Leading Edge Protective Coating Against Fluid and Particulate Erosion for Turbofan Blades

Presented to: FAA Office of Environment and Energy

By: Delta TechOps (DTO)

MDS Coating Technologies (MCT)

America's Phenix, Inc. (AP)

Date: 11 May 2020

LE Protective Coating Against Fluid and Particulate Erosion for Turbofan Blades

Benefits:

Based on 1% fuel savings for Mainline and Regional commercial carriers:

- Fuel savings between 80M to 100M gal per year
- 750M to 1.0B kg CO_2 / year
- 700M to 1.0B g NO_x / year

Risk

- Potential fatigue debit impact of coating Ti blades
- Insufficient coating durability

Mitigation

- Adjust coating process parameters
- Test & compare to eroded blades in operation

Objectives:

- Quantify performance degradation
- Optimize coating protection via component tests
- Demonstrate coating protection on operational a/c

Work Statement:

- Conduct engine tests on degraded & O/H[1] blades
- Conduct CFD analysis on degraded & O/H[1] blades
- Conduct fluid erosion tests at AFRL[2] SuRE[3] rig
- Flight certify optimal coating candidate
- Conduct flight service evaluation

[1] Overhaul [2] Air Force Research Lab [3] Supersonic Rain Erosion

Accomplishments / Milestones

- Engine test completed with used and new blades
- CFD[4] model completed on used blade
- SuRE test successfully completed
- Flight certification tests completed

Schedule:

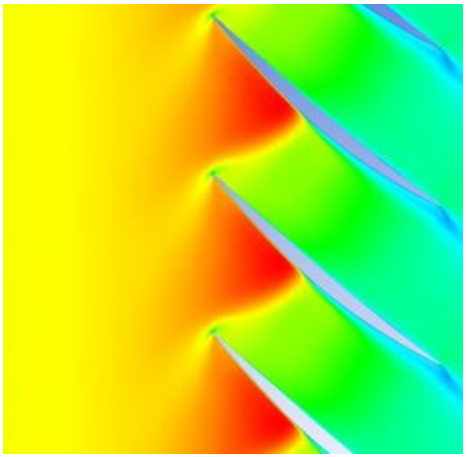
- Blade Condition / Operational Analysis – **COMPLETE**
- JT8D Fluid Erosion Component Test – **COMPLETE**
- Other Engine Types Fluid Erosion Test – **COMPLETE**
- Flight Certification – **COMPLETE**
- Flight Service Evaluation – **COMPLETE, March 2020***

[4] Computational Fluid Dynamics

Phase I – Data, Test & Simulate

Blade Condition Analysis

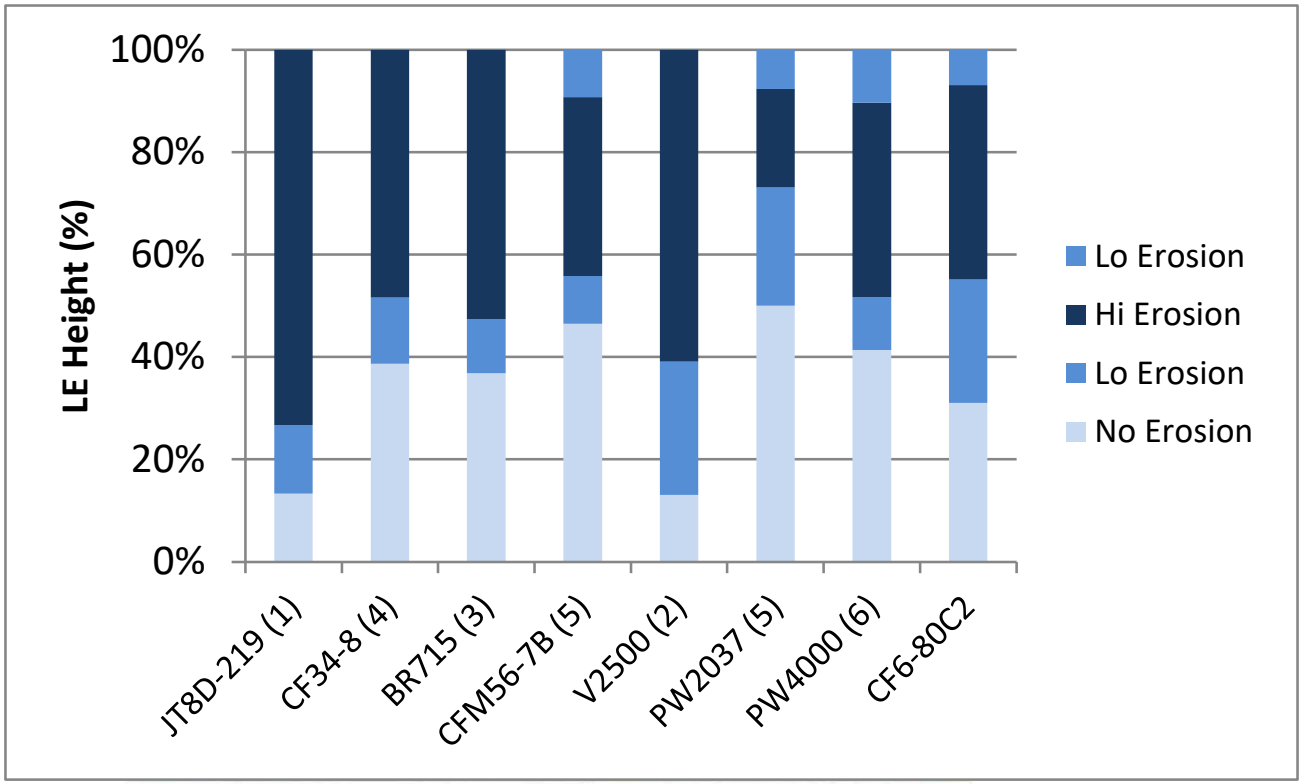
Engine Test Data

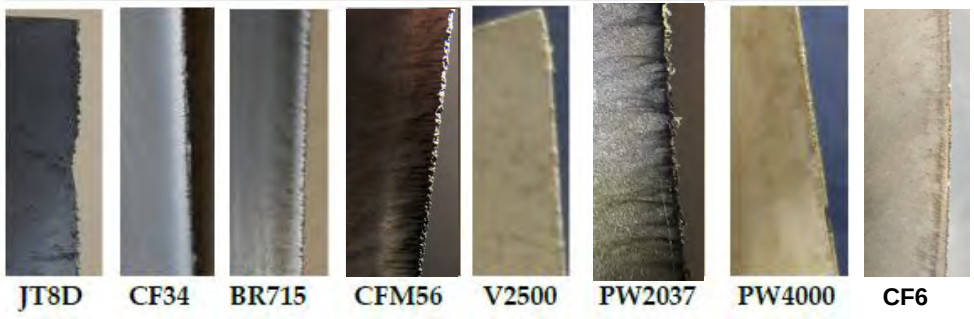


CFD Analysis

- Following 1st stage fan blades inspected and analyzed:
  - JT8D
  - BR715
  - CFM56
  - PW4000
  - V2500
  - CF34
  - PW2037
  - CF6
- Engine test completed on inducted JT8D engine with:
  - existing 1st stage fan blades
  - serviceable condition 1st stage fan blades
- CFD Analysis completed on serviceable and used blades at following conditions:
  - Take-off
  - Cruise

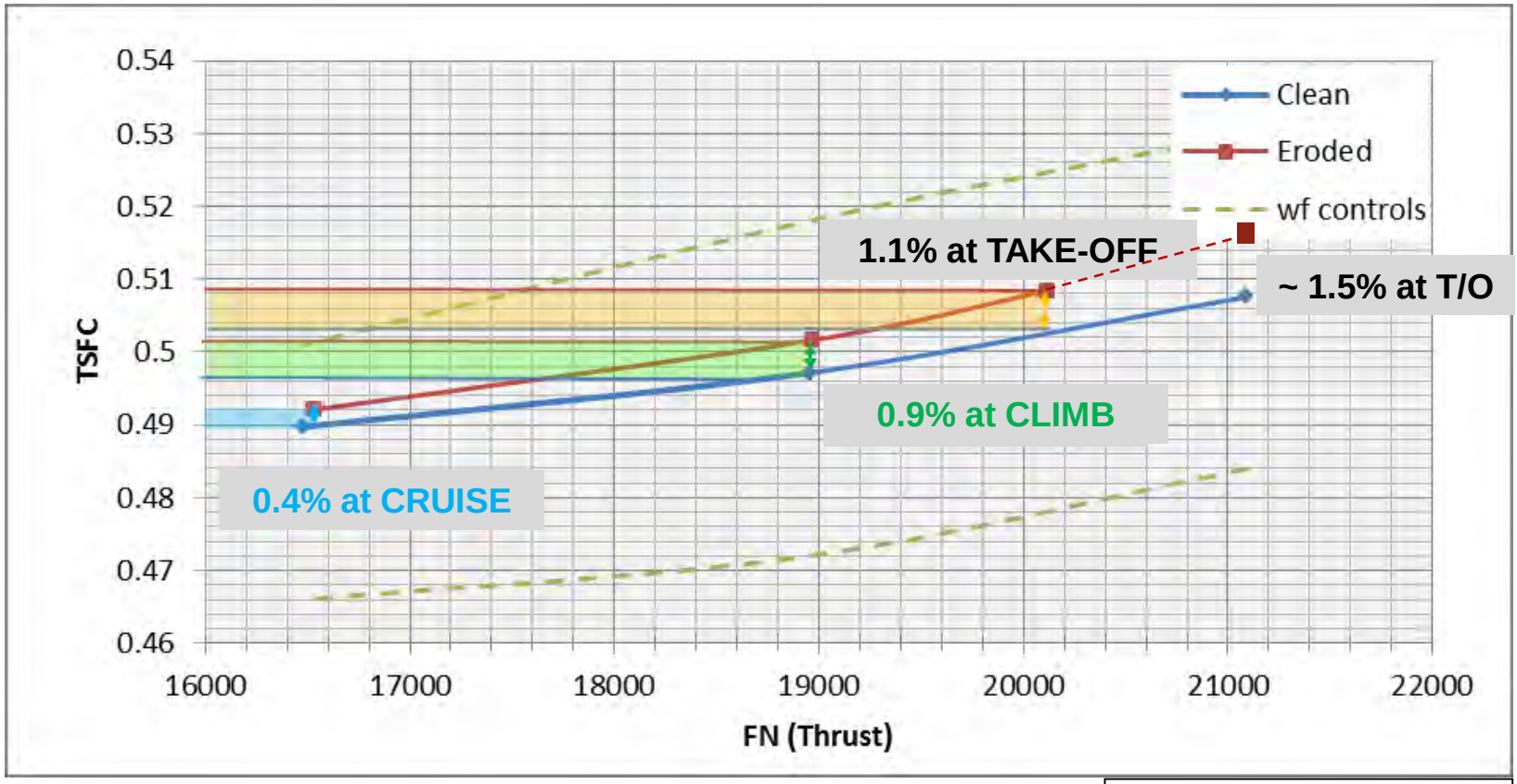
Blade Condition Analysis





Phase I – Engine Test

Thrust Specific Fuel Consumption (TSFC) Comparison
Eroded vs. Serviceable Fan blades

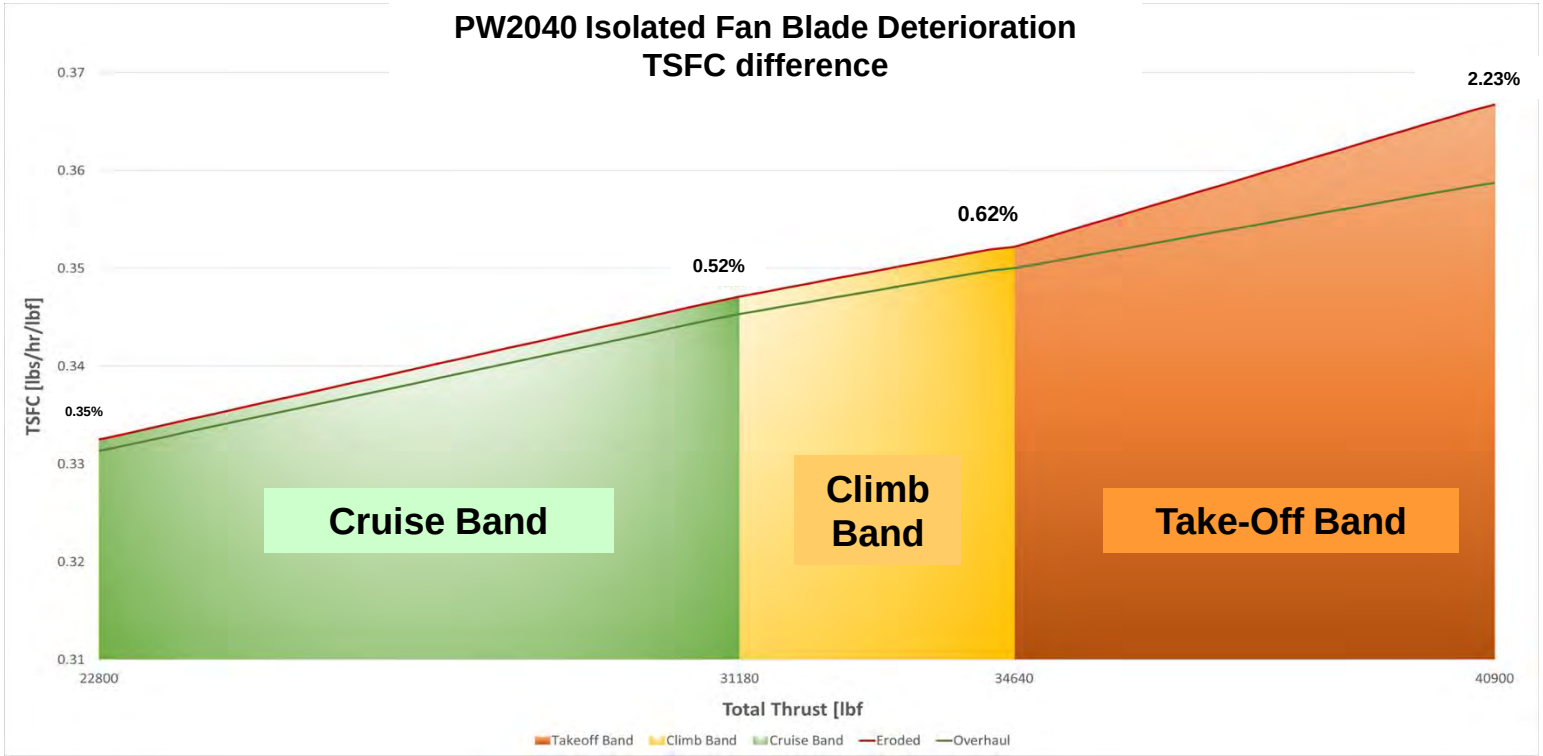


Clean = repaired, serviceable fan blades

JT8D Engine S/N 726044
Inducted May 2015
TSO = 3126 hours
Tests / Engine Service Manual: PN773128

Phase I – Engine Test

Thrust Specific Fuel Consumption (TSFC) Comparison
Eroded vs. Serviceable Fan blades

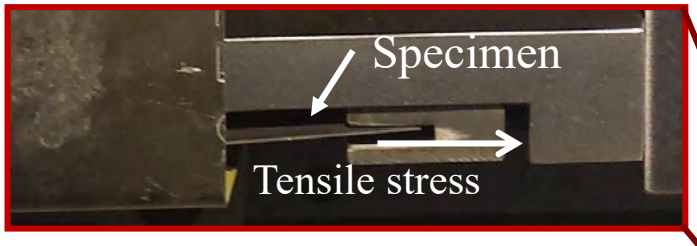


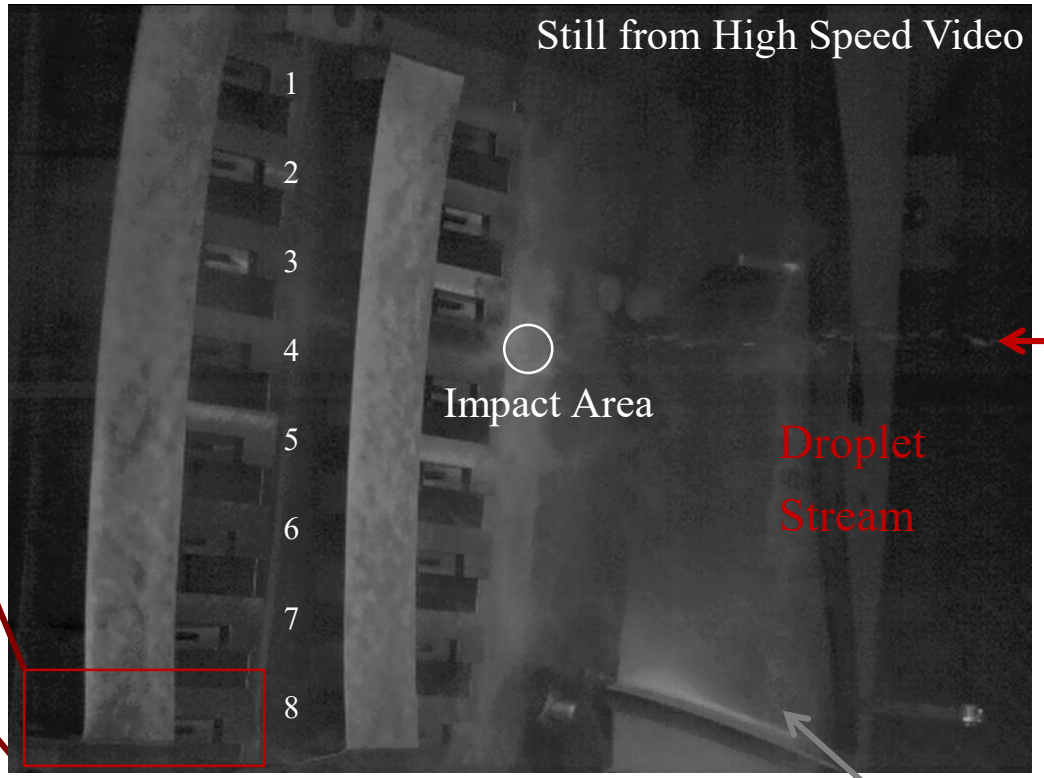
Phase II – Fluid Erosion Test

@ AFRL – Supersonic Rain Erosion (SuRE) Rig

Specimen Preparation

Specimen Tooling





Uncoated Blade Specimen

BlackGold® Coated Blade Specimen

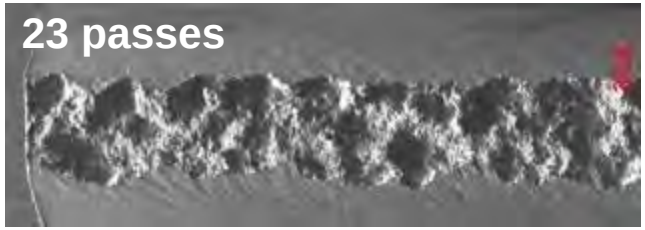
Coated Blade

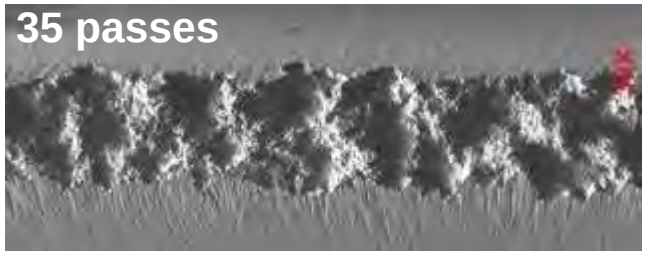
Fluid Erosion Tests @ AFRL

Phase IIA - February 2017 Tests

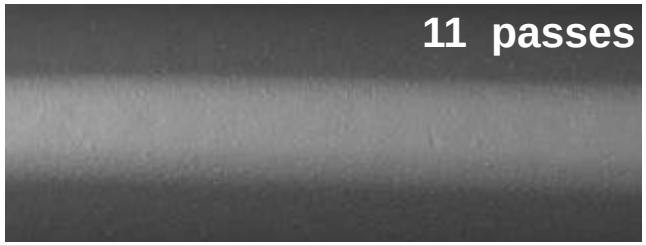
Uncoated PW2000

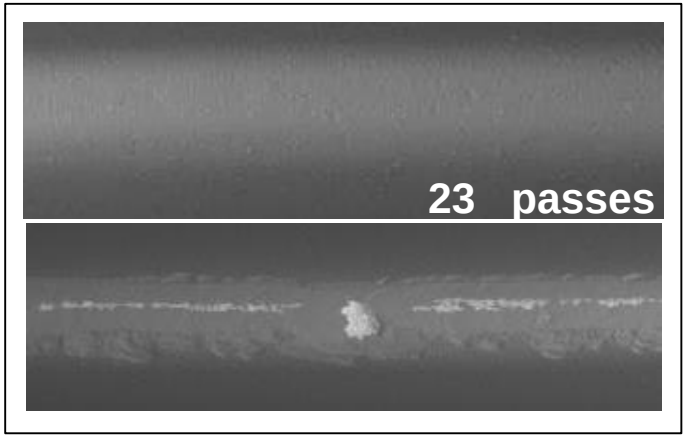
Breach evident @ 3 passes

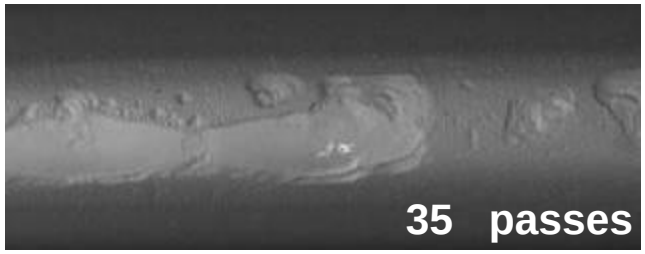




BlackGold® Coated PW2000







First substrate damage noticed after 23 passes

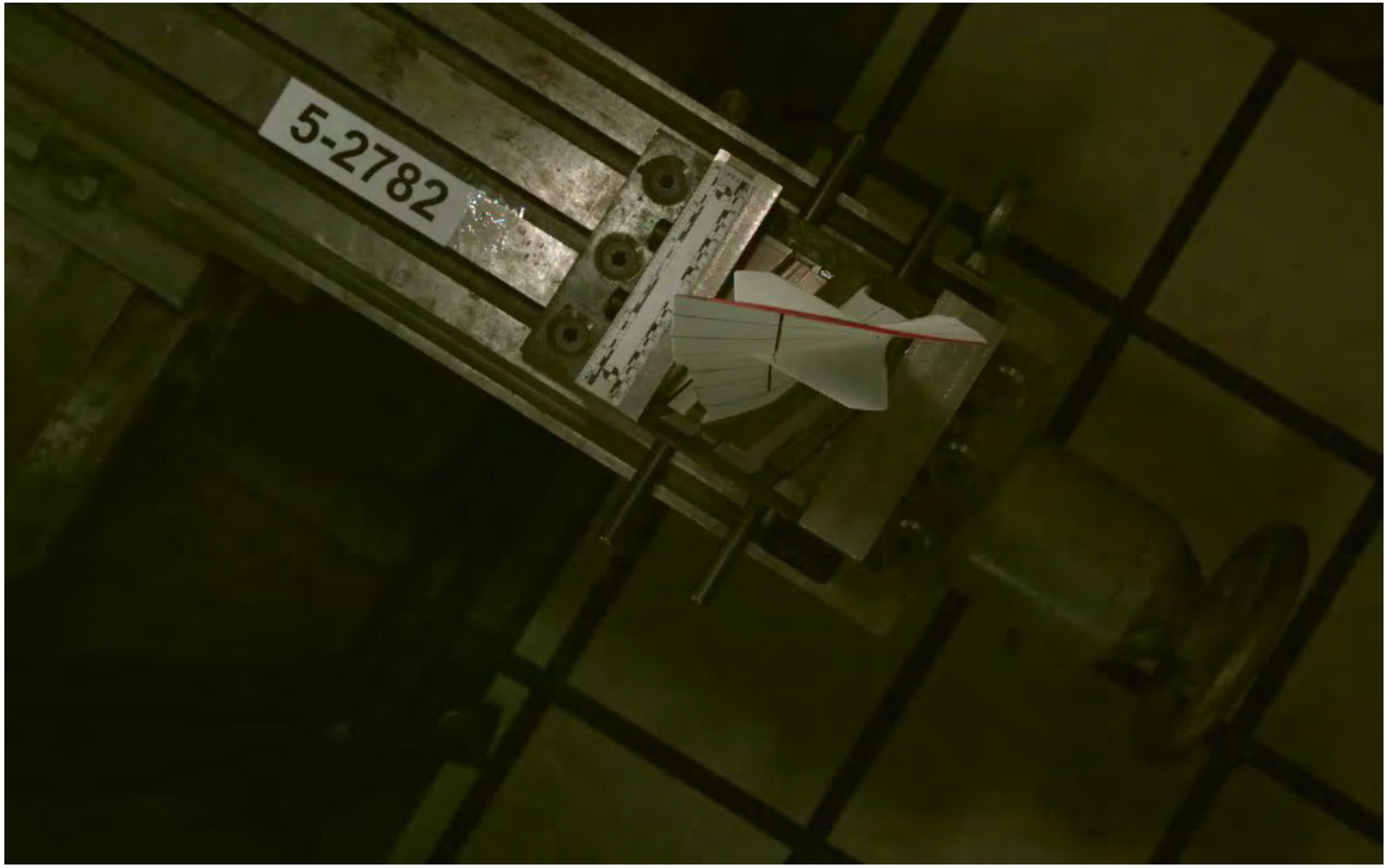
Phase III –
Air Worthiness Certification Tasks

- FAA Certification Plan Approval
- FAA Test Plan Approval
- Weight Analysis
- Metallographic Analysis
- Stress Analysis
- Frequency Analysis
- High Cycle Fatigue Tests
- Mechanical Property Tests
- Impact (Jelly Ball) Tests
- Ice Adhesion Analysis
- Compressor Wash Analysis

Phase III – Flight Cert Tests

Impact Test – Conducted at UDRI

BlackGold® Coated JT8D 1st Stage Fan Blade, Top View



Phase III – Flight Cert Tests

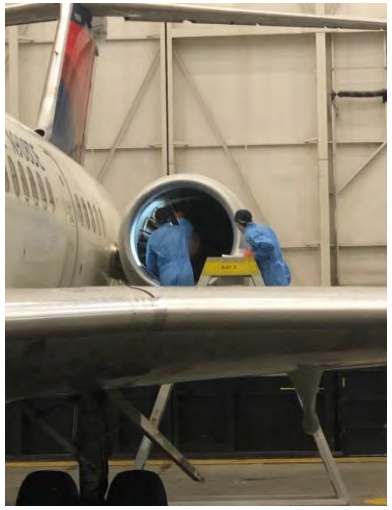
Impact Test – Conducted at UDRI

BlackGold® Coated JT8D 1st Stage Fan Blade, Front View


B1

Phase IV – Flight Demonstration

Flight Demonstration, Final Flight Hours



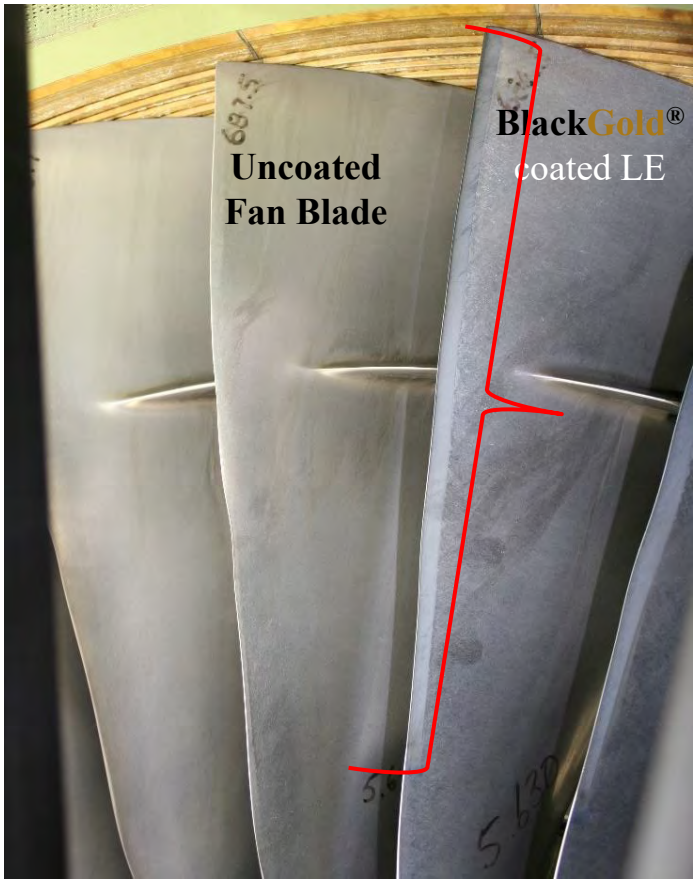
No.	Engine S/N	Status*	Notes
1	718045	2,378 hrs	4 Coated Blades.
2	725536	2,245 hrs	4 Coated Blades.
3	725558	284 hrs	4 Coated blades removed. Non-coating related in-flight shutdown.
4	No S/N ID	0 hrs	2 Coated blades. Unable to install pre COVID-19 shutdown.
5	718150	2,157 hrs	2 Coated blades. Still flying on 1 May 2020
Total Hours		**7,064 hrs**	

Phase IV – Flight Demonstration

Phase IV – Flight Demonstration
Fan Blade Inspections

- **BlackGold® coated 1st stage turbofan blades installed on four (4) JT8D engines for flight operations on MD88 aircraft**
  - Inspections ≈ every 250 to 500 hours

JT8D 1st Stage Fan Blades



Phase IV – Flight Demonstration

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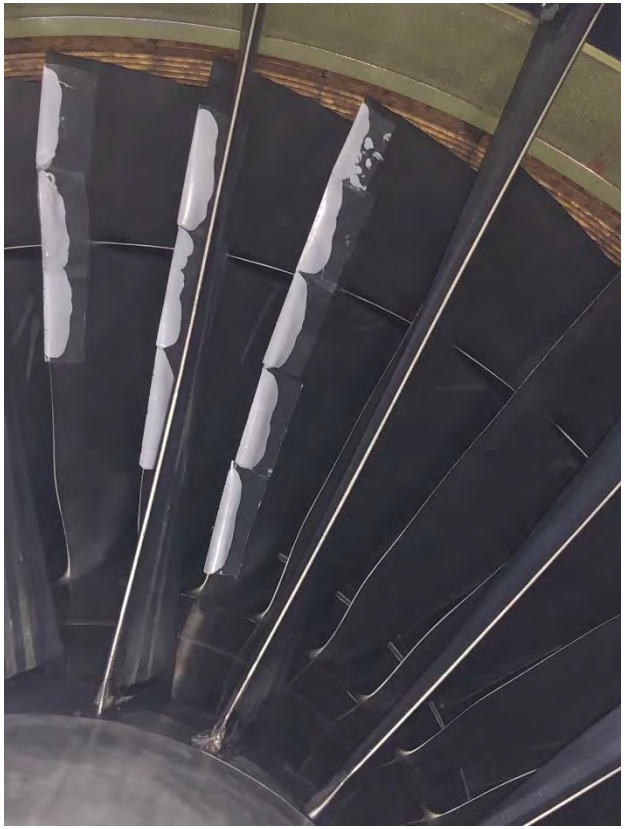
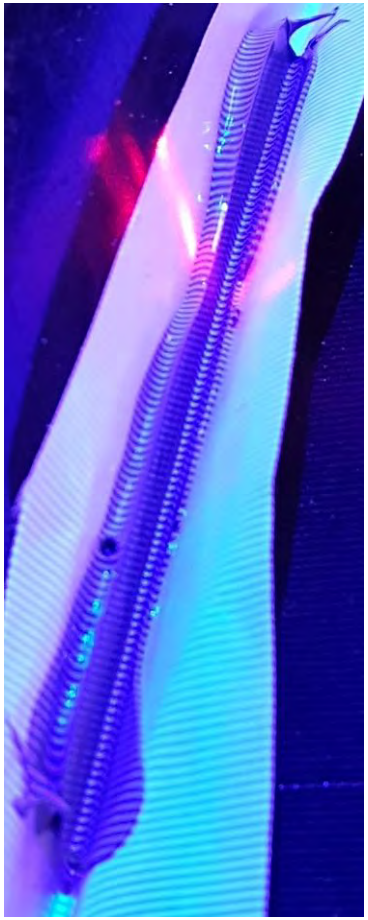
3D Scans of Micro-set Molds along Blade LE



JT8D Fan Blades with Molds



3D Mold Scans

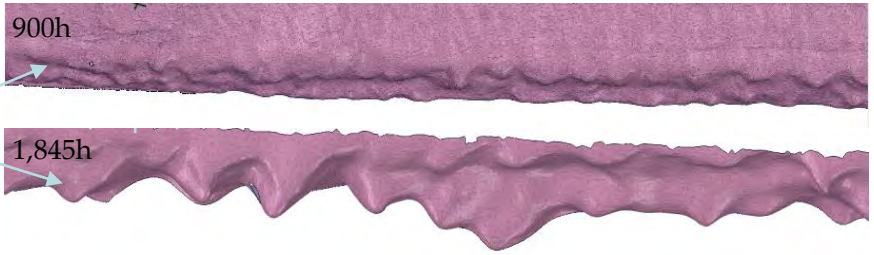
- LE molds placed in erosion area from tip towards root.
- Molds scanned with white-light 3D scanner.
- Damage depth measured along LE from scanned image and processed with appropriate software.

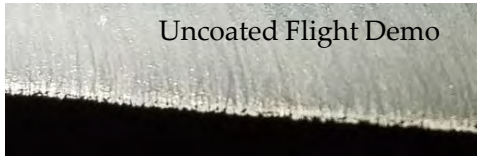
Phase IV – Flight Demonstration

Uncoated Turbofan Blade
Mid-Span Mold Measurements

AVG Damage:
900h = 147µm
1,845h = 401µm

3D scan of uncoated field blade LE mold

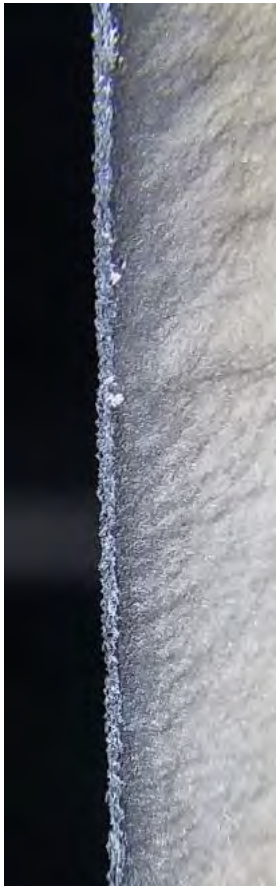




Blade Condition Analysis

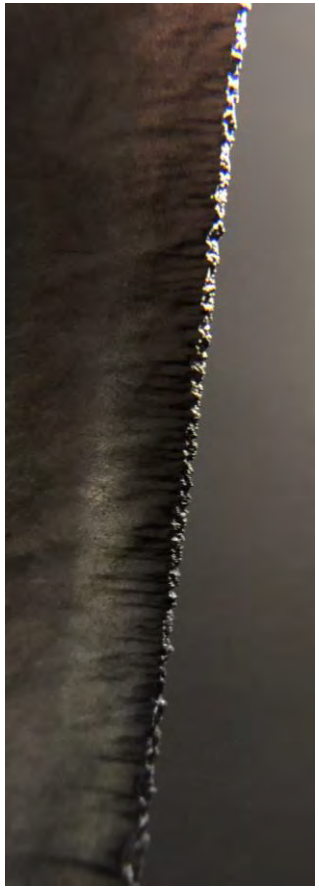
Comparing to JT8D Uncoated Fan Blade LE Erosion

JT8D



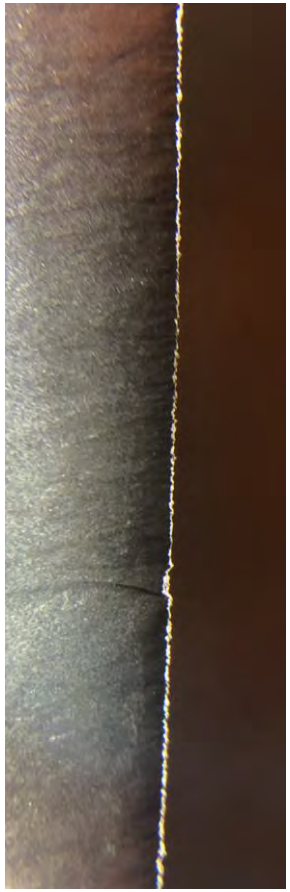
500 hrs
≈ 2.5 months
≈ 3.5% of tour

CFM56

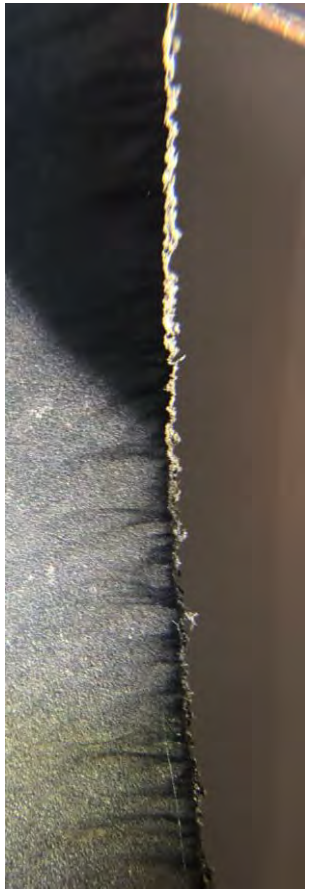


20,611 hrs
≈ 6.6 years
≈ 55% of tour

PW2037



3,094 hrs
≈ 1.25 years
≈ 20% of tour

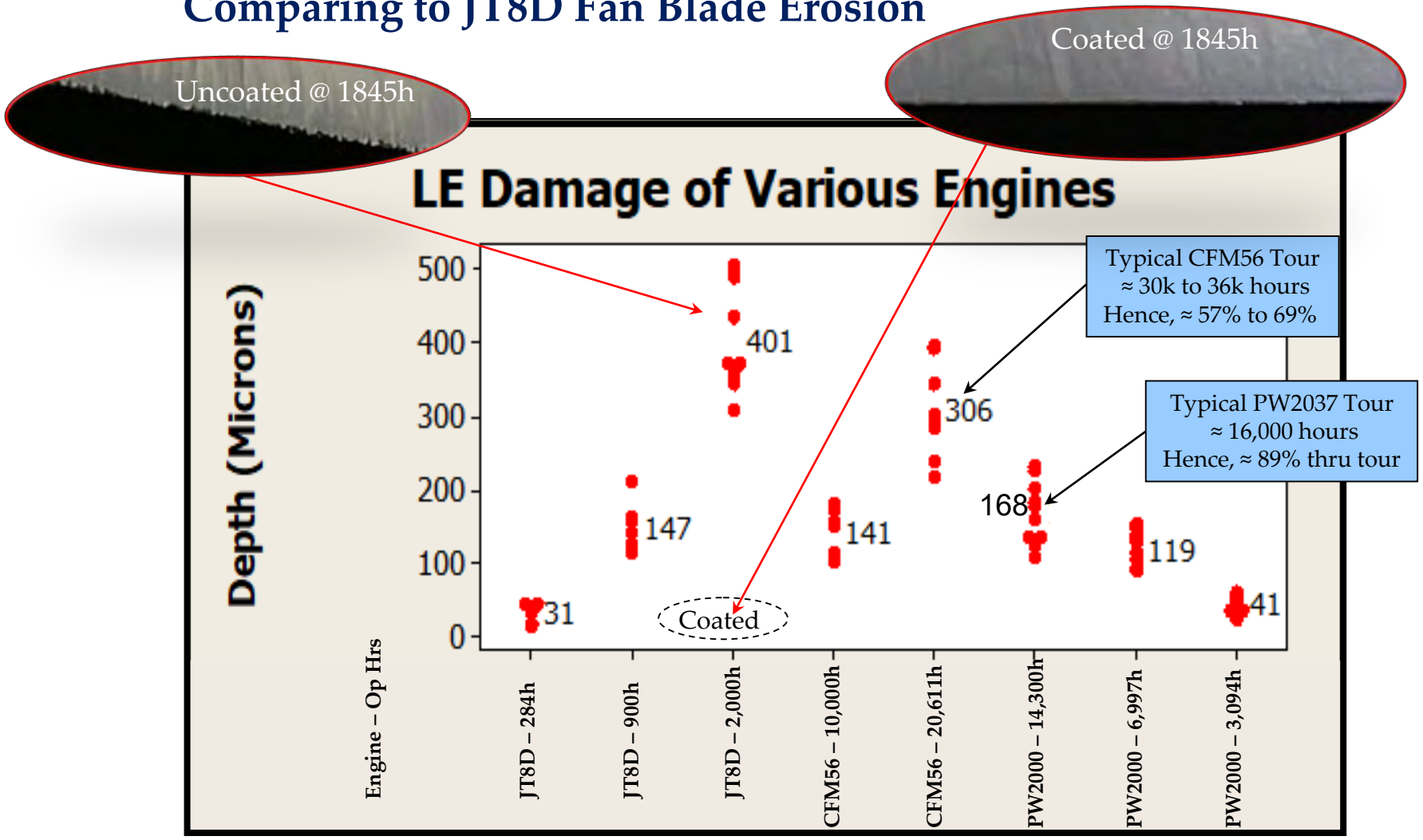


6,997 hrs
≈ 2.75 years
≈ 44% of tour

* Photos @ Delta TechOps Inspections

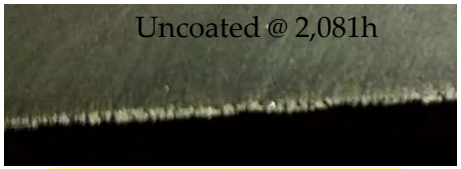
LE Depth Measurements

Comparing to JT8D Fan Blade Erosion



LE Depth Measurements

Comparing to JT8D Fan Blade Erosion



Chord loss not measured

- **JT8D Fan Blade LE Erosion very aggressive**
  - Highest rpm engine
  - Fuselage mounted engine
  - Uncoated Blade LE erosion => mean pit depth of 400 µm along LE erosion zone
  - Coated Blade LE erosion => mean pit depth at select breach points < 100 µm

- **PW2000 Fan Blade LE Erosion**
  - Typical tour averages 16,000 operational hours
  - At 14,300 hours or ≈ 90% of tour => mean pit depth of 168 µm along LE erosion zone

At 90% of PW2000 tour, uncoated LE pit depth ≈ 50% less than uncoated JT8D at 2,081 hrs
Coated JT8D blade LE protected at 2,081 hrs
Hypothesis … Coated PW2000 TF blade could protect LE for a complete tour

- **CFM56 Fan Blade LE Erosion**
  - Typical tour averages 30k to 36k operational hours
  - At 20,611 hours or ≈ 57% to 69% of tour => mean pit depth of 306 µm along LE erosion zone

At ≈ 60 to 70% of CFM56 tour, uncoated LE pit depth ≈ 75% less than uncoated JT8D at 2,081 hrs
Coated JT8D blade LE protected at 2,081 hrs
Hypothesis … Coated CFM56 TF blade could protect LE for a complete tour
Need more pit depth measurements at 30k+ hours

Phase IV Flight Demo Summary

- Three (3) JT8D engines flew with four (4) coated blades
- One (1) engine flew with two (2) coated blades and still flying!
- One (1) engine removed due to non-coating related, in-flight shut down
- One (1) engine with two (2) coated blades never installed on-wing

- Total flight hours = 7,064 hours
- Three engines > 2,000+ hours
- High time engine = 2,378 hours

- Extensive qualitative and quantitative data gathered on LE erosion
- Coating provided LE protection to ≈ 2,000 operational hours
- Exceeded initial goal of protecting JT8D LE to 1,000 hours by 2X

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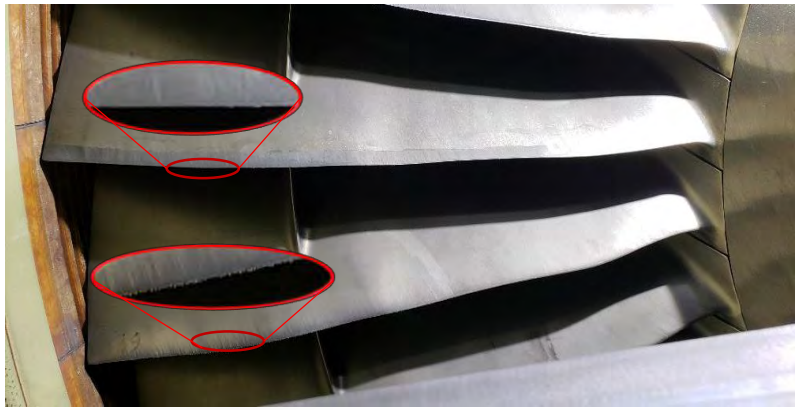
4	No S/N ID	0 hrs	2 Coated blades. Unable to install pre COVID-19 shutdown.
5	718150	2,157 hrs	2 Coated blades
Total Hours		**7,064 hrs**	

CLEEN II Program Summary

- **Blade Condition and Operational Analysis complete:**
  - LE erosion documented
  - Engine test confirmed 1.1%+ TSFC increase
- **Coating Component Level Tests complete:**
  - For JT8D, PW2037, CF6 and Ti strips
- **JT8D Flight Certification Tests Complete**
- **Flight Demonstration Engines**
  - Over 7,000 op hours
  - Visual and measured results confirms coating protecting LE



DELTA TechOps

MDS COATING

AMERICA'S PHENIX AEROSPACE CONSULTANTS for the Americas

THANK YOU