The Impact Volcanic Ash has on Jet Engines – Latest Understanding

2nd IUGG-WMO Workshop on Ash Dispersal Forecast and Civil Aviation – 18-20 November 2013

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Engine Environmental Protection

Rolls-Royce

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Introduction

- Qualitative understanding of engine damage mechanisms
- Quantitative understanding of engine damage mechanisms in 2010
- Rolls-Royce's activities 2010 – 2013
  - Including quantitative investigations 2011 – 2013
- Current Position

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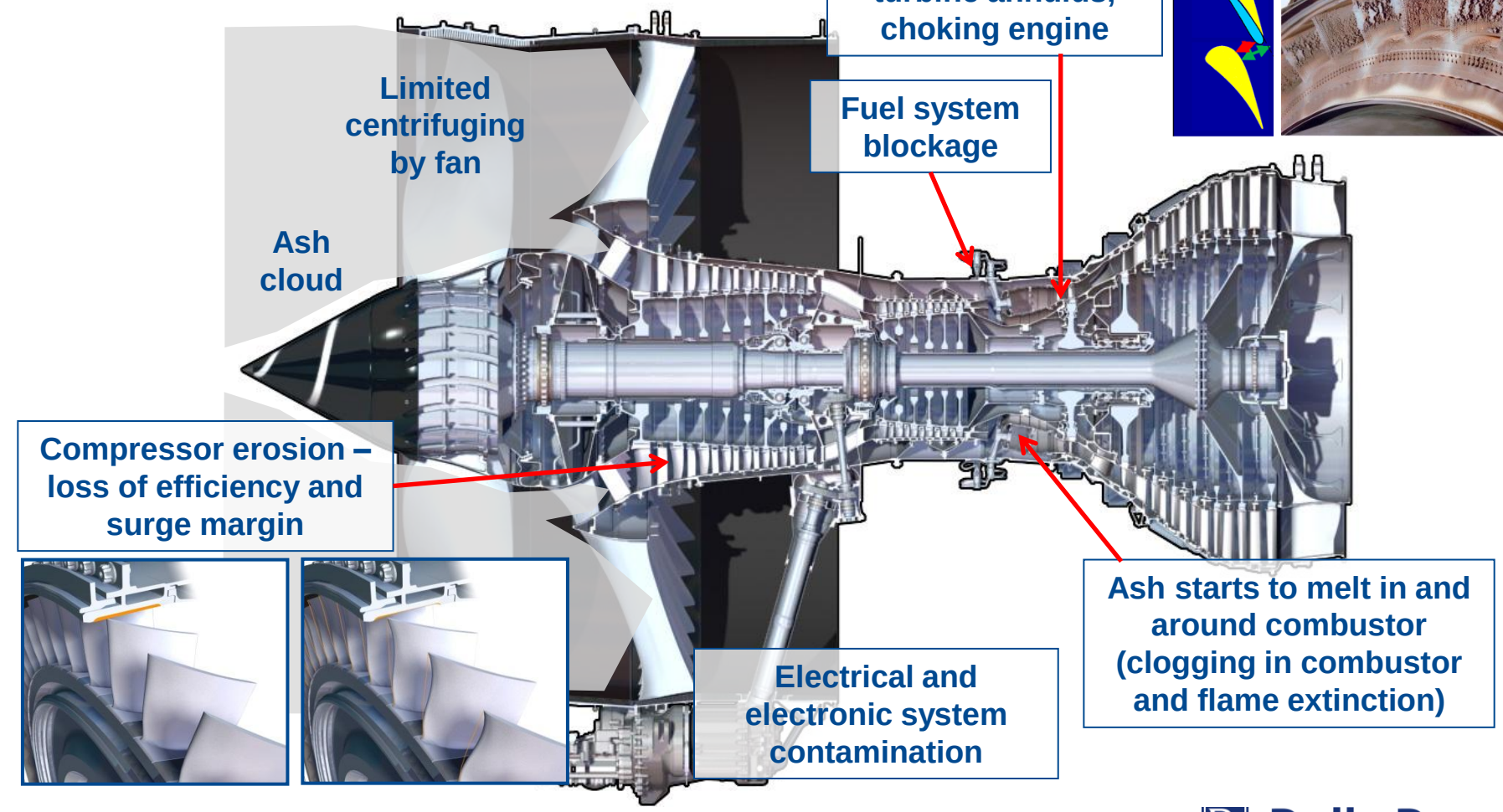
What We Know – Engine Damage Mechanisms

- Rapid impact effects



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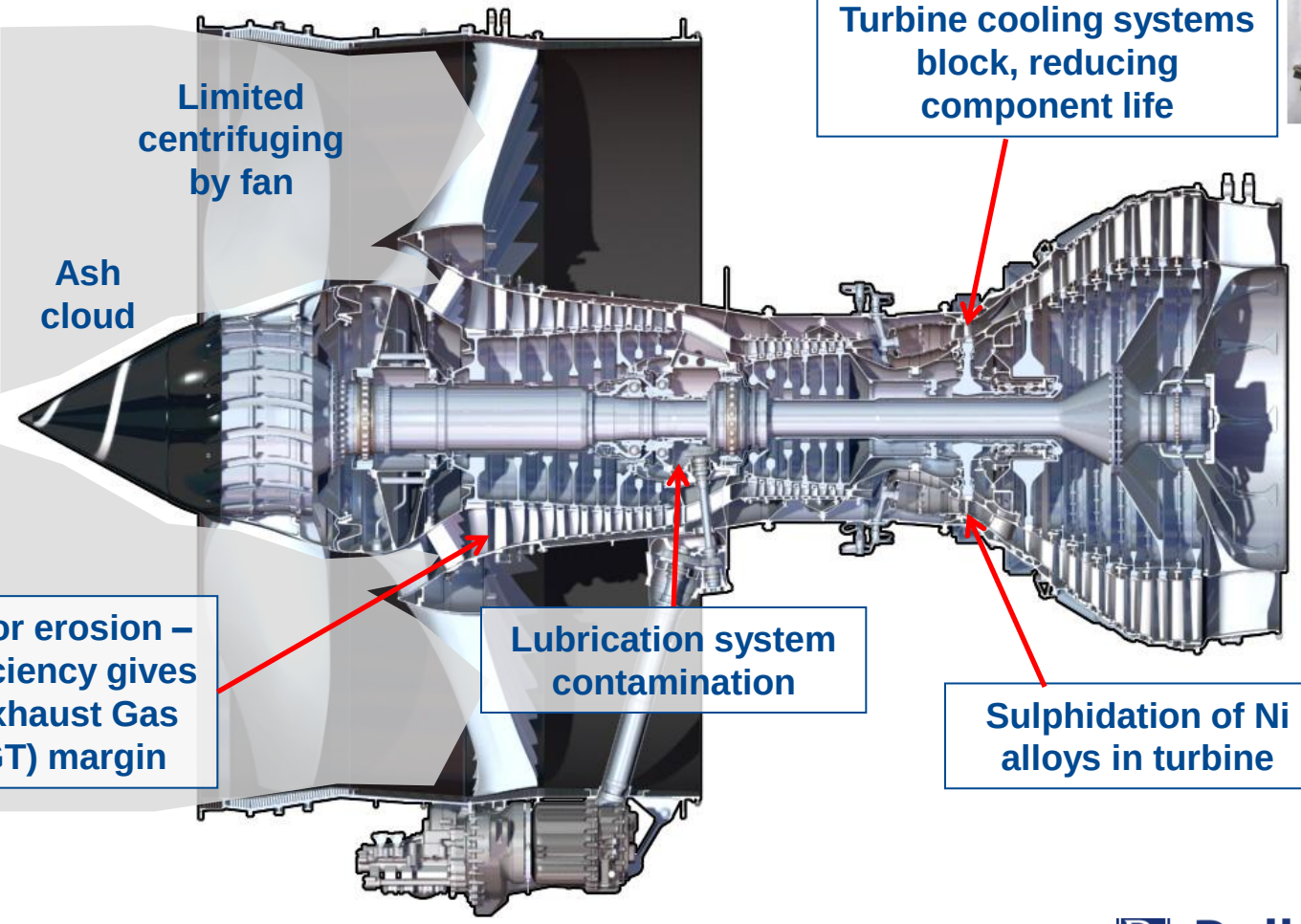
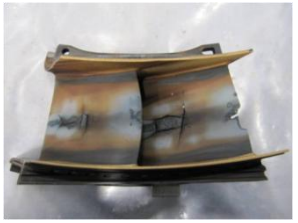
What We Know – Engine Damage Mechanisms

- Longer term ‘cost of ownership’ damage





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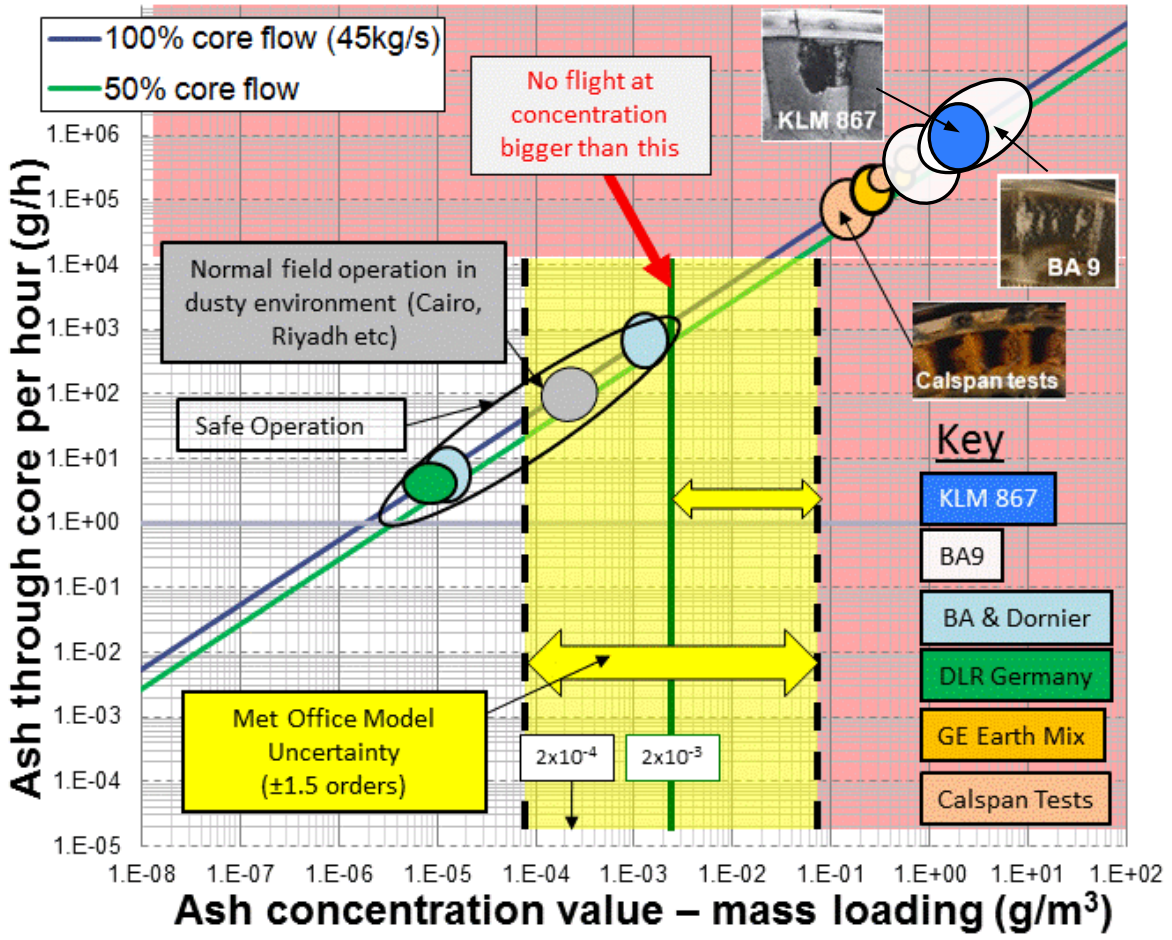
2010 Quantitative Understanding

- Engine susceptibility – 2010 RR engine ‘Safe-to-Fly’ chart



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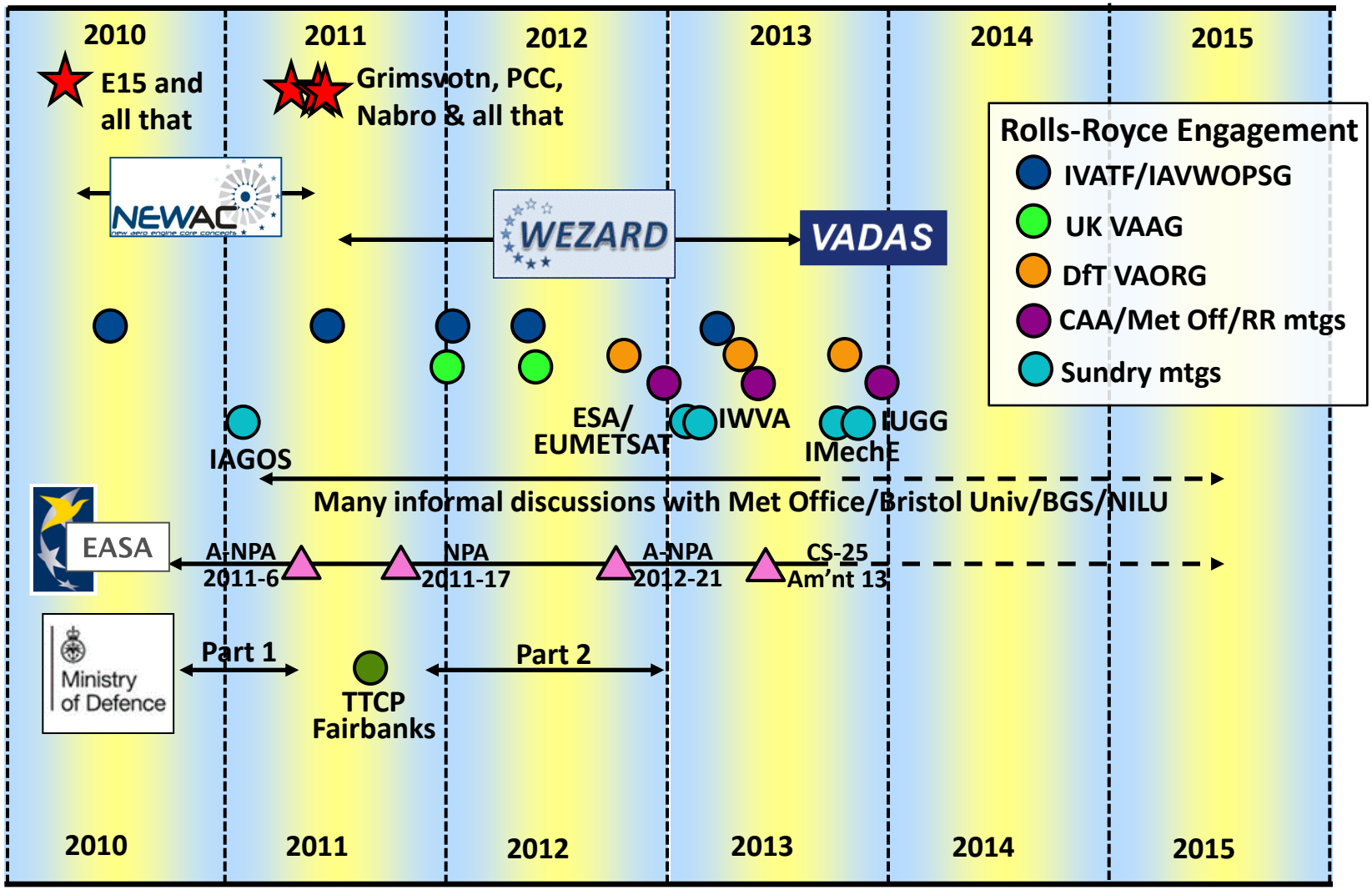
Rolls-Royce Activities 2010-2013



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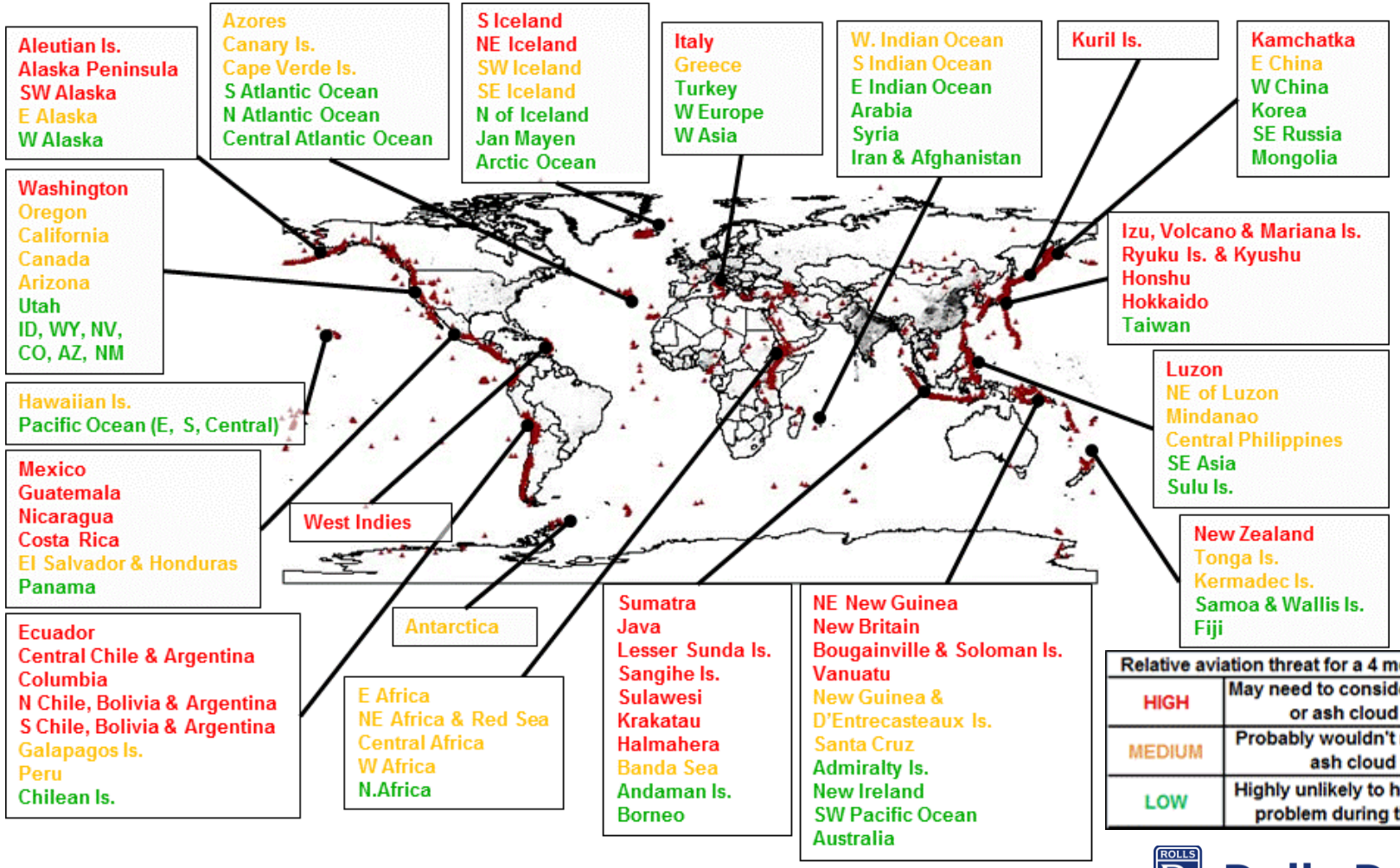
MoD Funded Research 2012

- Global VA Risk Assessment



Relative aviation threat for a 4 month deployment	
HIGH	May need to consider volcanic unrest or ash cloud avoidance
MEDIUM	Probably wouldn't need to deal with ash cloud problem
LOW	Highly unlikely to have an ash cloud problem during the deployment

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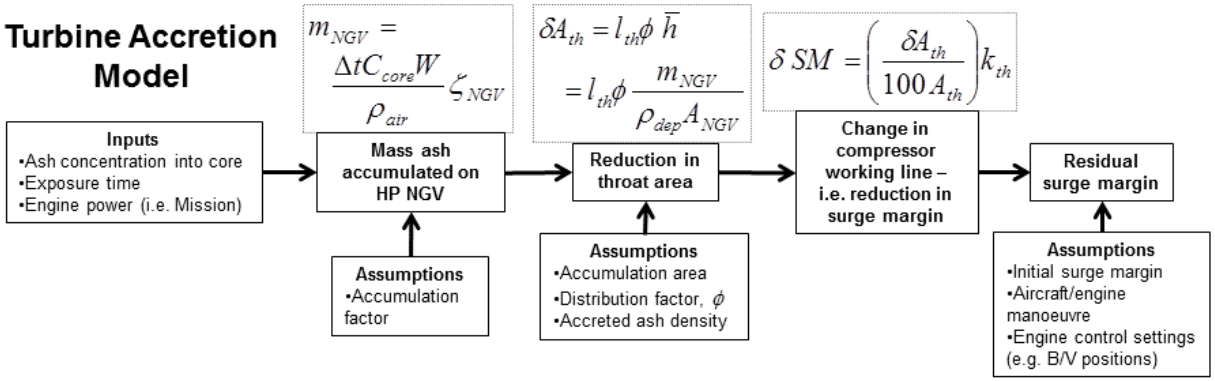
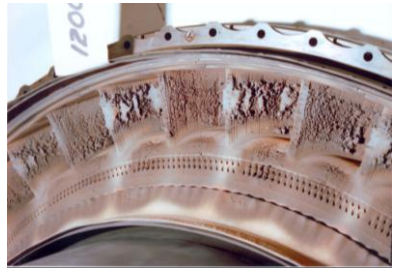
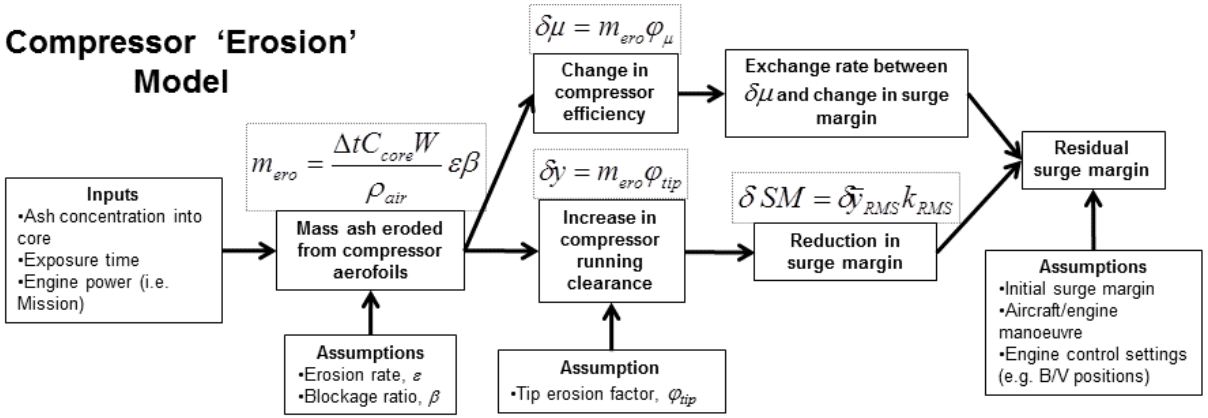
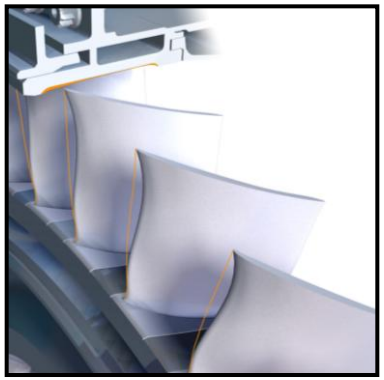
MoD Funded Research 2012

- Operability model uncertainty – duration of exposure before engine stops working









- Uncertainty greater than an order of magnitude

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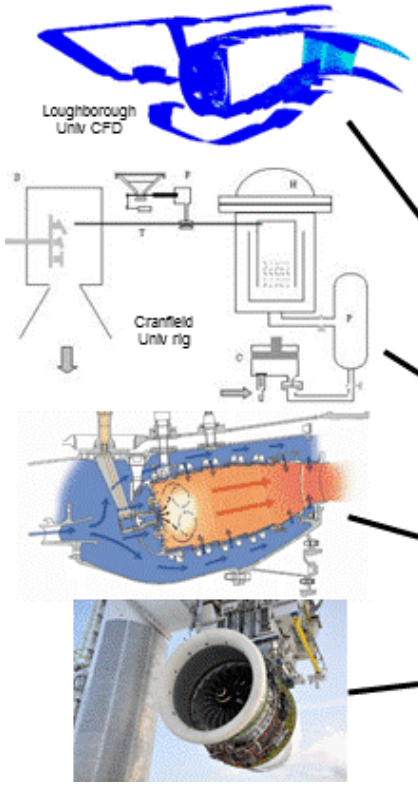
MoD Funded Research 2012

- Proposed Research Programme to reduce uncertainty



	Fan	Compressors	Combustors	Turbines
Phenomena	Particle centrifuging	Impingement, Erosion, Abrasion	Particle aggregation, Accretion	Ash accretion, Deposit shedding
Damage		Erosion, Rotor path lining abrasion	Fuel nozzle blockage	NGV throat blockage
CFD model	~£50k	~£100k	Combustor & NGVs ~£170k	
Sub-element test rig		Erosion ~£300k Abrasion ~£1M	Hot NGV accretion £500k-£1.5M	
Sub-assembly test rig		Compressor rig ~£4M	Combustor with NGV rig ~£2M	
Engine test		>£3M		

- Partial reduction in modelling uncertainty - £1.5M - £2M
- Substantial reduction in modelling uncertainty - >£15M

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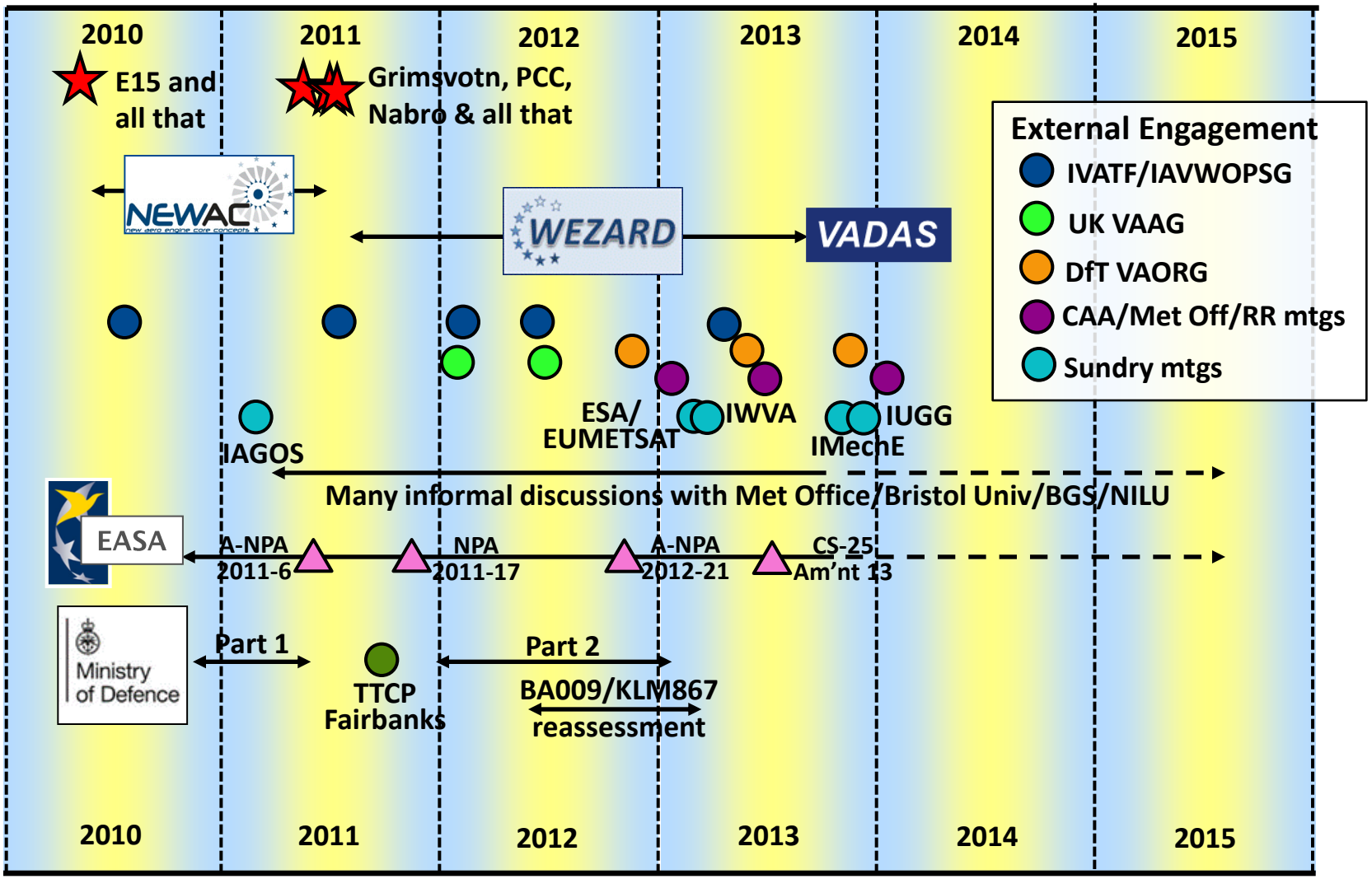
Rolls-Royce Activities 2010-2013



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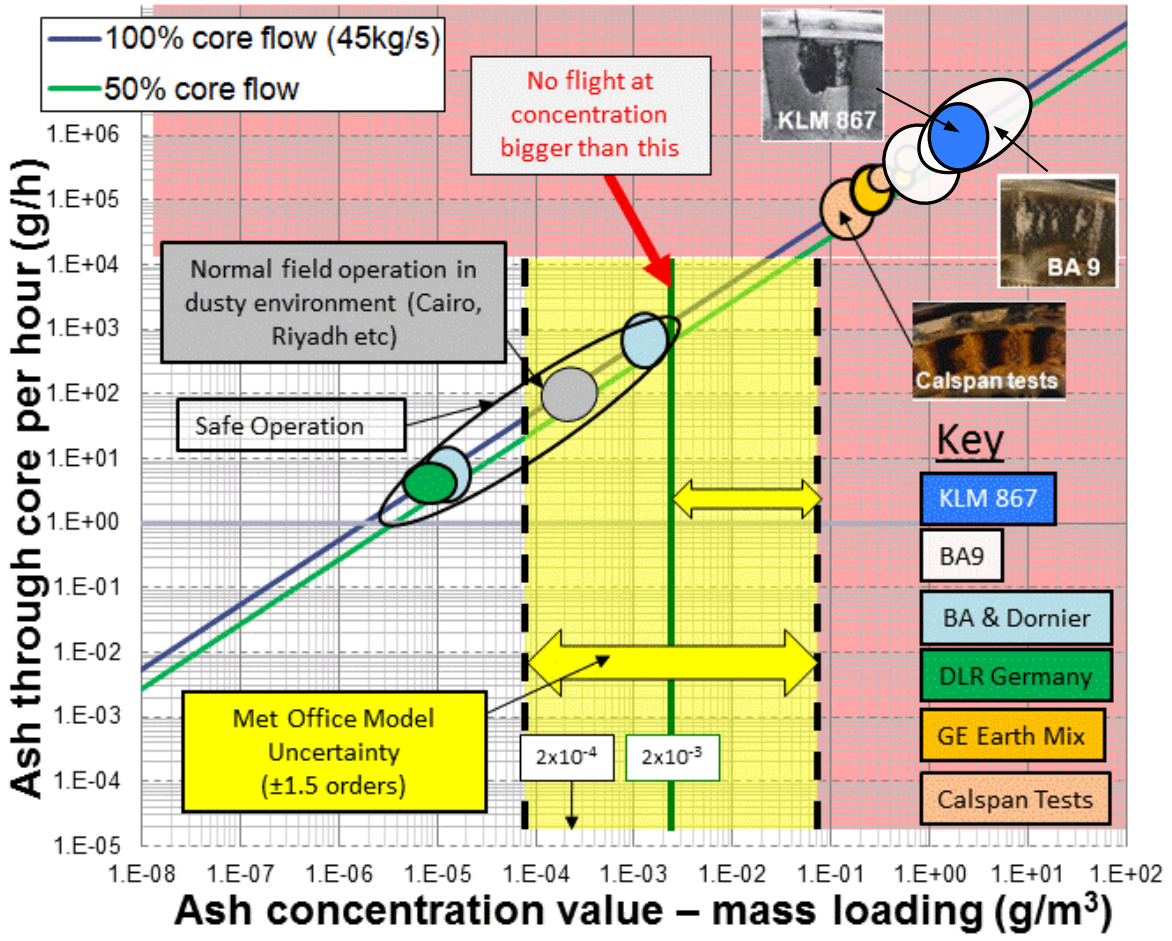
Reassessment of BA009 & KLM867 Events

- 2010 assessment based on compressor erosion & turbine accretion calculations



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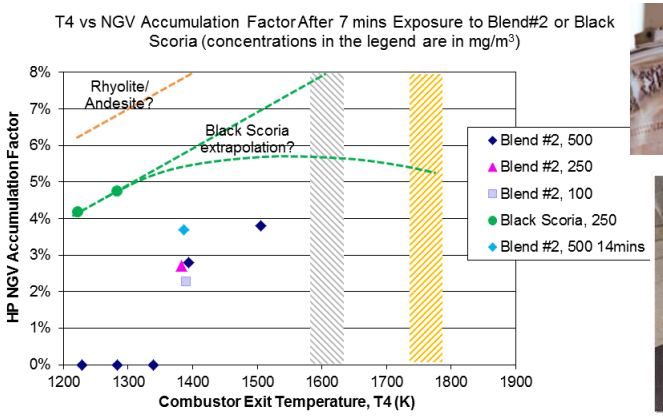
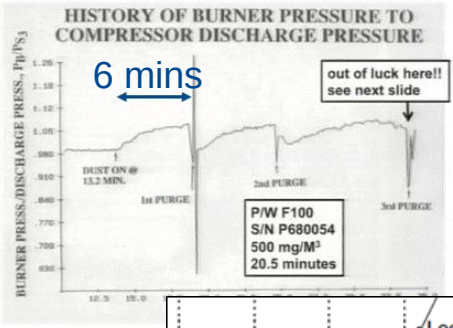
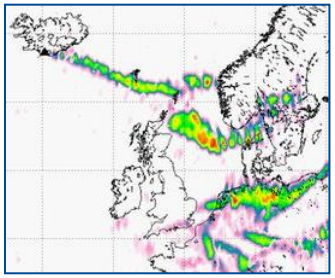
Reassessment of BA009 & KLM867 Events

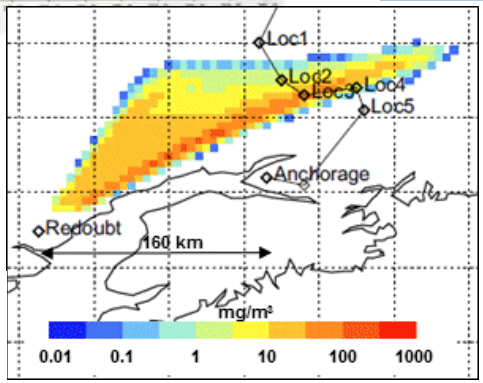
- Turbine accumulation factors
  - Calspan data and CFD studies
- BA9 compressor erosion rate calculations
  - Brite-Euram and NEWAC erosion rate data
- Times-to-surge compared to Calspan/GE tests
- VA concentrations from a VEI 4 100-200 km from vent
  - Satellite measurements
  - Dispersion modelling
- Visibility evidence







Satellite total column load [g/m²] – Meteo France



KLM867 Event Modelled by MetOffice

C [mg/m³]	$V = 1600/C$ [m]
2	800
20	80
200	8
2000	0.8

E15 Visibility Data - Environment Agency of Iceland 2010

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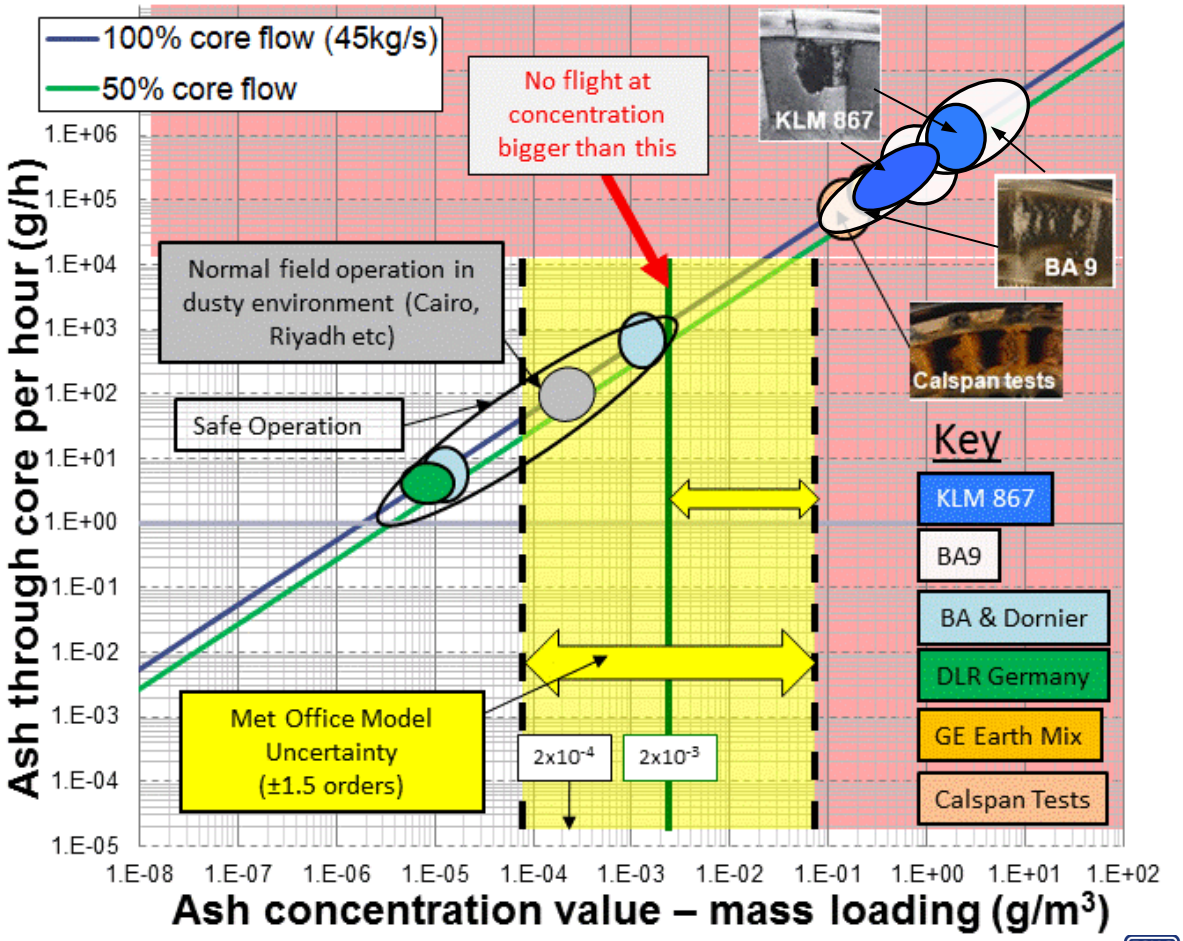
Reassessment of BA009 & KLM867 Events

- 2010 engine ‘Safe-to-Fly’ Chart - 2012 Revision



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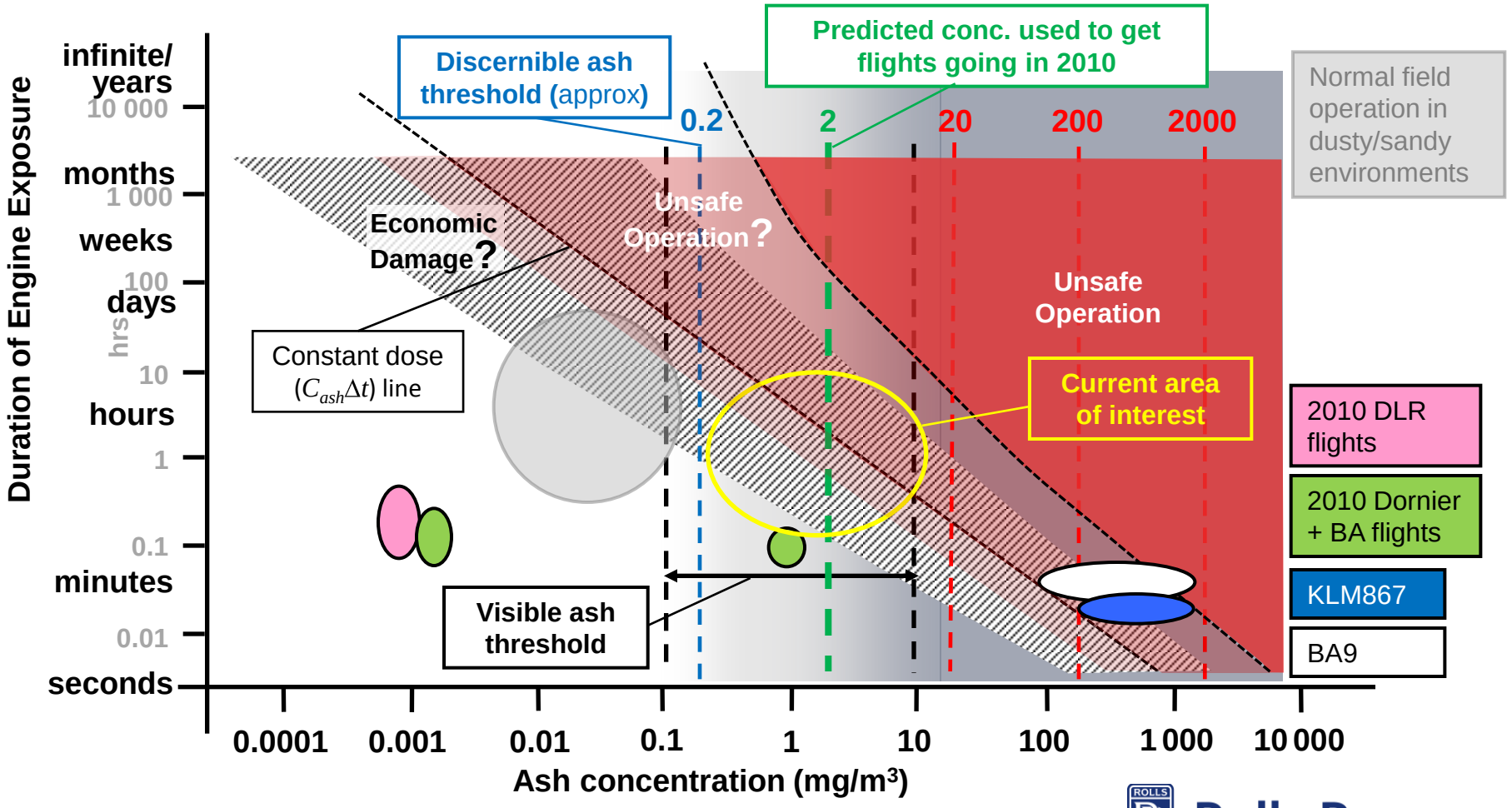
Reassessment of BA009 & KLM867 Events

- Duration of exposure v Ash concentration chart – a cartoon
  (Requested and funded by MoD)



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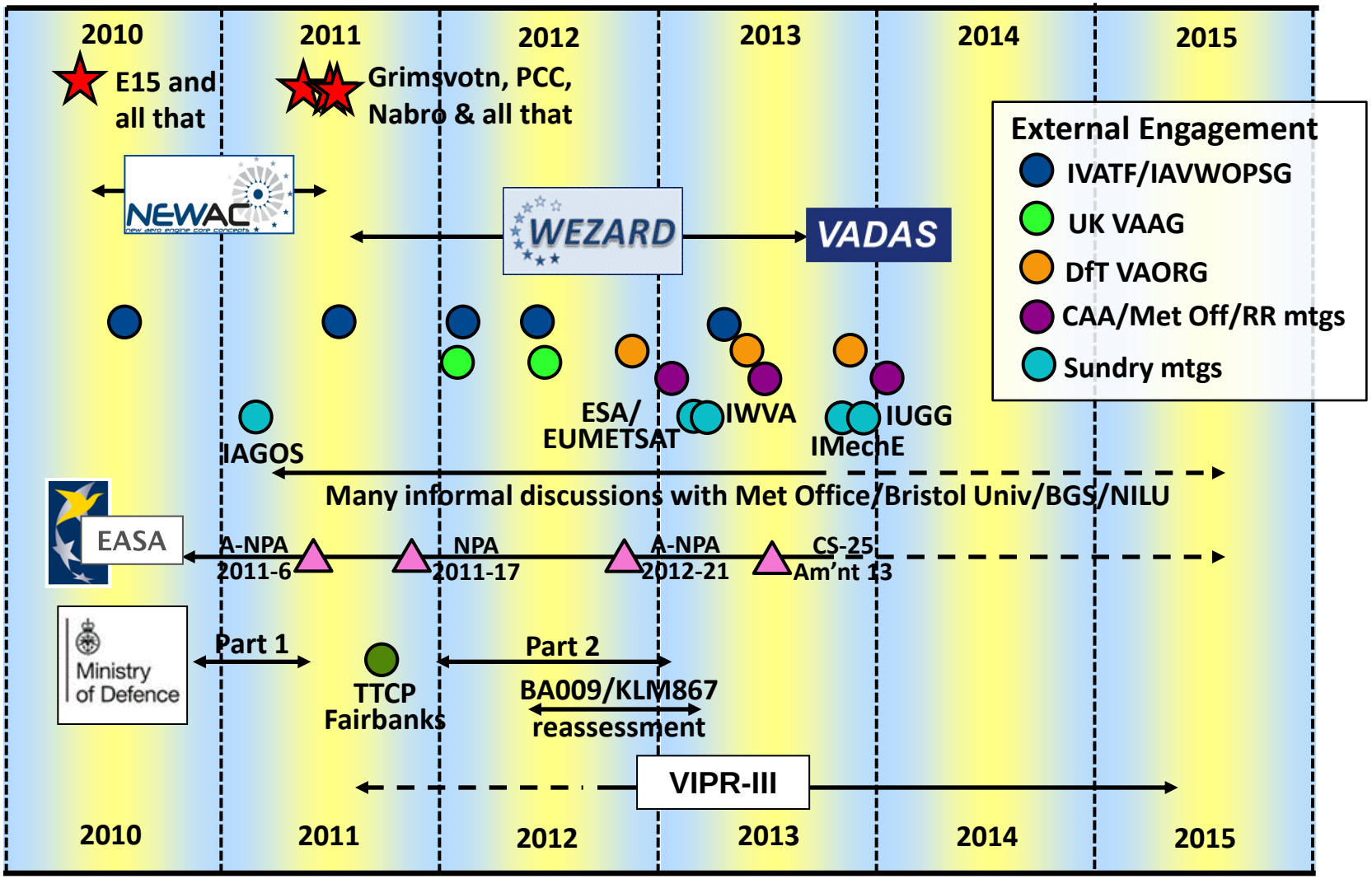

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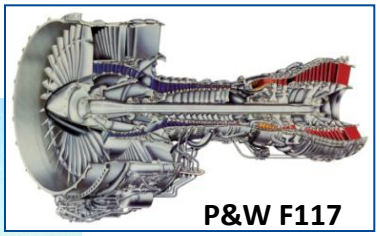
Vehicle Integrated Propulsion Research

- VIPR
  - NASA/USAF Engine Health Monitoring (EHM) technology development
  - Volcanic ash (VIPR-III) is a good way to deteriorate an engine



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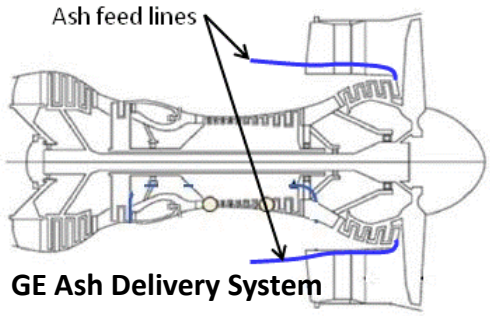

GE Ash Delivery System

VIPR-III Participants

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Vehicle Integrated Propulsion Research

VIPR-III Key Questions:

- FAA – Exposure to low concentration visible ash; safety or economic damage concern?
- What type of ash to use; fresh ash or 7,000 year old ash?
  - Mt Mazama (Crater Lake, Oregon)
  - Sakurajima ash
  - Eyjafjallajokull ash
- What ash concentrations to run test to?

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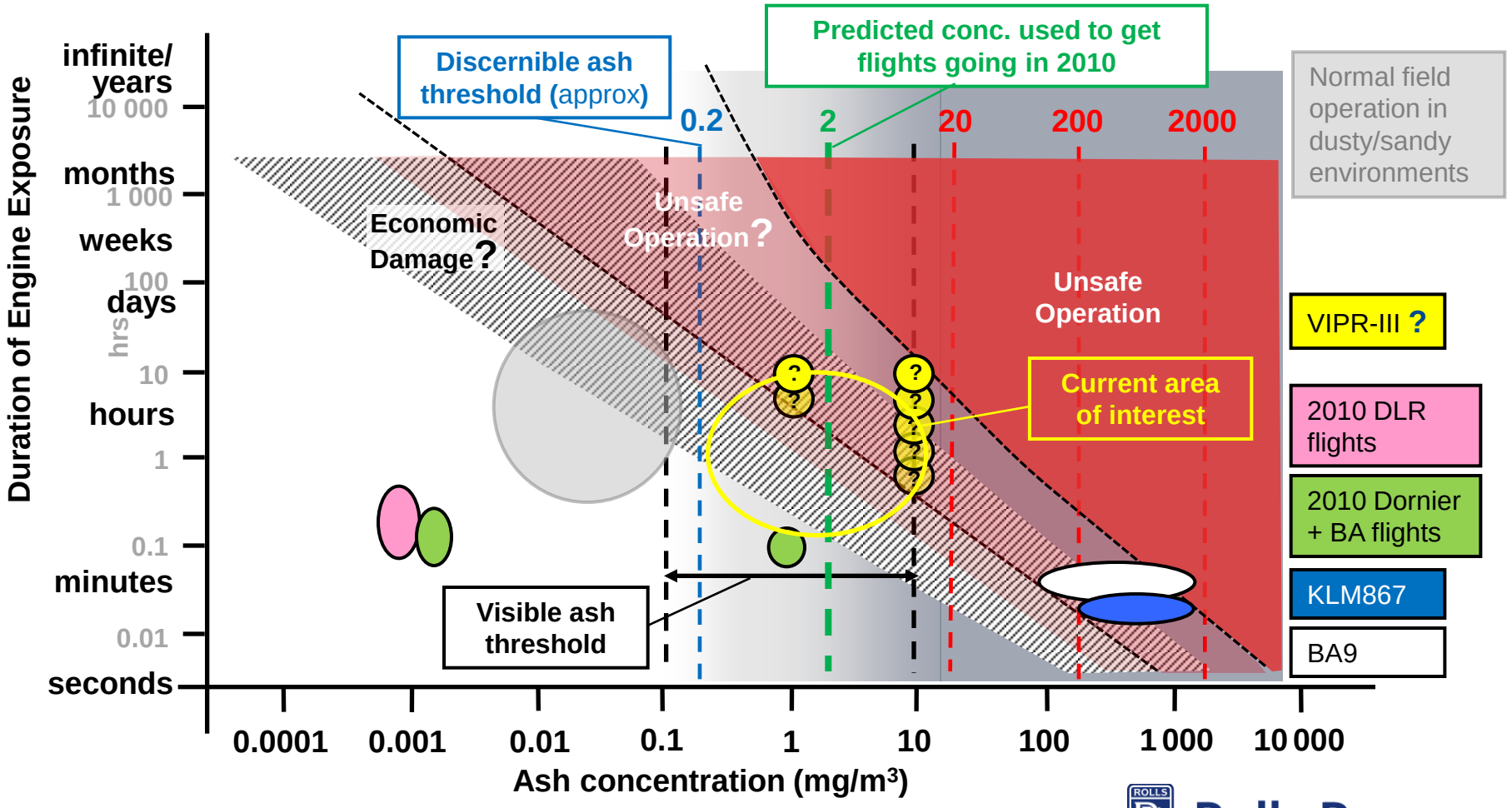
Vehicle Integrated Propulsion Research

- VIPR-III Test points?

MoD Requested & Funded
Duration of Exposure v Ash Concentration Chart



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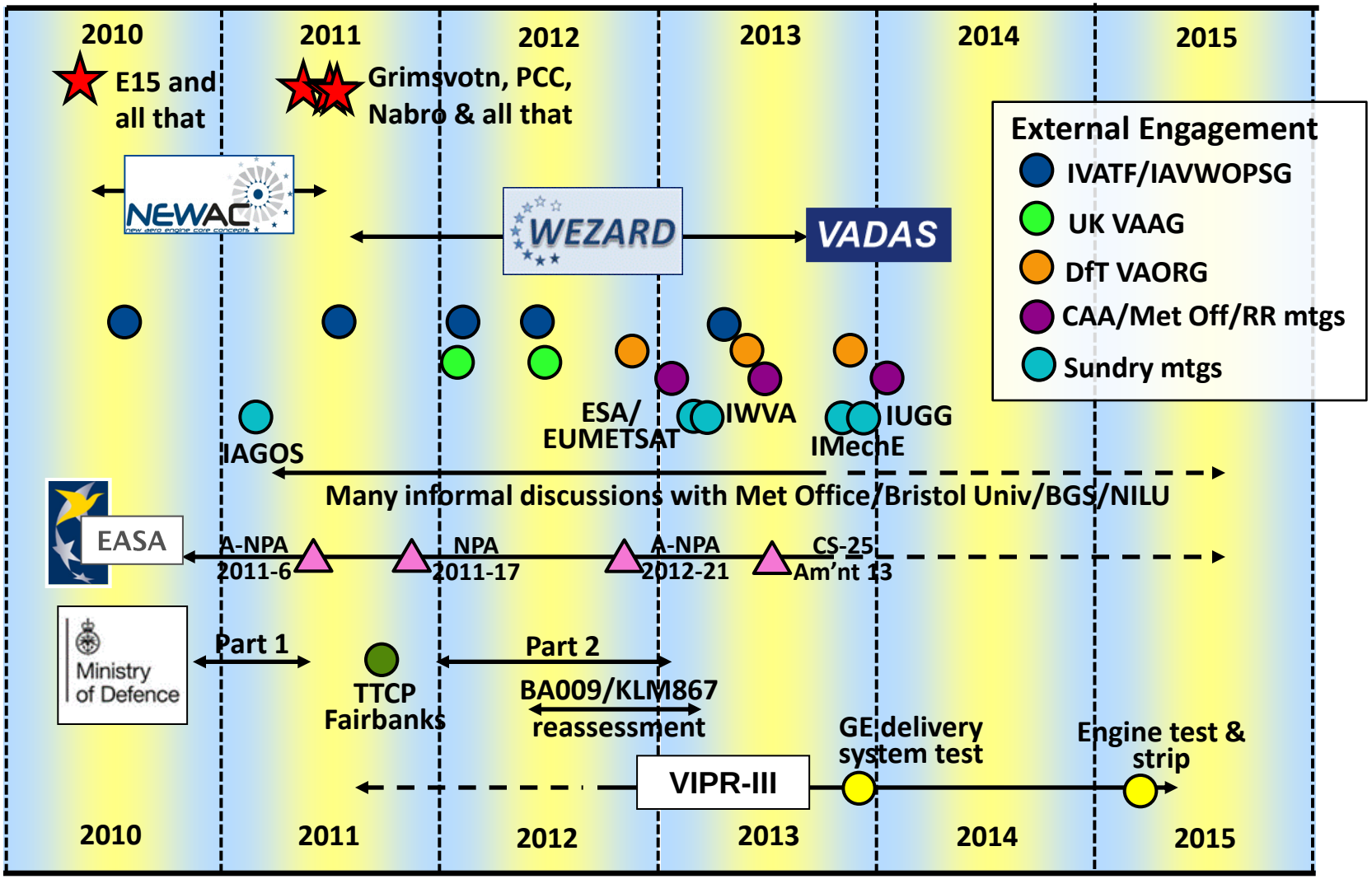

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Current Position & Conclusions

- Since 2010 work has continued on improving the engine manufacturers' understanding of the volcanic ash problem:
  - Better understanding of what we know and don't know
  - Better understanding of what it would take to improve our knowledge – should it be required
- There are various international initiatives running to address some of the gaps in our knowledge
  - Modelling and measurement of ash clouds – e.g. VADAS, ESA/EUMETSAT, …
  - Engine effects – e.g. VIPR-III
- EASA regulations have evolved slightly

and finally…

- We are in a better place than we were in April 2010 - discuss

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