



Impact of Mineral Dust on Jet Engines

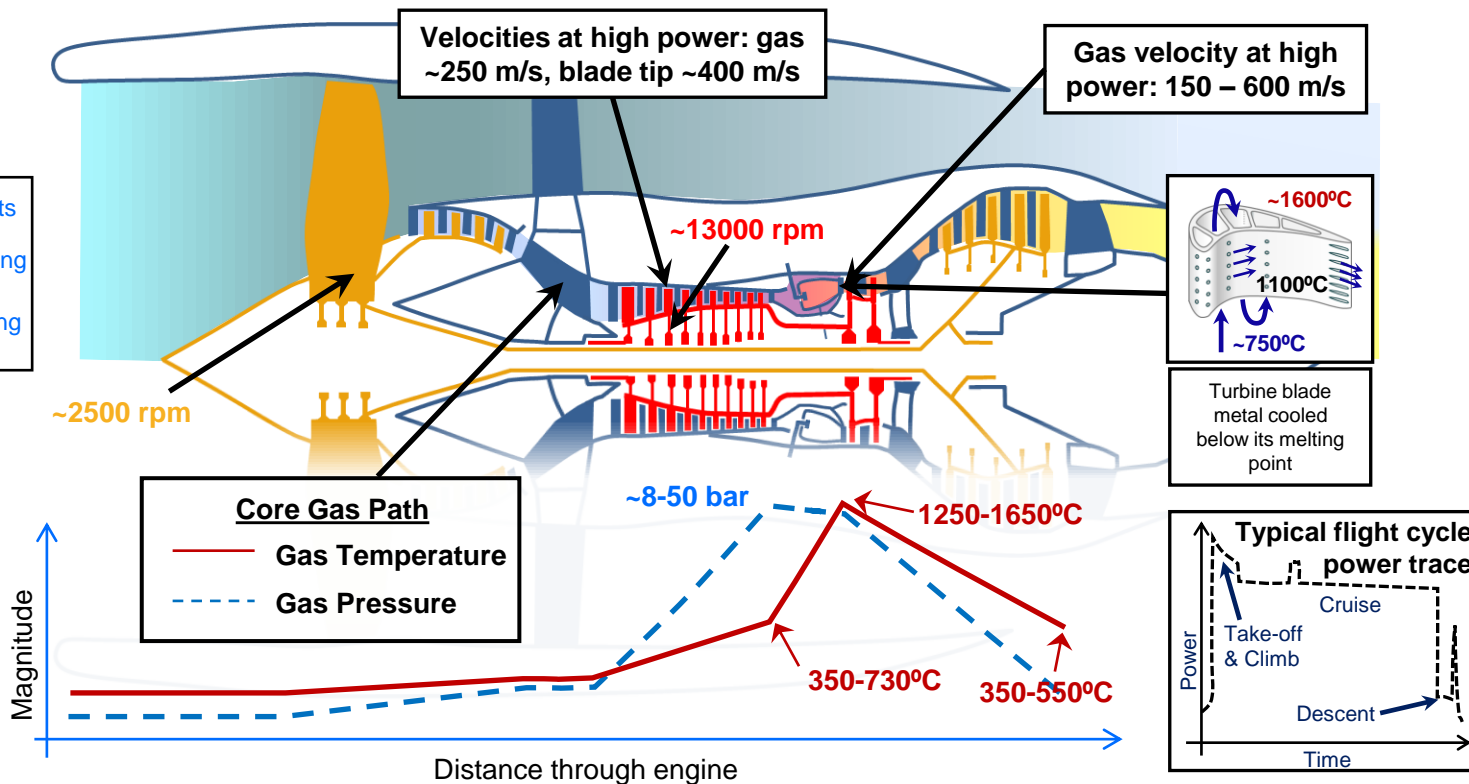
inDust User Workshop on Aviation

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Rolls-Royce

20 May 2021

Anatomy and Physiology of a Jet Engine

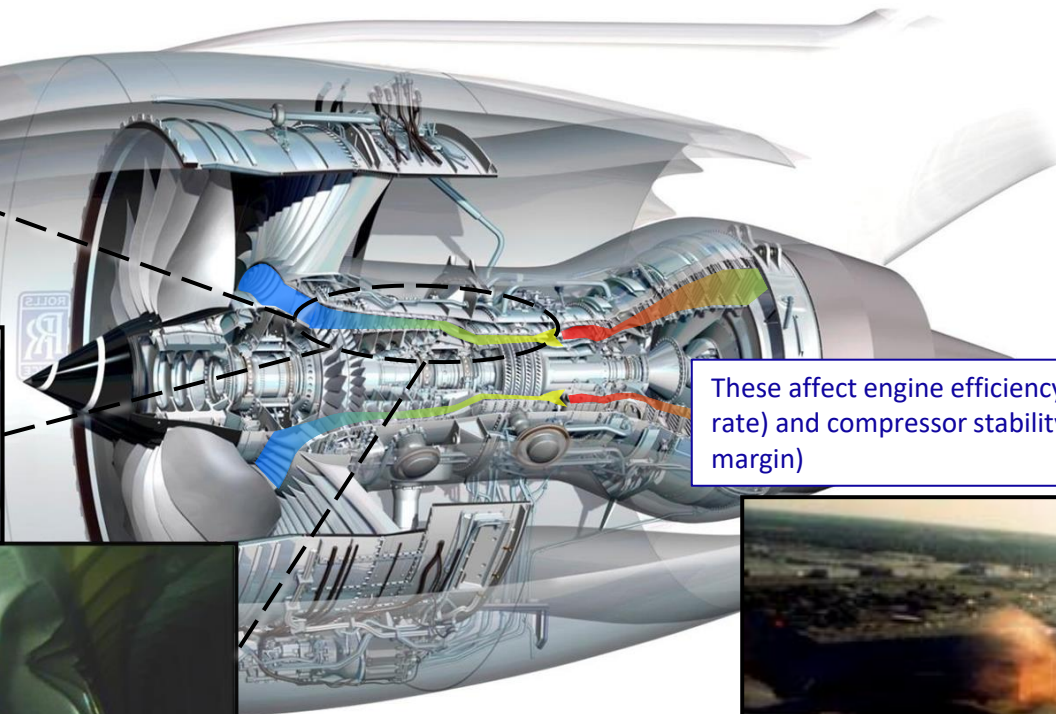
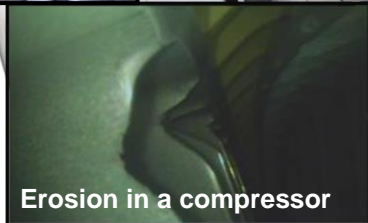
Engine
Environmental
Protection





Engine Damage Mechanisms – mineral dust and volcanic ash

Engine
Environmental
Protection



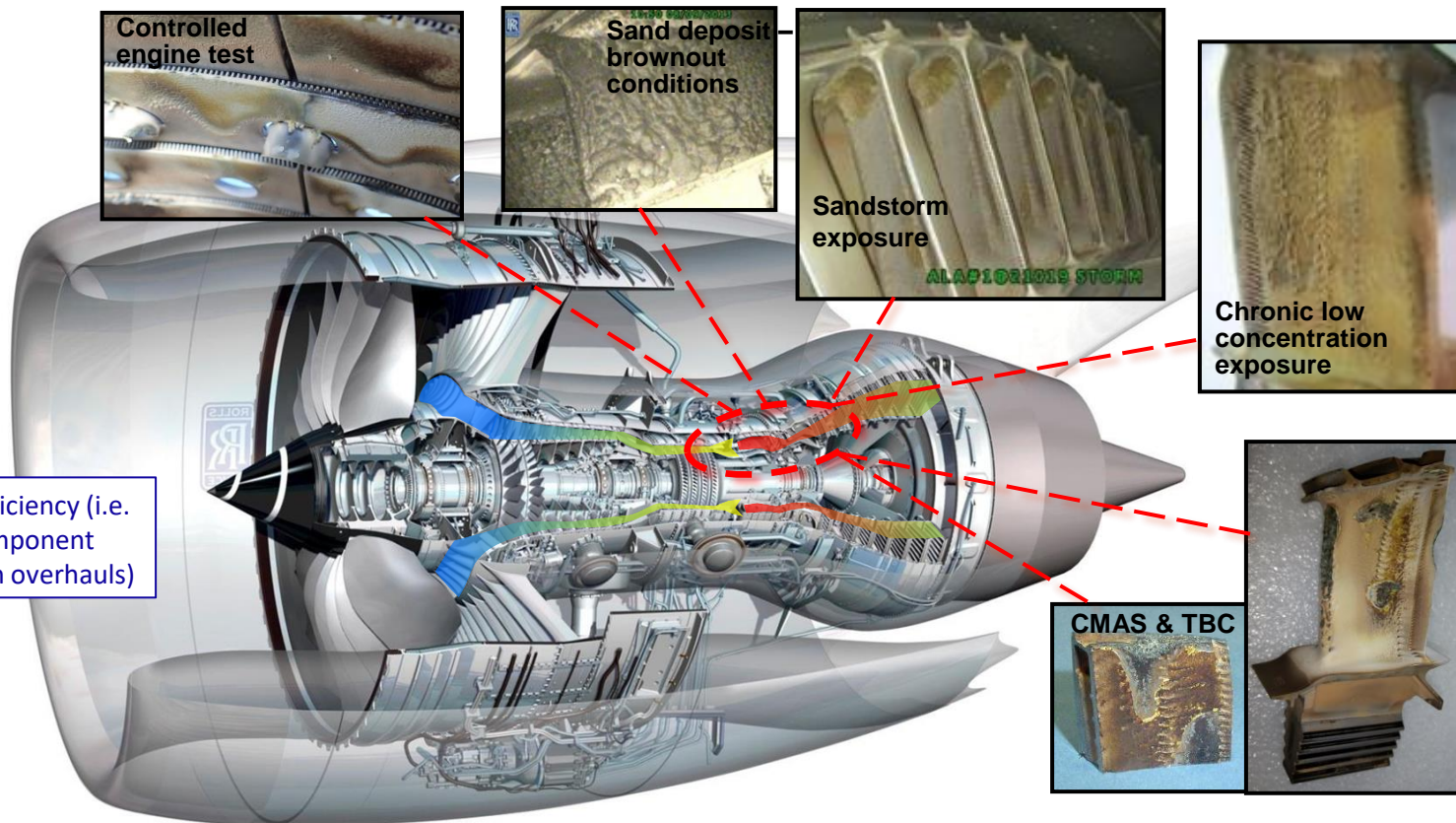
These affect engine efficiency (i.e. fuel burn rate) and compressor stability (i.e. surge margin)





Engine Damage Mechanisms – mineral dust and volcanic ash

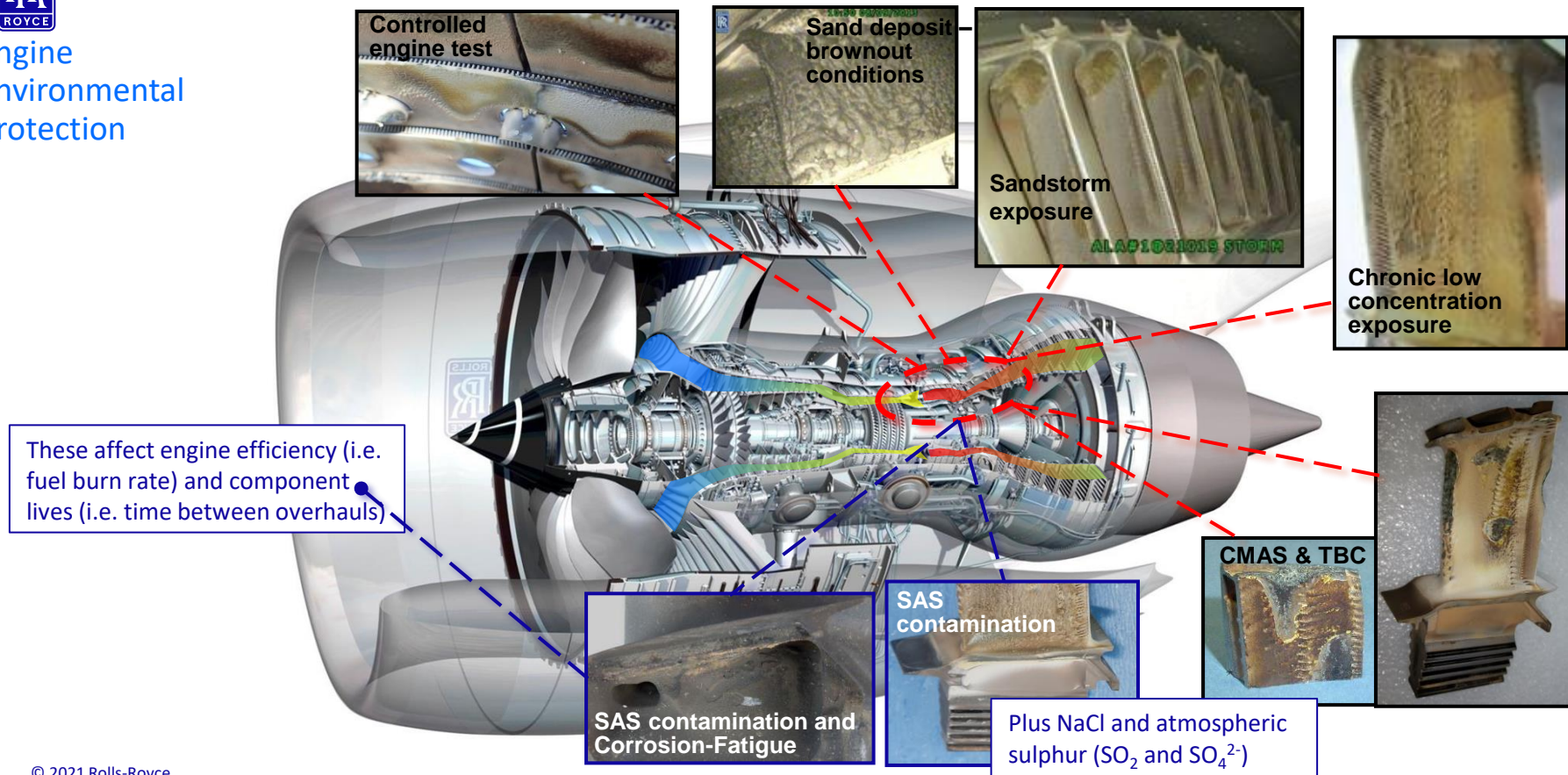
Engine
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Engine Damage Mechanisms – mineral dust and volcanic ash

Engine
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A Problem with Three Elements

Engine
Environmental
Protection

Element (i): The
external environment

Element (ii): Preconditioning
within the engine

Where in the engine, how much and in what form?
(e.g. change in phase, size & nature)

Atmospheric agents that can damage
or impair the operation of engines

- Aqueous threats
- Non-aqueous threats
- Exotica

What

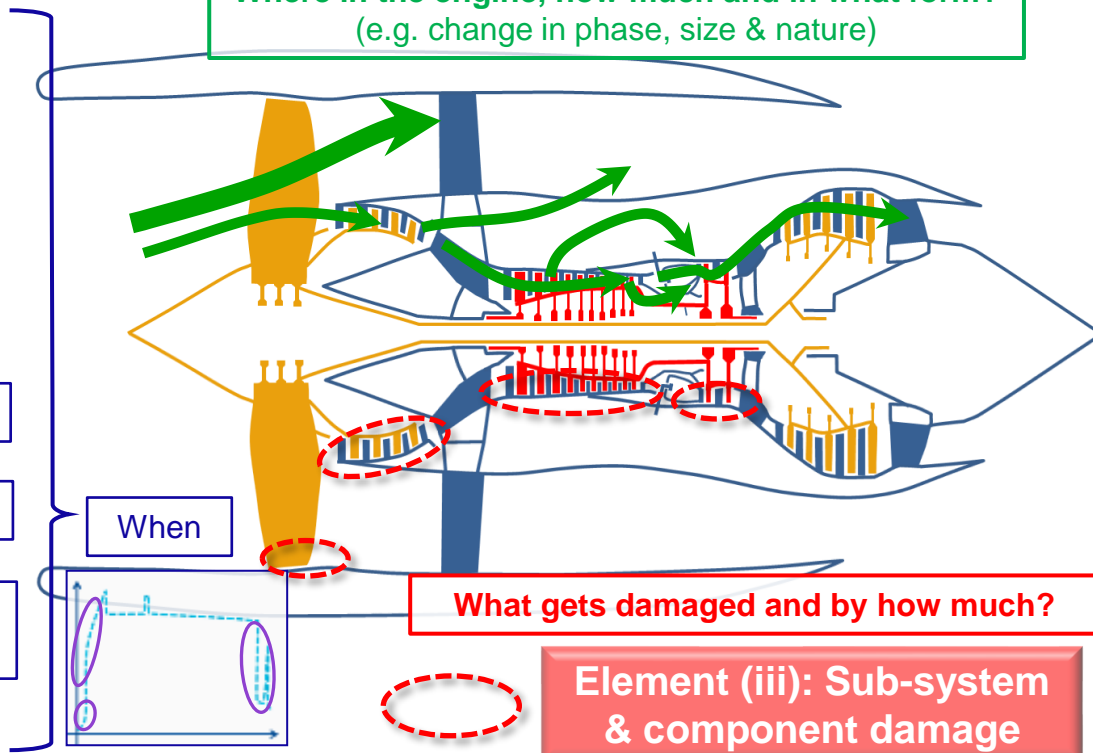
Where

When

How
much

What gets damaged and by how much?

Element (iii): Sub-system
& component damage





Sand and Dust

Engine Environmental Protection

Element (i): The external environment

Element (ii): Preconditioning within the engine

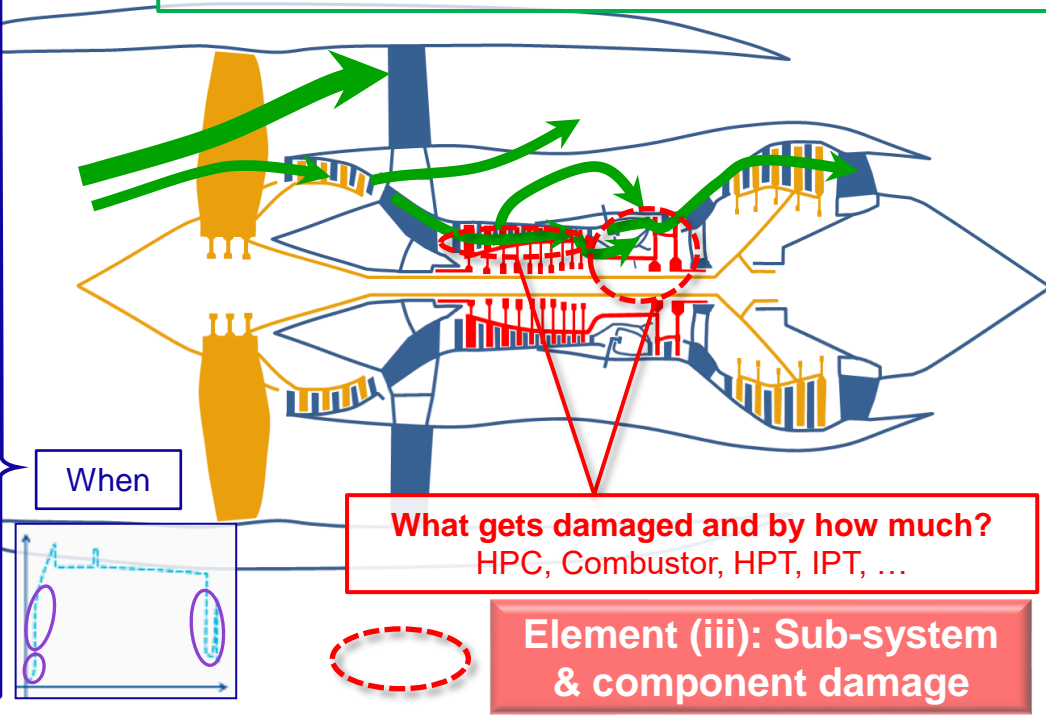
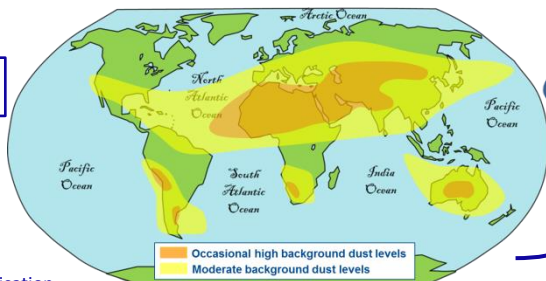
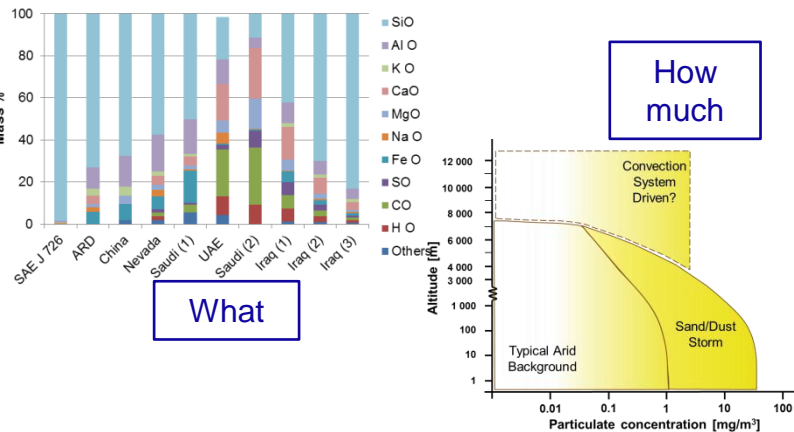
Where in the engine, how much and in what form?
(e.g. change in chemical comp and particle size distribution)

How
much

What

When

Where

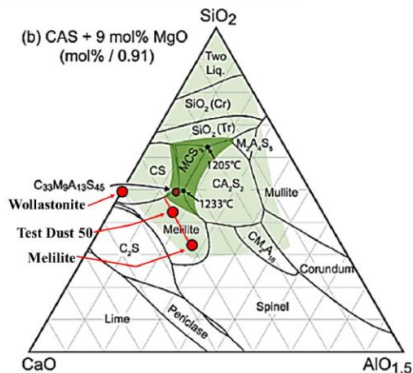


What gets damaged and by how much?
HPC, Compressor, HPT, IPT, ...

Element (iii): Sub-system & component damage

PSD and Chemical Composition Changes

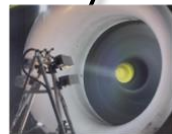
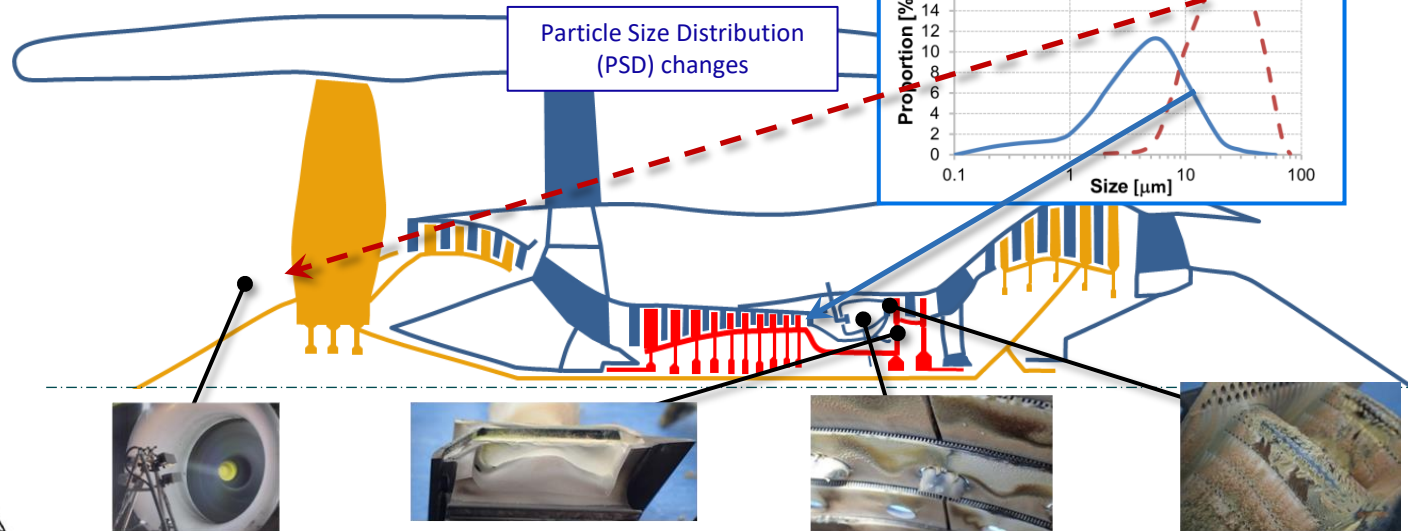
Engine
Environmental
Protection



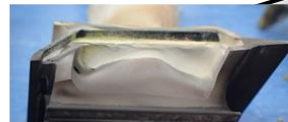
Chemical Change Notes:
(i) Rapid temperature increase
(ii) Heat soak and inter-species reaction
(iii) Melting and inter-species reaction

Dust mineralogy
& chemistry
changes

MANCHESTER
1824



TD50



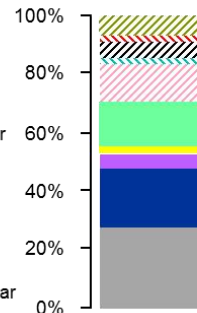
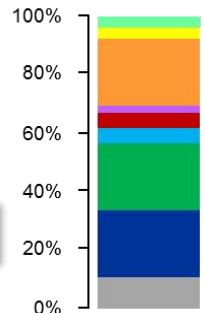
HPTB Shank



Combustor

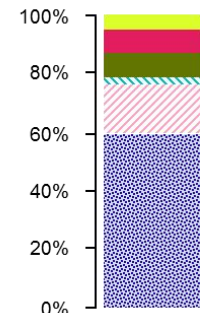


HP NGV



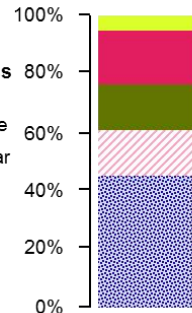
Newly formed
minerals via (i)
& (ii)

Periclase
Lime
Hematite
Anhydrite
Melilite



Newly formed
minerals & glass
via (iii)

Wollastonite
Ca-Feldspar
Diopside
Anhydrite
Melilite
Glass





Engine Environmental Protection

Sulphidation: The Protagonists

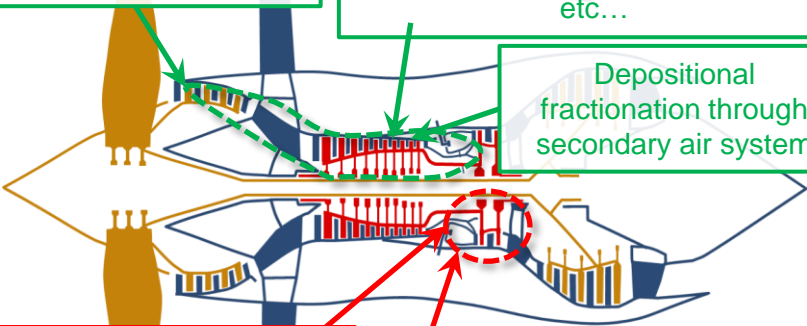
Occurrence			
Type	Agent	Geographic	Examples
Gas	SO ₂	Regionally high conc's	Volcanoes, transport and industry
Aerosol particles (i.e. <1 mm)	NaCl	Regional	Oceanic and coastal
	(NH ₄) ₂ SO ₄	Regionally high conc's	Urban pollution
	H ₂ SO ₄	Regionally high conc's	Volcanic and industrial sulphur emissions
Mineral particles (i.e. 1-30 mm)	CaSO ₄	Localised	Gypsum deposits at Doha and the Emirates
	CaCO ₃ , CaMg(CO ₃) ₂	Localised	Limestone based sands, building sites
	Alumino-silicates (embedded Ca, Na, K, Mg,...)	Ubiquitous but mainly arid regions	Sands, dusts, volcanic ash, urban dust,...

Conditioning in the engine

Mechanical break-up of dust particles >6 mm to ≤6 mm

Thermal disassociation:
 $(\text{NH}_4)_2\text{SO}_4 \rightarrow \text{SO}_2$
 $\text{H}_2\text{SO}_4 \rightarrow \text{SO}_3, \text{SO}_2$
 $\text{CaCO}_3 \rightarrow \text{CaO}$
 $\text{CaMg}(\text{CO}_3)_2 \rightarrow \text{CaO}, \text{MgO}$
 $\text{NaCl} \rightarrow \text{Na}_2\text{O}, \text{Cl}_2$
Clays \rightarrow amorphous $\text{SiO}_2, \text{Al}_2\text{O}_3$ etc...

Depositional fractionation through secondary air system



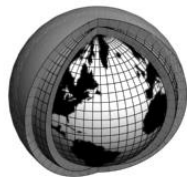
Chemical reactions:
 $\text{Na} + \text{SO}_2 \rightarrow \text{Na}_2\text{SO}_4$
 $\text{CaO} + \text{SO}_2 \rightarrow \text{CaSO}_4$
 $\text{K} + \text{SO}_2 \rightarrow \text{K}_2\text{SO}_4$

Agent deposition or formation at damage site

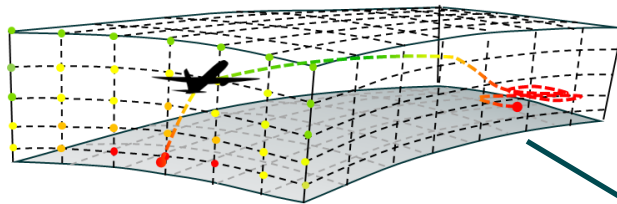
Aerosols/particle deposition:
(i) NaCl aerosol
(ii) <6 μm particles of; MgO, CaO, & aluminosilicate dusts

Atmospheric Contaminant Data

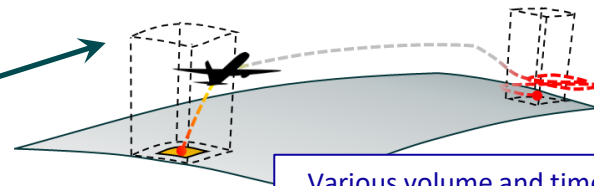
Airport Specific Data



Global 4D Mesh Data



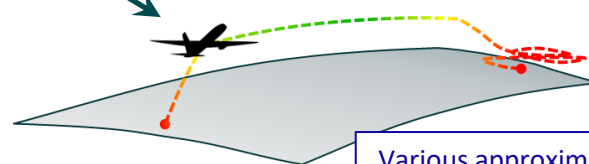
Data from ECMWF CAMS:
Concentrations of dust, SO_2 ,
 SO_4^{2-} , NaCl, H_2O ,...



Various volume and time
averaging approaches;
Loses cruise exposure

DAAC

- Detailed PSD with altitude
- Geographic dust compositions
 - Surface geology
- Dust composition with altitude
 - Surface geology
 - Wind transport
 - Dust dispersion modelling
 - Variations with time
- Atmospheric chemistry
- Volcanology
 - Ash and SO_2 dispersion



Flight Track Data

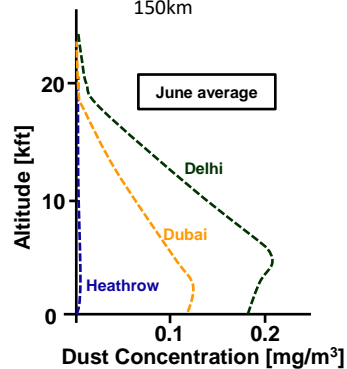
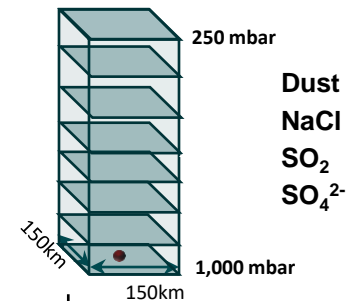
Various approximations for
flight route taken

- ECMWF CAMS data is free, but it does not give dust compositions, or include volcanic sulphur, and accuracy at climb, cruise, descent & hold altitudes needs assessing
- A Database of Atmospheric Agent Characteristics – the DAAC – to fill gaps in CAMS data



Importance of Dust Composition

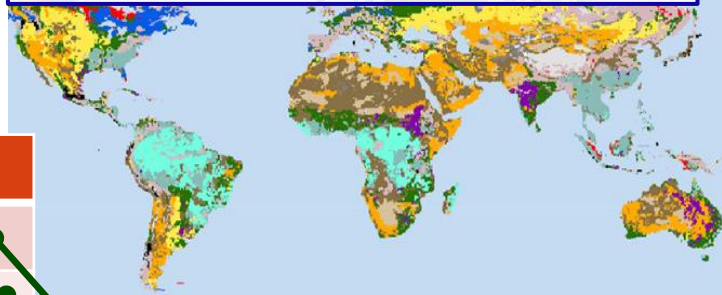
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Export Control Classification -
Not Listed

Mineral	Composition
Quartz	Framework silicate
Feldspars	Framework silicate (Al, Ca, Na, K)
Micas	Layer silicate (Al, K, Mg, Fe, OH)
Clays	Layer silicate (Al, Mg, Fe, K, OH)
Chlorites	Layer silicate (Fe, Mg, Mn... rich)
Calcite	Ca CO ₃
Dolomite	Ca Mg (CO ₃) ₂
Gypsum	Ca SO ₄ · 2(H ₂ O)
Anhydrite	Ca SO ₄
Halite	NaCl

Different combinations and proportions of sand/dust at the earth's surface



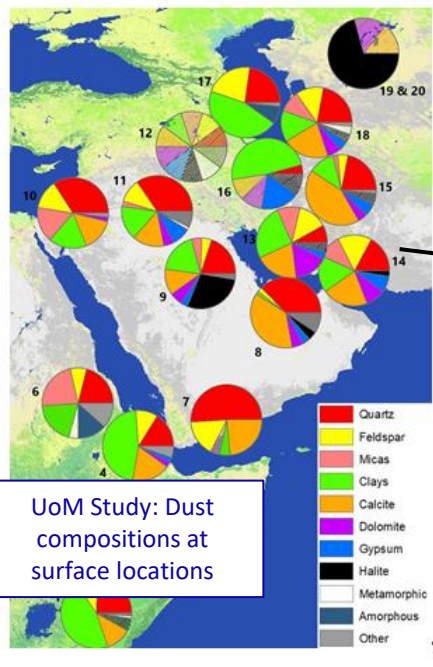
What is DAAC?

- A Database of Atmospheric Agent Characteristics
- DAAC v1.0 – partially populated database

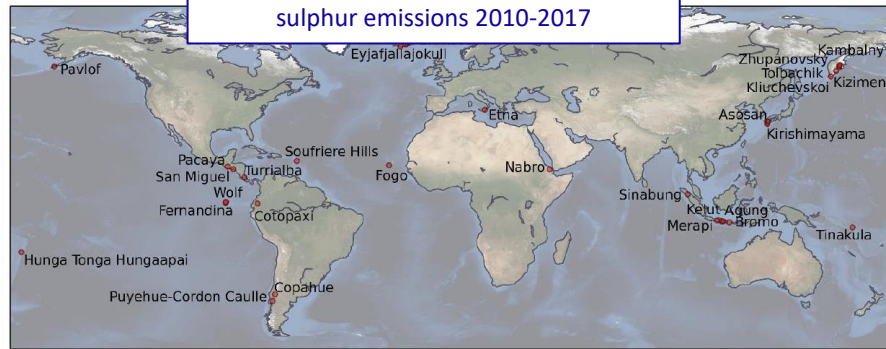
- DAAC v1.1 and DAAC v2.0 is planned but not funded

DAAC

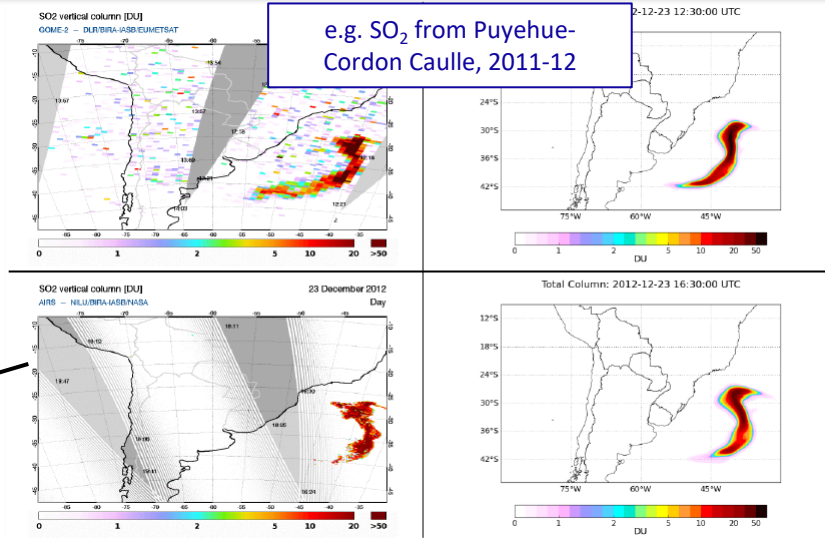
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UK Met Office Study: Significant volcanic sulphur emissions 2010-2017



e.g. SO₂ from Puyehue-Cordon Caulle, 2011-12





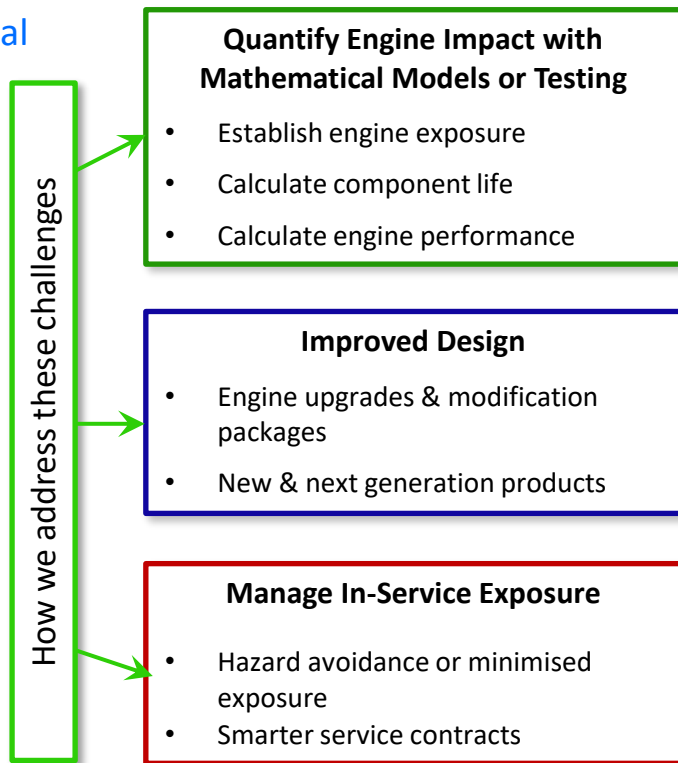
Summary & Conclusions

- We understand the main factors affecting the damage mechanisms
 - Atmospheric dust: concentration, composition, PSD
 - The effect of other atmospheric agents
 - And engine performance, design and use (its history)
- Using CAMS data as estimate of dust, SO_2 , SO_4^{2-} & NaCl concentrations (and thus exposure dose)
 - Looking to augment with volcanic SO_2 & SO_4^{2-} data
- Initial work started on dust composition – on surface
 - Needs to be extended – on the ground and airborne
- A big challenge is still engine data – the where, when and doing what
 - i.e. the engine lat, long, altitude, time and power/thrust

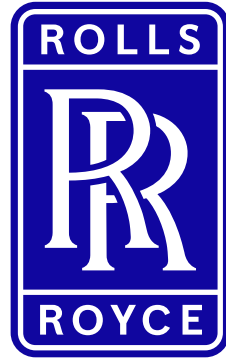


Dealing with Damaging Dust and Sulphur

Engine Environmental Protection



- We are getting a good understanding of the important factors
- But there is still much work to do to understand the level of exposure and quantify its impact on component life
- The traditional design solution is via protective coatings
- But Systems Engineering approaches are being considered – e.g. keep dust contaminants away from the turbines
- Because aircraft are mobile, the option of altering their exposure to contaminants is being considered – e.g. incentivise operators to minimise their exposure



Thank you