The Impact of Sand and Dust on Jet Engines

InDust Workshop - Cranfield

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Agenda

Introduction

- Overview
  - Damaging atmospheric agents
  - How mineral dusts damage jet engines
  - Commercial implications – abnormally corrosive and erosive environments
- Breaking down the problem into 3 Elements
  - Element (i) – the external environment
  - Element (ii) – the engine environment
  - Element (iii) – component and sub-system damage
- Where next

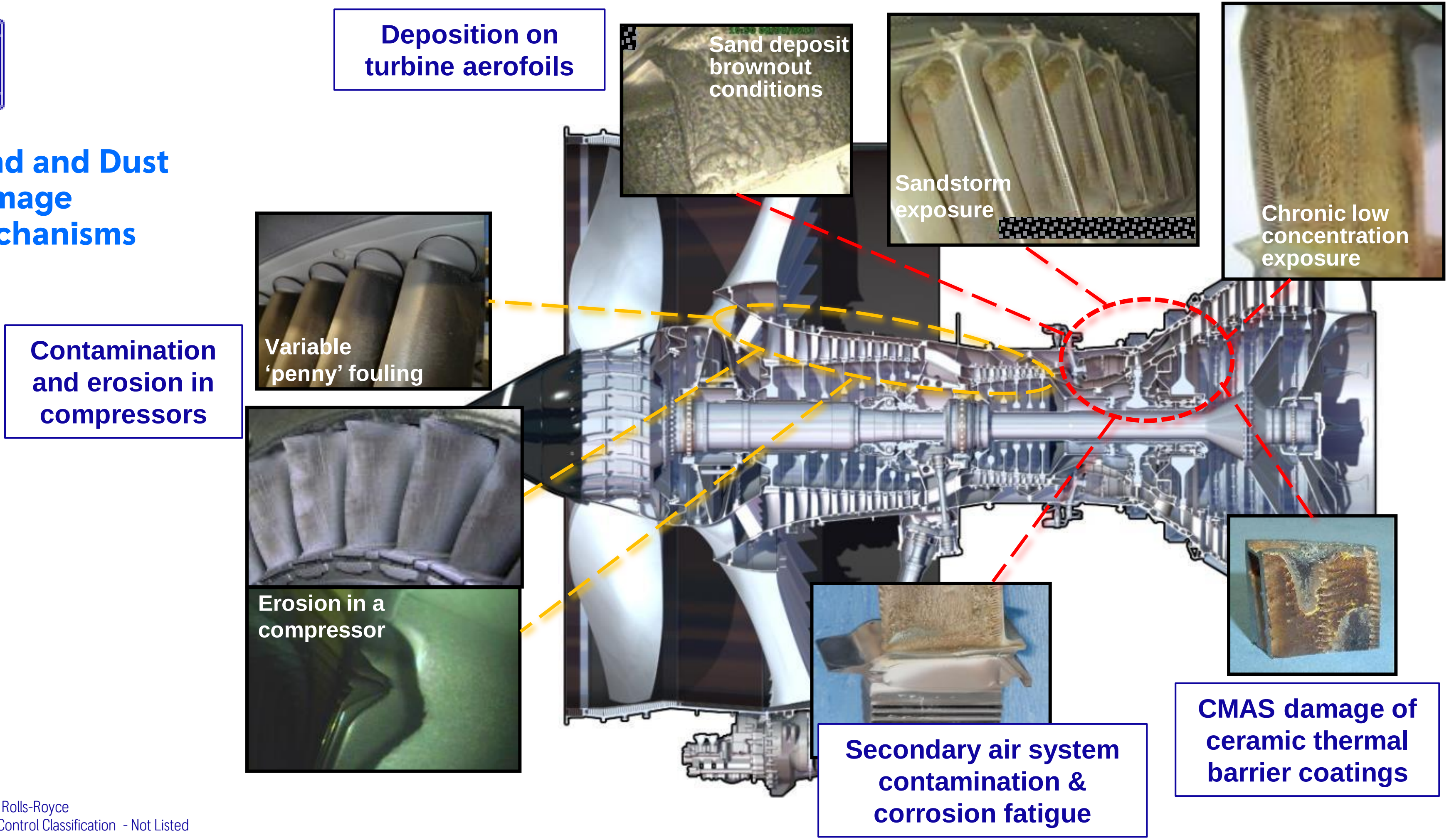
What we have traditionally design engines for....

Engine Environmental Protection

What we are starting to design engines for….

Engine Environmental Protection

Sand and Dust Damage Mechanisms



Atmospheric agents – Impacts of Engine Damage

Threat	Safety Implication	Cost of Ownership
Freezing cloud	✓	
Freezing fog	✓	✓
Ice crystal clouds	✓	✓
Rain	✓	✓
Hail	✓	✓
Snow	✓	✓
Sand and dust		✓
Volcanic ash	✓	✓
SO_2/SO_4^{2-}		✓
Halogen gases/aerosols		✓
Forest fire smoke		✓
Severe turbulence	✓	✓
Lightning	✓	✓
Space weather (HIRF)	✓	
Radioactive clouds		✓

Management strategies:

Operator

Avoid

Limit exposure

Monitor exposure

Rolls-Royce

Certification compliance

Monitor exposure

- Incentivise operators to minimise their exposure to damaging agents

Atmospheric agents – Impacts of Engine Damage

Engine OEM Business Model

- Like the other engine OEMs >50% Rolls-Royce’s income comes from power-by-the-hour service contracts

TotalCare® LessorCare® CorporateCare® MissionCare®

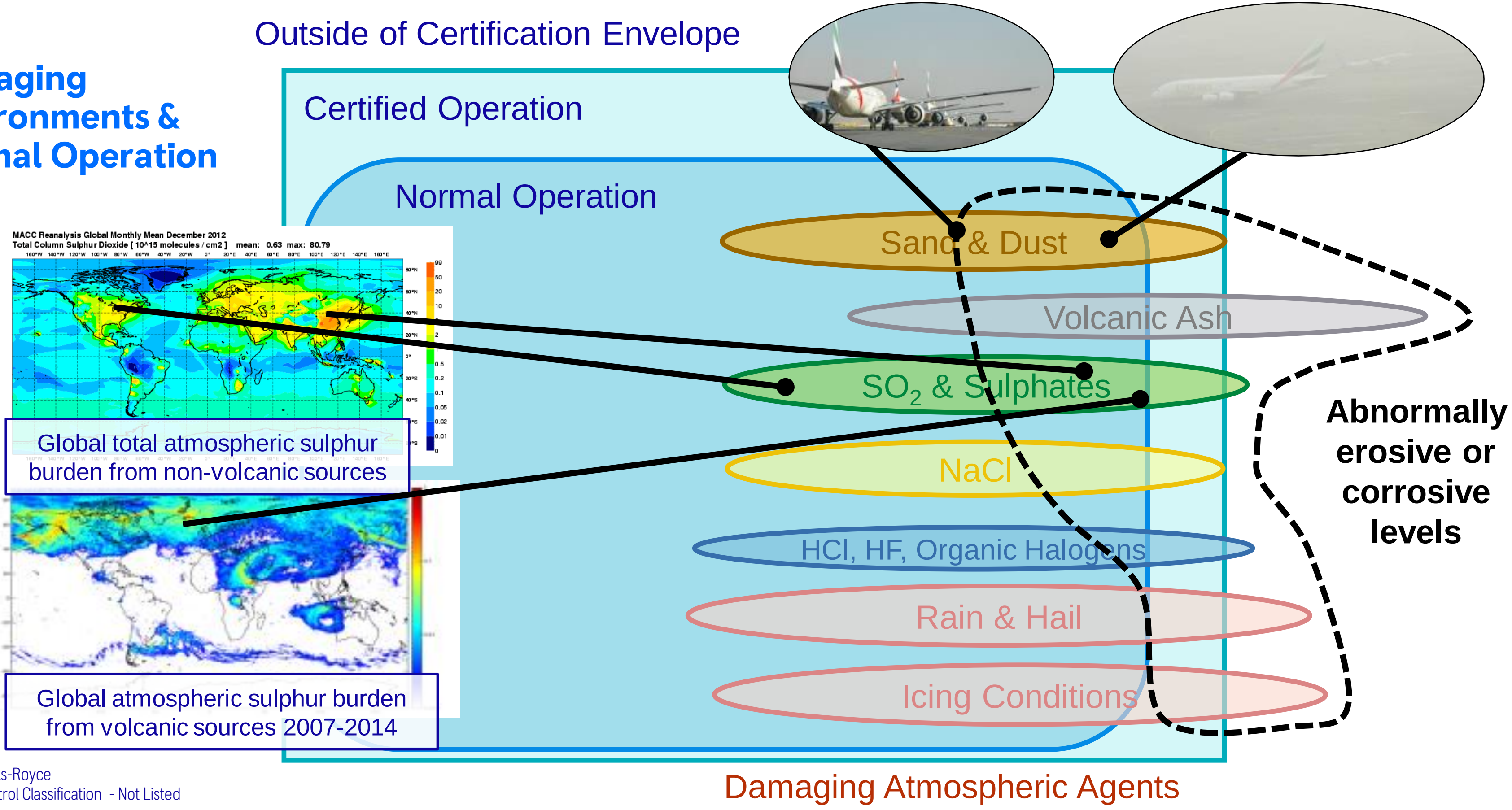
TotalCare summary

Fixes engine maintenance cost
Aligns business structures
Increases aircraft availability
Allows airlines to focus on core business
Fully transfers financial risk

- Care contract can cover exposure to ‘**abnormally erosive or corrosive**’ environments… but they are difficult to define

Abnormally Erosive or Corrosive Environments

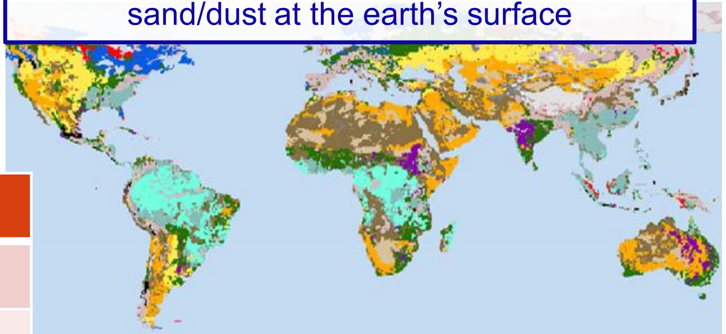
Damaging Environments & Normal Operation



Composition varies with location

Damaging Environments & Normal Operation

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



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)
Glauconite	Layer silicate (Fe rich)
Calcite	$Ca\,CO_3$
Dolomite	$Ca\,Mg\,(CO_3)_2$
Gypsum	$Ca\,SO_4 \cdot 2(H_2O)$
Anhydrite	$Ca\,SO_4$
Halite	NaCl

Mineral Dust

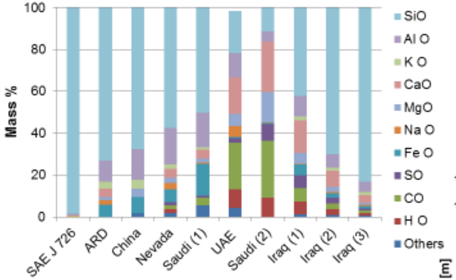
Breaking Down the Problem

Element (i): The external environment

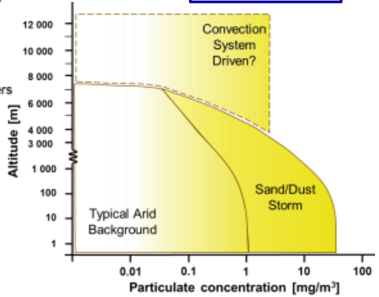
Element (ii): Preconditioning within the engine

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

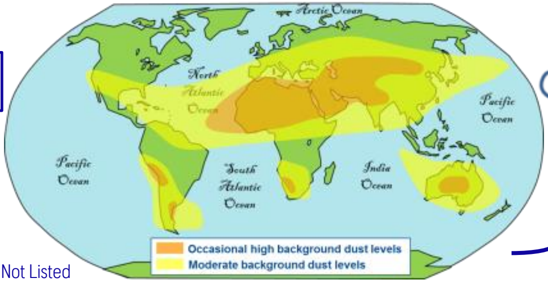
What



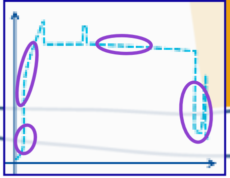
How much

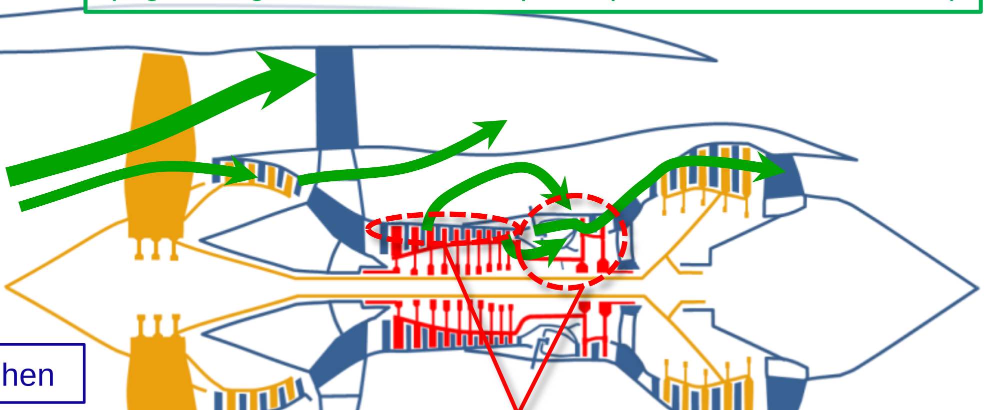


Where



When





What gets damaged and by how much?
HPC, Combustor, HPT, IPT, …

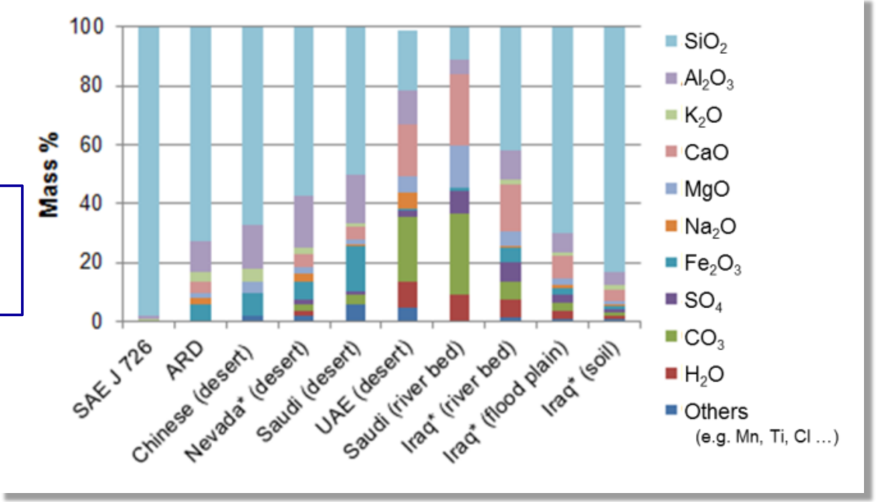
Element (iii): Sub-system & component damage

Compositional variations

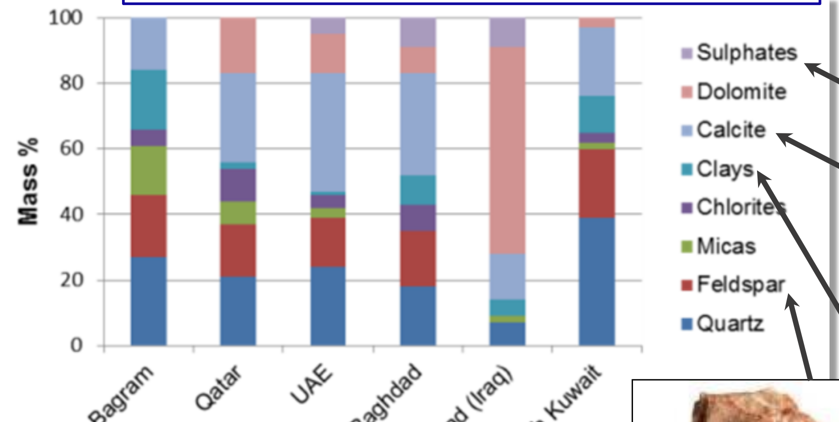
Element (i): Assessing Operational Exposure

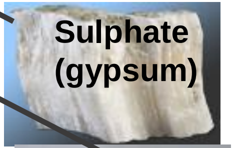
- Chemistry

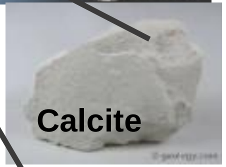
Test dusts compared to various locations around the world
(From various sources)



Various locations of interest to the military
(Taken from Engelbrecht and Derbyshire, 2010)







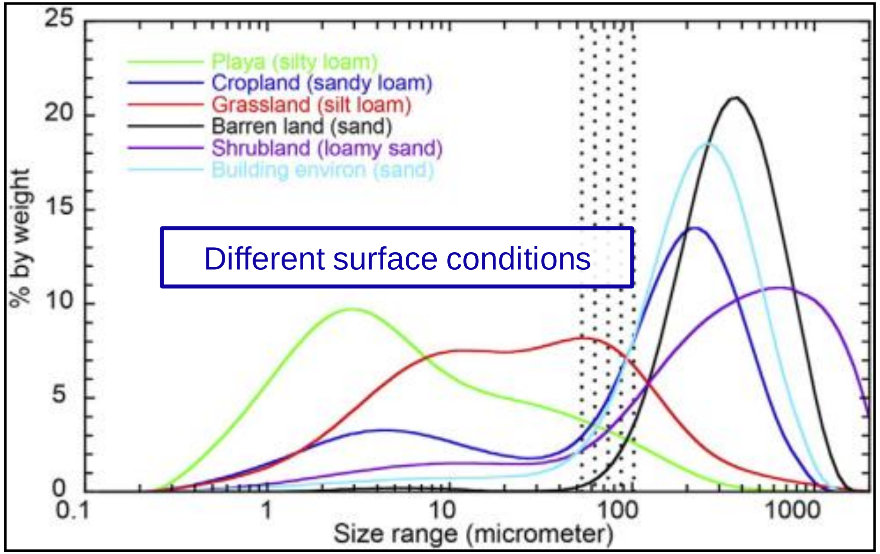
- Mineral composition: effects erosion and melting characteristics

Particle size distributions (PSD) in the atmosphere

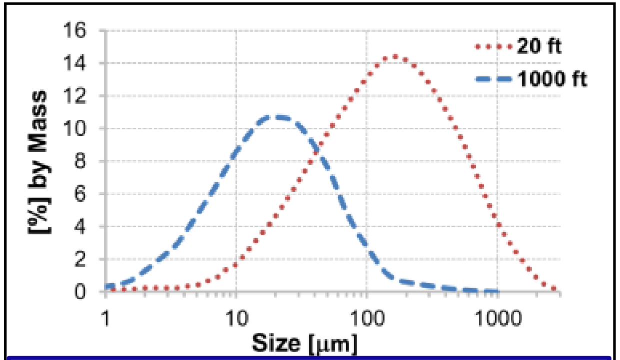
Element (i): Assessing Operational Exposure

During dust storms

Sample No.	Height (m)	Average Diameter (µm)	σ	Fitted PDF Distribution	Visibility (km)
1	21	18.4	8.9	Normal	1.6-2.0
2	15	19.6	10.3	Normal	
3	1	28	13	Exponential/lognormal	
4	21	17	7.7	Normal	1.6-2.0
5	15	18	9.7	Power law	
6	1	37	19	Power law	
7	21	16	6.3	Normal	5.0-6.0
8	15	17	9.4	Lognormal	
9	1	21	6	Lognormal	
10	21	16.4	8.8	Lognormal	3.0-4.0
11	15	17	7	Normal	
12	6	17	6.9	Normal	
13	21	16.5	7.5	Lognormal	0.6-1.0
14	15	19.3	8.9	Lognormal	
15	6	30.6	10.8	Lognormal	
16	1	42.5	16	Normal	



Different surface conditions

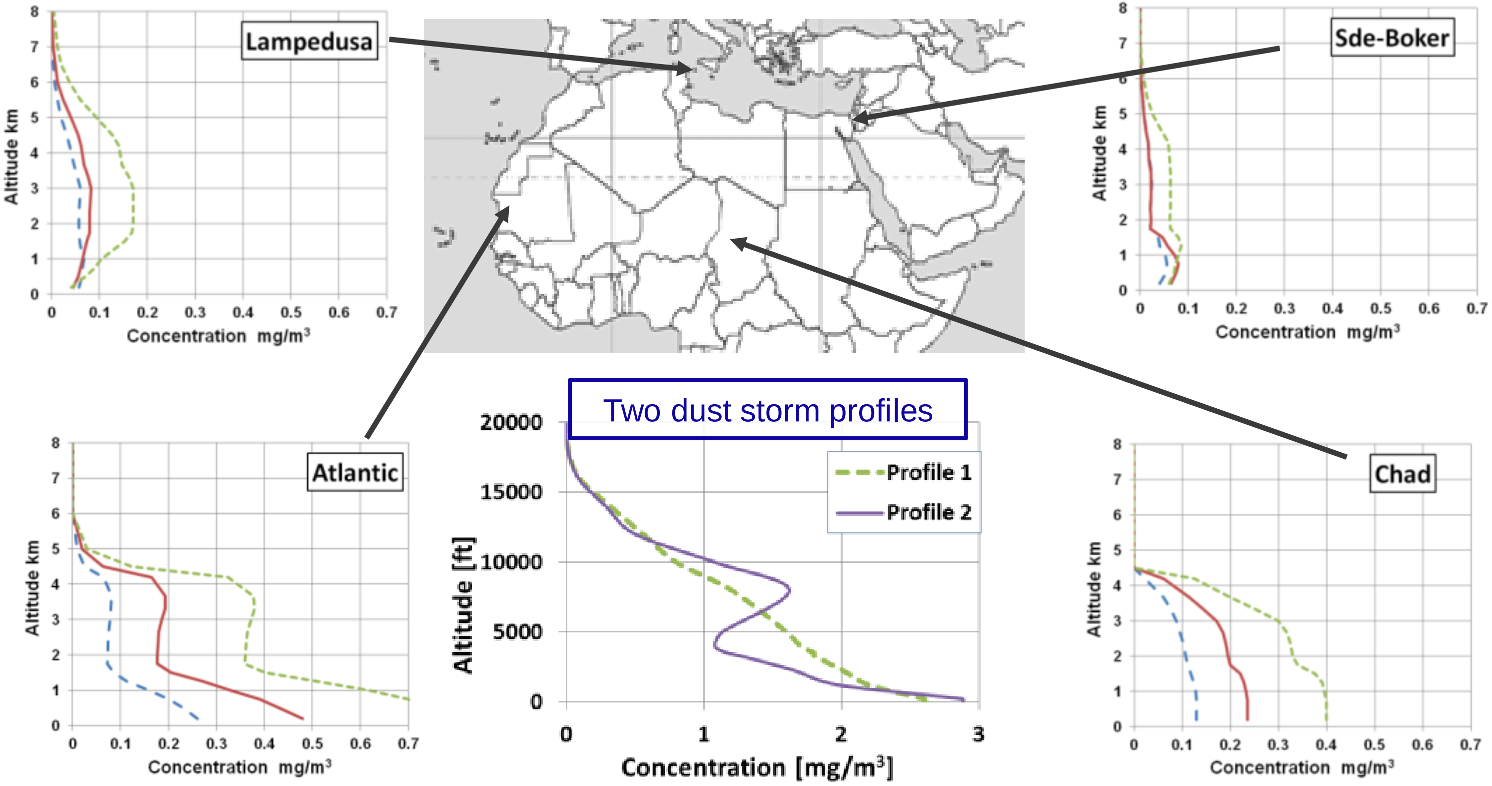


Possible PSD variation with altitude

Concentration distributions with altitude

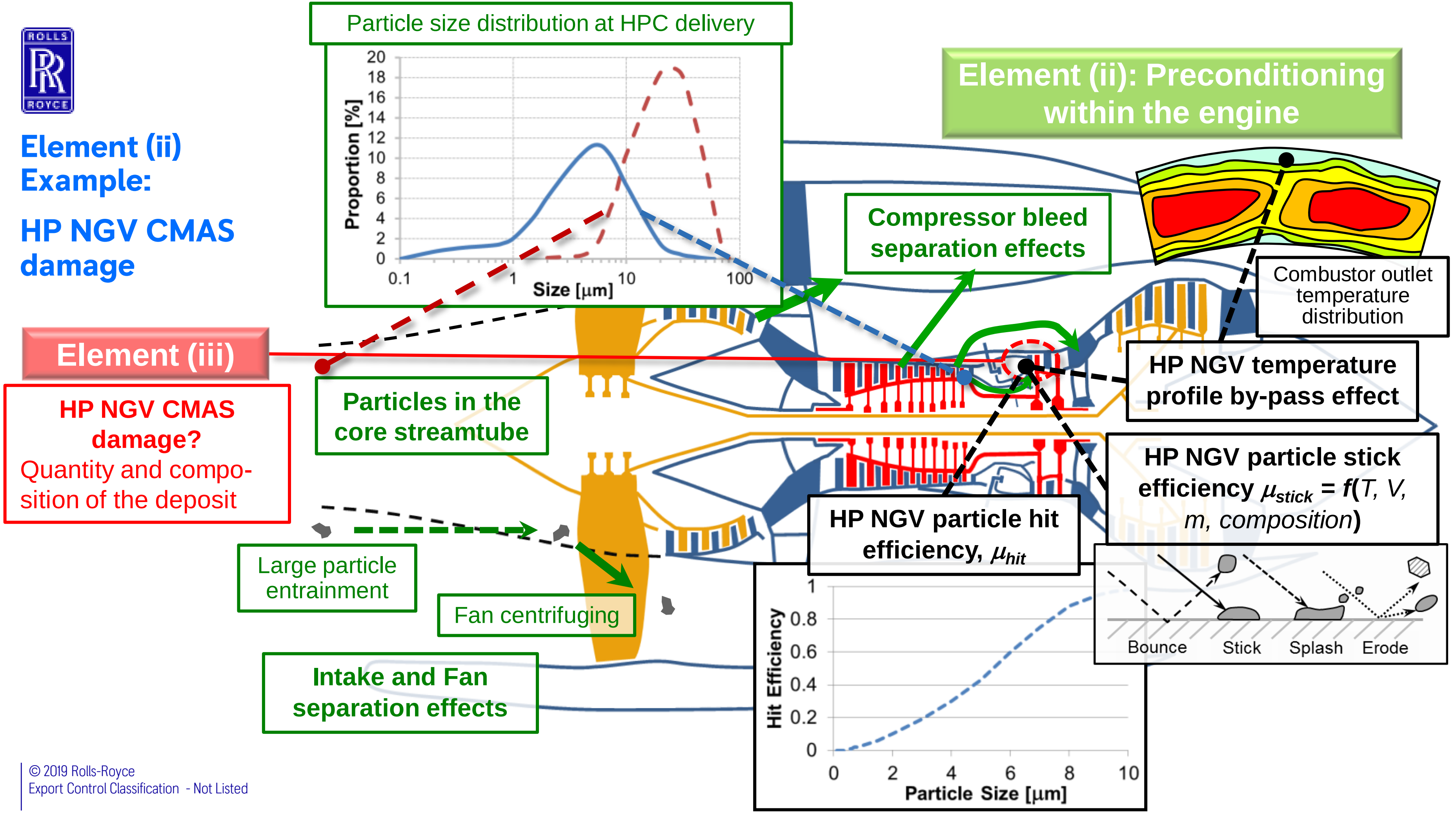
During dust storms

Element (i): Assessing Operational Exposure



Element (ii) Example:

HP NGV CMAS damage



Impact on Engines: Where Next?

Four Big Questions to Answer:

1. What gets into the engine, and in what form?
2. Where does it go and how does it change?
3. What state is it in at the damage site – i.e. how damaging is that state
4. Can the damaging characteristics be mitigated or even militated? e.g.:
   i. Avoid or minimise exposure from the atmospheric dust
   ii. Recover the cost of the engine damage
   iii. Make the dust benign within in the engine
   iv. Design in component protection features
   v. ….?

Thank you