Volcanic ash implications for aero engines

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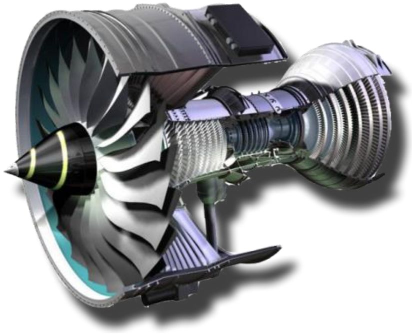
23rd June 2010



Outline

- Introduction
- Basic engine operation principles
- Ash ingestion into engines
  - Basic threats
  - Known ash cloud encounters
  - Available test data
- Conclusions and way forward

Introduction

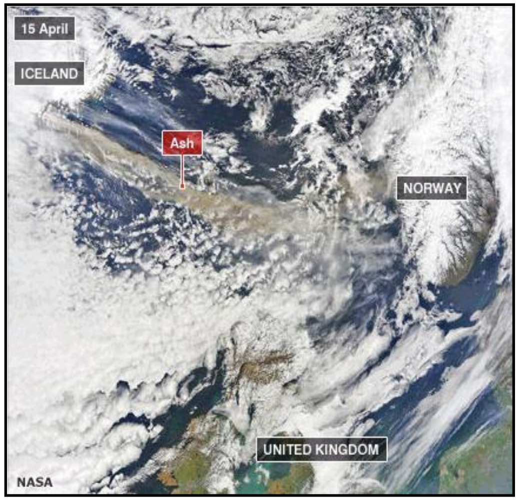
- Traditional volcanic ash management was based on exclusion zones around visible volcanic ash plumes (upper picture)

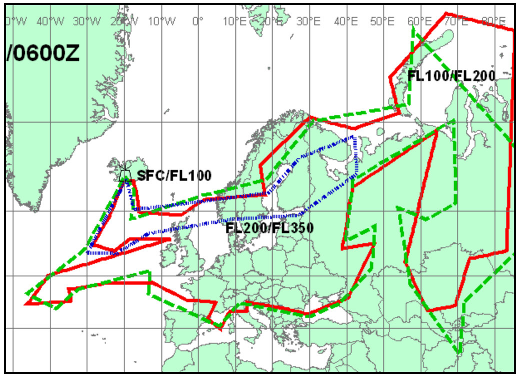
- New methodology emerged (Met-Office Model) which allowed a more numerate prediction with concentration level forecast (lower picture).

- However, this needed OEMs to define acceptable limits and the concentration modelling needs validation

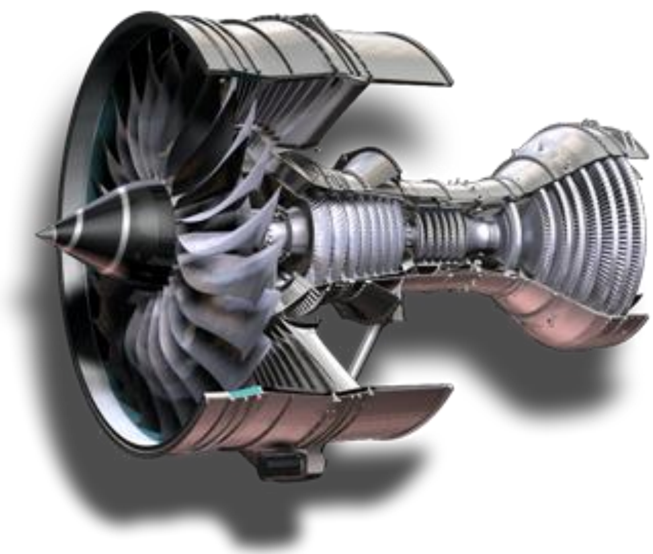
- Engine OEMs initiated risk assessment to support Authorities lifting of restrictions

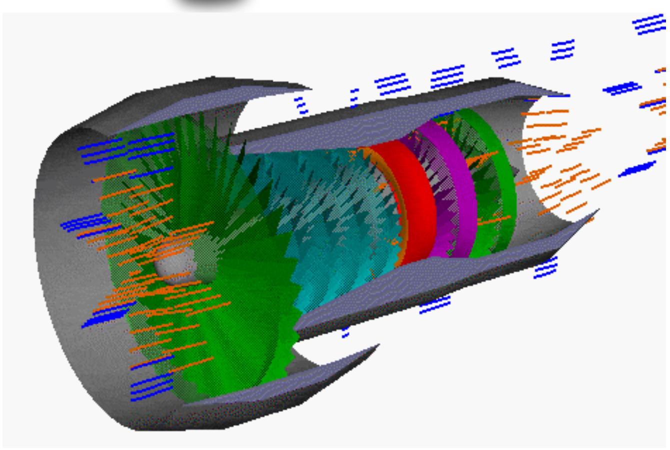
- Conclusion: At defined low levels of actual concentration in atmosphere:
  - No significant deposits on key components
  - No operational risk arises





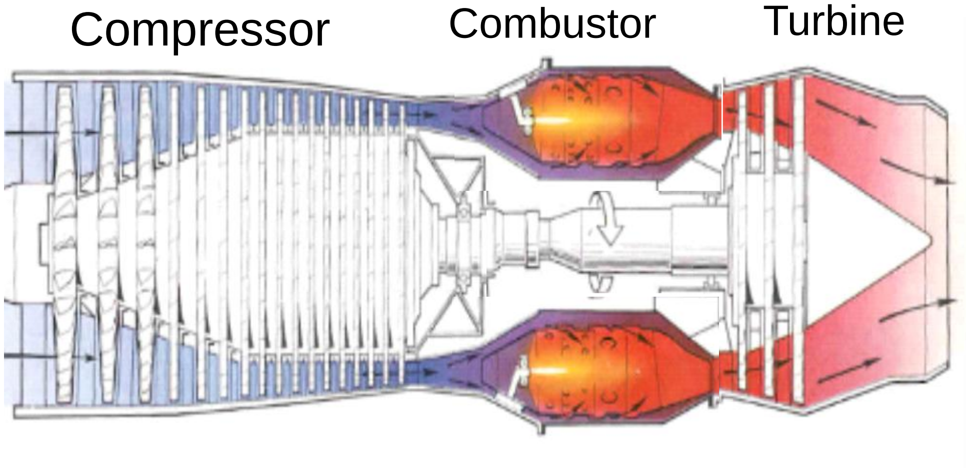
How engines work (1)

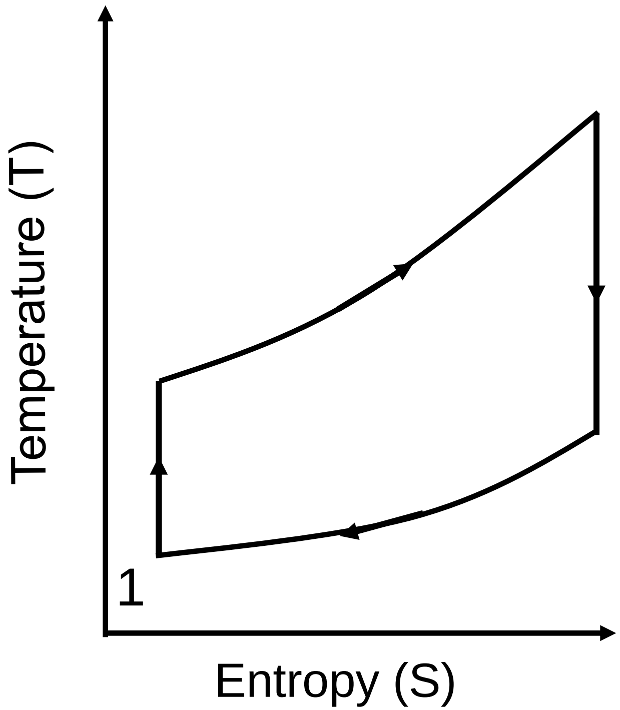


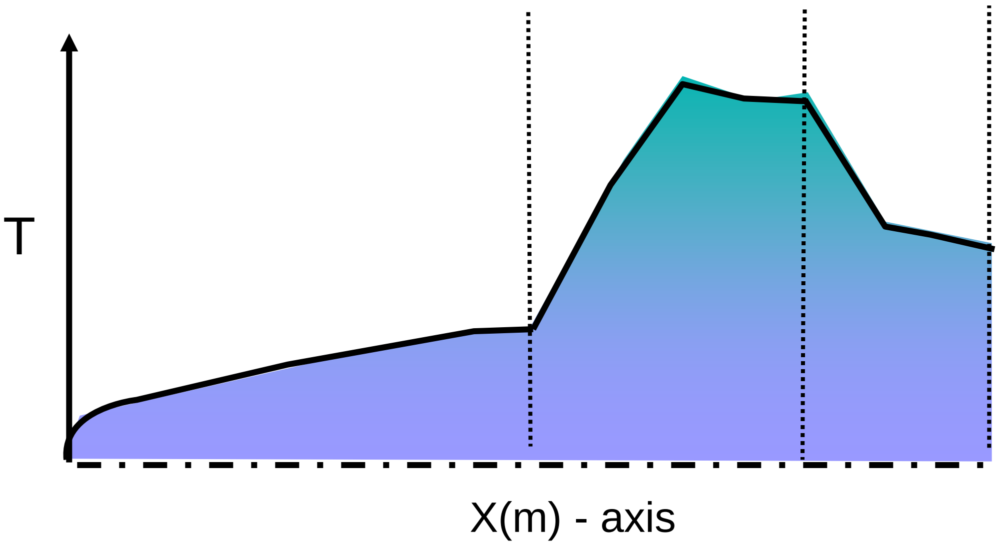


- Engines burn fuel to convert heat into mechanical (shaft) power to drive a by-pass fan
- This heat conversion is more efficient when done at high temperatures and pressures.
- The fan accelerates large amounts of air rearward and thereby generates thrust very efficiently (and quietly)
- A small portion of thrust also comes from the hot jet out of the core engine

How engines work (2)
Engine cycle

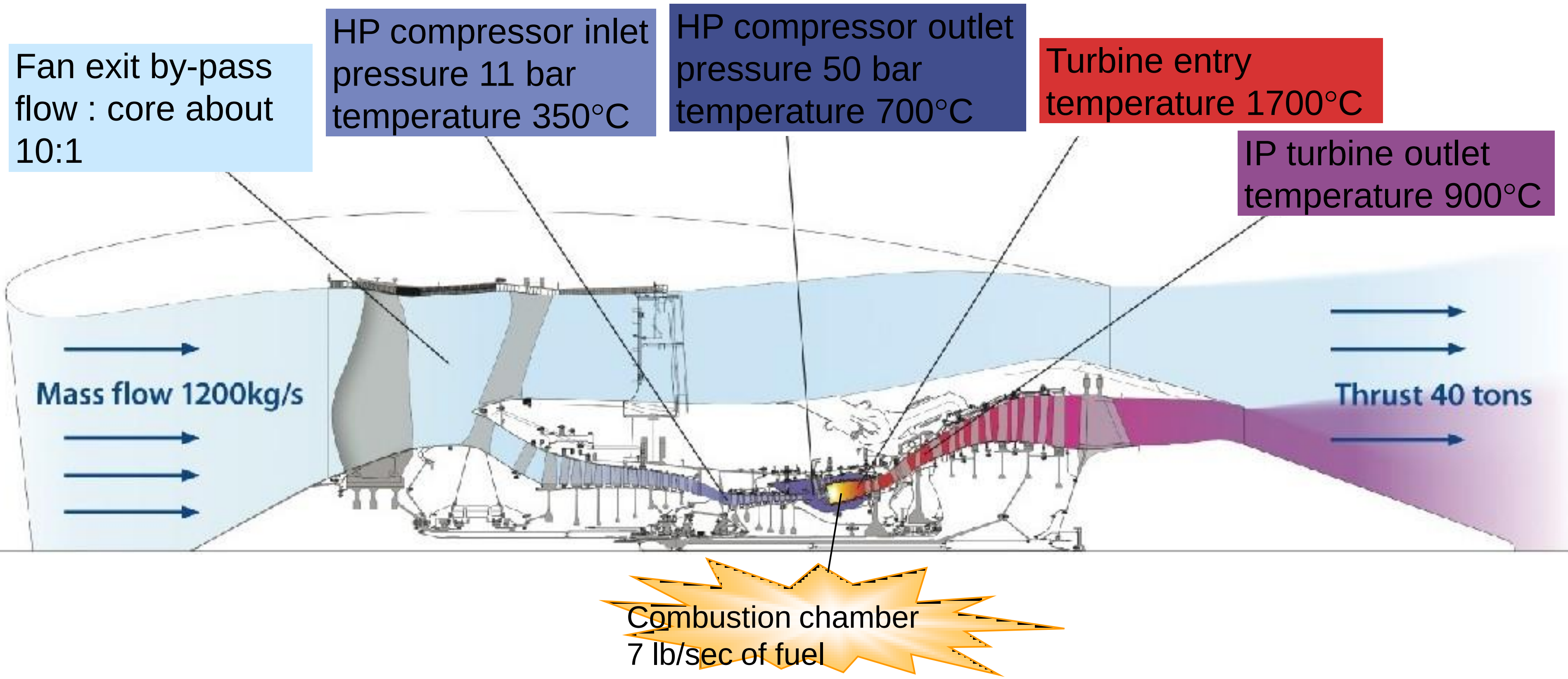






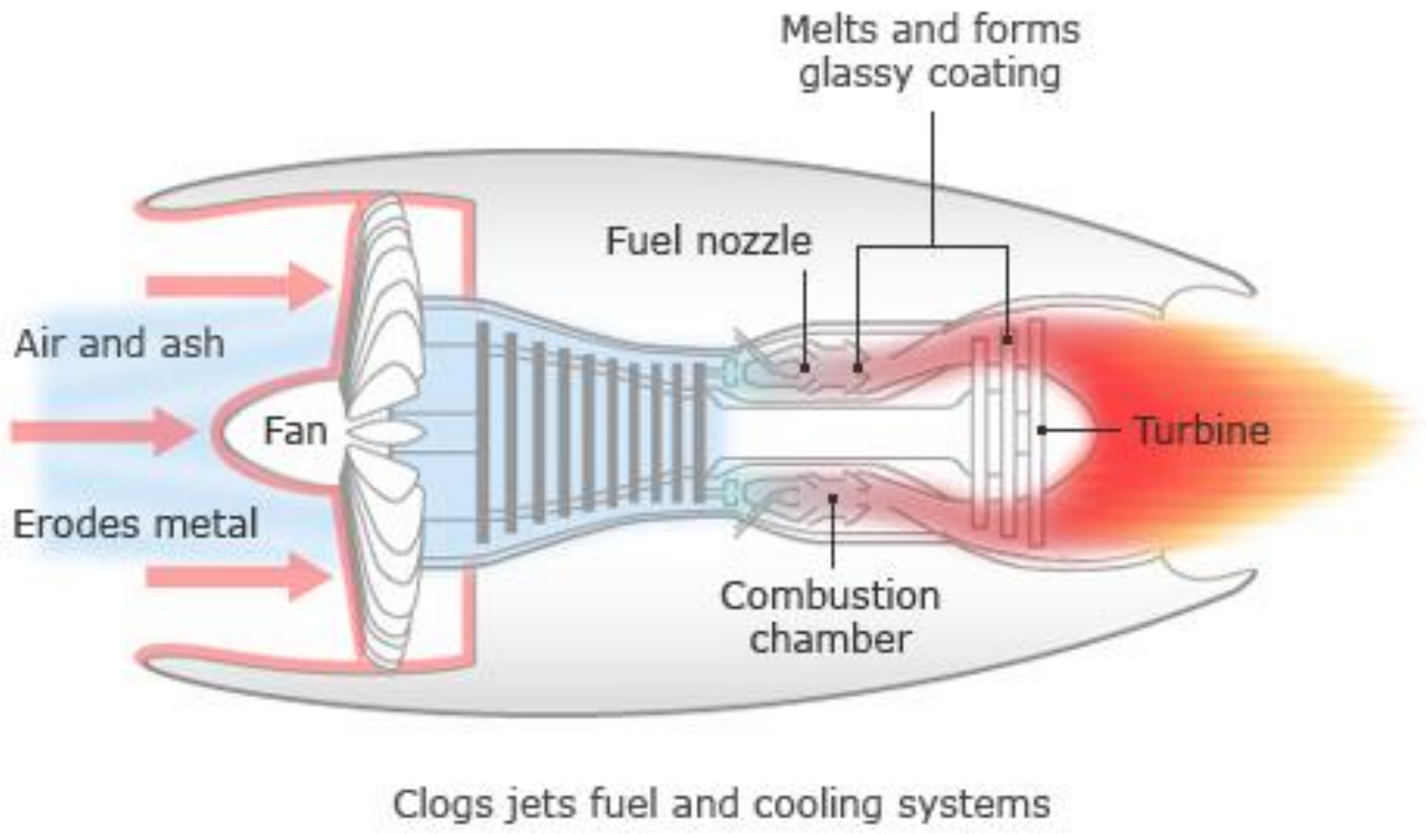
How engines work (3)

Operating principle of a modern jet engine and some key figures
Overall Pressure ratio: ~50



Steel starts to glow red at 700°C

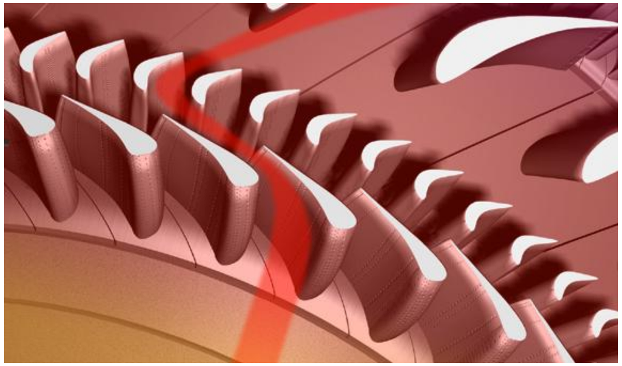
What does the ash do in the engine ?

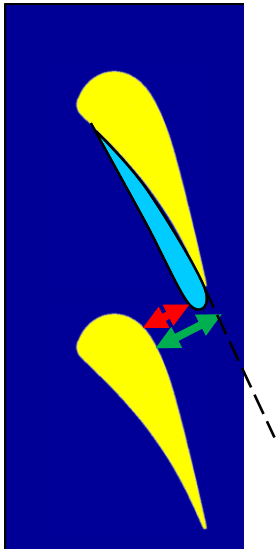


Why Is Operation In Volcanic Ash An Issue ?

- Ash melts in Combustor and deposits in HP Turbine – causing external blockage leading (in extreme) to engine instability and potential flame out
- Erodes compressor blades and liners
- Fine particles can get in to oil system and damage transmissions components
- Pneumatic control items may be sensitive to small particles

Strong NGV contamination
(BA 9, Jarkarta 1982)





BA Flight 9 (1982) - Jakarta

On 24 June 1982, the route was flown by the *City of Edinburgh*, a 747-236B. The aircraft flew into a cloud of volcanic ash thrown up by the eruption of Mount Galunggung (circa 180 kilometres (110 mi) south-east of Jakarta, Indonesia), resulting in the failure of all four engines. The reason for the failure was not immediately apparent to the crew or ground control. The aircraft was diverted to Jakarta in the hope that enough engines could be restarted to allow it to land there.

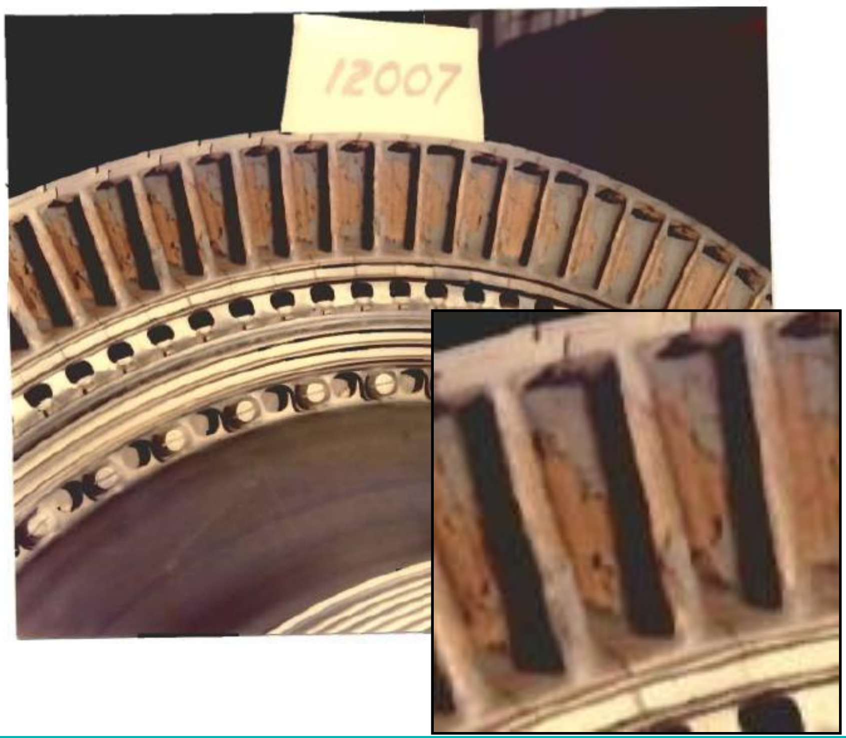
Date	24 June 1982
Type	Flameout of all engines due to blockage by volcanic ash
Site	Mount Galunggung, West Java, Indonesia
Passengers	248
Crew	15
Injuries	0
Fatalities	0
Survivors	263 (all)
Aircraft type	Boeing 747-263B
Aircraft name	*City of Edinburgh*

BA Flight 9 (1982)

pictures of 1 engine which was not re-started

HP NGV leading edge

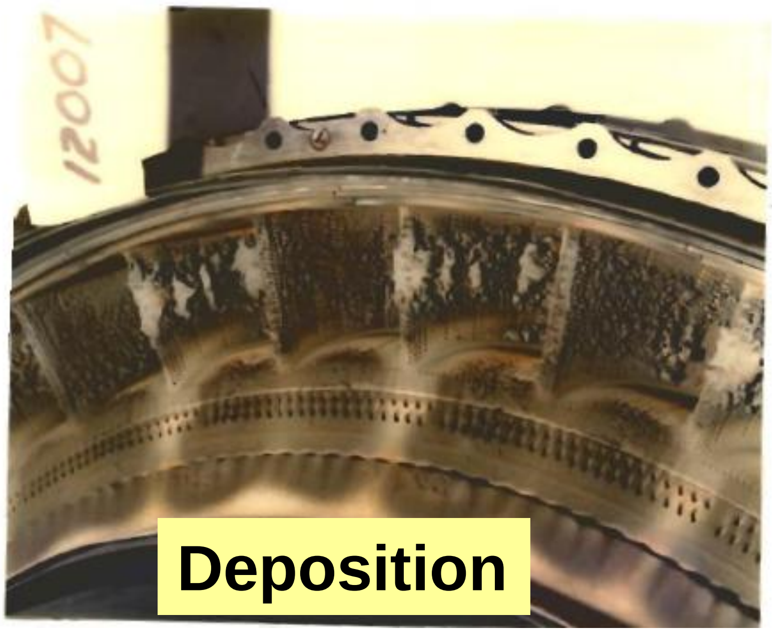
HP turbine blade leading edge



BA Flight 9 (1982)

Not-re-started engine

HP NGV leading edge



Re-started engine

HP NGV L.E. after flying home

What testing has been done in the past?

- Whole Engine ash ingestion tests have been conducted at a research laboratory in between 1980 – 1995*
- A good portion of this data has been openly reported in the literature
- In addition, a US based engine OEM conducted various engine tests with different 'earth mixes'**
- Engine OEMs have recently shared all relevant data amongst each other for safety purposes

* Dunn, Baran and Miatech , *ASME J Gas turbines power, vol.118, 1996 pp 724-731*

** *private communication*

Lab/Engine tests (1)

- **Testing**
  - Range of engines with different Overall pressure ratio and turbine entry temperature (TET) tested
  - Ash concentration levels ranged from 0.1 to 0.3 g/m3
  - Engine were tested at idle & high power
  - Ash from various sources was ingested
- **Findings**
  - All tested engines showed signs of St-Elmo’s fire and engine surge when exposed to medium to high levels of ash concentration
  - Low power idle (lower TET) test did NOT show any signs of surge
  - One engine was damaged severely in tests with highest concentration (HP Blade L/E thermal distress and L/E loss, NGV blockage at high level of T/A reduction + F/C holes blocked, HPC erosion)

Lab/Engine tests (2)

Engine parameters unaffected (idle)

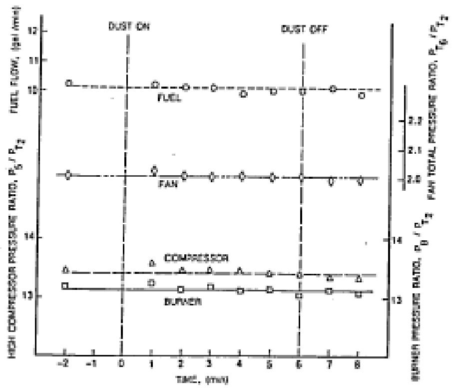
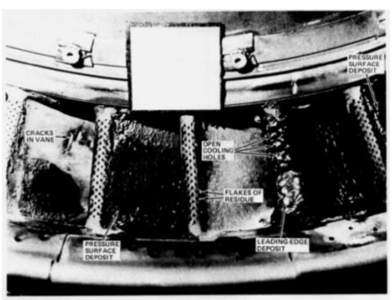


Fig. 8 Time history of engine parameters during dust experiments for relatively low turbir



Higher TET

Engine parameters affected (higher power)

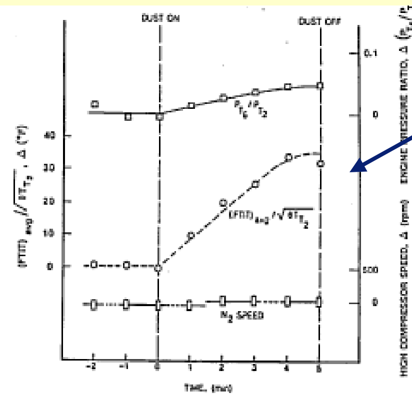


Fig. 7 Time history of engine parameters during dust experiments for relatively high

Increase in compressor deliver pressure

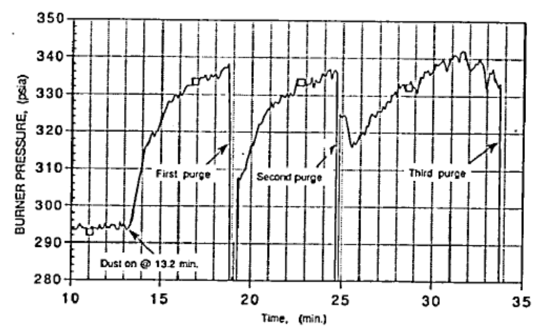
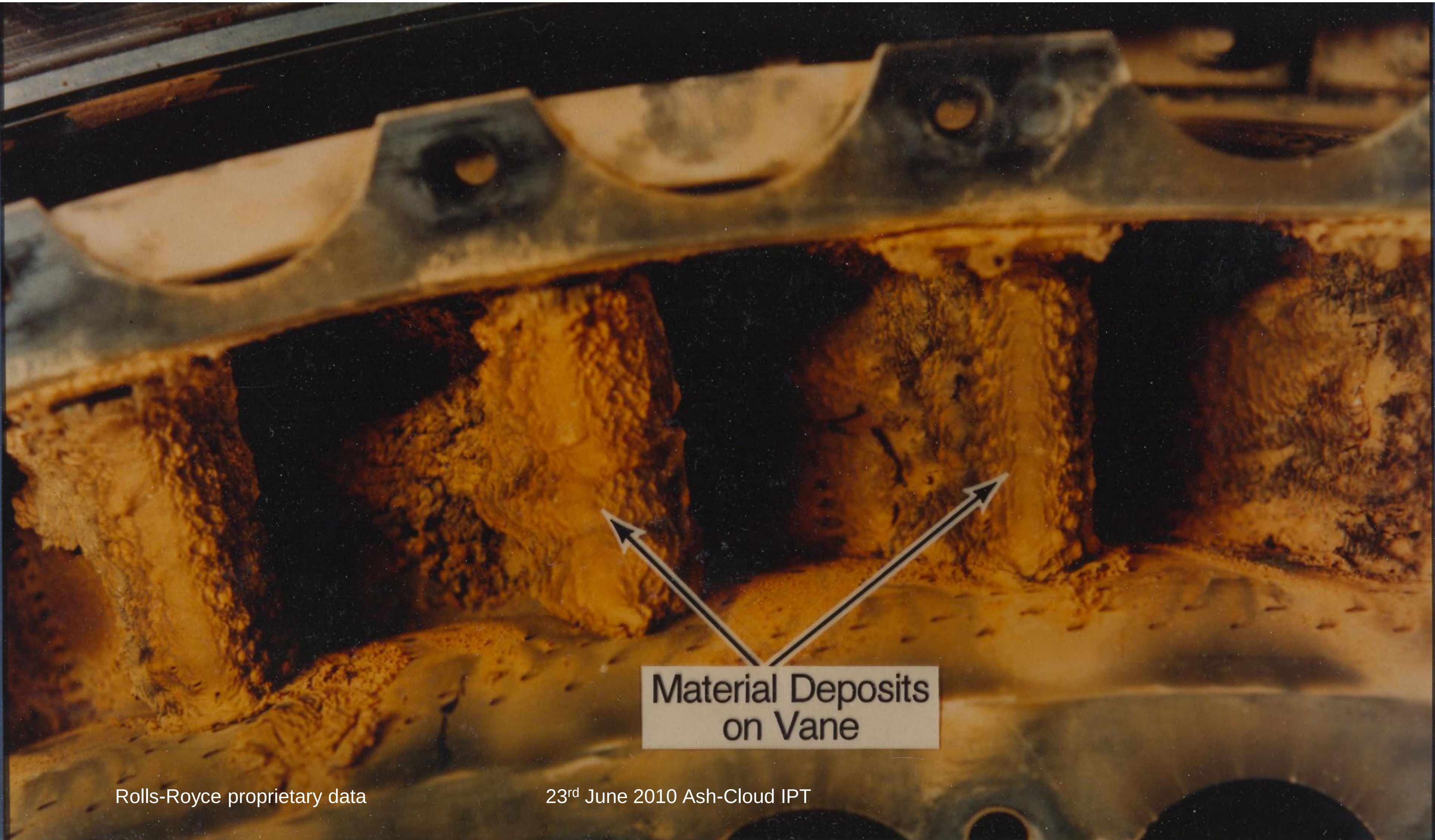


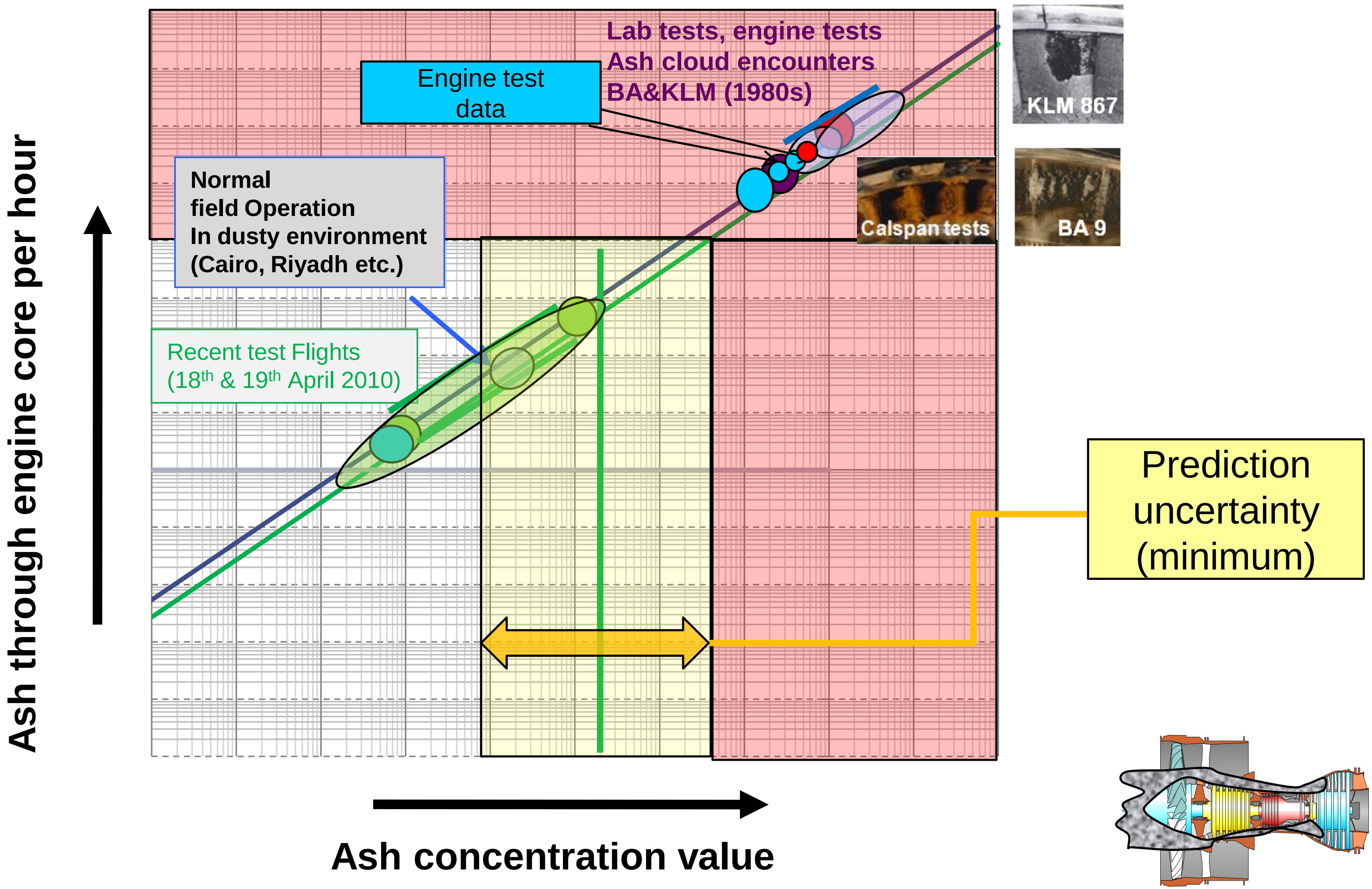
Fig. 9 History of burner pressure

Engine parameters are influenced if engine is operated at higher temperature (above idle) – this is caused by assertion of ash on HP Nozzles blocking throat and influencing adversely engine operability

HPT Vane; After Dust Exposure
(concentration about >2x10-1 g/m3)
(exposure around 1 hour)



The safe to fly – Chart



Conclusions and way forward

- Engine OEMs know what happens if known quantities of ash get inserted into engine
- A series of different engine tests with regards to ash ingestion had been reviewed
- Previous service experience of ash encounters has been analysed to validate the ‘safe to fly’ chart
  - Met office re-cast plots
  - Intensity of ash ingestion
- Based on the above safe to fly limits for ash concentrations have been agreed between the Engine OEMs. This limit is $2\text{x}10^{-3}$ g/m^3 actual concentration of ash in the atmosphere.
- Remaining uncertainties in ash concentration modelling need to be addressed via joint expert teams (ongoing).