Erosion / Corrosion Resistant Coatings for Compressor Airfoils






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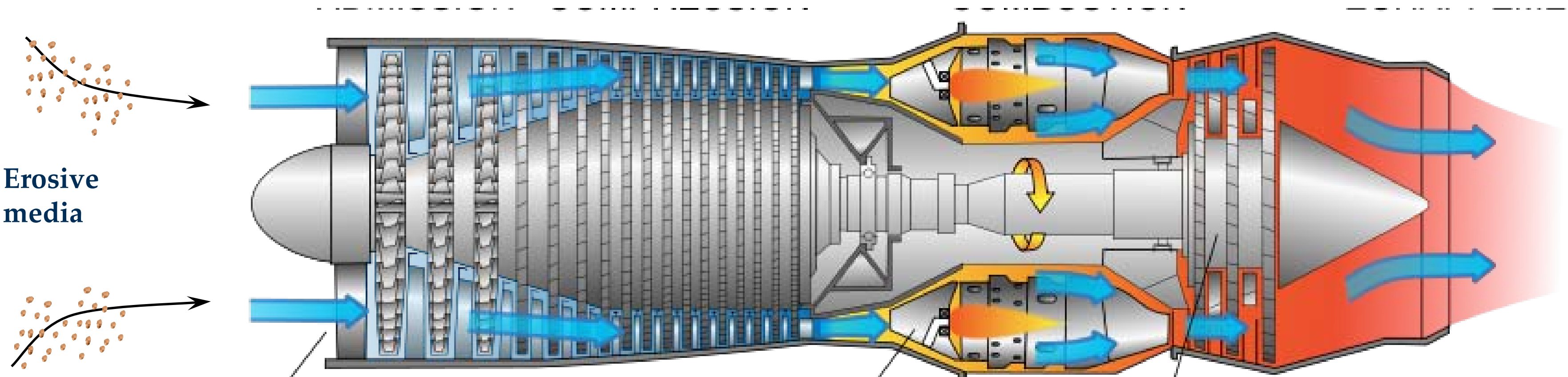
The Problem

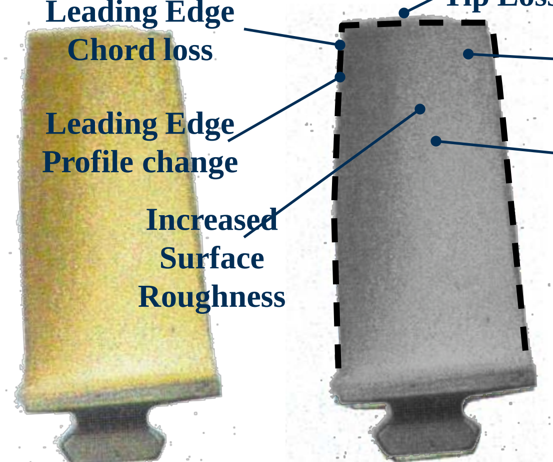
- DoD Maintenance cost $84B in 2010
- Gas Turbine Engine Mx costs exceeded $7.5B in 2010
- Low Power accounts for ≈ half unscheduled removals
- Engine erosion a leading contributor to low power
- Compressor airfoil corrosion major MRO cost driver
- DoD consumes ≈ $13B in aviation fuel annually
- Eroded engines emit 10 to 25% greater pollutants

The Problem

GAS TURBINE ENGINE

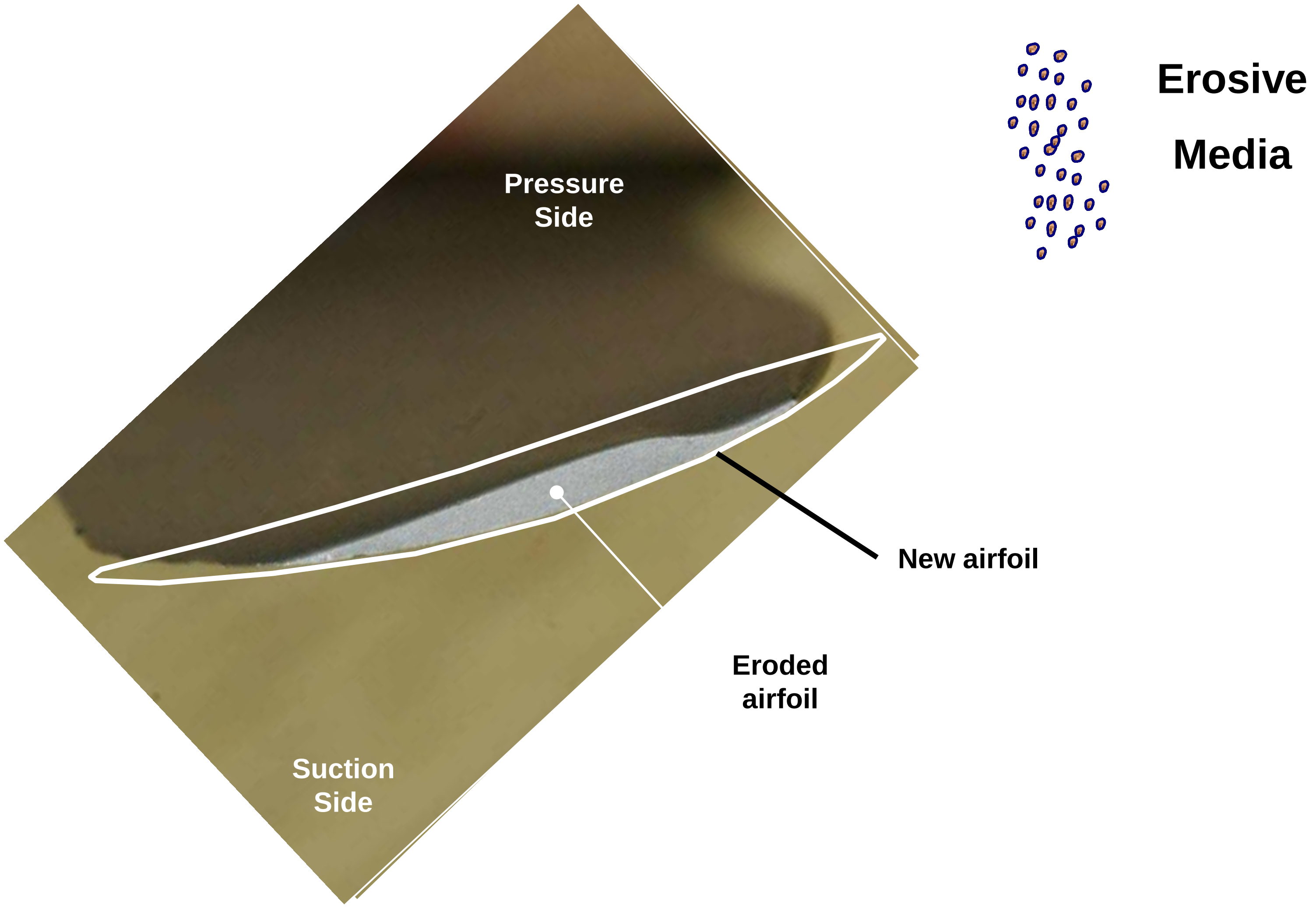


Erosion of compressor blades



Actual results from engine test

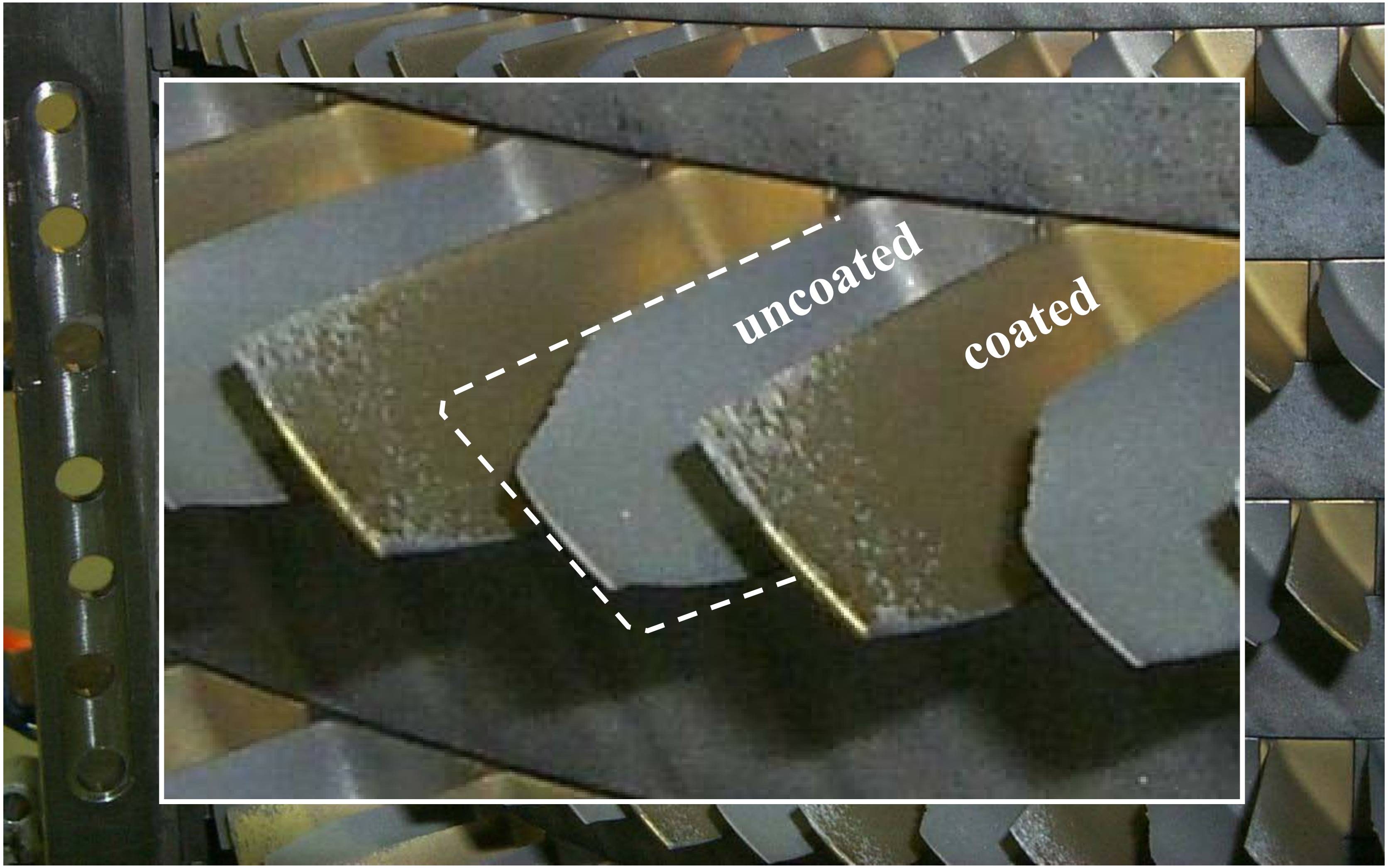
Typical Erosion Mechanism




Gem for Lynx
T64 for H-53
T58 for H-46
Gnome for Sea King
T55 for MH-47
Platforms in Production
Platforms in Evaluation / Qualification
AGT1500 for M1A Tank
AE1107 for V-22
RTM322 for Merlin
T700 for H-60
Arriel for LUH
GE38 for H-53K
CF6 for B767
JT8D for MD-88
Makila for Super Puma/Cougar
Honeywell
HPW3000
Pratt & Whitney
A United Technologies Company
T56 for C-130
CFM56 for B737
CF34 for E170
CFM56 for B737 / A320

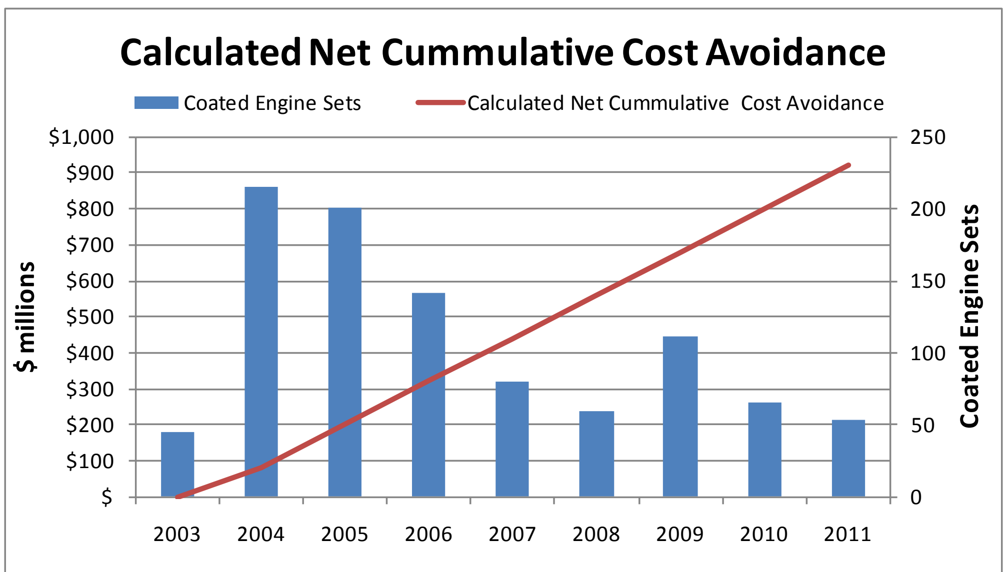
CH-53 Engine Test Results

T64 Engine Sand Ingestion Test



CH-53 Engine in Desert Ops

- T64 engine overhaul costs $750,000; 771 engines in fleet
- > 1,000 T64 engine compressor sets coated since 2003
- > 750,000 operational hours in-theatre
- Uncoated TOW ≈ 113 hrs; Coated TOW ≈ 1100 hrs[1]
- H-53/T64 readiness rates consistently met during OIF/OEF
    - Compared to numerous bare firewalls during Desert Storm
- PMA 261 calculated $120M cost avoidance in 2005[2]



[1] First 60 uncoated vs first 60 coated in OIF

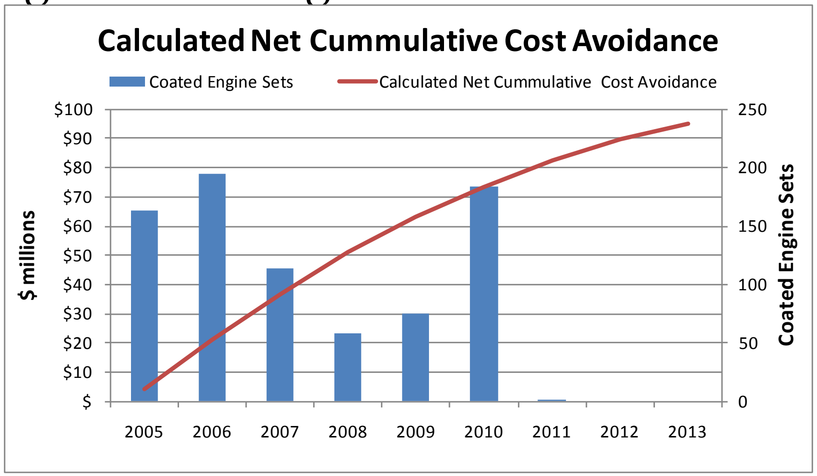
Uncoated engine
at 113 hours
≈ 3 months
Time-On-Wing

Coated engine
at 2,023 hours
40 months
Time-On-Wing

[2] **Based on reduced frequency of engine repair only, concurrent airfoil replacement and other logistics elements not considered**

CH-46 Engine in Desert Ops

- Blade coating initiated in 2005 to enhance durability and TOW
- 19 Uncoated engine blade failures (2003-2007); 2 class A Mishaps (2005 &2008)
- Zero Coated engine blade failures, Coating mandated for Safety of Flight
- > 500 T58 engine compressor sets coated since 2005
- > 250,000 operational hours in-theatre; T58 overhaul cost ≈ $285K
- Uncoated engine average TOW ≈ 530 hrs [1]
- Coated engine average TOW ≈ 798 hrs [1]
- Sand IngestionTesting demonstrates 3% reduction in fuel consumption



[1] Based on PMA-226 engine study data

[2] Based on reduced frequency of engine repair only, concurrent airfoil replacement and other logistics elements not considered

T56 Performance Summary
Uncoated vs Coated Engine

Uncoated Engine (April – May 2011)

With "sand turbine" at San Antonio:

~ 104% shp at START
~ 95% after ~ 70 lbs sand ingested
~ 80% after 135 lbs sand ingested

With reference turbine at Winnipeg:

~ 88% shp after 135 lbs sand ingested

Coated Engine (July – Oct 2011)

With "sand turbine" at San Antonio:

~ 102.5% shp at START
~ 95% after ~ 110 lbs sand ingested
~ 91% after 135 lbs sand ingested

With reference turbine at Winnipeg:

~ 97.5% shp after 135 lbs sand ingested
~ 12% less specific fuel consumption

Coated Engine

1,000 hours > TSO

~ 3X power retention

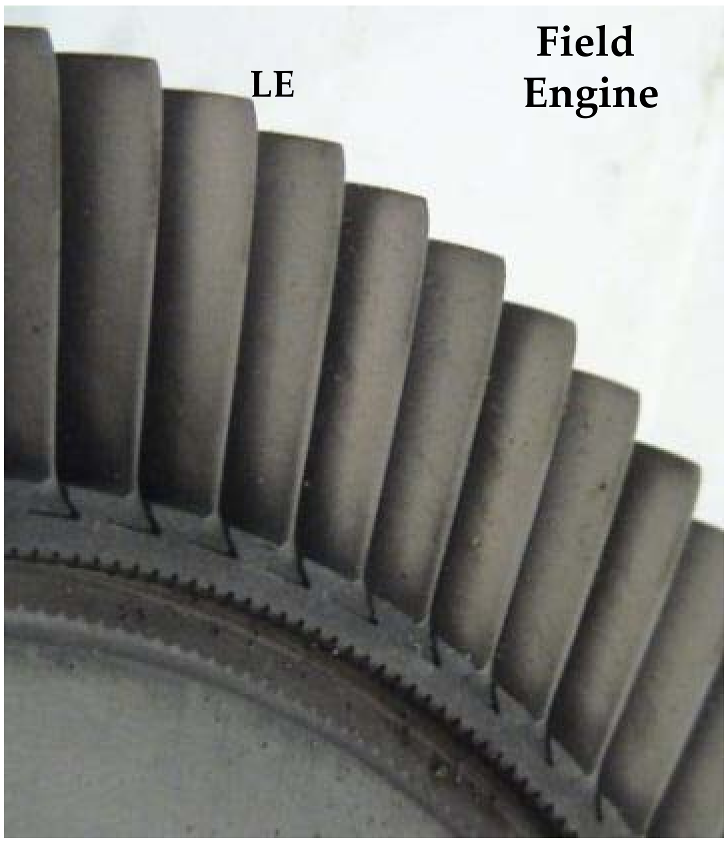
2-3% Corrected Fuel Flow

1-2% Specific Fuel Consumption

decrease @ 95% shp

6th Stage Blade @ 135 lbs Sand Ingested

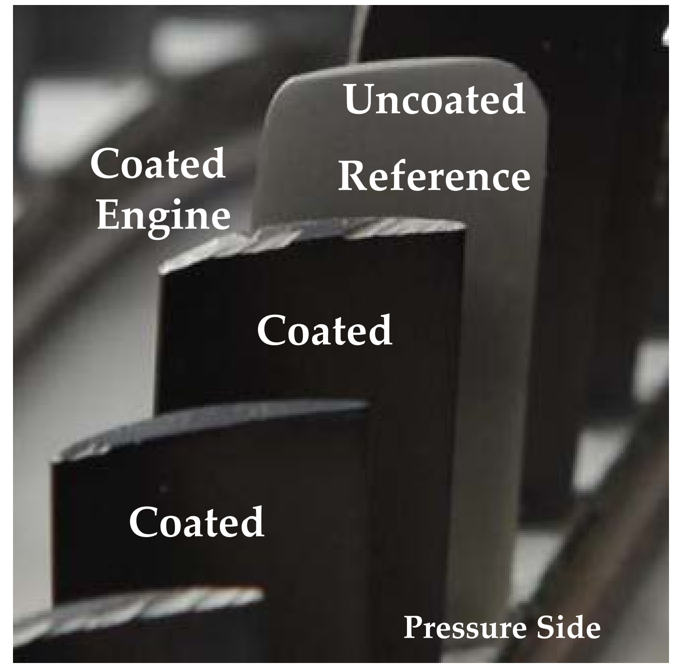
Pressure Side



2005, Depot Induction

2011

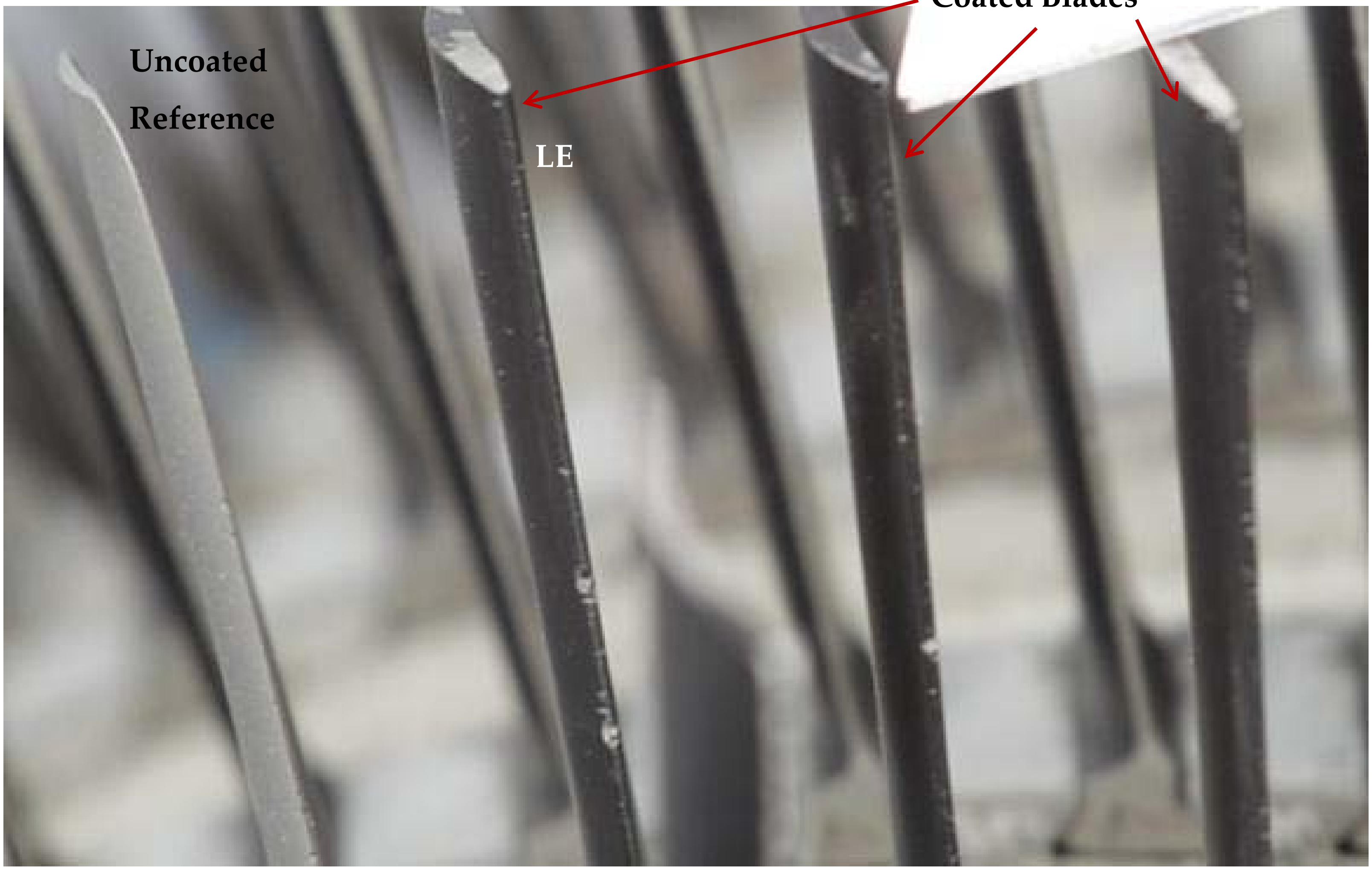
135 lbs SITE



2011

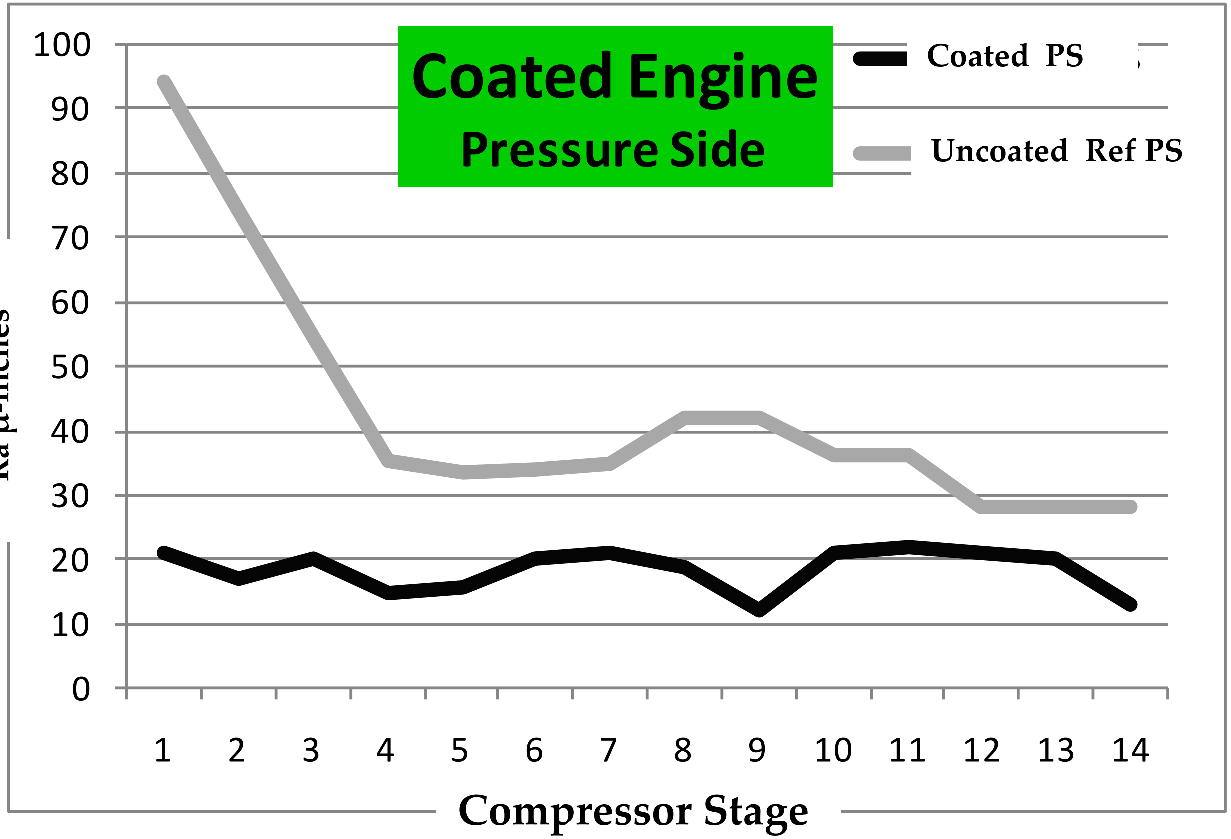
135 lbs SITE

6^{th} Stage Blade @ 135 lbs Sand Ingested



6^{th} Stage Blade @ 135 lbs Sand Ingested

Post-Test Surface Finish



Retaining low surface finish contributes to lower fuel consumption

Pressure Side (PS)
Roughness Average (µ-in)

Uncoated Engine = 45

Uncoated Ref Blades = 42.9

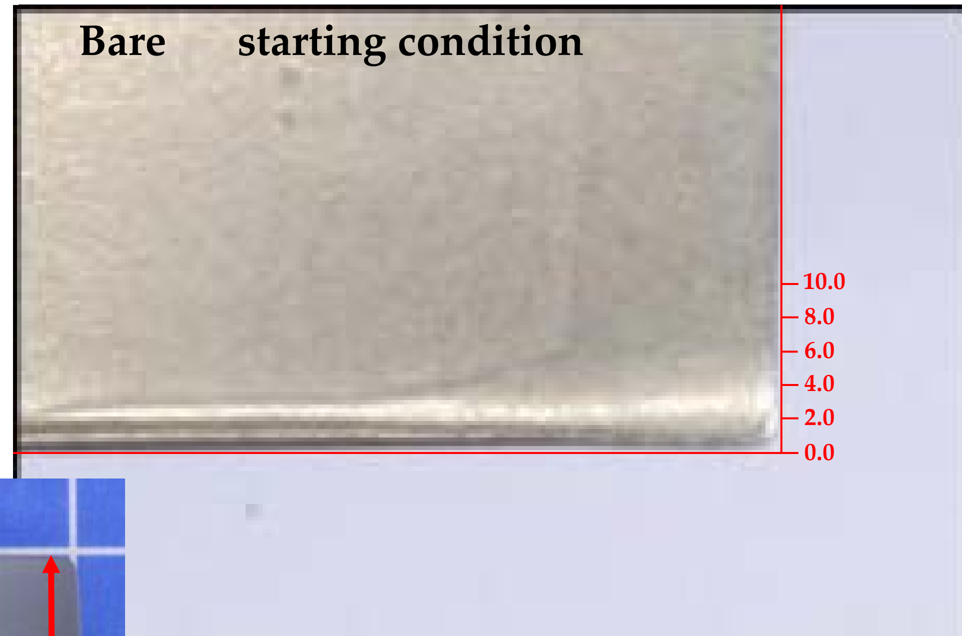
Coated = 18.4

135 lbs sand consumed

90% ARD A4: 10% C-Spec

Commercial Aero Fuel Savings

Chord Loss Testing
Commercial Turbofan



≈ 0.5% to 2.0% SFC impact on Commercial Turbofan

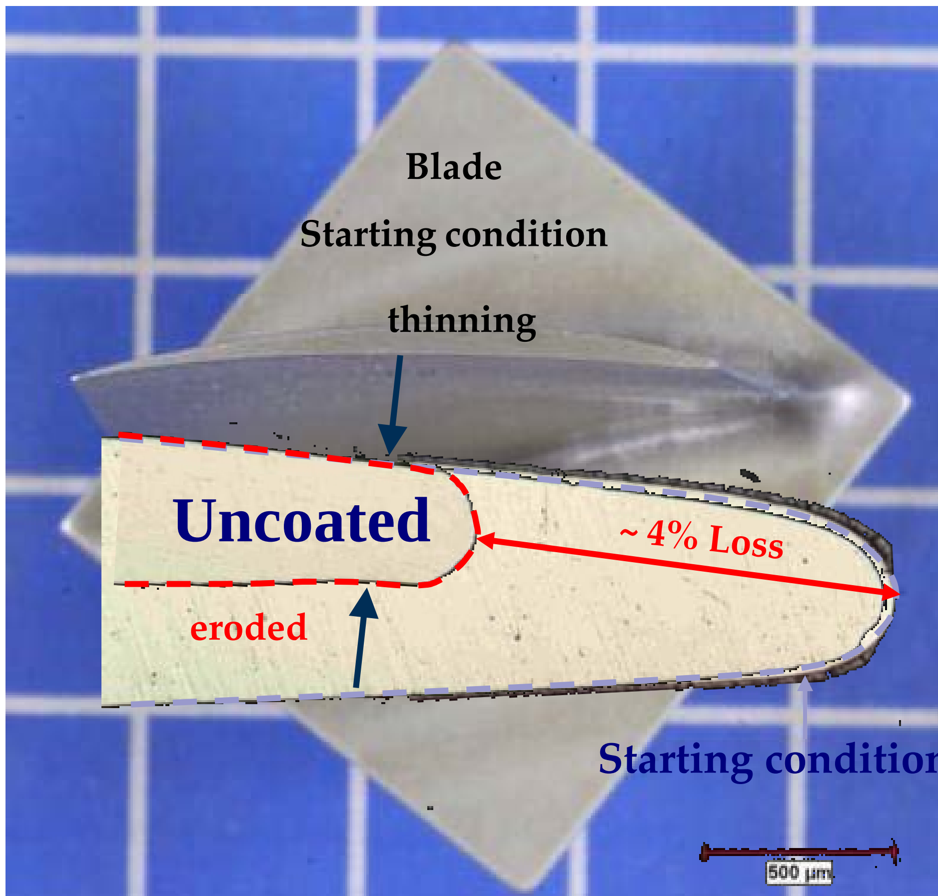
pending areas of operation

Thickness Impact
Leading Edge Configuration

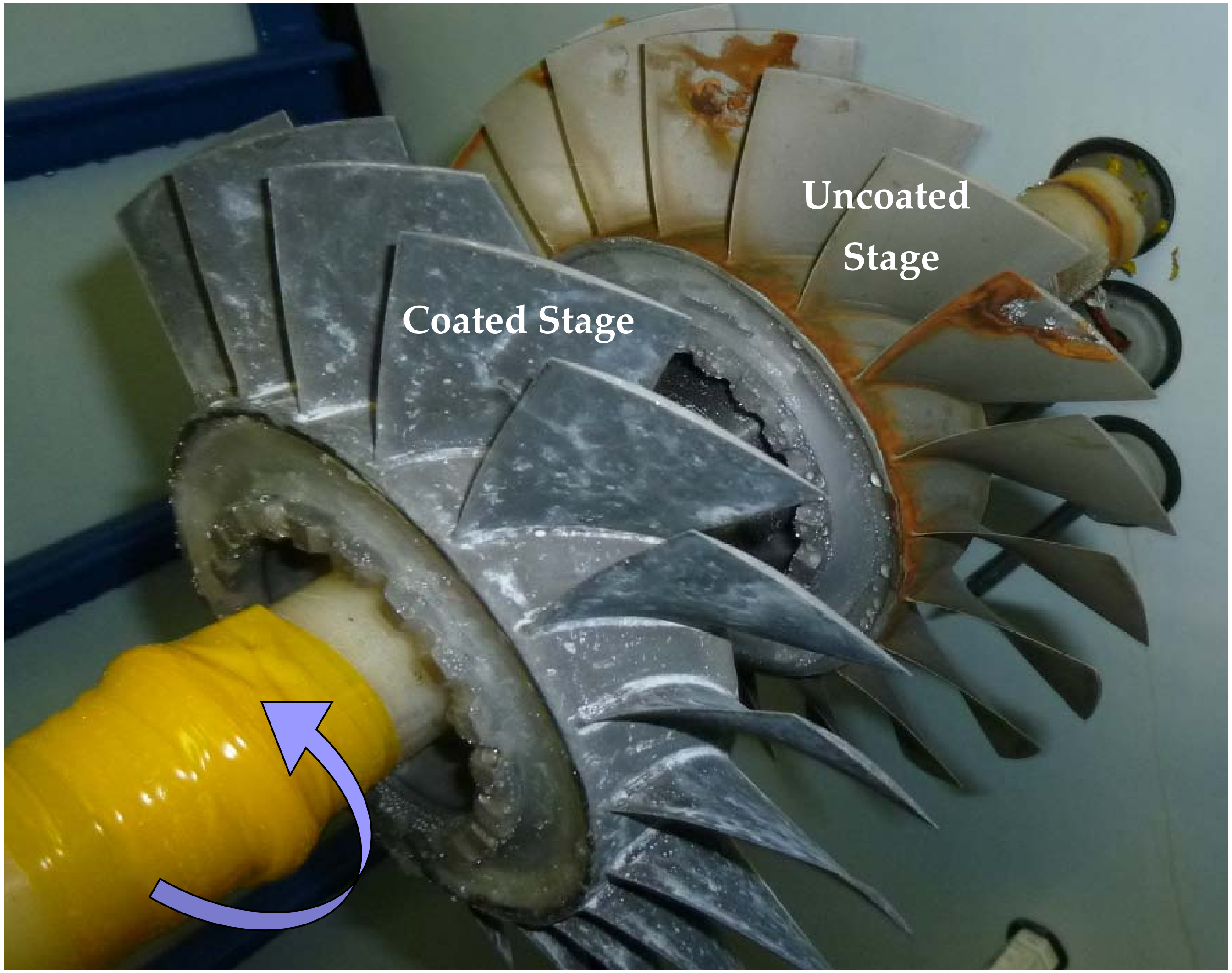
- Thinning of Eroded Blade

Blade after 2 cycles

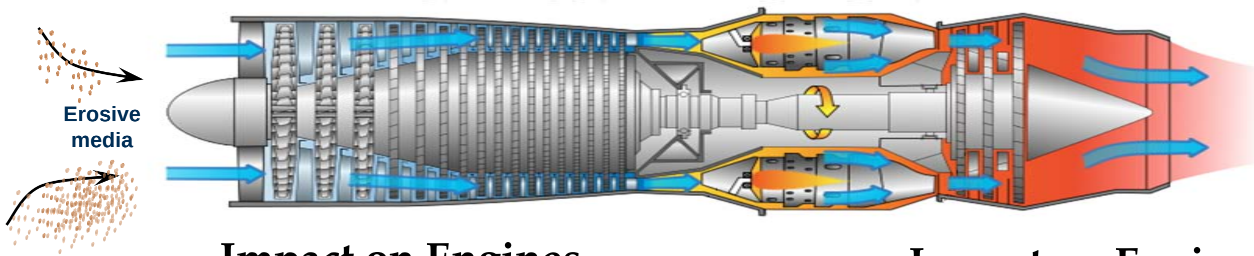
or ≈ 4% chord loss



Uncoated vs Coated Compressor Stage Corrosion Test



14 days exposure 5% Salt Fog
per B117 Test Standard



Operations

Impact on Engines No Coating

113 hrs ≈ 3 months Time-On-Wing

Blade Curling => Blade Failure

- Low engine power
- Eroded / Corroded blades

- Unscheduled Removals
- Increased Field and Depot Maintenance
- Increased compressor airfoil scrap rates
- Decreased Mission Completion Rates
- Compressor Stalls and Blade Failures
- Increased Fuel Consumption / Emissions

SAFETY $\downarrow$

READINESS $\downarrow$

COST $\uparrow$

Impact on Engines with Coating

2022 hrs ≈ 40 months Time-On-Wing

NO Blade Curling => NO Failures

- Engine power retention
- Blade structural integrity

- Increased Service Time
- Decreased Field and Depot Maintenance
- Increased airfoil reuse during maintenance
- Increased Mission Completion Rates
- Safe Engine Operations
- Decreased Fuel Consumption / Emissions

SAFETY $\uparrow$

READINESS $\uparrow$

COST $\downarrow$


I've got the Power!