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

Presented to: FAA Office of Environment and Energy, Public Presentation

By: Delta TechOps (DTO)

GKN Aerospace (GKN)

MDS Coating (MDS)

America's Phenix, Inc. (AP)

Date: 3 May 2023

Project Overview

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

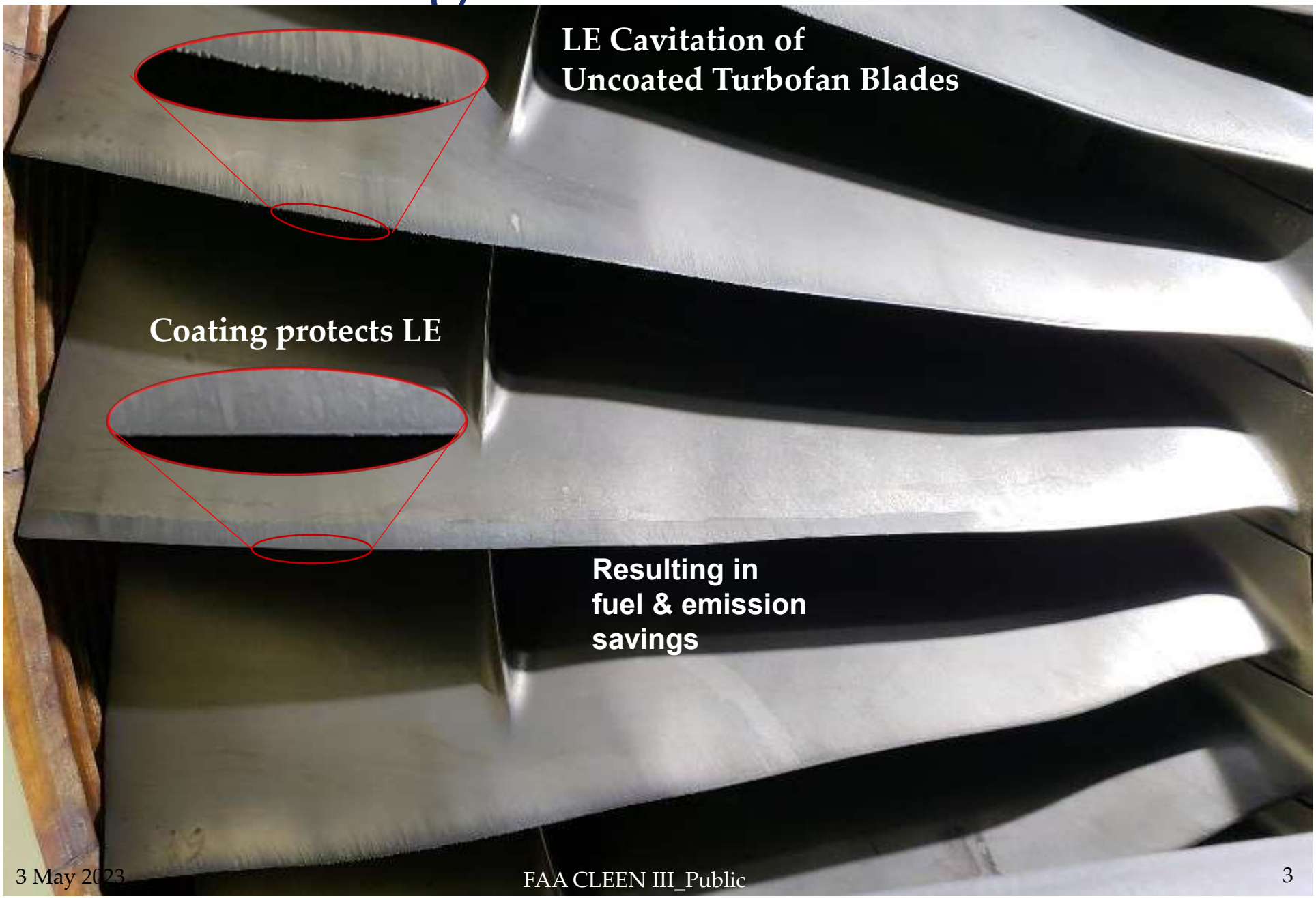
High AR
Blades

LE
Ti Strips

Hollow
Fan Blades

LE Repair
and Low AR
Blades

CLEEN II Flight Demo



Rainy Day Take-off

Wet Runway Landing

Phase I – Data Collection

- Measured & photographed LE condition of various engines at DTO in Oct 2021, Oct 2022 and April 2023
- Measured on-wing or on inducted blades for following engines:
  - PW2000
  - PW4000
  - CF34
  - CFM56
  - BR715
  - PW1100
  - Trent 1000
  - Trent XWB
- V2500 engine test @ United, 3Q / CY23
- V2500 measurements at IAD or DEN, TBD

On-wing Repliset @ DTO

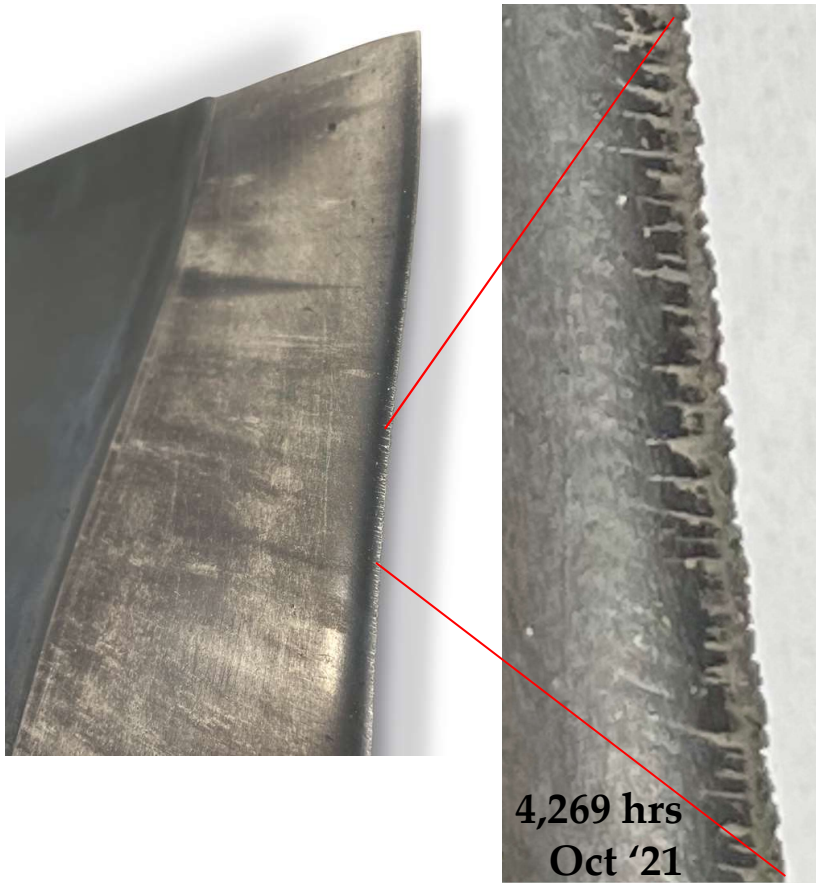
Measuring @ DTO, Oct 2022

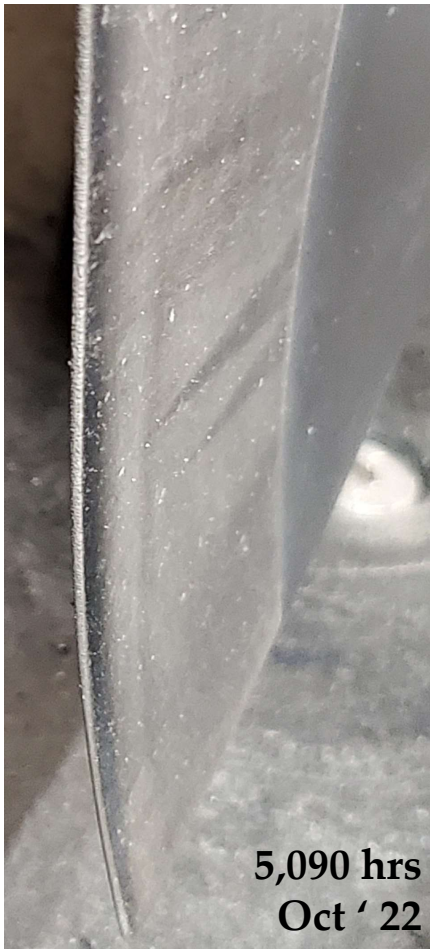
Measuring @ DTO, April 2023

Phase I – Data Collection

PW1100, In-Shop at DTO

Wing mount, Low AR, hybrid Al-Li with Ti LE





Phase I – Data Collection

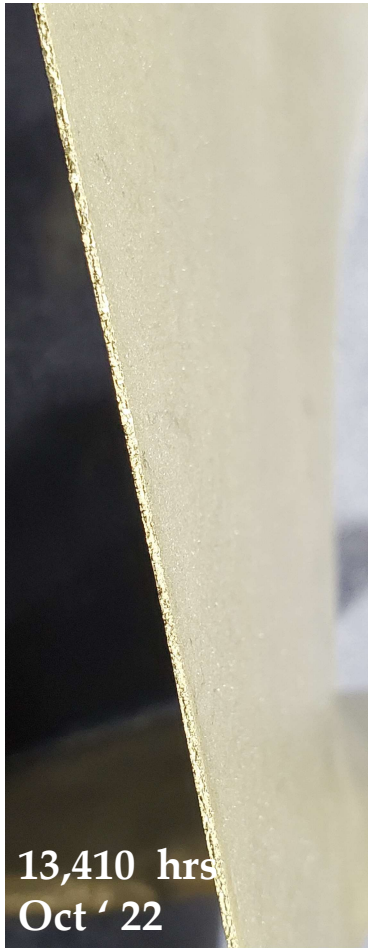
CF34, Regional Jets @ DTO

Fuselage mounted engine – Low AR solid Ti blade

Phase I – Data Collection

PW2000, B757 @ DTO

Wing mounted engine – High AR solid Ti blade



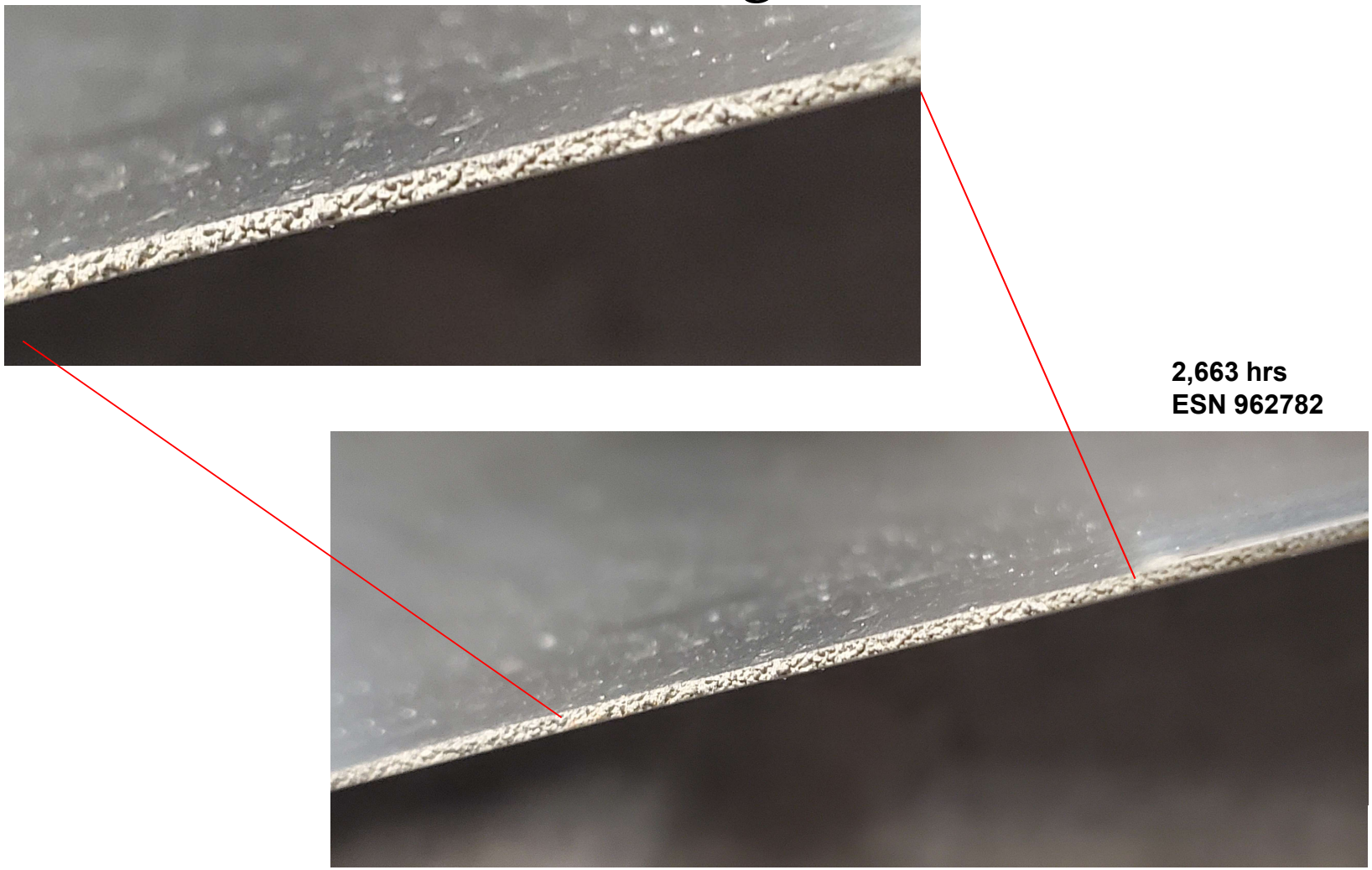
Phase I – Data Collection

CFM56s, On-wing @ DTO

Wing mounted engine
High AR (-5B) and Low AR (-7B) solid Ti blade

Phase I – Data Collection

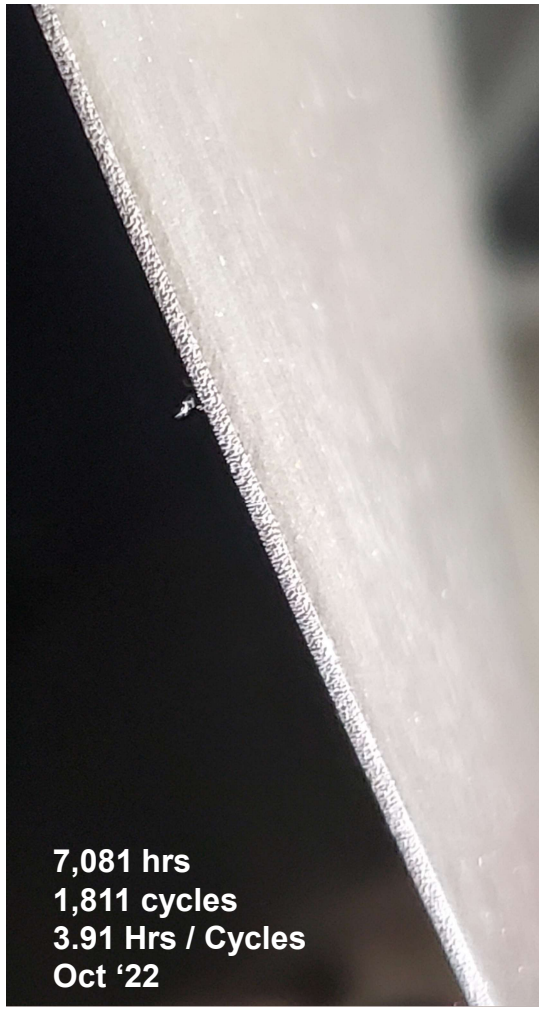
CFM56-7B, B737 On-wing



Phase I – Data Collection

PW4000 @ DTO

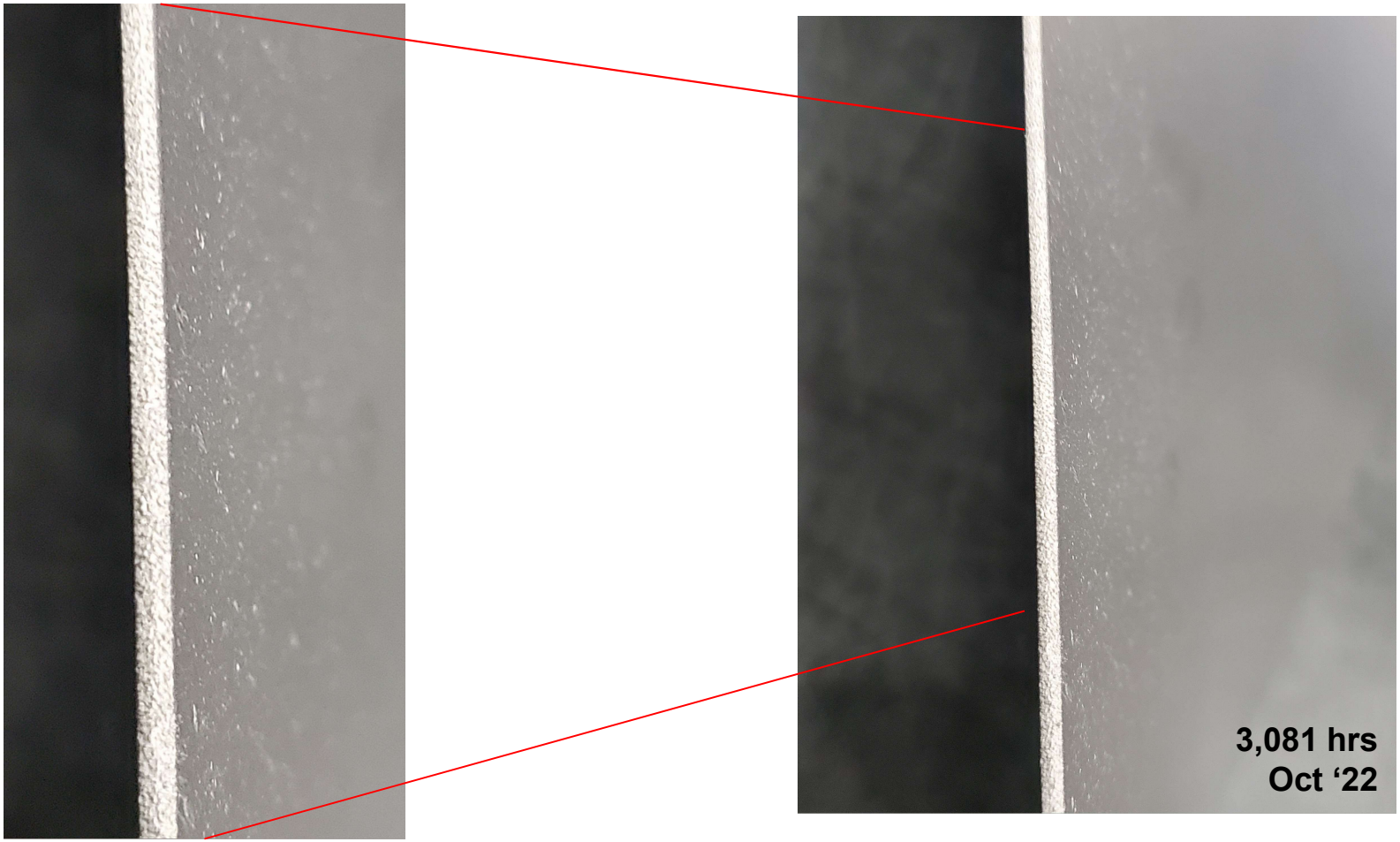
Wing mounted engine – High AR solid Ti blade



Phase I – Data Collection

BR715, In-Shop @ DTO

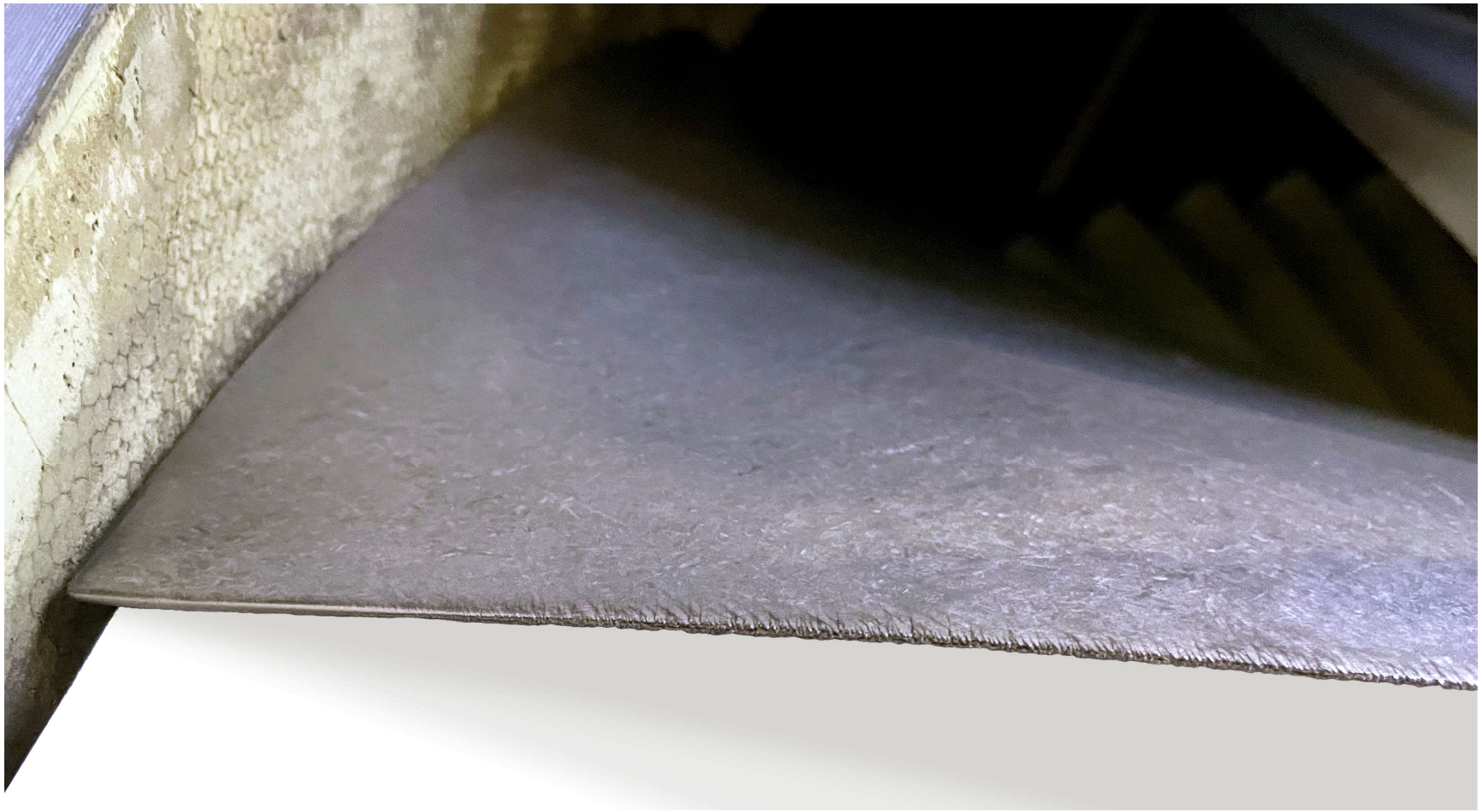
Fuselage mounted engine – Low AR hollow Ti blade



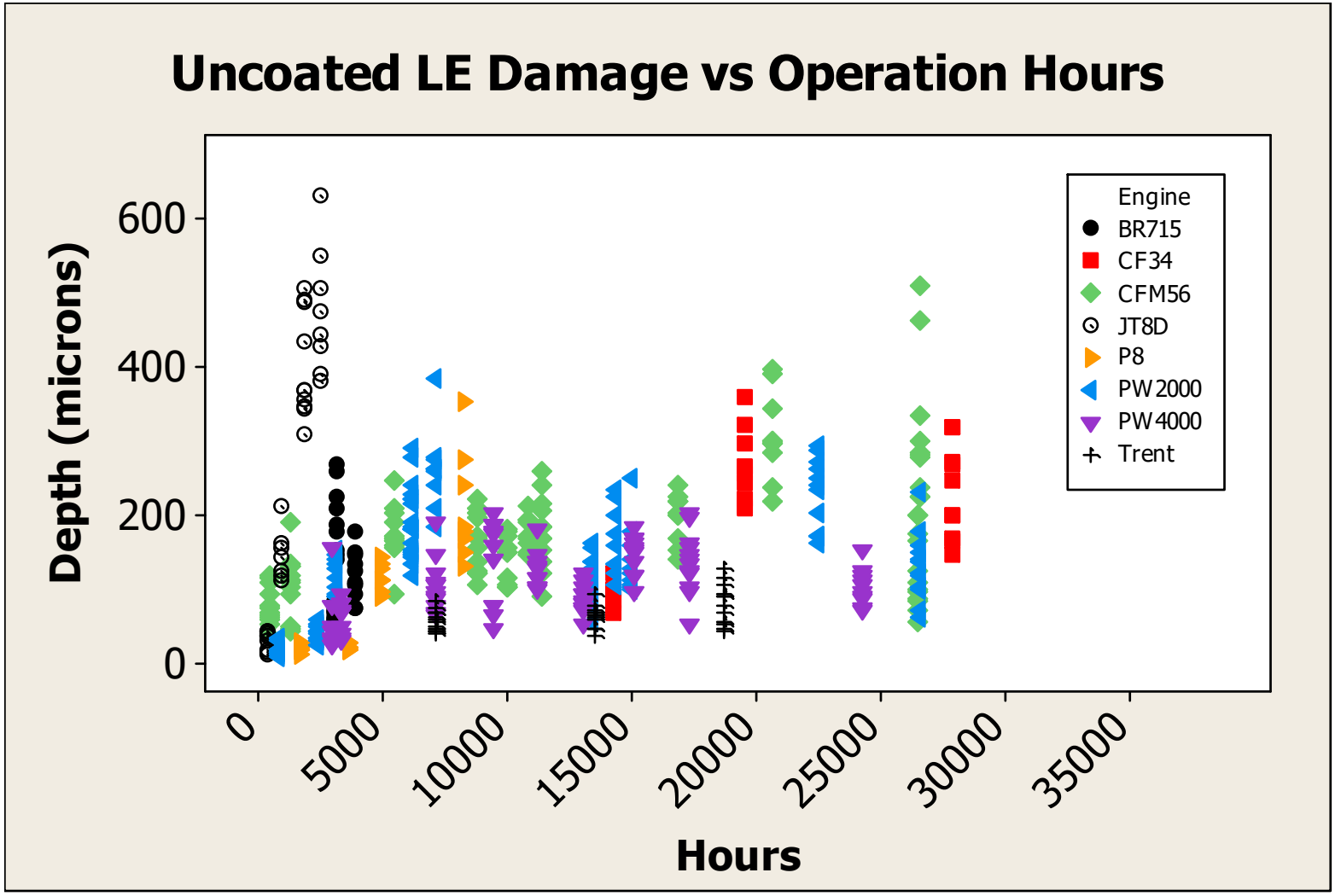
Phase I – Data Collection

V2500, A320 On-Wing at United Tech Ops

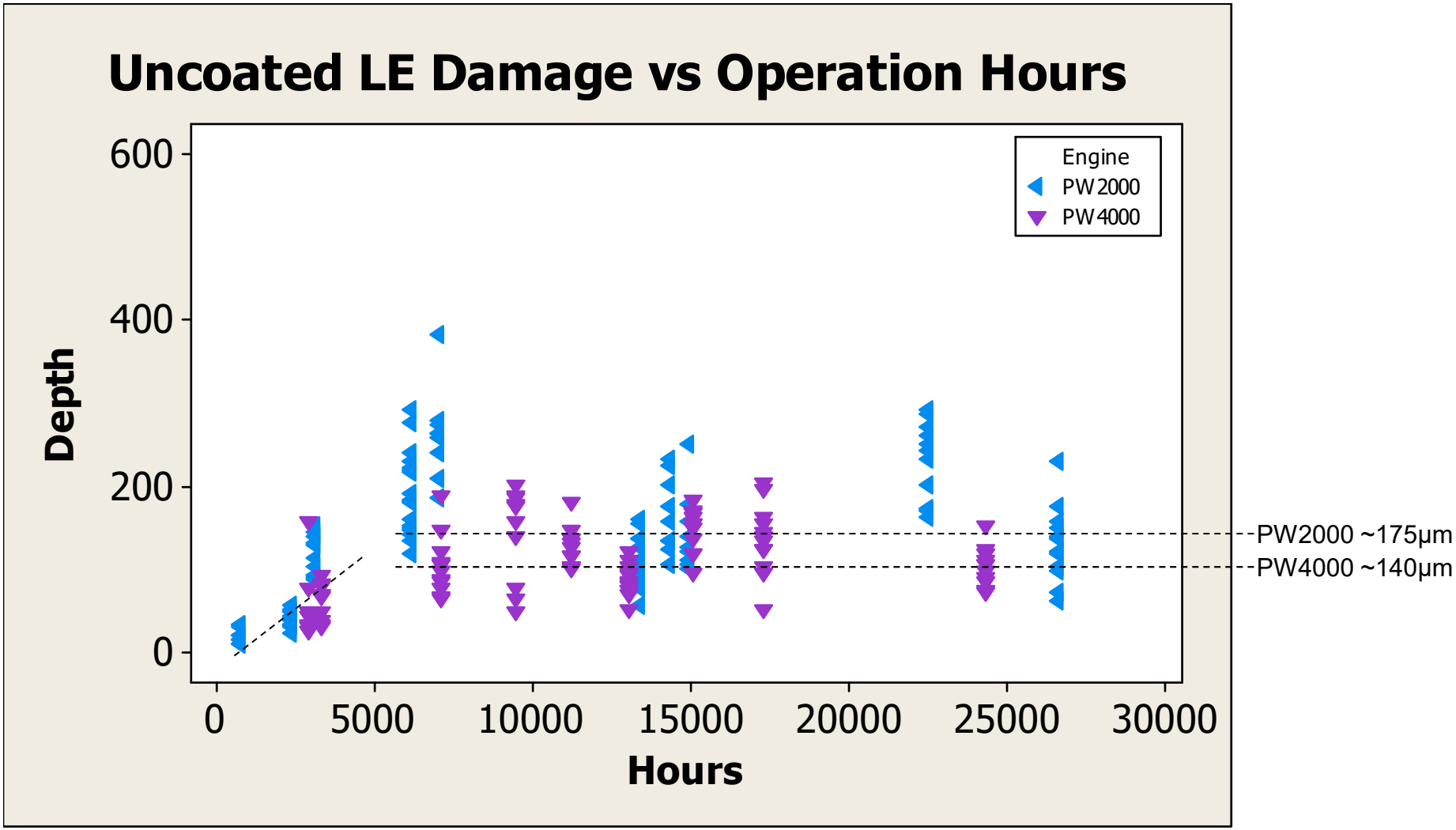
Fuselage mounted engine – Low AR hollow Ti blade



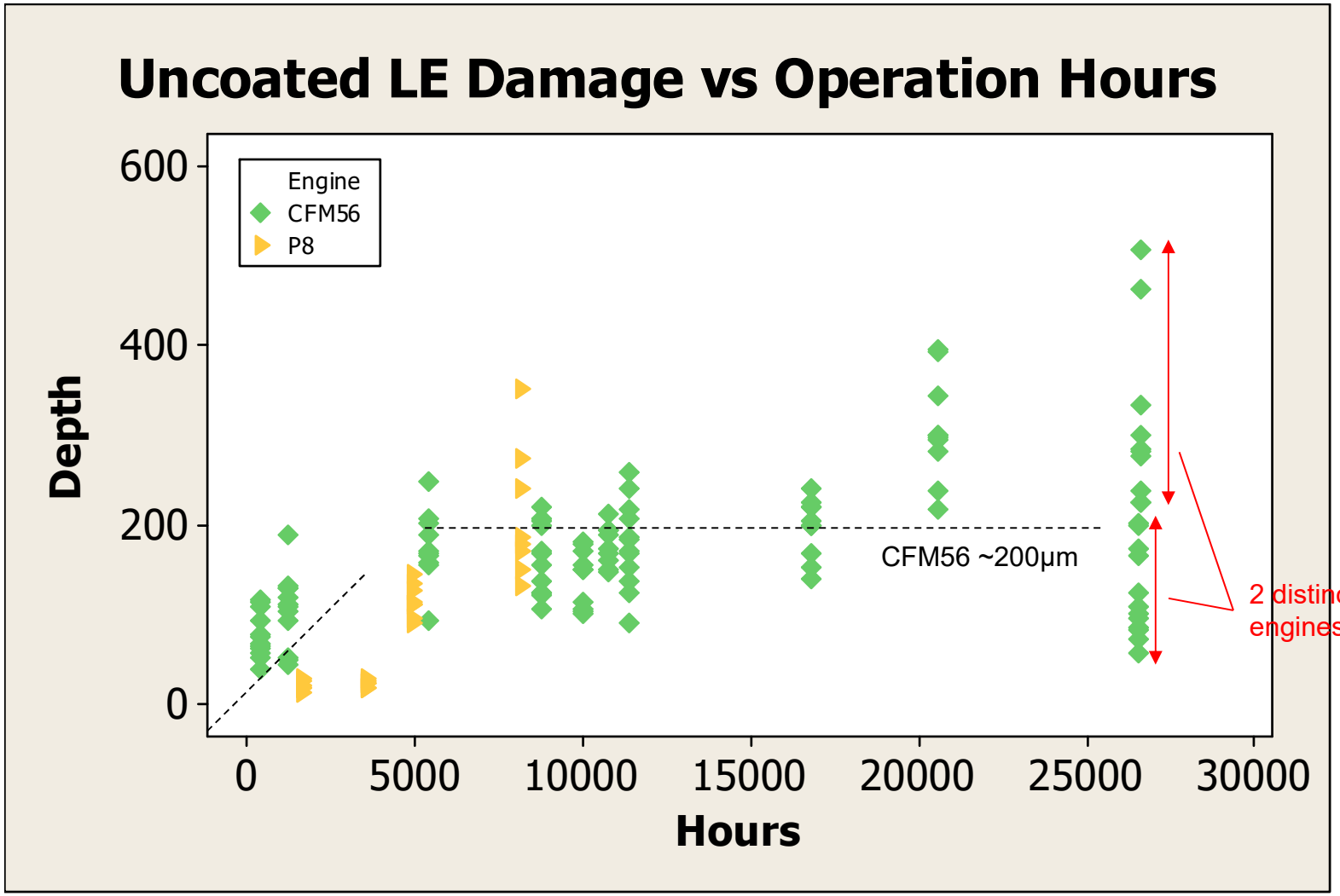
Phase I – Data Collection



Phase I – PW2000 and PW4000



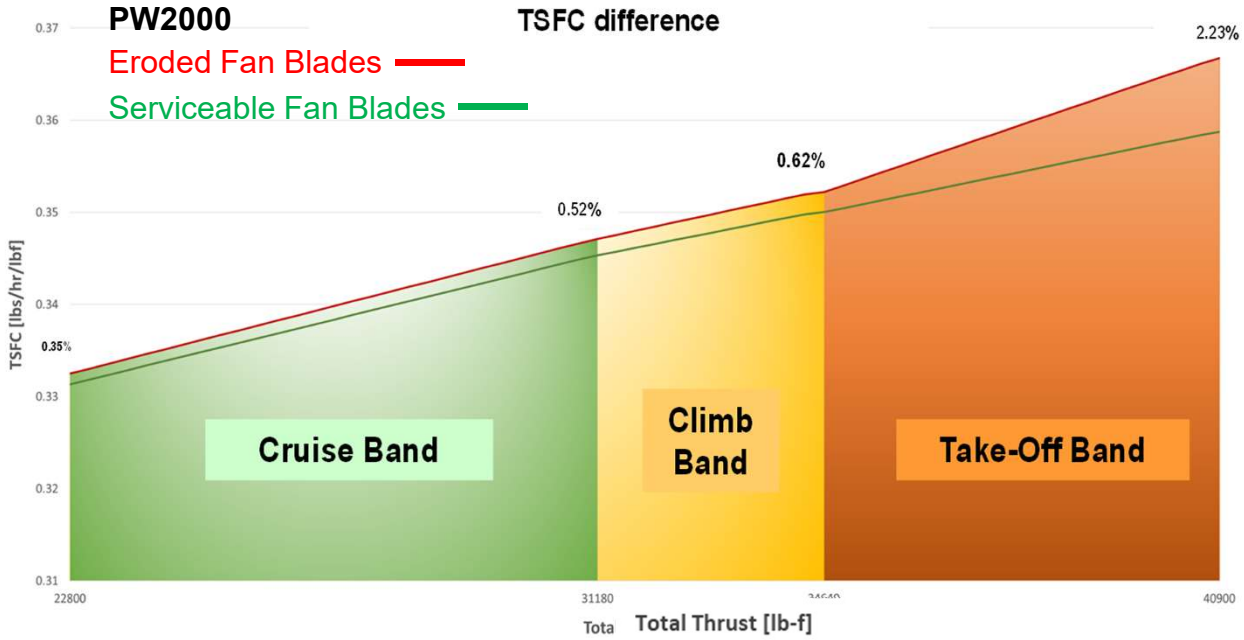
Phase I – P8 and CFM56



Phase I – Data Collection

Fuel Consumption Impact

- Isolated fuel consumption differences between eroded and serviceable fan blades on same inducted engine
- Delta completed tests on JT8D and PW2000 engines



Phase I Data Collection

Fuel Consumption Impact

- Supplement engine tests with CFD analysis

CFD Work Scope

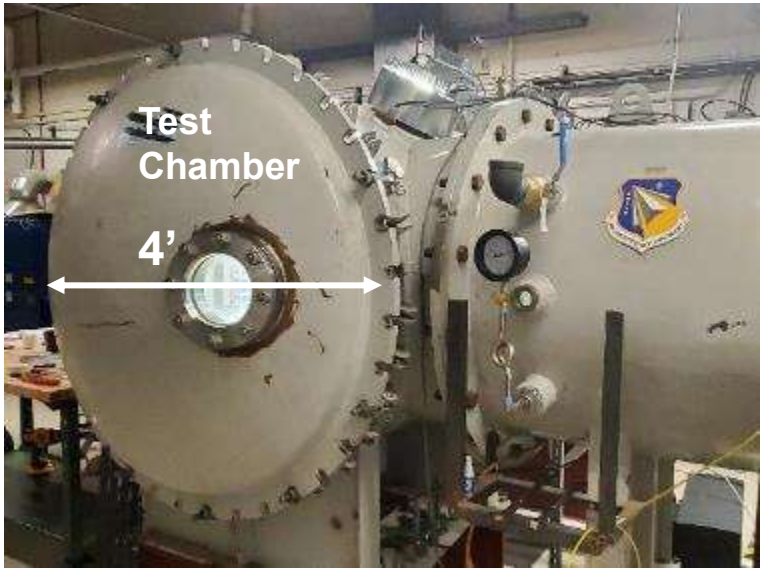
- U. Maryland to conduct CFD analysis on following engine types w/ restored & eroded LE:
  - V2500
  - CF34
  - CFM56
  - PW4000 or CF6
- Scans of restored and eroded LE fan blades
- Boundary and operational conditions provided by Delta & United
- CFD Analysis will compare results from one engine test

Phase I – Data Collection

Data Collection Summary

- Over 50 engines measured / photographed
  - CFM56 = 16
  - CF34 = 3
  - PW2000 = 10 / F117 = 2
  - PW4000 = 7
  - PW1100 GTF = 3
  - BR715 = 4
  - Trent 1000 = 7 / XWB = 1
- Documenting fuel savings
  - JT8D & PW2000 tested
  - V2500 testing in 3Q, CY23
  - U. Maryland CFD analysis on V2500, CFM56, CF34, PW4000 / CF6 and GTF
- LE cavitation measurements
  - Cavitation pits as early as 1,000 hours
  - Tends to increase between 3,000 to 5,000 hours and then flattens for remaining tour

Phase II – Fluid Erosion Test



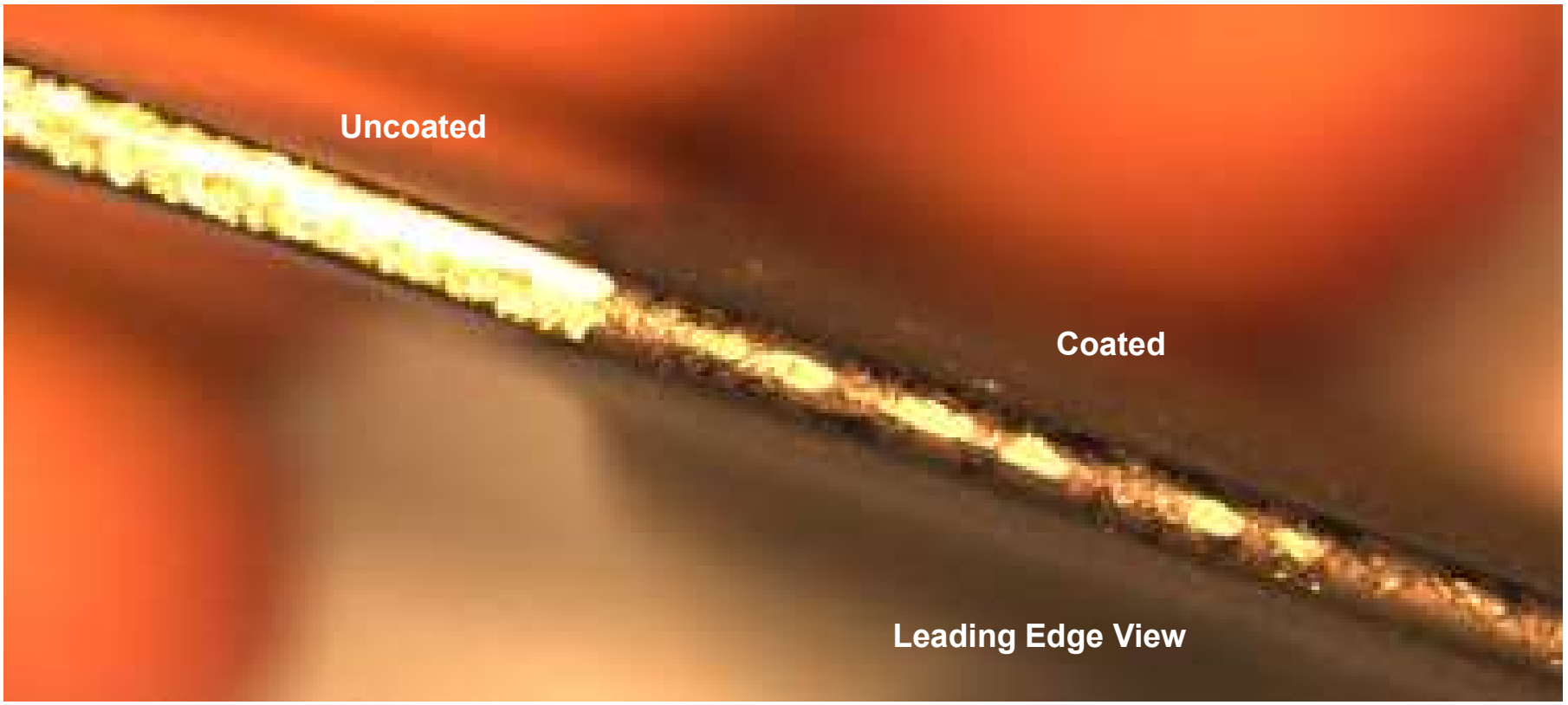
As part of CLEEN II and III, project used the SuRE rig at AFRL to reproduce field damage

SuRE Test

SuRE Test

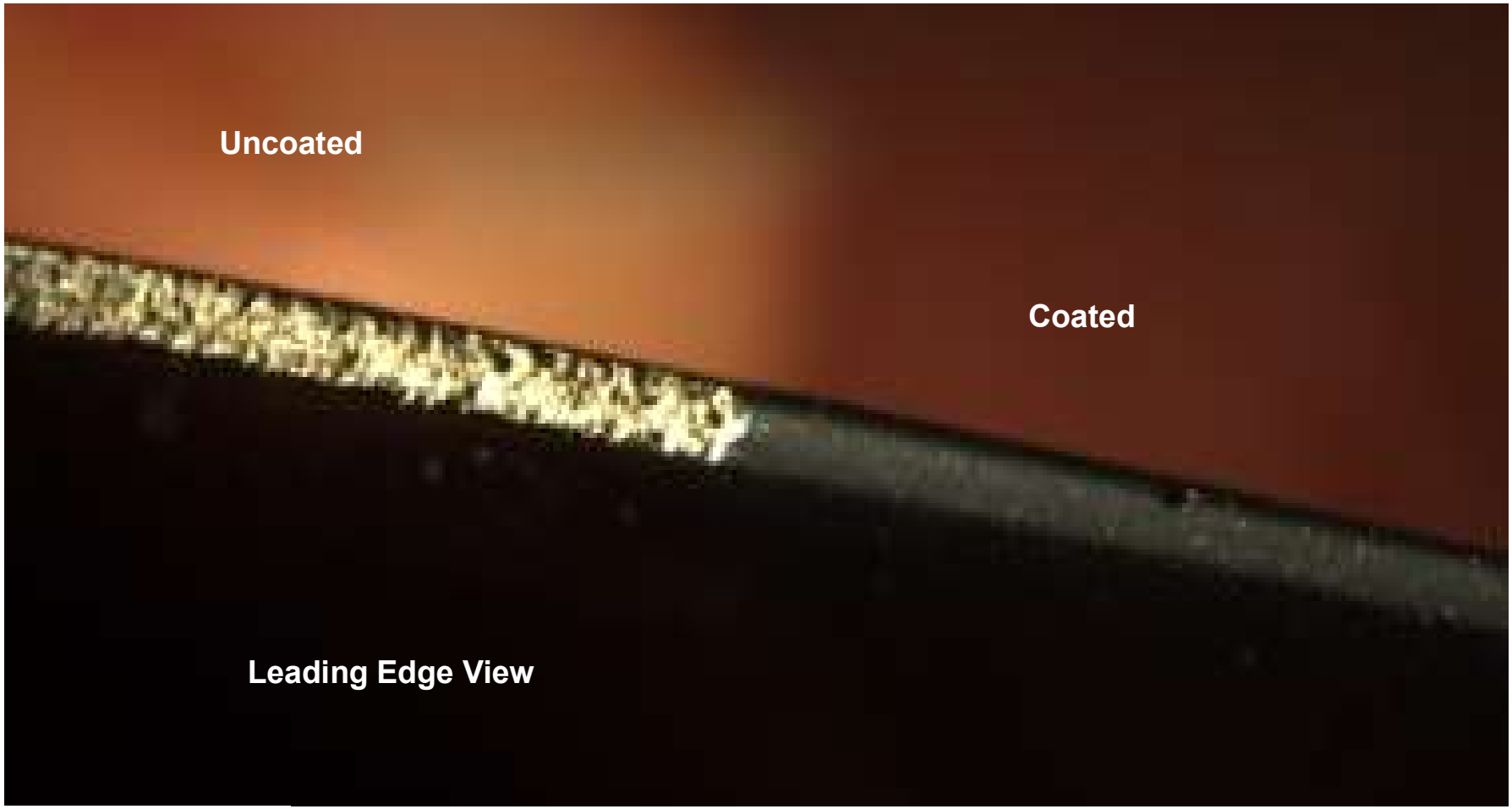
V2500 Test Specimen

BlackGold® v12.1
MD-88 Flight Demo



PW2000 Test Specimen

BlackGold® v12.2
With coating enhancements

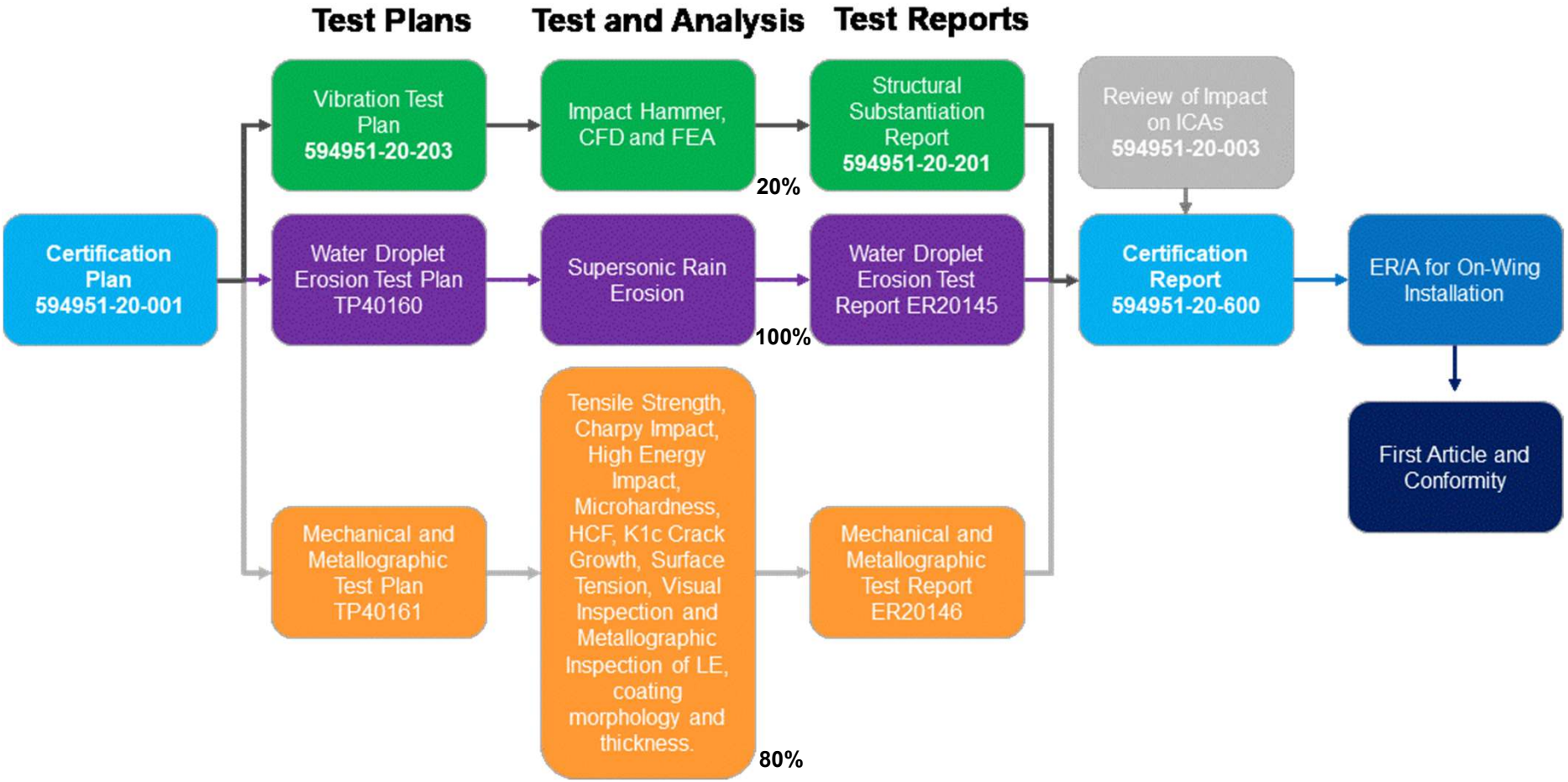


Phase III – PW2000 Certification

- Contracted FAA Authorized RS-DER
- Approval using Major Repair
  - PW2000 Type Certificate E17NE Rev 15
  - Following Certification Plan (594951-20-001)
- Current work
  - Executing Mechanical test plan
  - Finalizing Vibration test plan

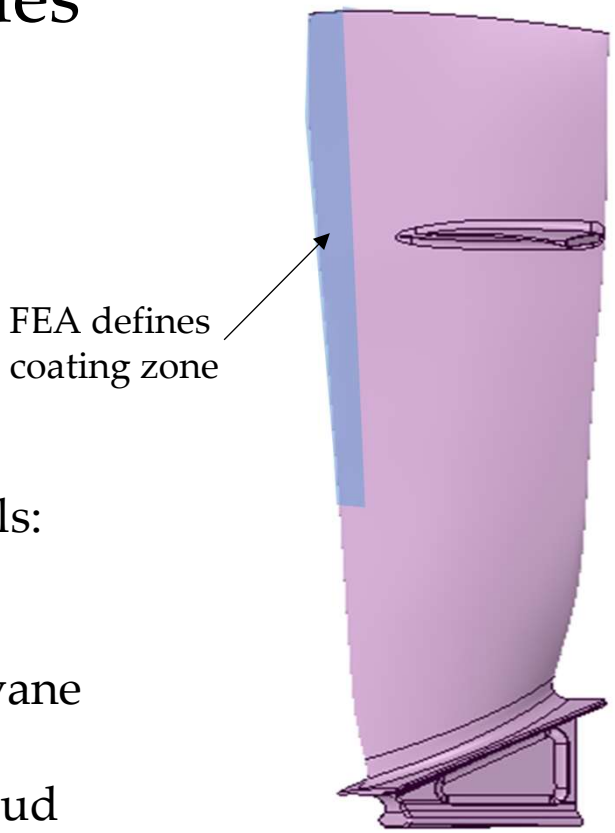
PW2000 Certification

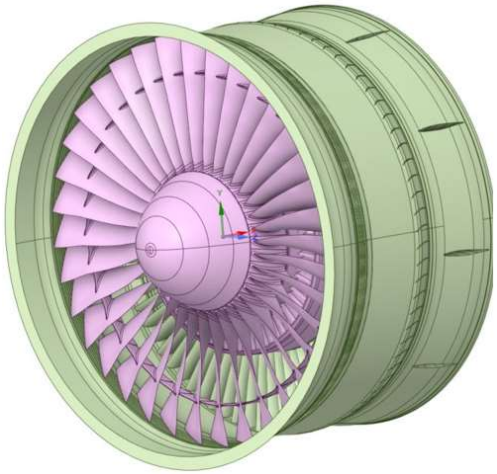
Certification Overview



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





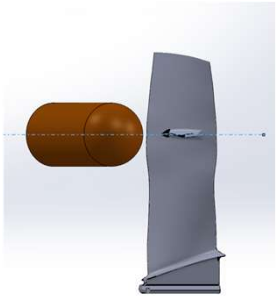
PW2000 models:
- Fan Blade
- Casing
- Exit guide vane
- Stator vane
- Fan-to-Shroud
- Fan-to-Disk

High Energy Impact

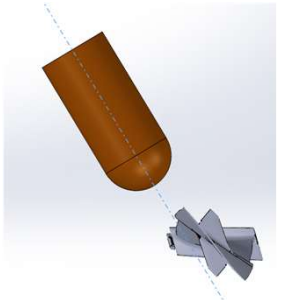
- High Energy Impact testing scheduled for Q3, CY23
  - GKN repaired all the fan blade for testing
  - Coating applied by MDS in July 2023
  - Testing performed by UDRI

Test Gun at UDRI

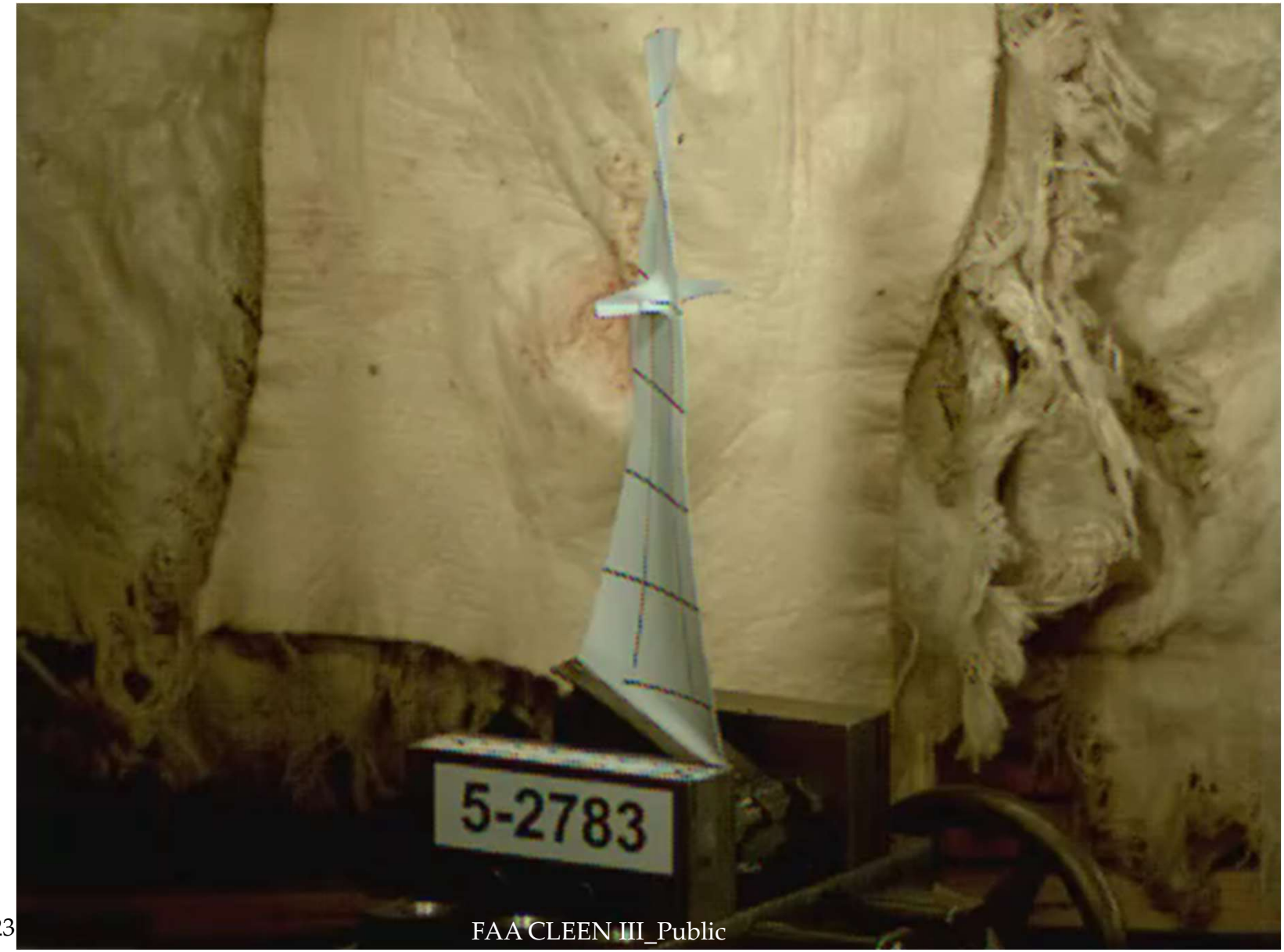
Impact
Side View



Impact
Top View



Jelly Ball Impact Test



Summary

Data Collection

- Expanded data collection. Photographs and LE depth measurements on various engine types including military engines.
- LE cavitation confirmed as low as 1,000 hours.
- LE cavitation depth tends to increase to between 3,000 and 5,000 hours and appears to flatten-out (constant mean pit depth) for remainder of tour

Engine Test / Fuel Consumption Analysis

- V2500 engine test at United Airlines
- CFD analysis by U. Maryland on V2500, CF34, CFM56, PW4000 / CF6 and an engine with LE strips

Summary (continued)

PW2000 Certification

- Certification & Test Plans approved by FAA ODA
- Exposed uncoated & coated fatigue test specimens at AFRL, SuRE facility
- Conducted HCF tests on fatigue test specimens
- Conduct mechanical evaluation tests (2Q / CY23)
- Conduct jelly ball impact test at UDRI (3Q / CY23)

First full PW2000 coated sets supplied by MDS Coating, 4Q / CY23

First full PW2000 coated sets installed by Delta Airlines 1Q / CY24

Saving 1% of fuel results in:

$114M USD

1.15M barrels of oil

495,717,516 kg of CO_2

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-calculatios-and-references

MDS COATING

DELTA TechOps

GKN AEROSPACE