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: 21 November 2019

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:

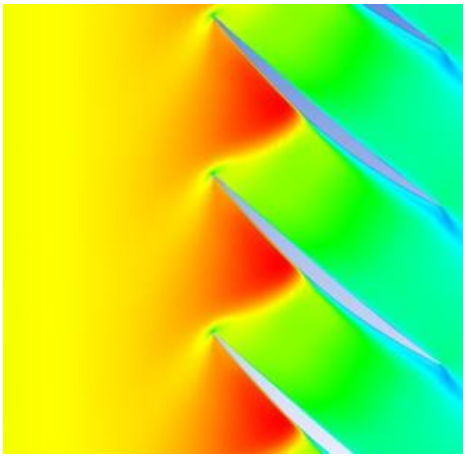
- Blade Condition / Operational Analysis – **COMPLETE**
- JT8D Fluid Erosion Component Test – **COMPLETE**
- Other Engine Types Fluid Erosion Test – **COMPLETE**
- Flight Certification – **COMPLETE**
- Flight Service Evaluation – **April 2018 to Dec 2020**

[4] Computational Fluid Dynamics

Phase I – Data, Test & Simulate

Blade Condition Analysis

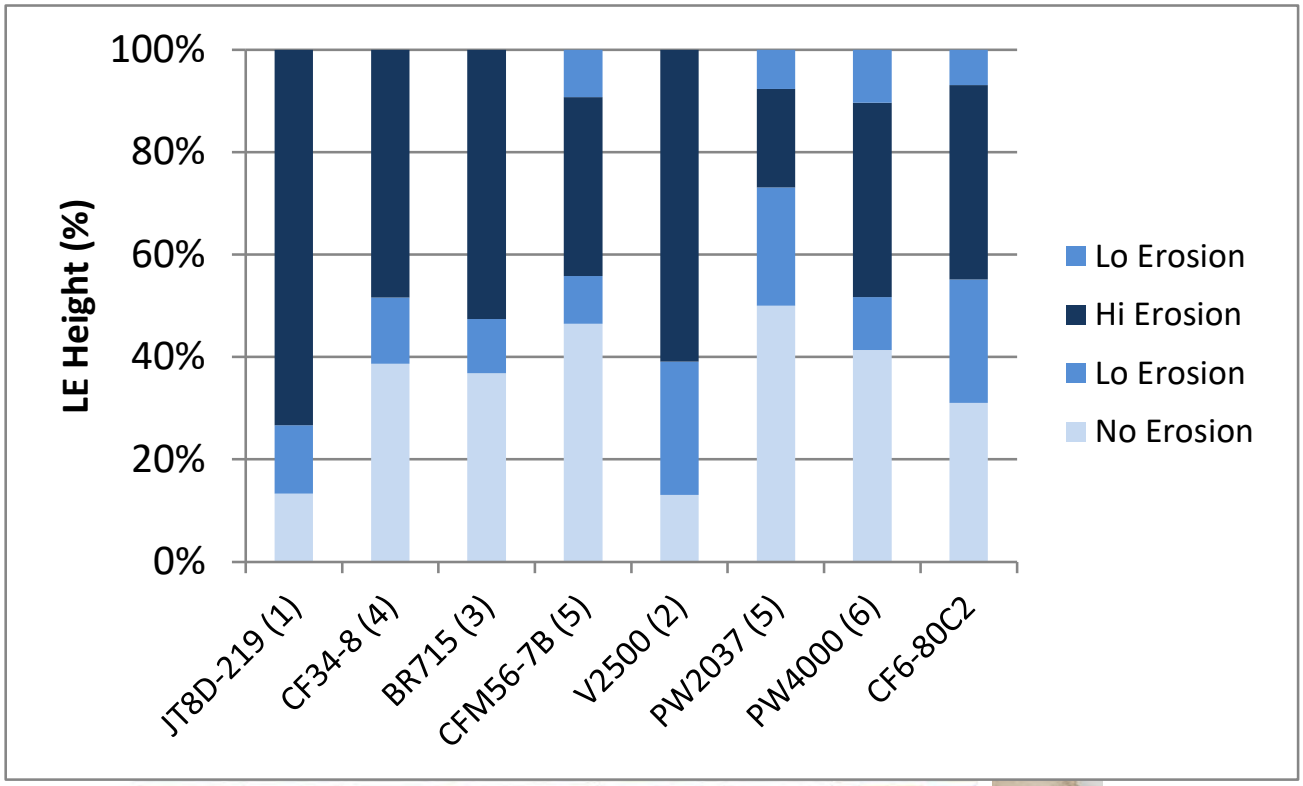
Engine Test Data

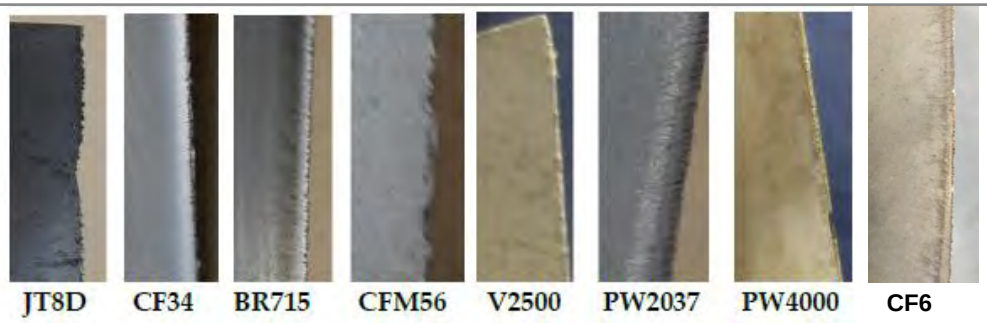


CFD Analysis

- 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

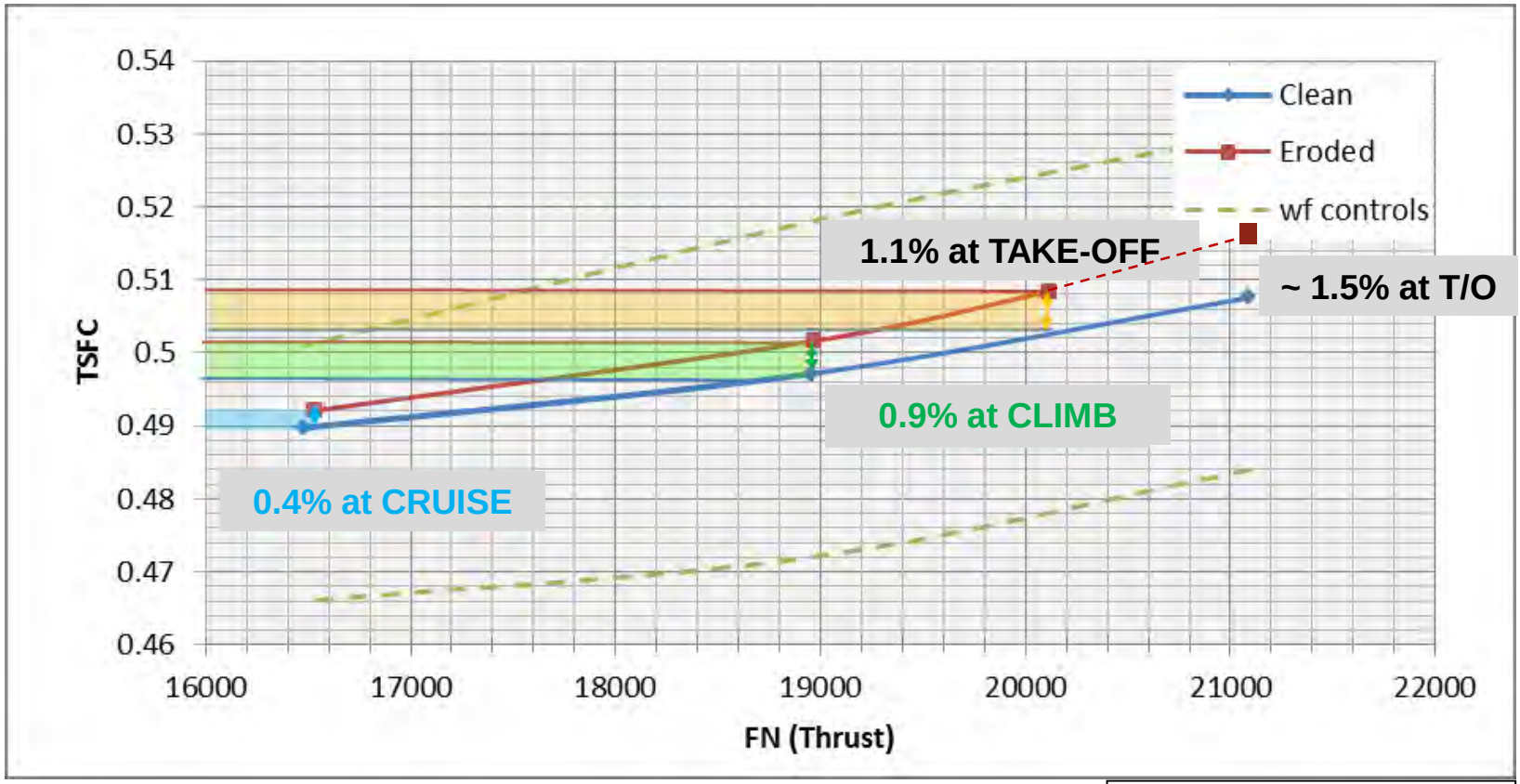
Blade Condition Analysis





Phase I – Engine Test

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



Clean = repaired, serviceable fan blades

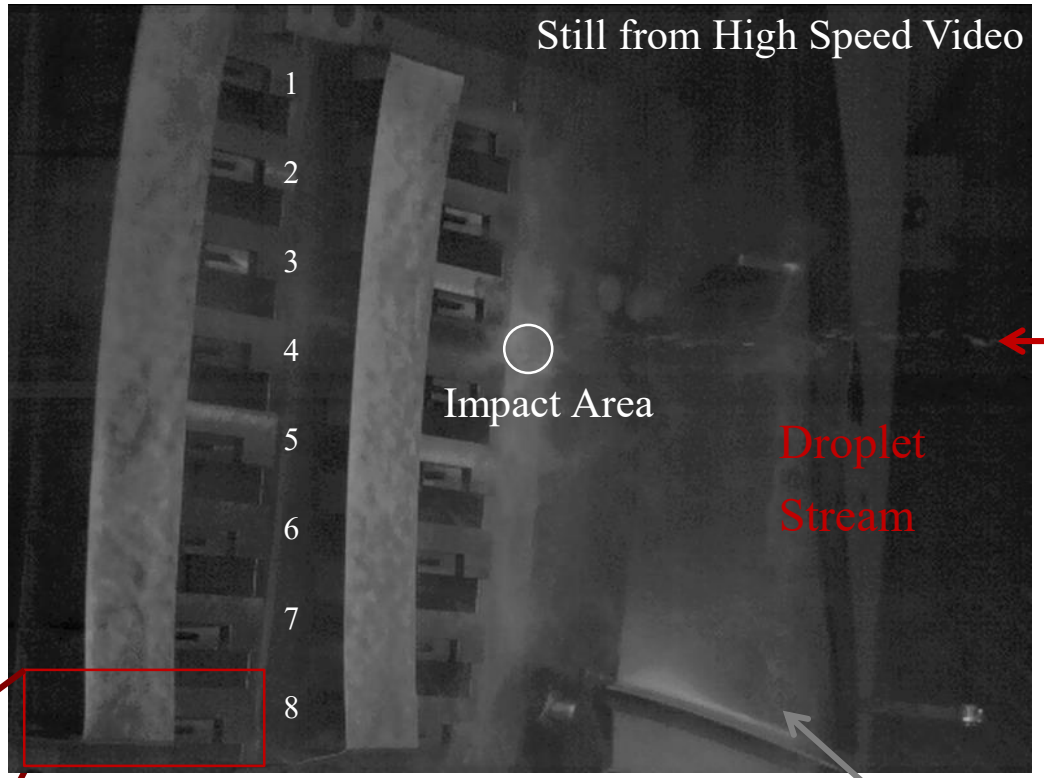
JT8D Engine S/N 726044
Inducted May 2015
TSO = 3126 hours
Tests / Engine Service Manual: PN773128

Phase II – Fluid Erosion Test

@ AFRL – Supersonic Rain Erosion (SuRE) Rig

Specimen Preparation

Specimen Tooling



Uncoated Blade Specimen

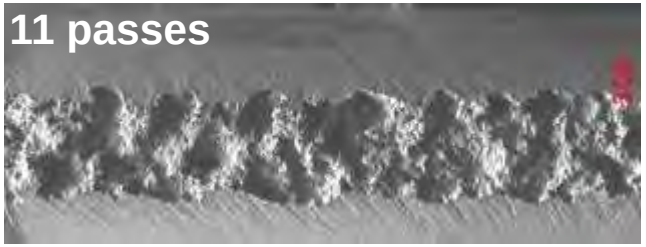
BlackGold® Coated Blade Specimen

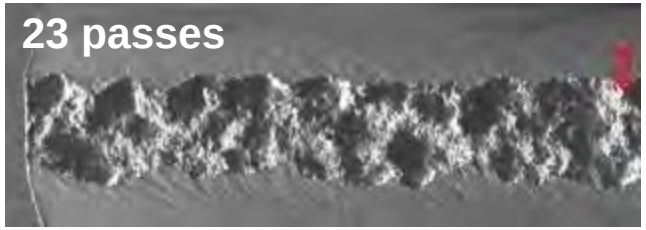
Coated Blade

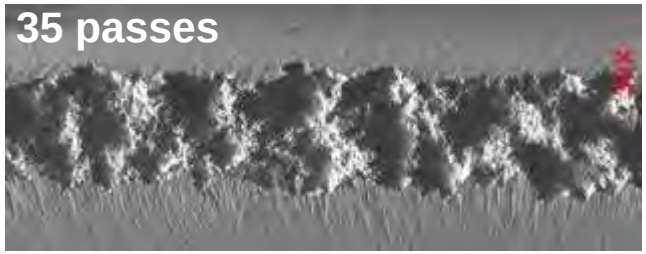
Fluid Erosion Tests @ AFRL

Phase IIA - February 2017 Tests

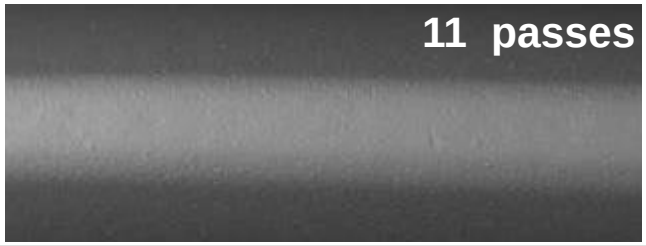
Uncoated PW2000

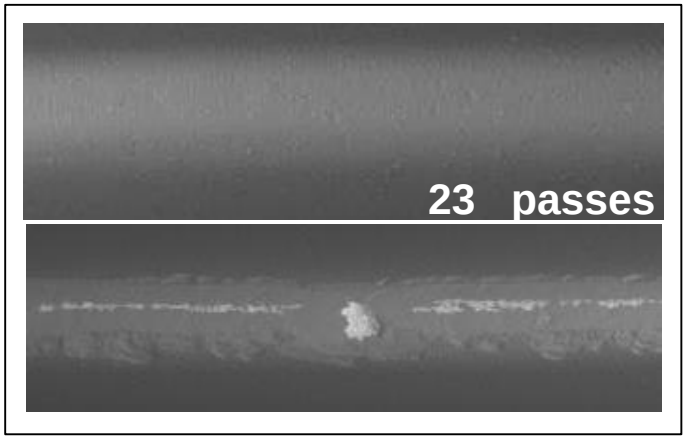


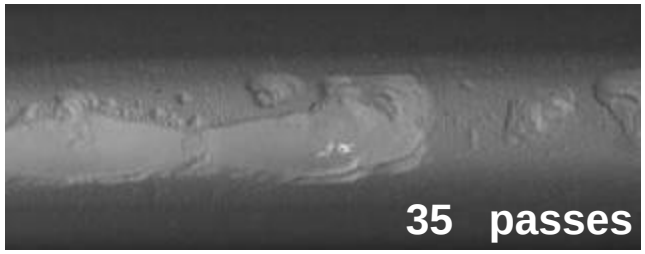




BlackGold® Coated PW2000







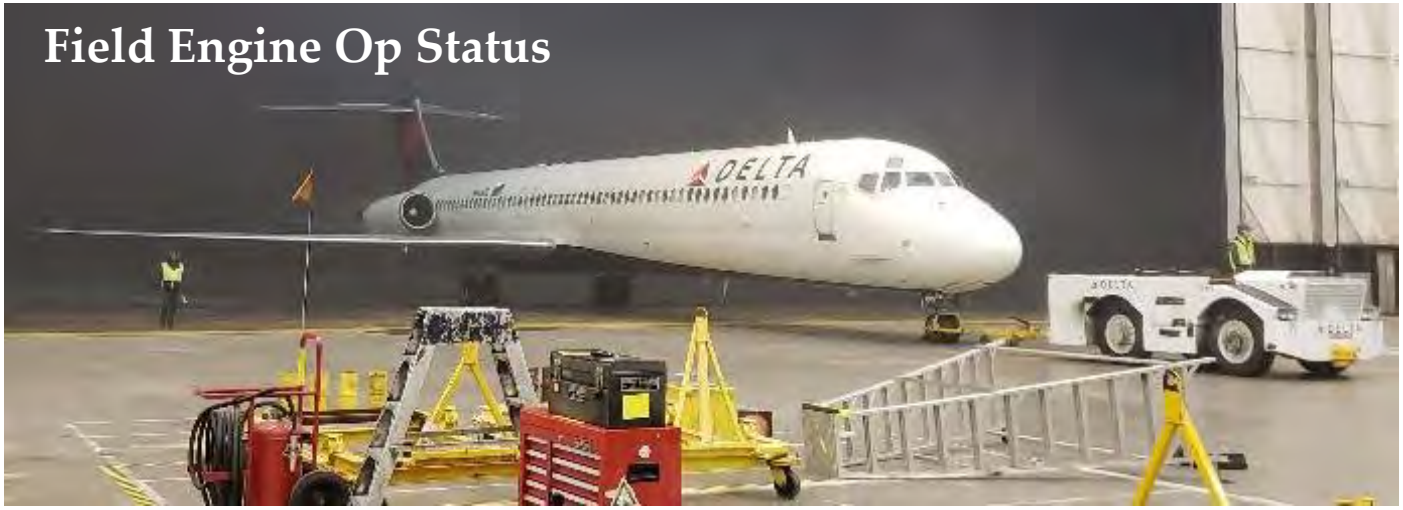
First substrate damage noticed after 23 passes

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 IV – Flight Demonstration

Flight Demonstration, Field Engine Op Status



No.	Engine S/N	Status*	Notes
1	718045	2,378 hrs	4 Coated Blades. Currently off-wing awaiting installation. Estimated date early March 2020.
2	725536	2,245 hrs	4 Coated Blades. Removed, in-storage in Birmingham. Not expected to be re-installed. Scheduled for final inspection.
3	725558	284 hrs	4 Coated blades removed. Engine experienced non-coating related in-flight shutdown.
4	No S/N ID yet	0 hrs	2 Coated blades. Engine awaiting on-wing installation. Expected installation late Jan 2020.**
5	718150	1,489 hrs	2 Coated blades installed and flying**

* *As of 18 November 2019*

** *Engines 4 and 5 have only two (2) coated blades in order to maintain four (4) flight demo aircraft*

Phase IV – Flight Demonstration

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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

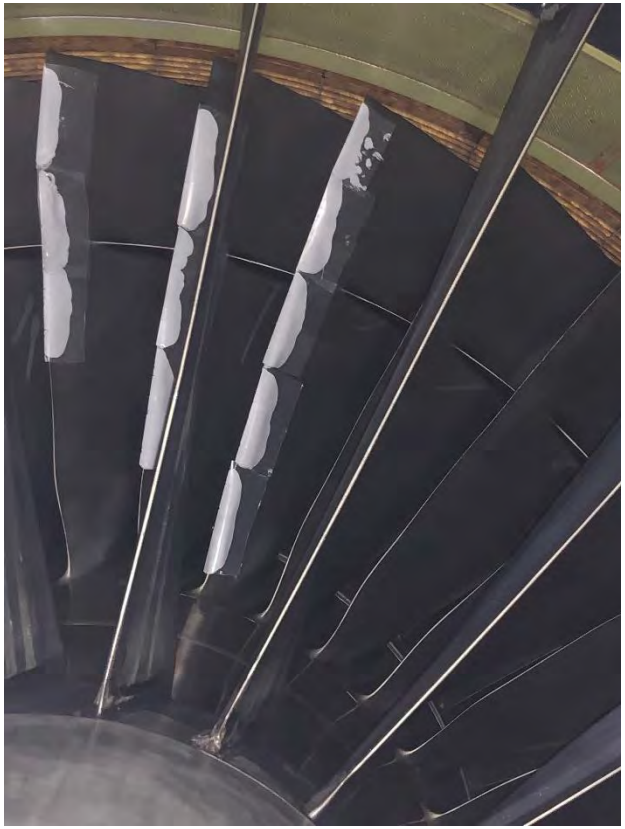
Phase IV – Flight Demonstration

Flight Demonstration, Field Engine Op Status

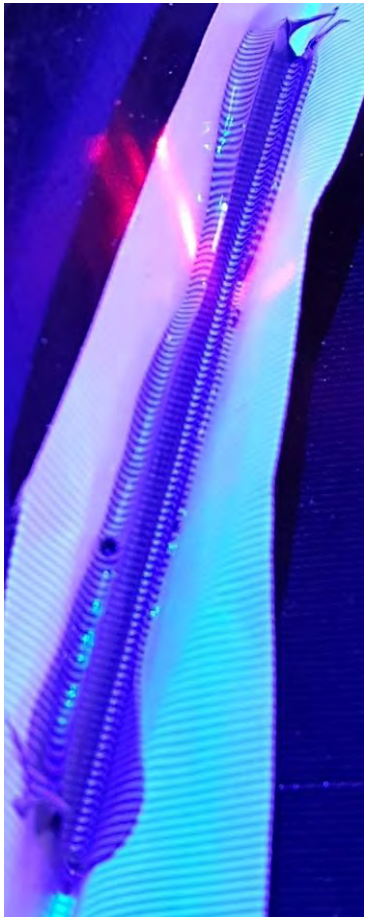
Inspection date: 12 Feb 2019
1,845 hours

Phase IV – Flight Demonstration

3D Scans of "Dental Mold" LE Blade Specimens



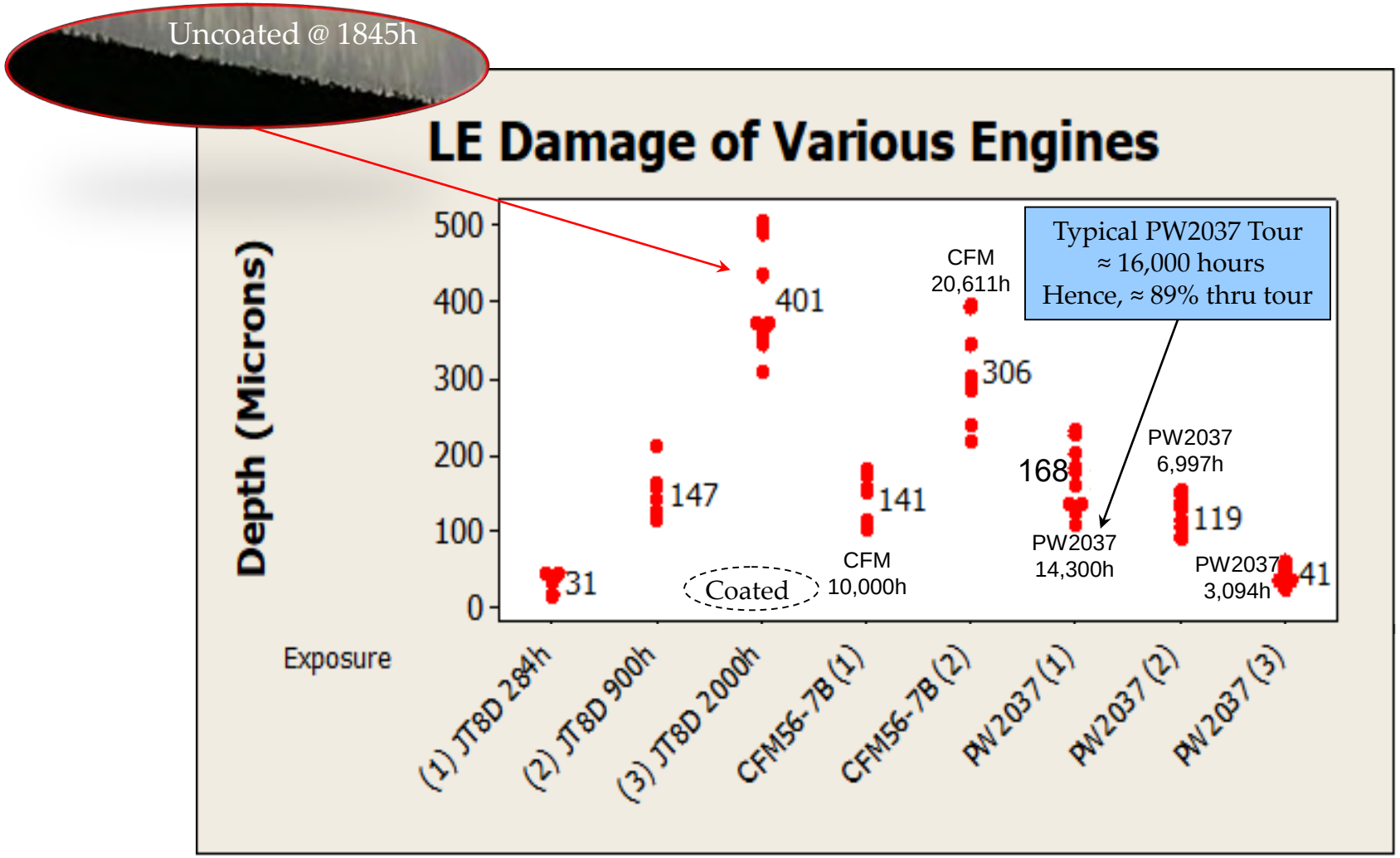
JT8D Fan Blades with Molds



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.

LE Depth Measurements



Phase IV Schedule

Estimated remaining inspection schedule

- **Engine # 1 @ 2,378 op hours. Status – on-wing by March 2020**
  - 2,500 + hours by April 2020
  - 3,000 + hours by July 2020
  - 4,000 + hours by December 2020
- **Engine # 4 @ 0 hours. Status – awaiting installation Jan 2020.**
  - 500 + hours by March 2020
  - 1,000 + hours by May 2020
  - 2,000 + hours by October 2020
  - 2,500+ hours by end-of-Dec 2020
- **Engine # 5 @ 1,489 op hours. Status – currently flying.**
  - 1,700 + hours by January 2020
  - 2,000 + hours by March 2020
  - 3,000 + hours by July 2020
  - 4,000 hours by end-of-Dec 2020
- **Engine # 2 – completed flying @ 2,245 hours**
- **Engine # 3 – completed flying @ 284 hours**

Total Op Hours as of 18 Nov 2019
= 6,396 hours

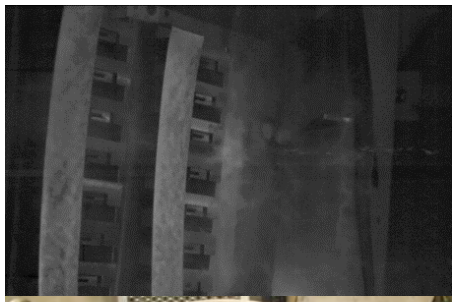
Delta's MD-88 fleet scheduled for sunset at the end of CY20

Estimate > 12,000 total op hours by end of CY20

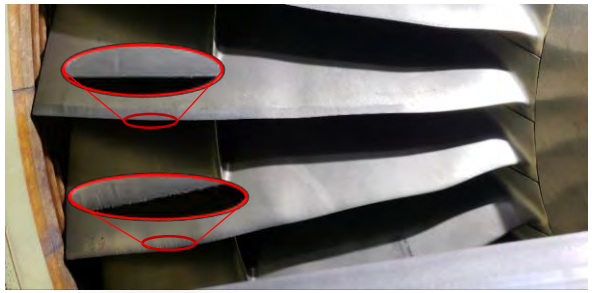
Estimates based on 50 hours / week average

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
- **Flight Certification Tests Complete**
- **Flight Demonstration Engines**
  - Over 5,000 op hours
  - Visual and measured results confirms coating protecting LE
  - Project over 12,000 op hours by end of CY20
- **Installing up to four (4) completely coated engines to track fuel savings benefits**



DELTA TechOps

MDS COATING

AMERICA'S PHENIX AEROSPACE CONSULTANTS for the Americas

THANK YOU

Federal Aviation Administration