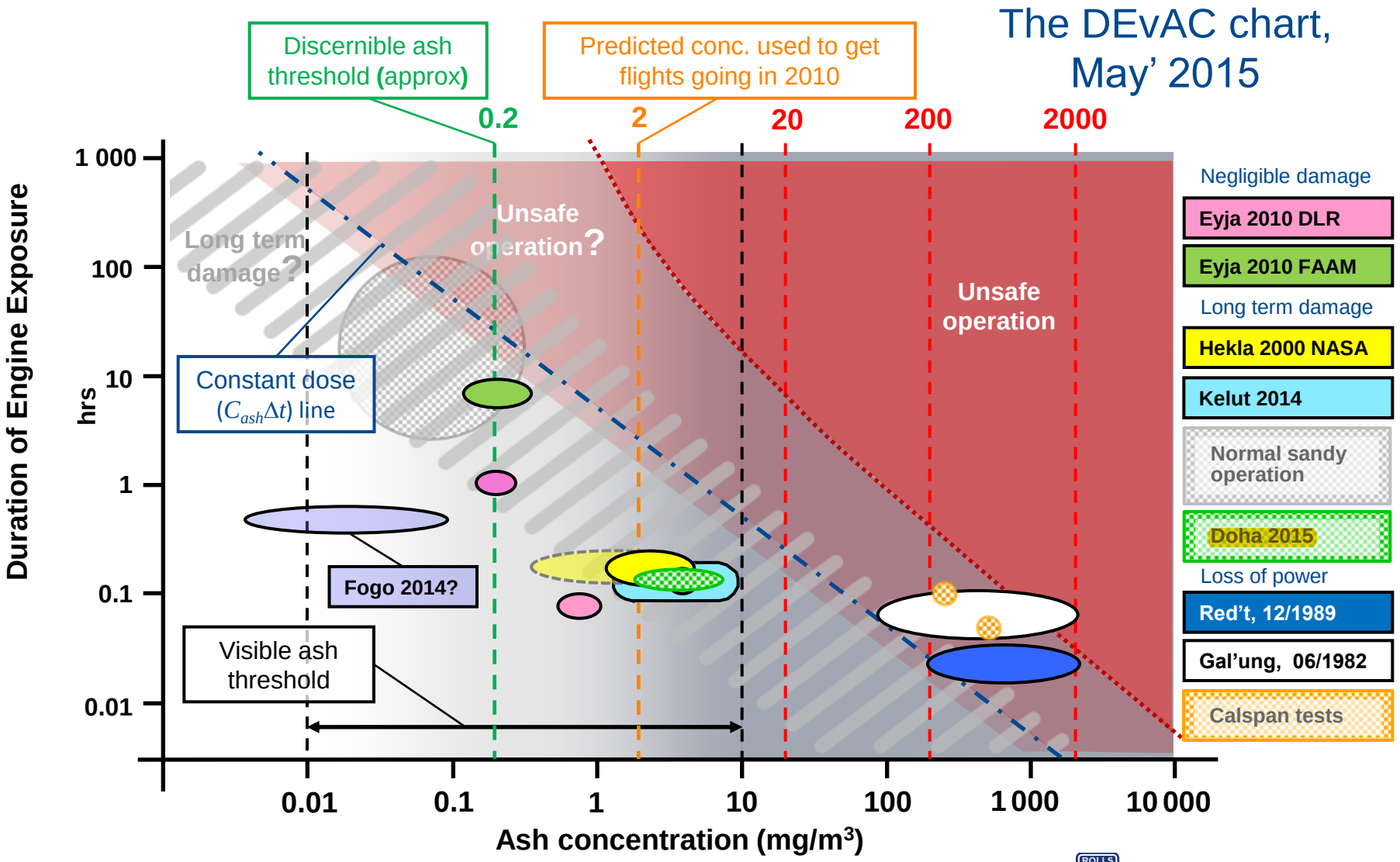
Fogo and Doha Events



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Research Currently in Place or Planned

Project	Content	Funding & Partners	Delivery Timescales
Global VA Risk Model	Probabilistic risk model on impact of VA on aviation	UK Gov and Willis funded: Bristol Univ, Met Off	2016 (?)
VIPR-III	F117 ash test on a C-17	Consortium of: NASA, USAF, P&W, GE, RR,…..	July 2015
easyJet CFM56 tests	CFM56-3 ash tests	EasyJet funded:	?
VERTIGO	Ash interaction with engine fan and core intake	EC funded ITN: Oslo Univ, SINTEF	2014 - 2017
PROVIDA	Loose collection of institutions looking at TBC durability and hot section accretion	UK & Indian Gov funded Camb Univ, Cranfield Univ, ARCI, easyJet, Oxford Univ, …	2014 - 2016
MoD hot section testing	Combustor and turbine accretion rig	Awaiting MoD funding	2014 - 2016
TTCP/NATO Durability	TBC lifing	NATO partner nation funding:	2014 - 2016
Oxford Univ	Turbine/Combustor cooling system degradation	Oxford Univ PV: Oxford Univ,	2012 onwards
DLR	Multi-million € programme	DLR funding:	2014 onwards

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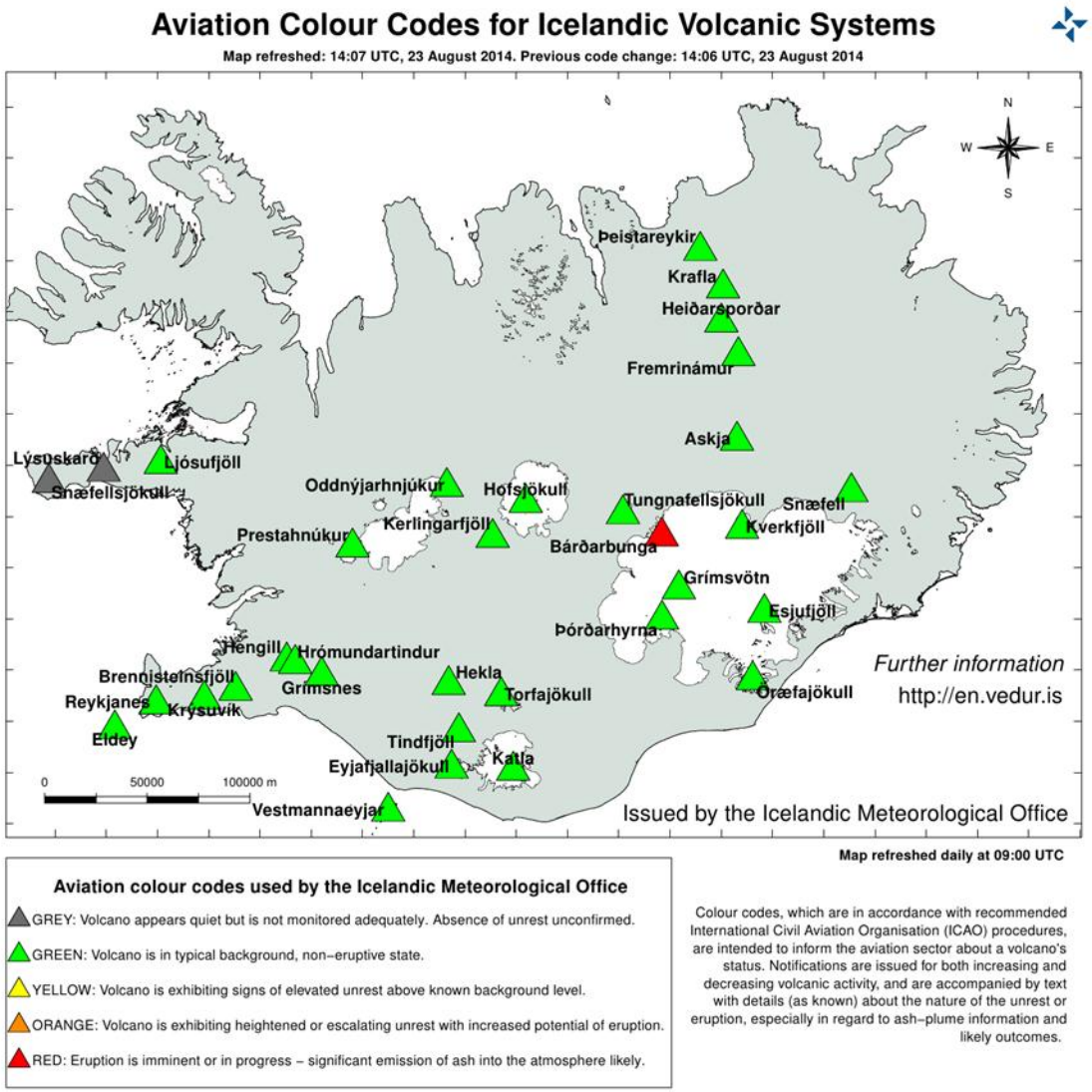
Support for Flight Operations

- Bardarbunga 2014

- EASA reissue VA SIB
- RR internal review of VA Guidelines



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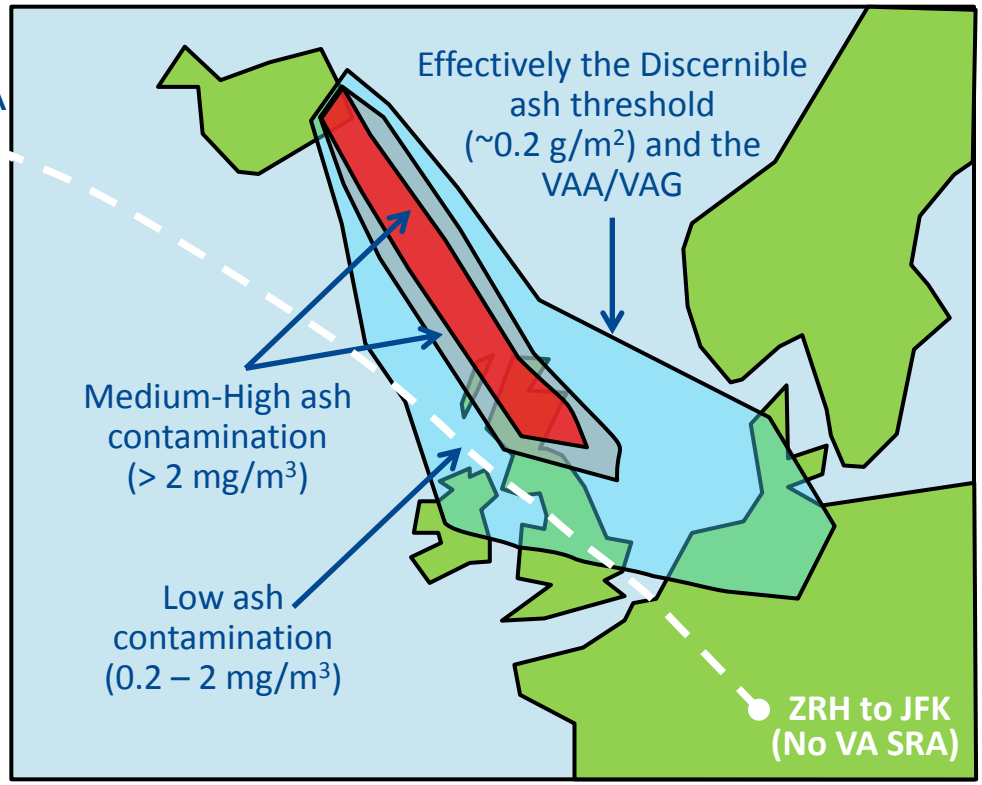
Support for Flight Operations

- ICAO EUR VA Contingency Plan and EASA VA SIB 2010-17R6
  - Avoid operation in visible or discernible ash
  - If ash forecast for Europe, SRA needed to fly in Medium-High contamination
  - i.e. No SRA to operate up to **predicted** 2 mg/m^3?



SRA – Safety Risk Assessment

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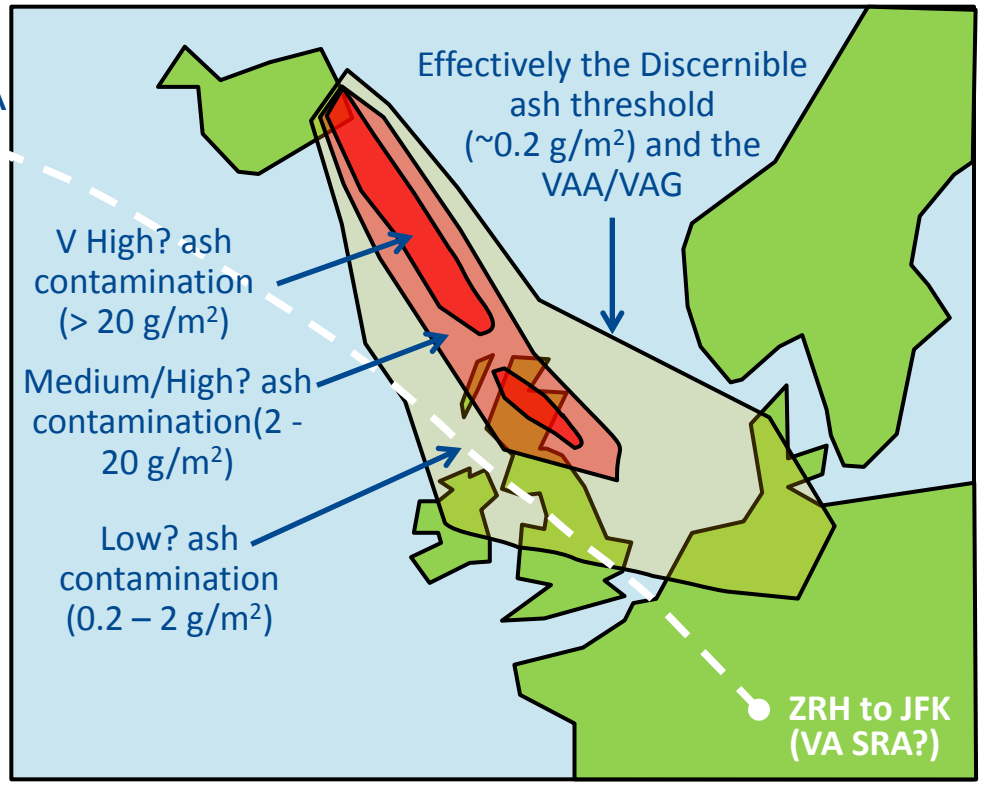
Support for Flight Operations

- ICAO EUR VA Contingency Plan and EASA VA SIB 2010-17R6
  - Avoid operation in visible or discernible ash
  - If ash forecast for Europe, SRA needed to fly in Medium-High contamination
  - i.e. No SRA to operate up to **predicted** 2 mg/m^3?
- VAAC London/Toulouse total column loading proposal, 4 levels of contamination
  - Predictions more reliable
  - Can be compared directly to satellite measurement
  - But no predicted concentrations for SRAs



SRA – Safety Risk Assessment

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Support for Flight Operations

- ‘Visible’ ash and flight deck window – FAA, Boeing, experience,….

What flight crews can see out of the flight deck window cannot be relied upon as a means of avoiding volcanic ash clouds

- Ash visibility does have some limited value in relation to operational procedures
  - Taking off near an erupting volcano e.g. Catania Airport, Kagoshima Airport, Mexico City, …
  - Emergency action during a flight

- Discernible ash has substantial value for operational/flight planning
  - Works at night
  - Can be established remotely – satellites
  - Can be based on a total column loading value so can be modelled, and validated, reasonably accurately
    - Useful when water cloud obscures satellite image
    - Useful for ash cloud forecasting at T+3, T+6, T+18, ….

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EASA and Regulation

- CS-E 540(b)

> **(b) The Engine must be designed so that the strike and ingestion of foreign matter that is likely to affect more than one Engine in any one flight will not preclude the continued safe flight and landing of the aircraft as a consequence of a Hazardous Engine Effect or an unacceptable:**
>
> **(1) Immediate or subsequent loss of performance;**
>
> **(2) Deterioration of Engine handling characteristics;**
>
> **(3) Exceedence of any Engine operating limitation.**

- RR Response for Trent XWB-84 (2013)
  - Provided operators operate the engines according to RR's guidelines – i.e. avoiding 'visible' ash
  - Engines are not vulnerable to VA related flameout or loss of operability (loss of surge margin)
  - Position is backed up by service history of similar engines produced since early 1970s
  - And that new engines don't have novel systems that would make them more vulnerable

EASA and Regulation

- CRD 2012-21 to A-NPA 2012-21 – volcanic ash ingestion in turbine engines

EXECUTIVE SUMMARY

This combined Explanatory Note and Comment-Response Document (CRD) contains the comments received on A-NPA 2012-21 (published on 28 November 2012) together with a summary of the Agency's conclusions and proposed future activities.

The feedback provided during the consultation showed that stakeholders considered that there was no rationale to depart from the current ICAO operator-centric approach and that the concept of avoiding operations in visible ash clouds remained a strongly supported principle.

Based on stakeholders' views and taking into account available knowledge, reports and evidence, the Agency has concluded that there is no safety case that would justify an immediate and general rulemaking action to introduce a new volcanic ash airworthiness requirement for turbine engines.

The Agency will continue to monitor and assess volcanic ash related risks and to encourage further research activities that can contribute to a better understanding of volcanic hazards.

- CS-25 1593
  - Implemented into CS-25 Amendment 13 in June 2013
  - Applies to A350-1000 certification, and thus to Trent XWB-97
- CS-E 1050
  - Will be incorporated with CS-E Amendment 4, issued 12 March 2015

EASA and Regulation

CS 25.1593 Exposure to volcanic cloud hazards (See AMC 25.1593)

The susceptibility of aeroplane features to the effects of volcanic cloud hazards must be established.

AMC 25.1593

Exposure to volcanic cloud hazards

The aim of CS 25.1593 is to support operators …….. part of an established management system.

Acceptable means of establishing the susceptibility of aeroplane features to the effects of volcanic clouds should include a combination of experience, studies, analysis, and/or testing of parts or sub-assemblies.

- CS-E 1050 is very similar
- Essentially:
  - Declare a volcanic ash susceptibility
  - Demonstrate engine operates acceptably up to susceptibility level by: similarity, analysis or test (or a combination of these)

loss of thrust but also to failures of electrical, pneumatic, and hydraulic systems;

b. …….

e. Volcanic ash and/or toxic chemical contamination of cabin air-conditioning packs, possibly leading to loss of cabin pressurisation or noxious fumes in the cockpit and/or cabin;

f. …..

(2) …….

(6) The recommended continuing airworthiness inspections associated with operations in volcanic cloud contaminated airspace and to/from volcanic ash-contaminated aerodromes; this may take the form of Instructions for Continued Airworthiness or other advice.

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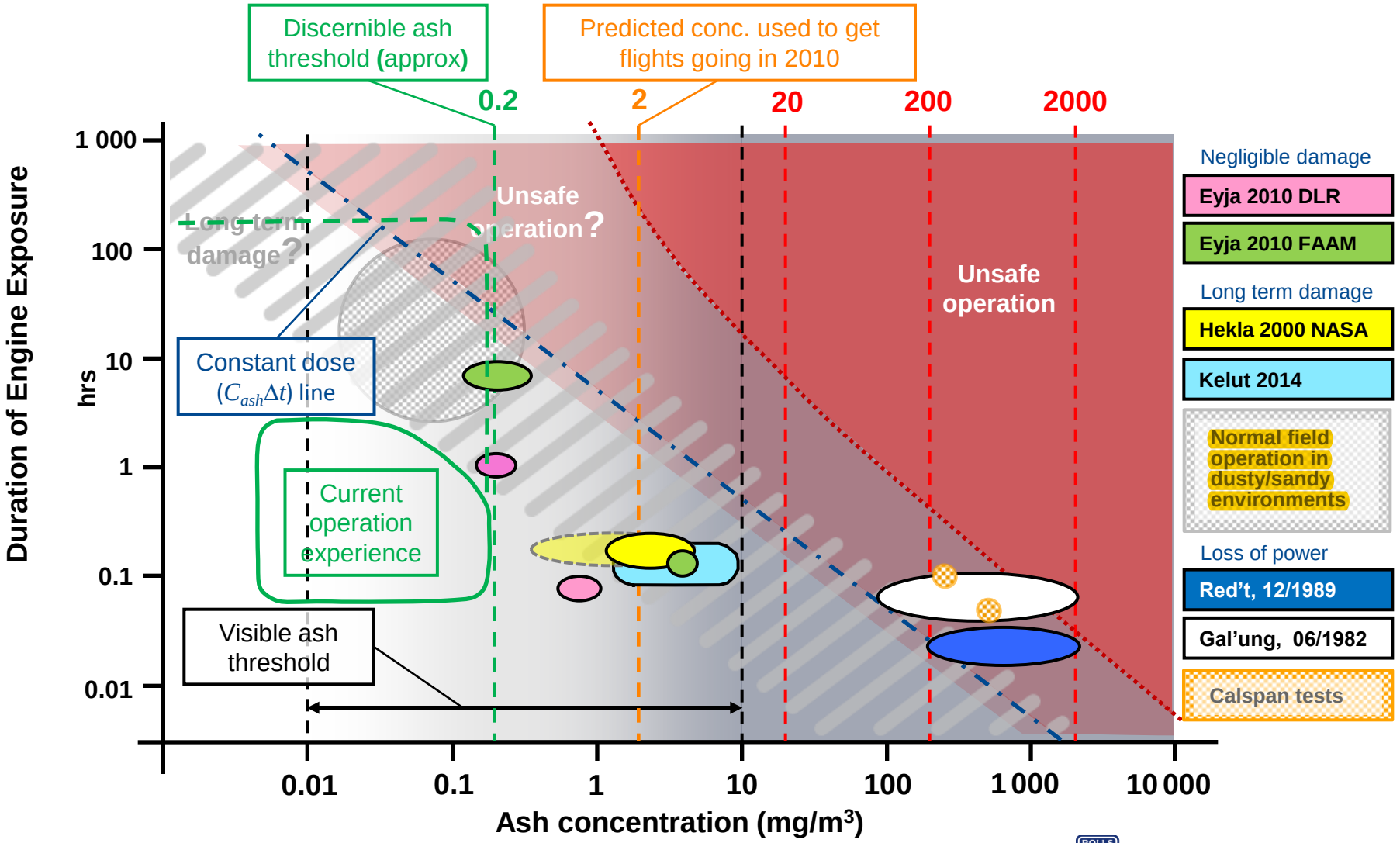
EASA and Regulation

- Oct 2014 – EASA guidance on CS-25 1593 and CS-E 1050

  - ❑ Purpose is to provide data to support operators' SRAs
    - ➢ Still apply principle: "*Volcanic ash encounters shall be avoided (do not operate in visible + discernable ash)*"
    - ➢ Operators need to know susceptibility to volcanic ash to understand operational risk
  - ❑ Requires manufacturers to investigate and understand the hazards associated with exposure to the harmful effects of volcanic clouds
  - ❑ A statement to avoid visible or discernible ash is not acceptable for compliance – such a statement is an operational recommendation not a susceptibility
  - ❑ Engine testing required if susceptibility declared to be between 4 mg/m^3 to 1000 mg/m^3
    - ➢ No need to test if susceptibility set at <4 mg/m^3 (and presumably >1000 mg/m^3 ☺)
  - ❑ Applies to <u>new</u> and <u>changed</u> products

Engine Susceptibility

- Effectively no susceptibility up to discernible (i.e. ~0.2 mg/m^3)



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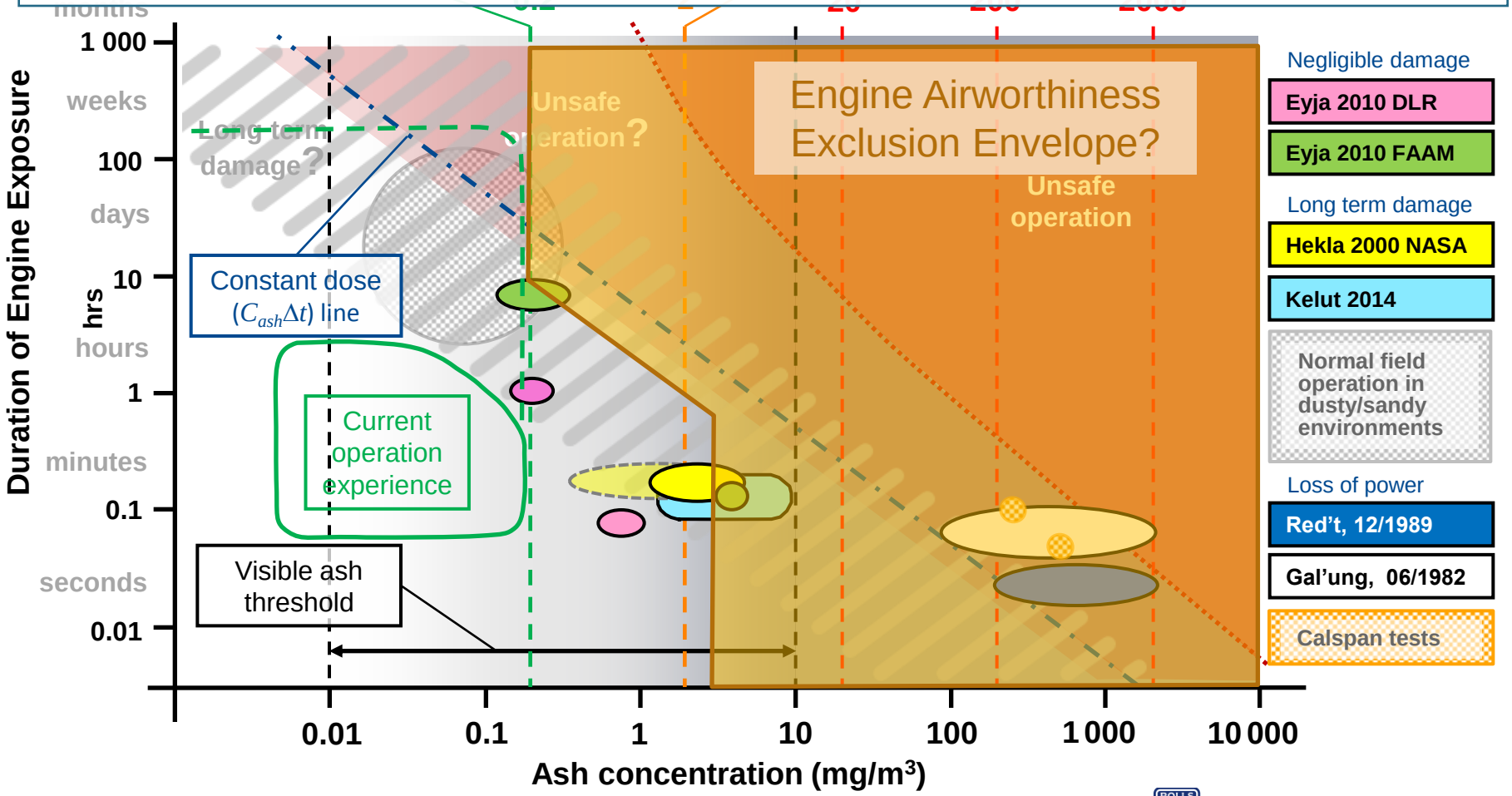
Engine Susceptibility – Airlines' Requests

- Why not use a number? e.g. x mins at 4 mg/m^3 or equivalent dose at lower concentrations
  - i.e. 2x mins at 2 mg/m^3, 4x mins at 1 mg/m^3, …, to unlimited at 0.2 mg/m^3



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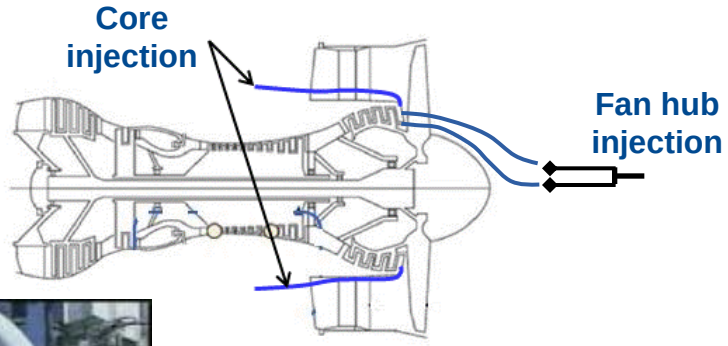
CS-E 1050 Compliance – Test

- No engine VA test has ever been conducted
  - Sand and dust tests have been run



CFMI sand test

GE90 hail test – similar set up used for sand testing

CALSPAN dust test

- VIPR-III is planned for mid-2015
  - Will use (7000 yr old) Mt Mazama ash

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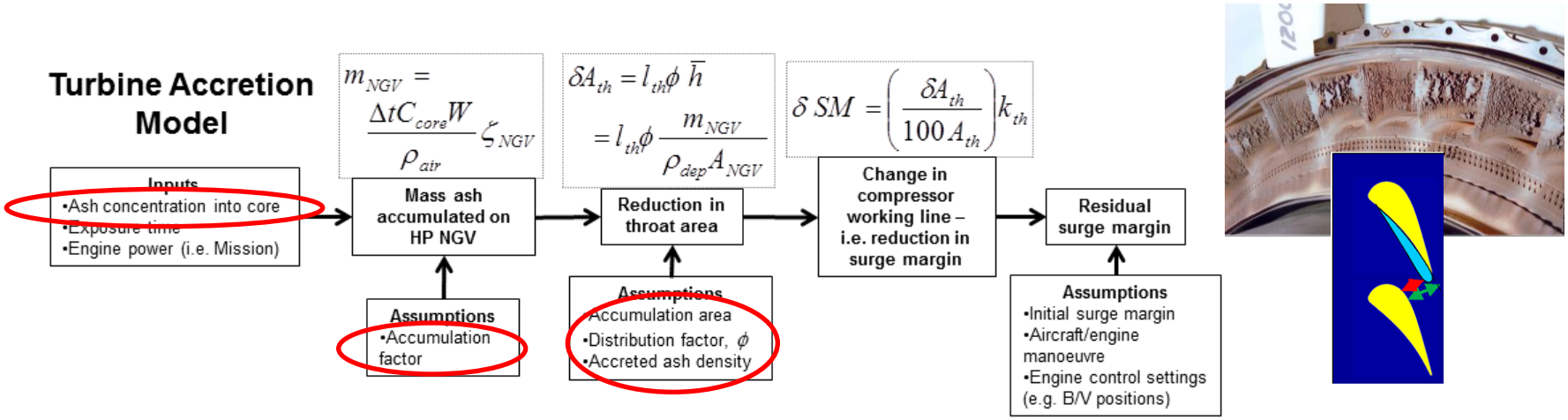
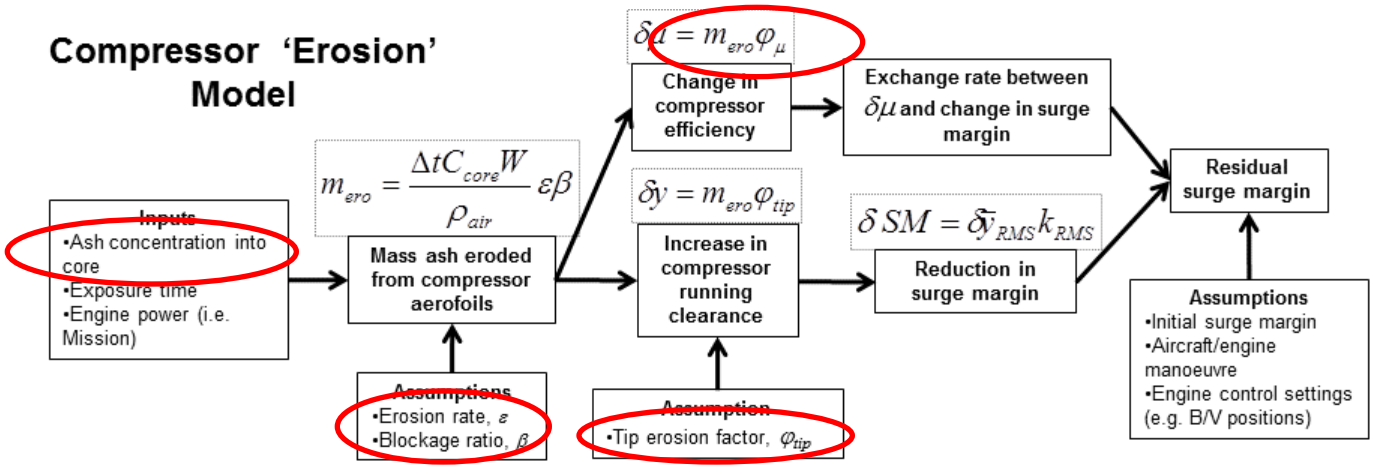
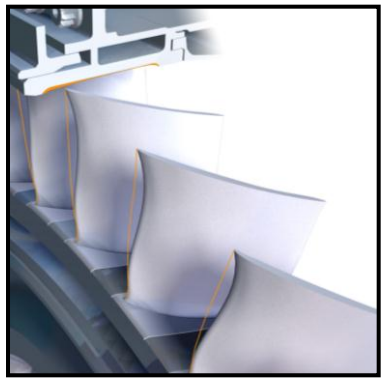
CS-E 1050 Compliance – Analysis

- High level engineering correlation based approach







High uncertainty

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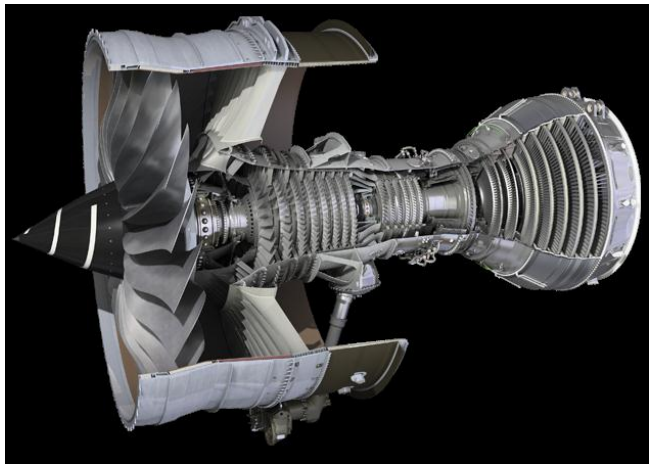
CS-E 1050 Compliance – Similarity

- Trent 1000

- Trent XWB



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And Finally to Conclude

- Gradually the quantitative understanding of engine VA susceptibility is improving – but still a lot that isn't known
- Some limited engine effect research being undertaken
- Still some confusion in relating current susceptibility understanding to operational guidelines, particularly in Europe
- New EASA regulations exist for certifying engines

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