Navy Compressor and Turbine Coatings Update

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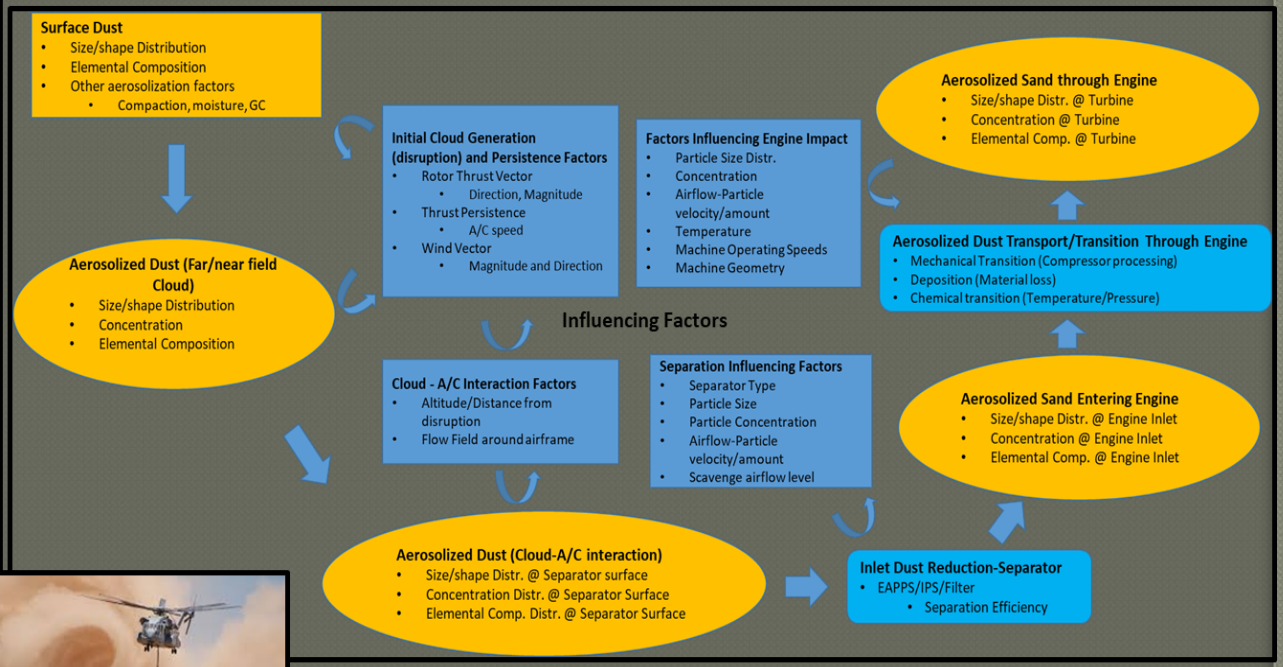
Understanding the complex problem of dust Ingestion

- Desert Operational Impacts to Modern Turbine Engines are Highly Complicated
  - Variability of the Environment
  - Variability of the Mission Type
  - Increasing Demands on the Engines
    - Driving Higher Turbine Temperatures
    - Lower Margins
- Technology Development in this Area
  - Historically Lagged the Requirement
  - Requirement was not Well Defined
- Commercial and Military Demand has Driven Recent Attention
  - DoD, NATO, Industry, and Industry Collaboration
  - Developing
    - Representative Analytical Tools
    - Design Concepts
    - Verification Methods



Process Flow and Factors that Influence Dust Transport to and Through the Engine

NAVAIR has been collaborating in significant efforts to understand the physics, modelling, design, and verification approached to dust and its impacts.

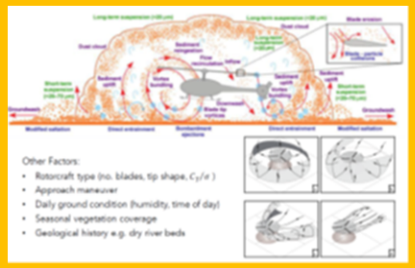
Sand and Dust- Solution Areas

Solution areas focus on strategies that impact Time in Sand and Time on Wing (ToW) include the following:

Navigate:

Strategy- Reduce formation of and/or interaction with the cloud

Impact- Reduced Particulate Ingestion to slow performance deterioration rate.

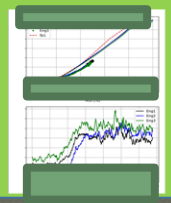


Awareness of State:

Strategy- Improve weapon system state awareness of:

1. External threat (Cloud concentration and composition)
2. Internal system reaction (Real Time Power and Stall Margin)

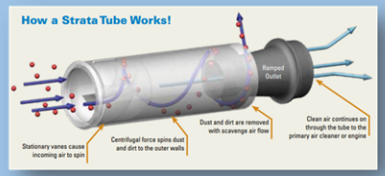
Impact- Real time environment/system status delivered to aircrew for optimized decision making/ORM.



Separate:

Strategy- Improve A/C and/or engine inlet separation and/or filtration.

Impact- Reduced Particulate Ingestion to slow performance deterioration rate.



Tolerate:

Strategy- Improve engine tolerance to ingested particulates through:

1. Increase initial engine performance margin.
2. Reduce internal impacts of dust on turbo-machinery.

Impact- Increased overall performance margin for deterioration consumption and/or reduced deterioration rate.

Maintenance:

Modify maintenance strategy to maximize readiness and TOW during austere operations:
Solution area to explore: Periodic or condition based maintenance requirements, equipment, methods, and solutions

NAVAIR has been working many areas as a systems approach to mitigate the dust threat

Fielded Navy/MC Platform Coating Summary

Engine (Aircraft)	Coating Configuration	Mitigation Target	Stages Coated	Coating Status
T58-16A (H-46)	ER-7/BlackGold	Erosion	Rotor Stages	Qualified Engine Sundowned
T64-416/419 (H-53D/E)	ER-7	Erosion	Rotor Stages and Vane Stages	Qualified/Fielded
T408 (H-53K)	BlackGold	Erosion	Axial Rotor and Vane Stages	Production Configuration LRIP

1. Multiple fielded coating systems have consistently shown significant reduction in chord loss/airfoil thinning

2. Early stage (1st and sometimes 2nd) show vulnerability to high impingement angle, leading edge plastic deformation (LE rollover)
   - This LE protection shortfall continues to be an active area for technology improvement

On-Going Navy/MC Platform Coating Summary

Engine (Aircraft)	Coating Configuration	Mitigation Target	Stages Coated	Coating Status
T700-401C (H-1/60)	BlackGold	Erosion & Corrosion	Axial Rotor Stages	Field Service Evaluation (FSE)
AE1107C (V-22)	BlackGold	Erosion & Corrosion	Rotor Stages	Field Service Evaluation Ended (Contracts Issues) Program Cancelled
T56-427/A (C-130/E-2/C/D	BlackGold	Erosion & Corrosion	Rotor Stages	Qualification Completed Program On Hold (BCA)

1. T700
    1. Testing showed clear improvement in chord retention and airfoil thinning.
    2. T700 coating system qualified, hardware awaiting install, ECP processing for FSE (~20 rotors) BCA being updated for repair line upgrades.
2. AE1107C FSE was not completed within the timeline of the contract requirements and terminated. Data that was returned was inconclusive.
3. T56 testing showed clear improvement. Program has been put on hold awaiting updated BCA for production/repair consideration.

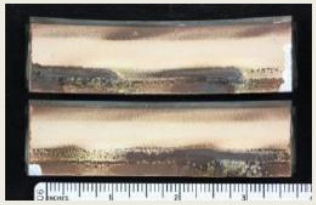
Turbine Sand Accumulation Mitigations

Two turbine failure modes and effects areas have been identified while operating certain Navy/Marine Corps Aircraft in austere regions

1. Potential Airworthiness Impacts-Turbine blade/vane/shroud sand glassing and accumulation
2. Durability Impacts- CMAS glass infiltration and TBC/EBC distress

Typical build-up on vane

Typical build-up on blade



CMAS Damage on Shroud

NAVAIR/ARL/NASA completed an advanced coating demonstration program in 2016

- Evaluated coating options to reduce surface accumulation and/or retention as well as overall durability
- Learning from this program has informed follow on coating development programs.
- Currently collaborating on a follow on set of demonstrations of updated coating options in multiple engine lines

Questions?