

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

Presented to: FAA Office of Environment and Energy

By: Delta TechOps (DTO)
GKN Aerospace (GKN)
MDS Coating (MDS)
America's Phenix, Inc. (AP)

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Project Overview

Objective - Demonstrate MRL & TRL 8-9 the application of a LE protective coating for all Turbofan Blade configurations:



High AR
Blades



LE
Ti Strips



Hollow
Fan Blades



LE Repair
and Low AR
Blades

Wet Runway Landing

DCA, June 2021



CLEEN II Flight Demo

**LE Cavitation of
Uncoated Turbofan Blades**

Coating protects LE

**Resulting in
fuel & emission
savings**

Schedule (Overview)

- **Phase I – Data Gathering (throughout CLEEN III program)**
 - Blade Condition Analysis on inducted engines and TF blades
 - Engine Tests: CF34, CFM56, V2500, CF6, PW4000, PW1100
- **Phase II – Coating Optimization Tests (March 2022)**
 - Conduct tests at AFRL Supersonic Rain Erosion (SuRE) Rig
- **Phase III – Flight Certification (PW2000 by Jan 2023)**
 - Certification Plan
 - Test Plan
 - Metallographic Analysis
 - Mechanical Testing & Frequency Analysis
 - Impact Tests
 - Instructions for Continued Airworthiness (ICA) analysis
- **Phase IV – Flight Demo at TRL8-9 – Fully Coated 1st stage TF sets**
 - PW2000 on B757 by 2Q, CY23
 - Other engine types to follow

Phase I – Data Collection

- Measured & photographed LE condition of various engines
- Measured on-wing or on inducted blades for following engines:
 - PW2000 = 3 on-wing, 2 in-shop
 - PW4000 = 2 on-wing, 1 in-shop
 - CF34 = 2 in-shop
 - CFM56 = 3 on-wing
 - BR715 = 1 in ship
 - PW1100 = 1 in-shop



In-Shop @ DTO



On-wing Repliset @ DTO

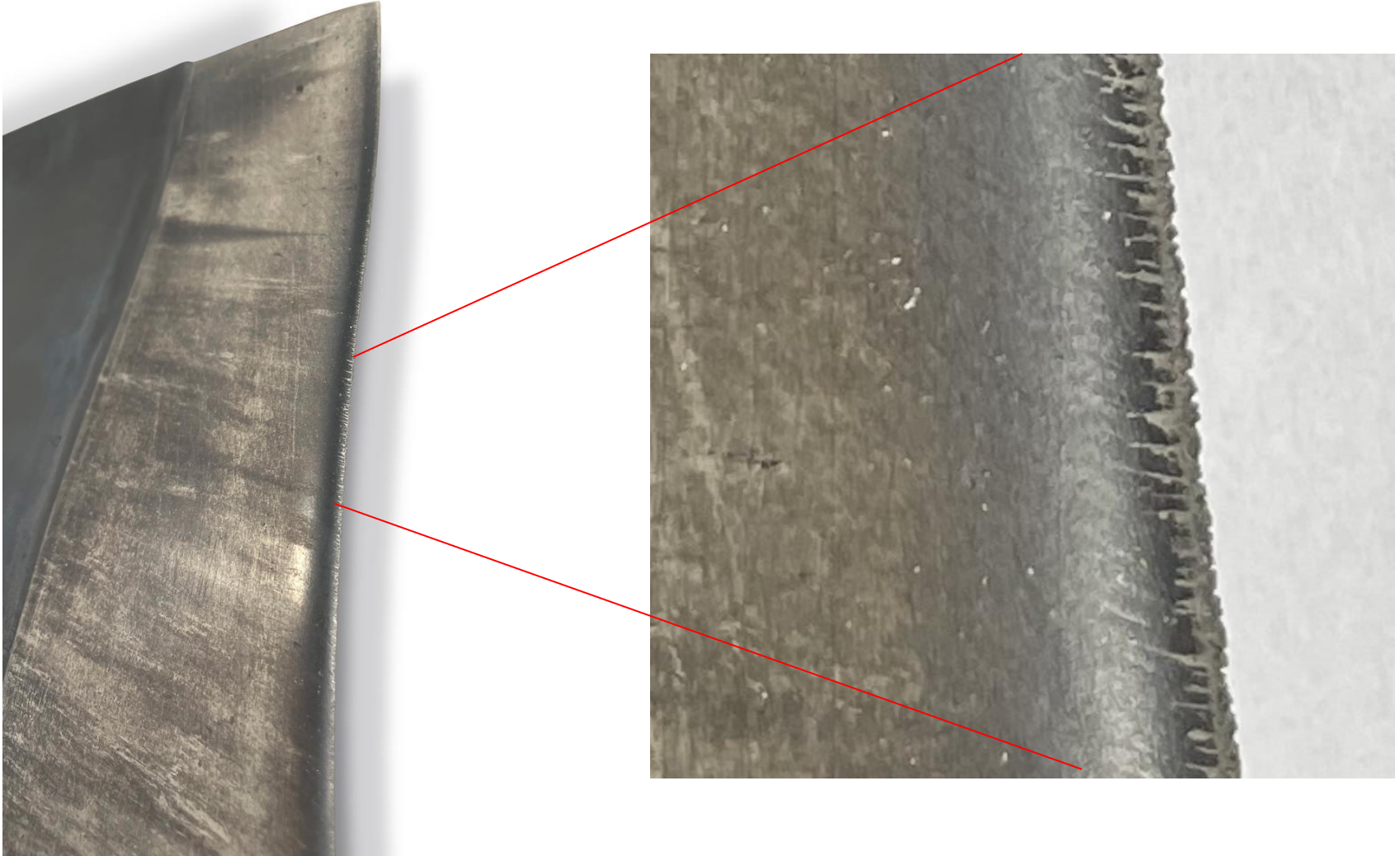


Measuring @ DTO

- V2500

Phase I – Data Collection

PW1100, A320neo



Phase I – Data Collection

CFM56-5B, A321



PW2000, B757



Phase I – Data Collection

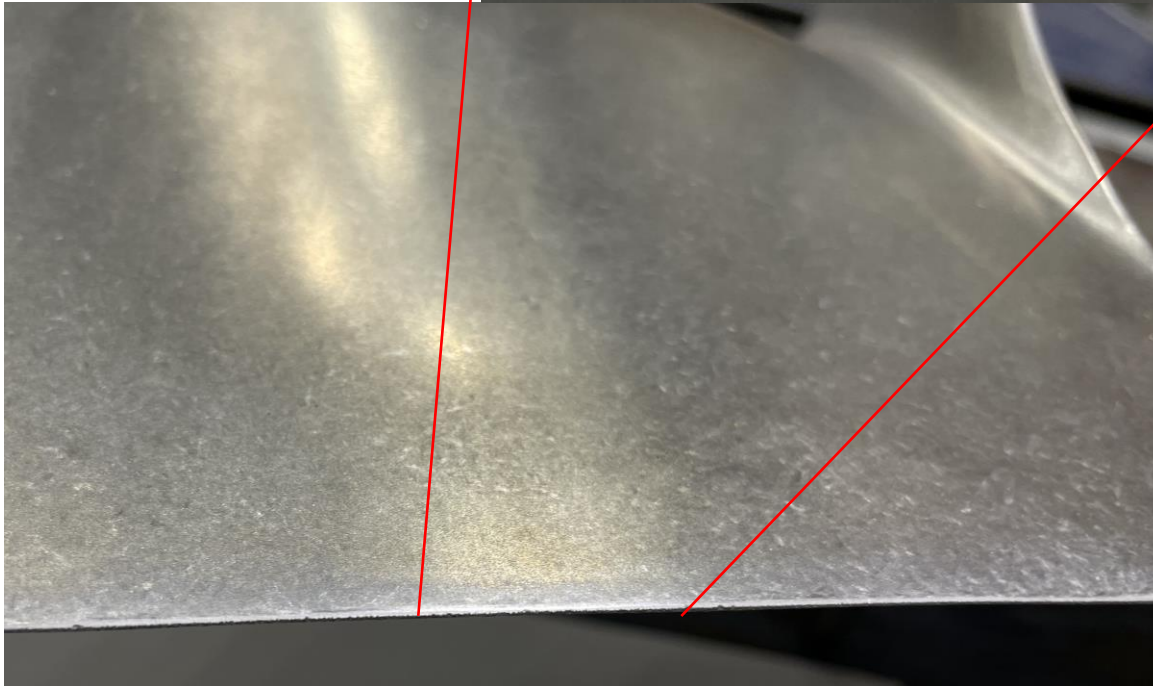
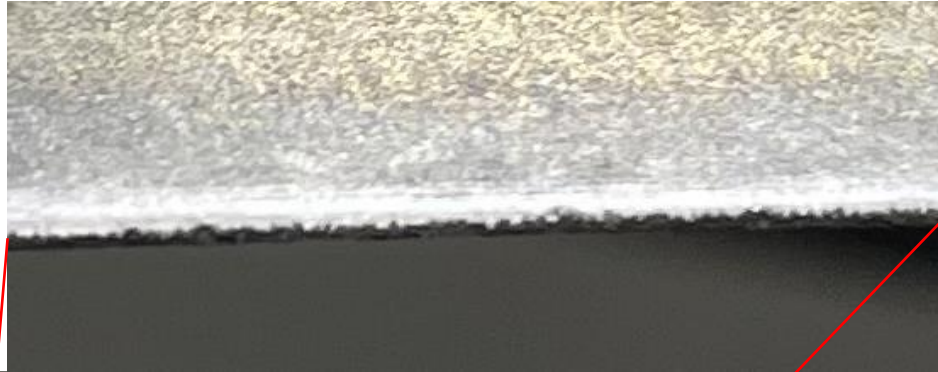
V2500, A320



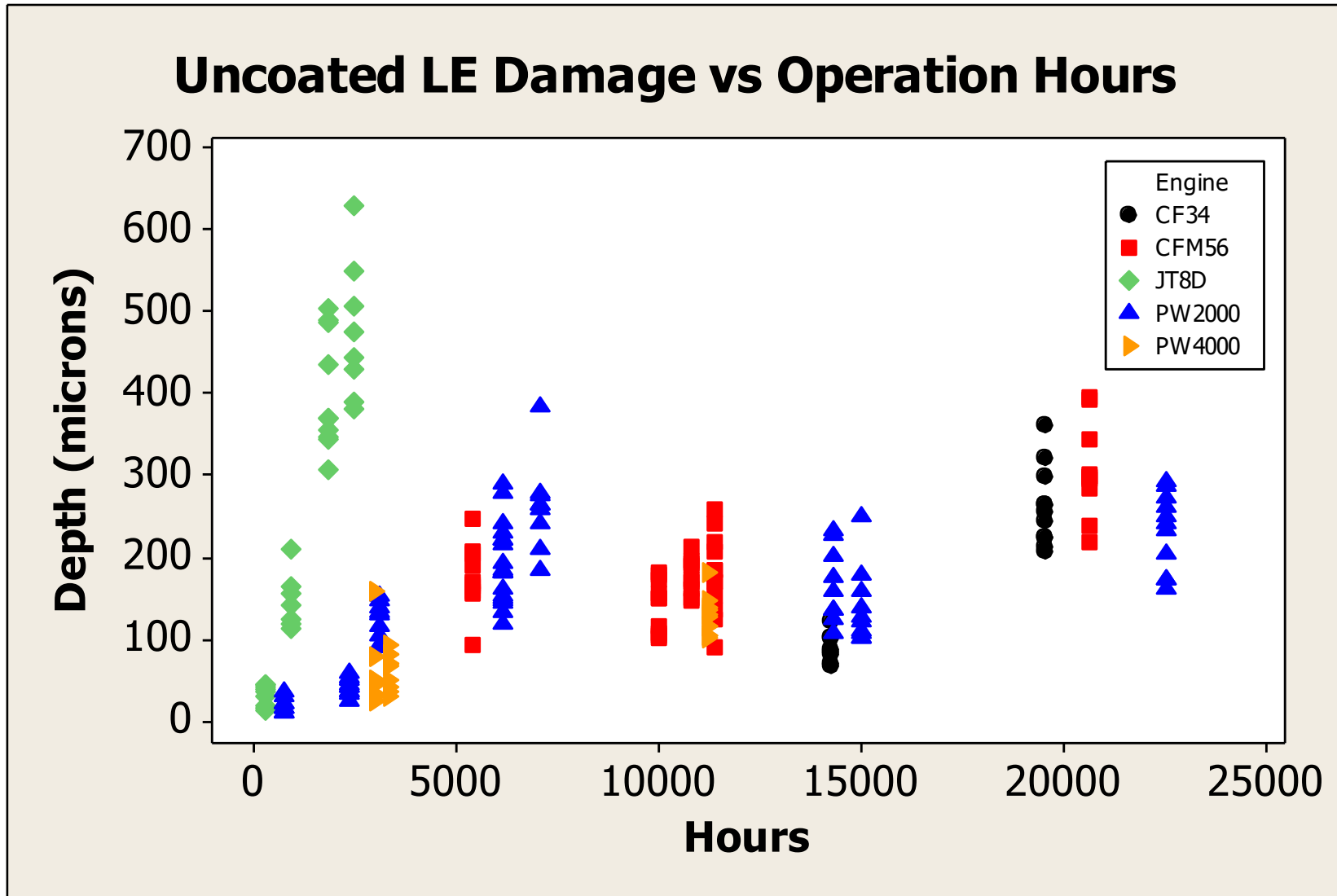
Phase I – Data Collection

F117, C-17

4,844 hours TSO

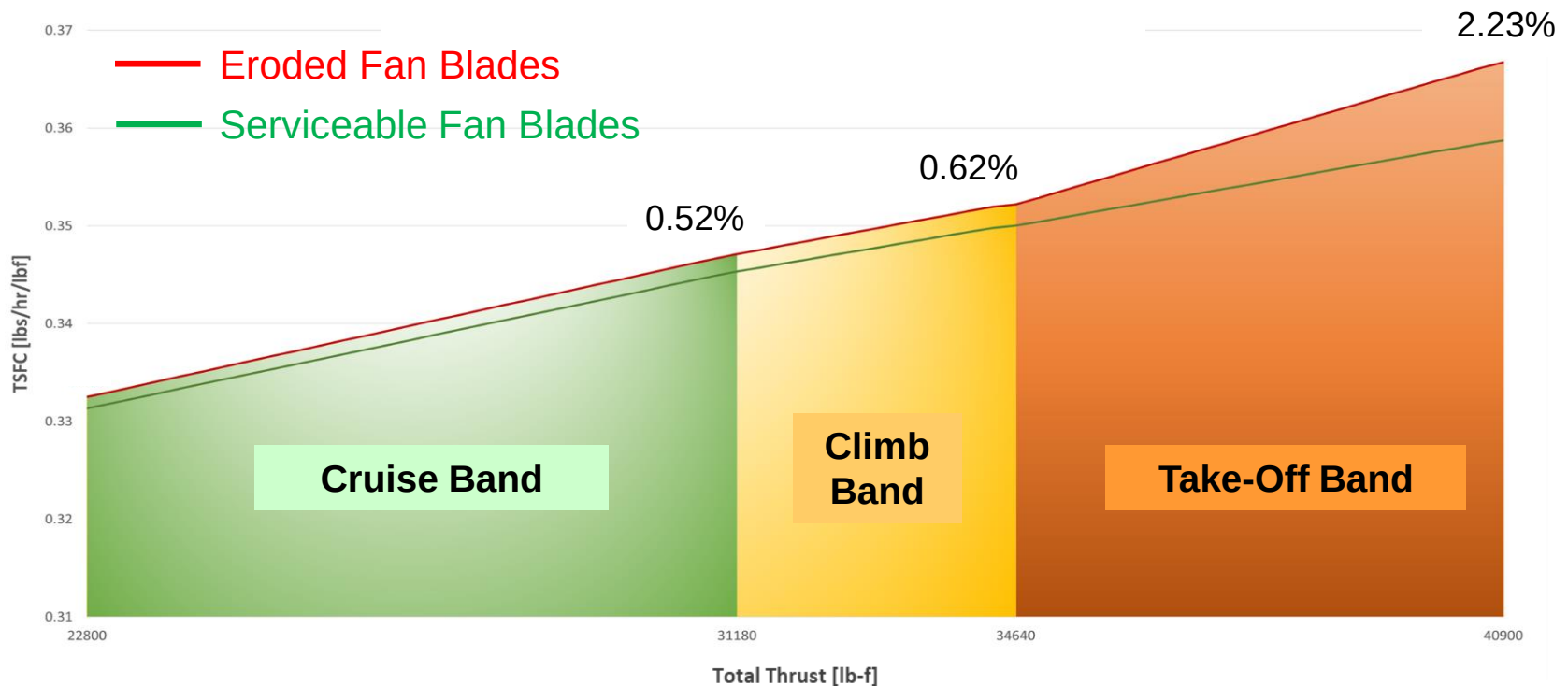


Phase I – Data Collection



Fuel Consumption Impact

- B757 / PW2000 Test cell data
- Isolated fuel consumption differences between eroded and serviceable fan blades on same inducted engine



Eroded fan blade negatively impacts fuel consumption

Phase II – Fluid Erosion Tests

Conducted at AFRL's Supersonic Rain Erosion (SuRE) rig facility

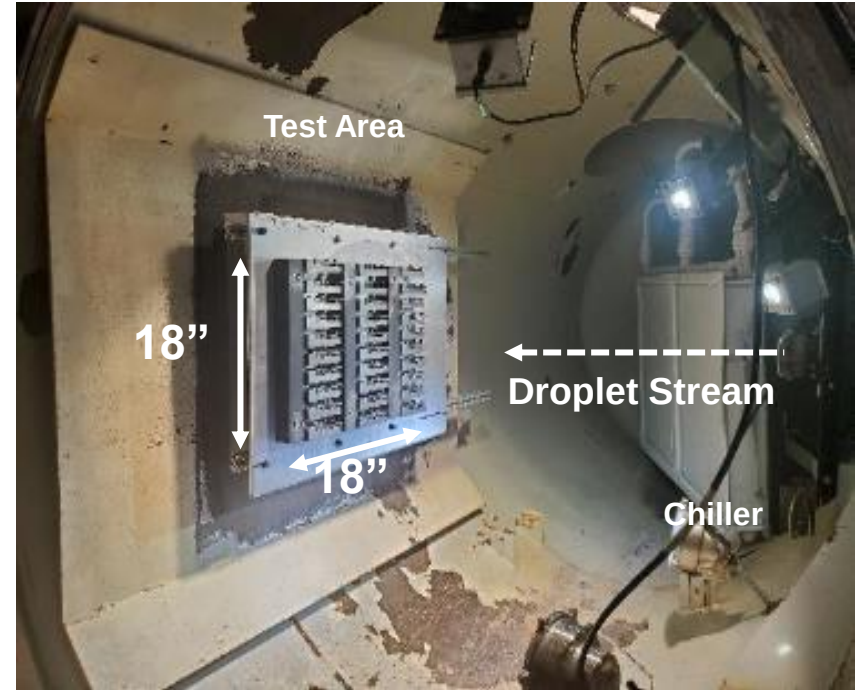
- PW2037, CF6, CFM56, CF34, V2500, F414, Ti sheaths



SuRE Test Rig



Chamber became very hot during testing ($\sim 30^{\circ}\text{C}$)



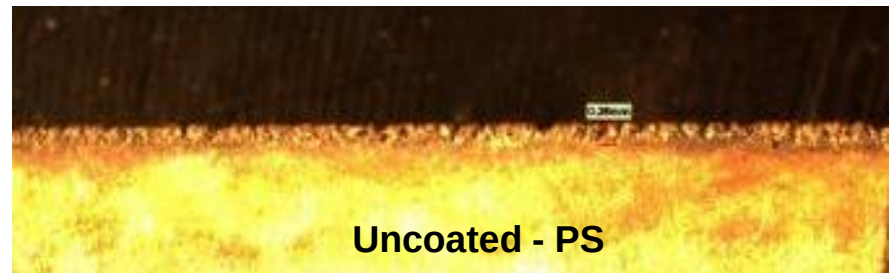
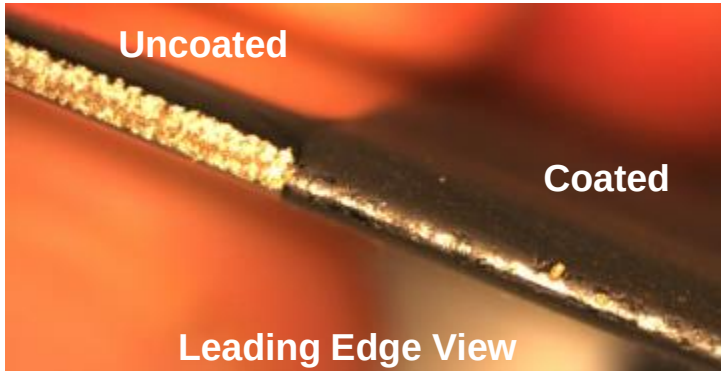
Droplets stream rasters along x-y directions on the specimens in the test area

AFRL Supersonic Rain Erosion Test



CFM56 Test Specimen

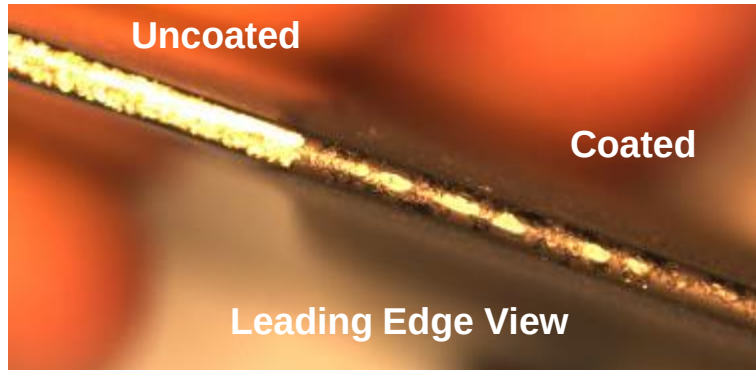
BlackGold® v12.1



V2500 Test Specimen

After 80 passes

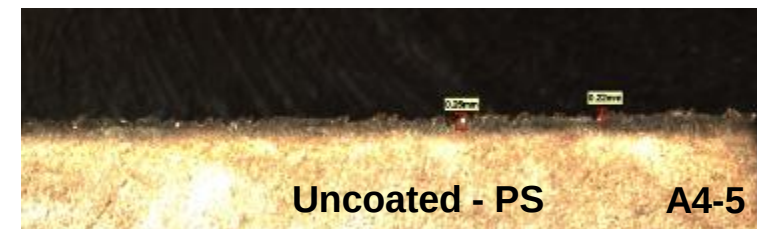
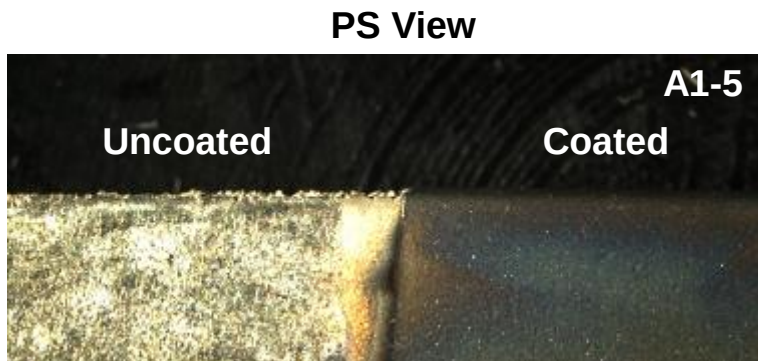
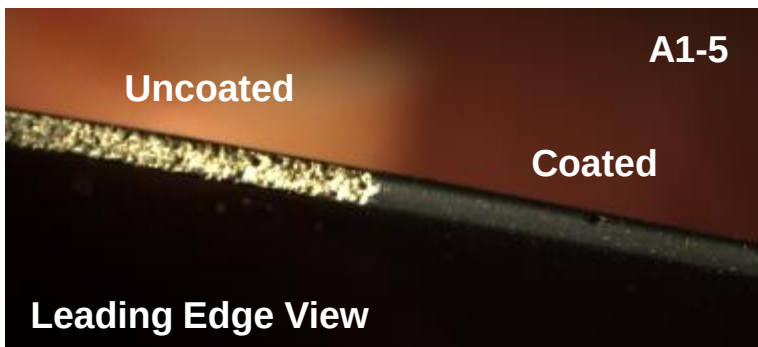
BlackGold® v12.1



PS View

PW2000 Test Specimen

BlackGold® v12.x
With coating enhancements



Future Work

AFRL Test Data Reduction

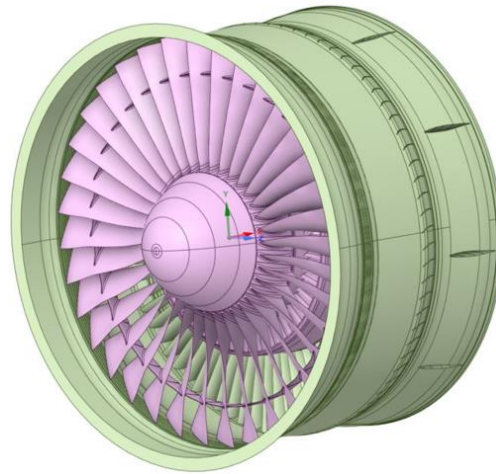
- Months of analysis to characterize the specimens
 - Visual Inspection, MET, microscope, SEM/EDX, Nanovea, 3D scanning and more
 - Plot pit depth versus number of passes

Phase III – PW2000 Certification

- Approval using Major Alteration
 - PW2000 Type Certificate E17NE Rev 15
- Current work:
 - Preparing part specific certification plan (594951-20-001)
 - Completing CFD / FEA analysis on loaded fan blades
 - Preparing familiarization plan for FAA
 - Coordinating with ACO for Multi-Use Major Alteration

PW2000 Certification

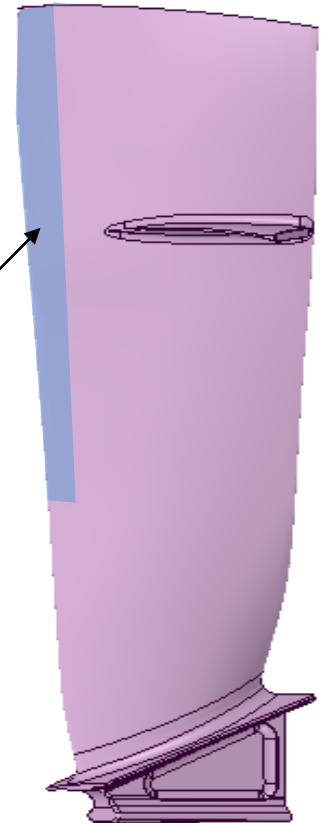
- CFD and FEA of PW2000 fan blades
 - Aerodynamic loads on the fan blades
 - Natural frequencies and mode shapes
 - Stress fields for significant modes
 - Determining the coating zone



PW2000 models:

- Fan Blade
- Casing
- Exit guide vane
- Stator vane
- Fan-to-Shroud
- Fan-to-Disk

FEA defines
coating zone



Summary

Data Collection

- Continuing LE condition data collection as a function of TSO
- Working with United Airlines in documenting V2500 condition on-wing

AFRL Fluid Erosion Test

- Results confirm significant LE protection with **BlackGold**® v12.1 coating
- Results confirm further protection with **BlackGold**® v12.x coating
- Data reduction in-process

PW2000 Certification

- Reviewing final FEA stress analysis models
- Confirming Certification & Test Plans with FAA ODA
- Conduct required certification tests through Nov 2022

Saving 1% of fuel results in:



\$114M USD

1.15M

barrels of oil



495,717,516 kg
of CO₂



107,570

cars off the
road



81,793,390

Trees



Thank You

Delta Air Lines consumed 4.566B gal of fuel in 2019

Based on \$2.50 / gal fuel price

<https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references>