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

Presented to: FAA Office of Environment and Energy – Industry Day

By: Delta TechOps (DTO)

GKN Aerospace (GKN)

MDS Coating Technologies (MCT)

America's Phenix, Inc. (AP)

Date: 3 November 2021

Project Overview

Objective - Demonstrate MRL & TRL 8-9 via application of LE protective coating for potential Turbofan Blade configurations:

LE Repair

High Aspect Ratio

Hollow Fan Blades

LE Ti Strips

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

- Protect for entire tour on all TF engine types

Mitigation

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

Objectives:

- Quantify performance degradation
- Optimize coating protection via component tests
- Demonstrate on various TF types at TRL8-9

Work Statement:

- Conduct engine tests on degraded & O/H[1] blades
- Conduct fluid erosion tests at AFRL[2] SuRE[3] rig
- Flight certify for PW2000
- Optimize coating protection for other TF types
- Install fully coated sets for various engine types and demonstrate at TRL8-9

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

Accomplishments / Milestones

- Commenced accumulating further data to quantify rate of erosion
- Commenced certification process for PW2000 engine

Schedule:

- Blade Condition / Operational Analysis – thru 2025
- Engine tests – thru 2022
- AFRL SuRE tests - Jan 2022
- Flight Certification, PW2000 – Jan 2023
- Flight Certification, other engines – thru May 2026
- Flight Service Evaluation – 2023 thru May 2026

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

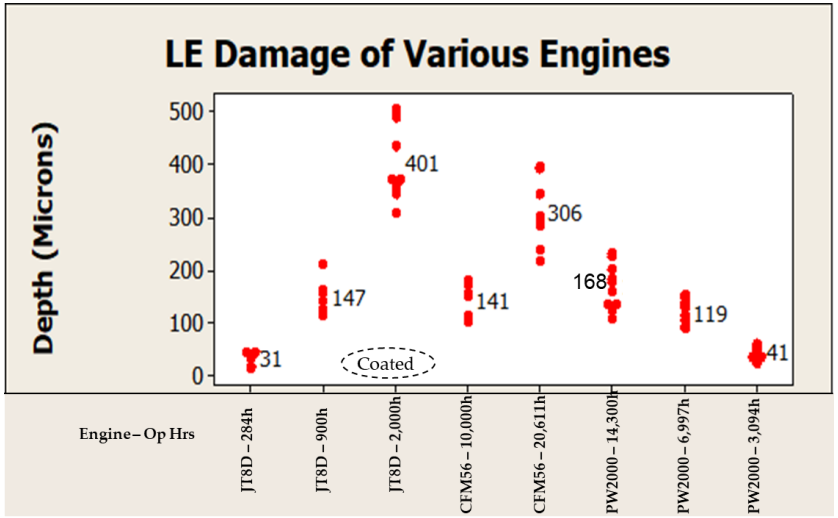
Delta Air Lines consumed 4.566B gal of fuel in 2019
Based on $2.50 / gal fuel price
https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculatios-and-references

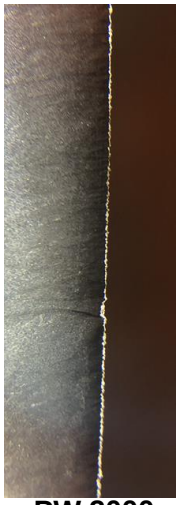
Schedule - Overview

- Phase I – Data Gathering (throughout CLEEN III program)
  - Blade Condition Analysis on inducted engines and TF blades at GKN
  - Engine tests on various engine types
- Phase II – Coating Optimization Tests (Jan 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 pending AFRL SuRE Results

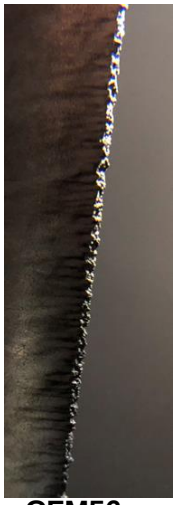
Phase I – Data Collection

LE Measurements @ % Tour						
Engine	<10%	20%	40%	60%	80%	100%
PW2000		20%	44%		89%	
Hours		3,094	6,997		14,300	16,000
PW4000						
Hours						
CFM56				55%		
Hours				20,611		36,000
CF34						
Hours						
V2500						
Hours						
Ti Strips						
Hours						

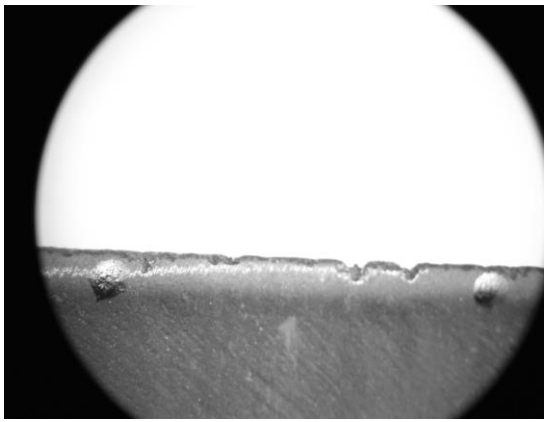




PW 2000
~20%
3,094 hrs



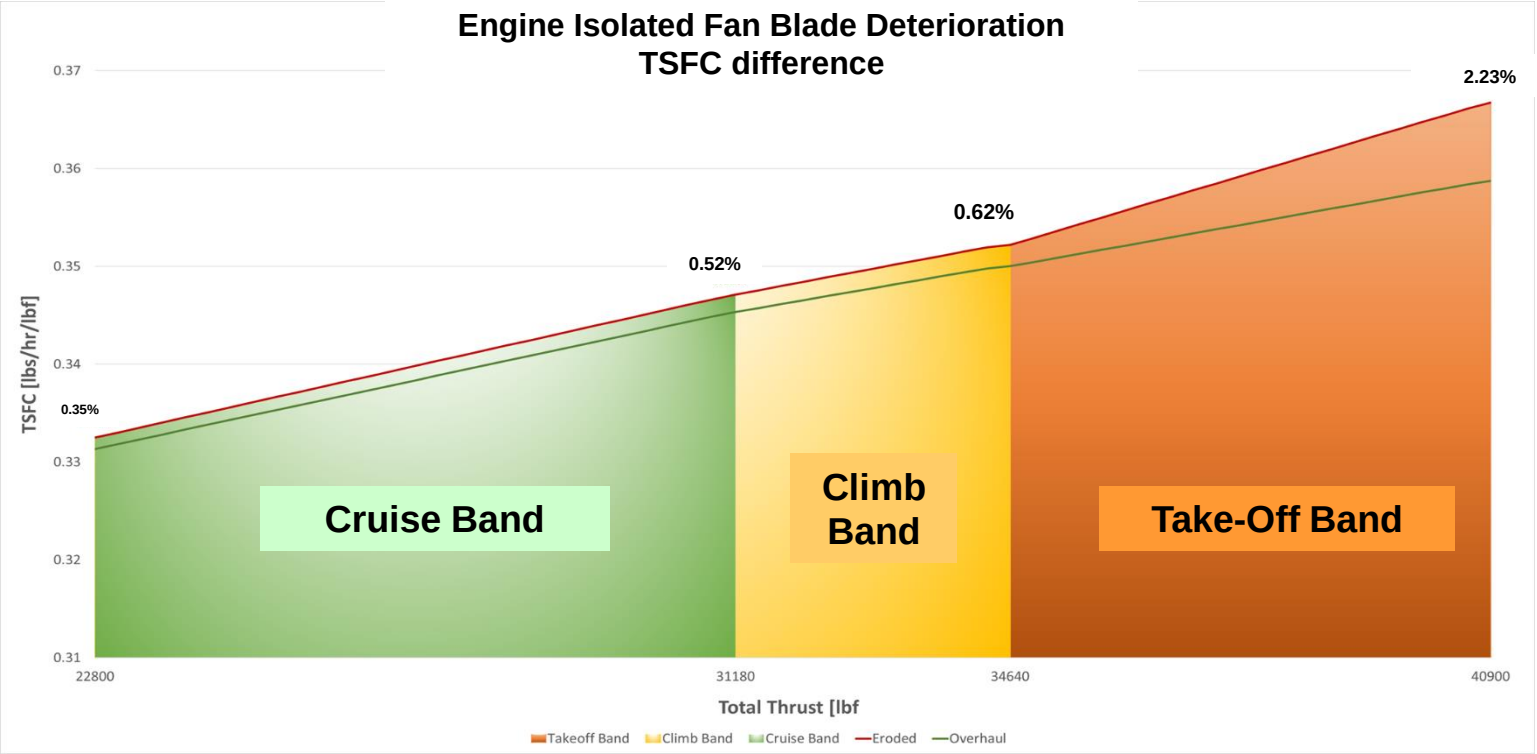
CFM56
~55%
20,611 hrs



Developing new tool

Phase I – Data Collection

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



Will conduct similar comparative engine tests on various engine types

Phase I – Data Collection

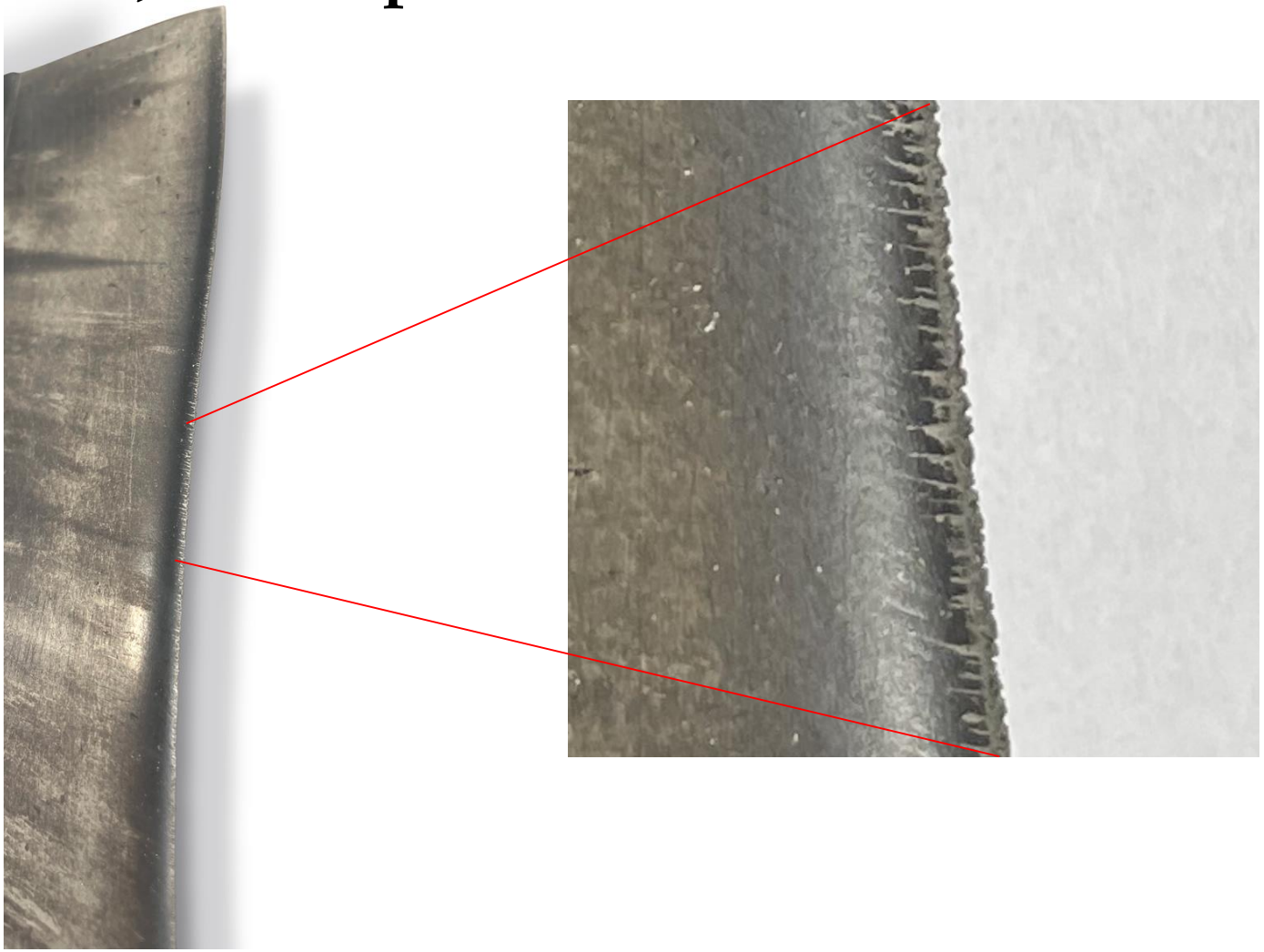
- Measured & photographed LE condition of various engines at DTO in October 2021
- Measured on-wing or on inducted blades on various engine engines

On-wing Repliset @ DTO

Measuring @ DTO

Phase I – Data Collection

LE Sheaths, In-Shop

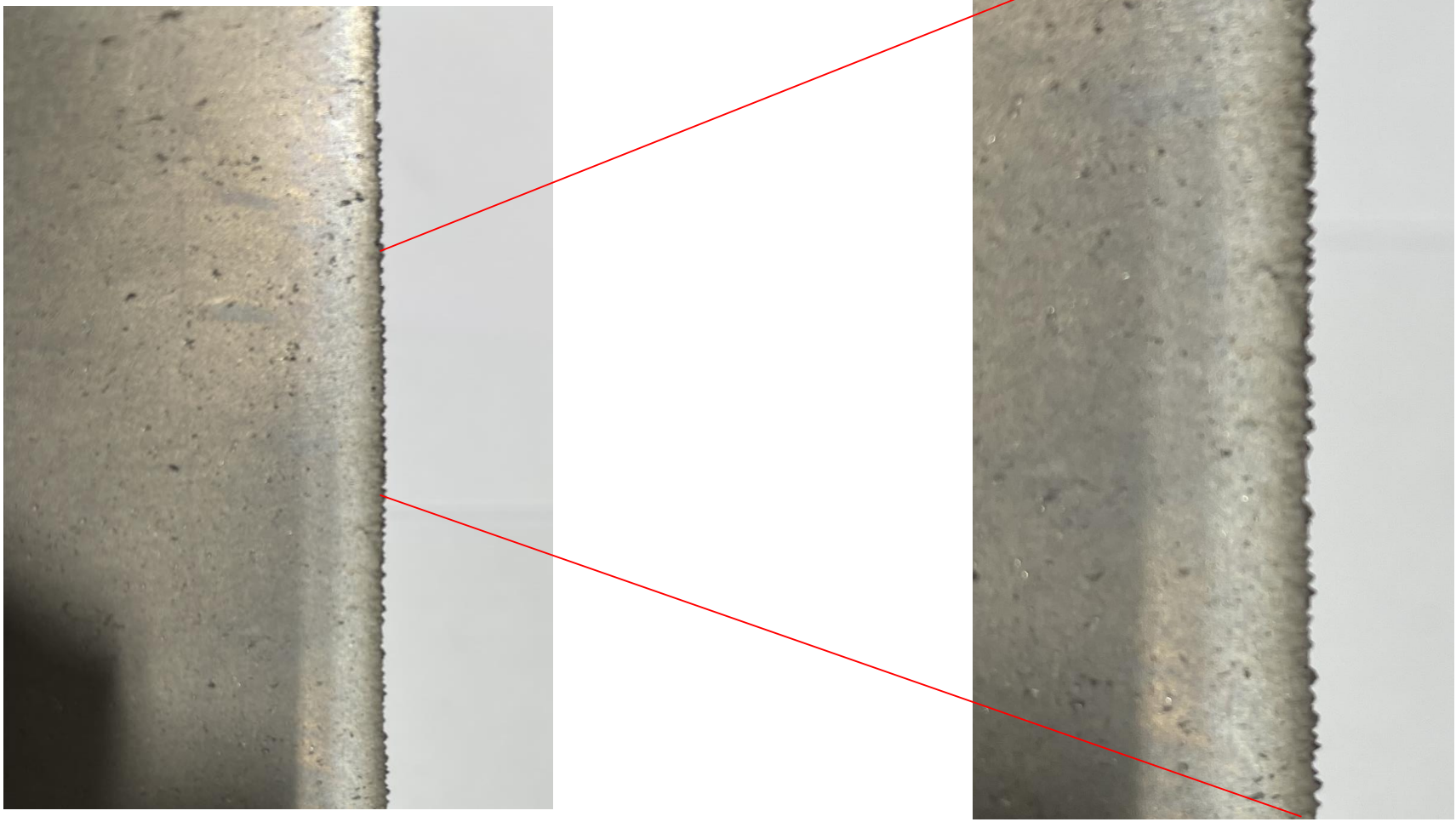


Phase I – Data Collection

Regional Jets, In-Shop

Phase I – Data Collection

Hi Aspect Ratio (AR), In-Shop

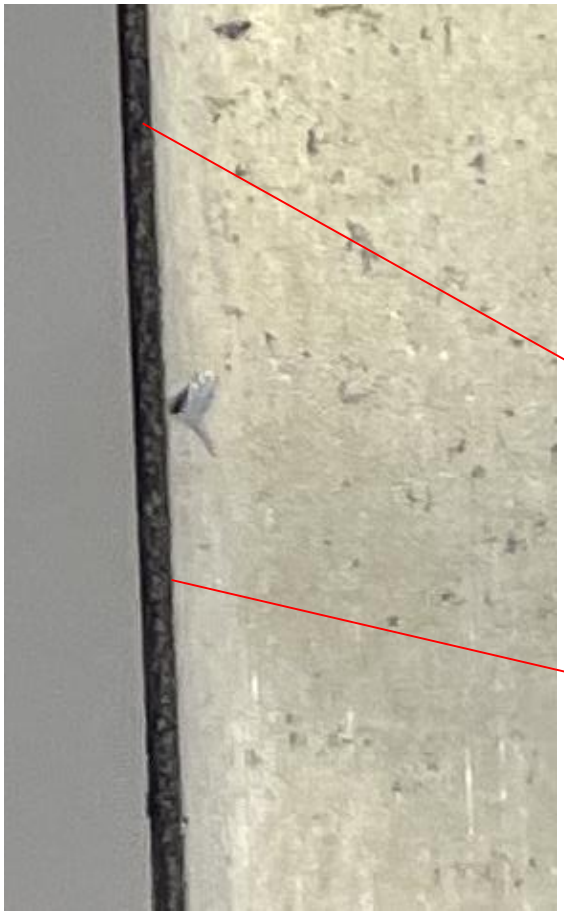


Phase I – Data Collection

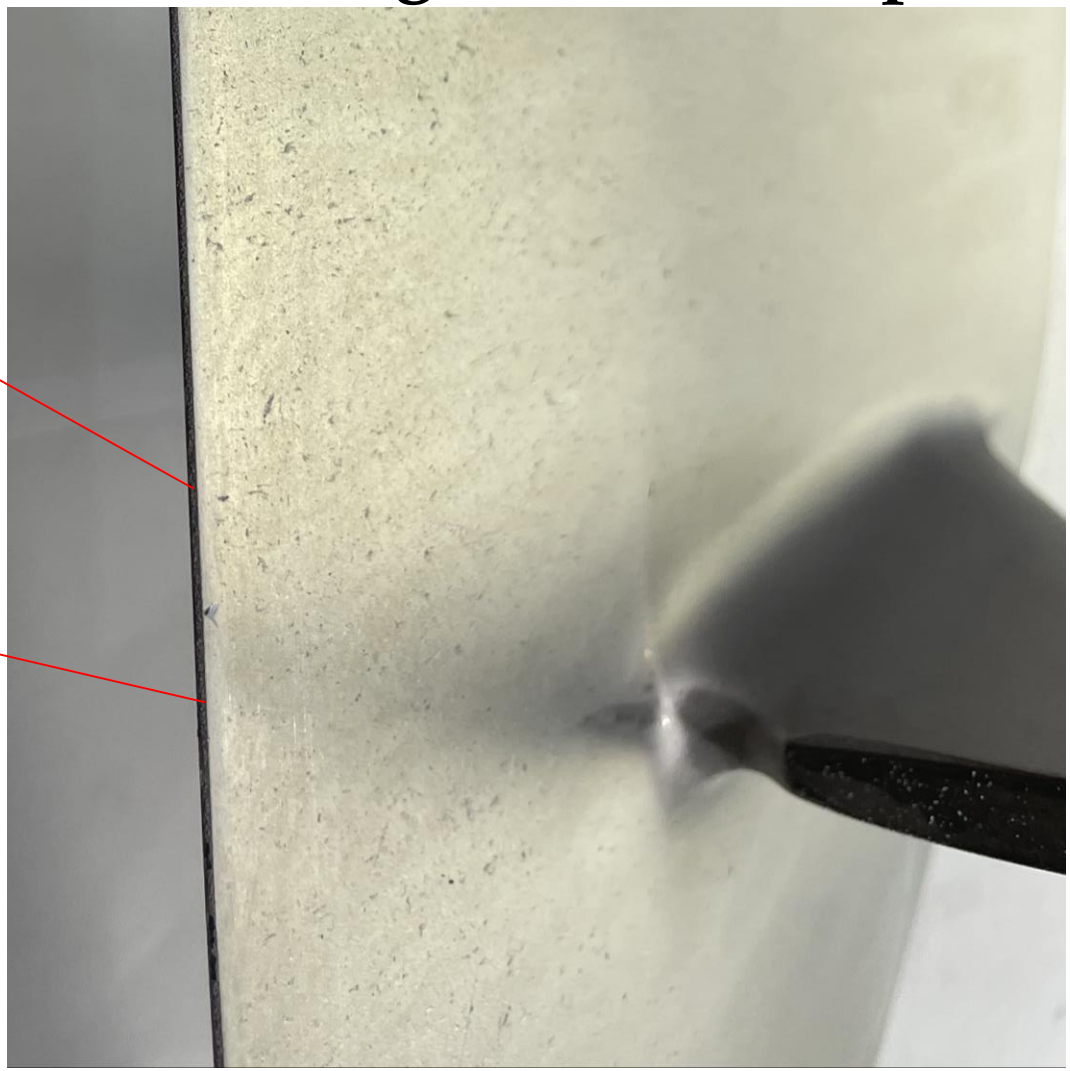
High AR, On-wing

Low AR, On-wing

Phase I – Data Collection



High AR, In-Shop

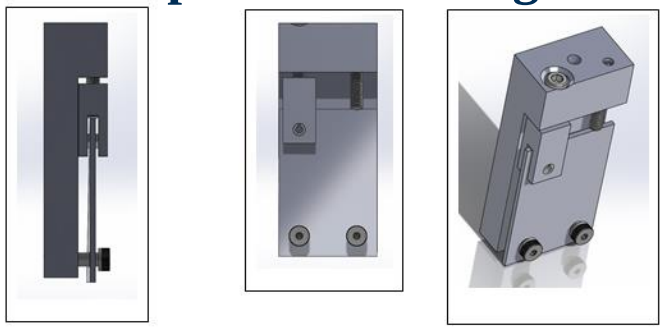


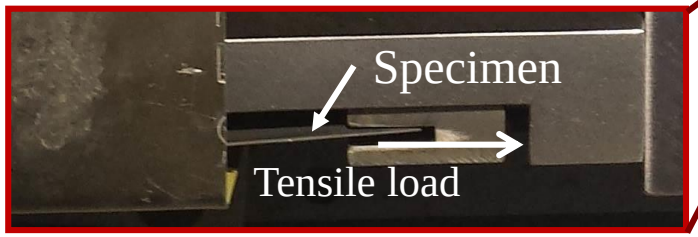
Phase II – Fluid Erosion Test

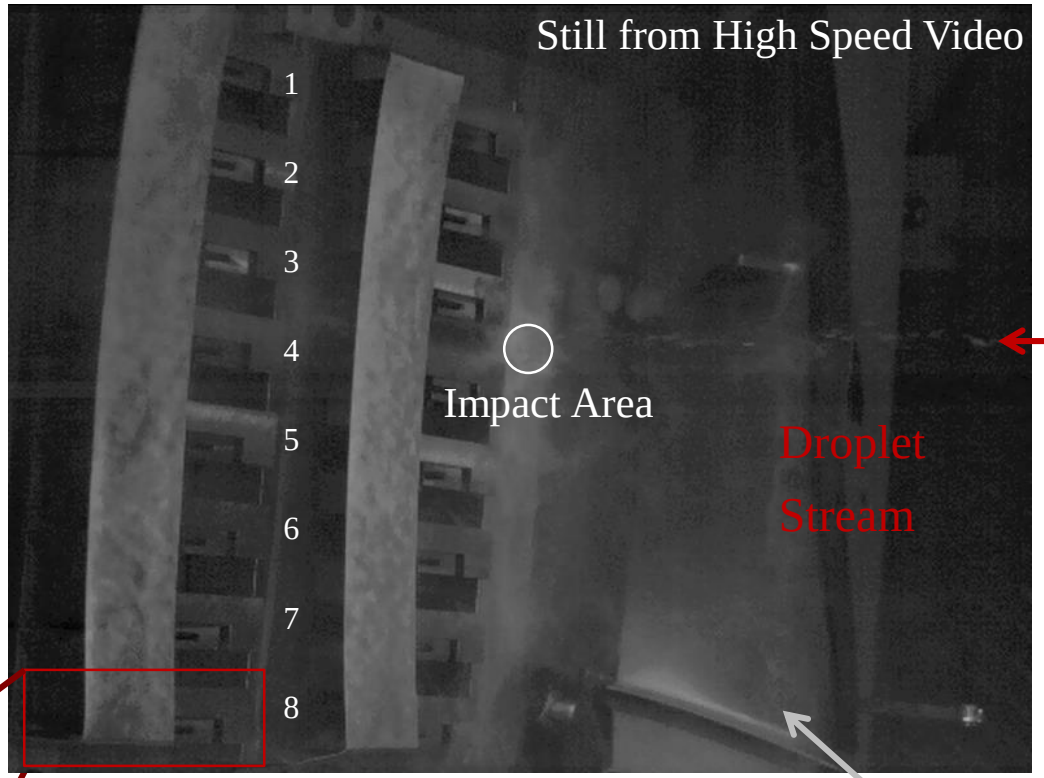
@ AFRL – Supersonic Rain Erosion (SuRE) Rig

Specimen Preparation

Specimen Tooling





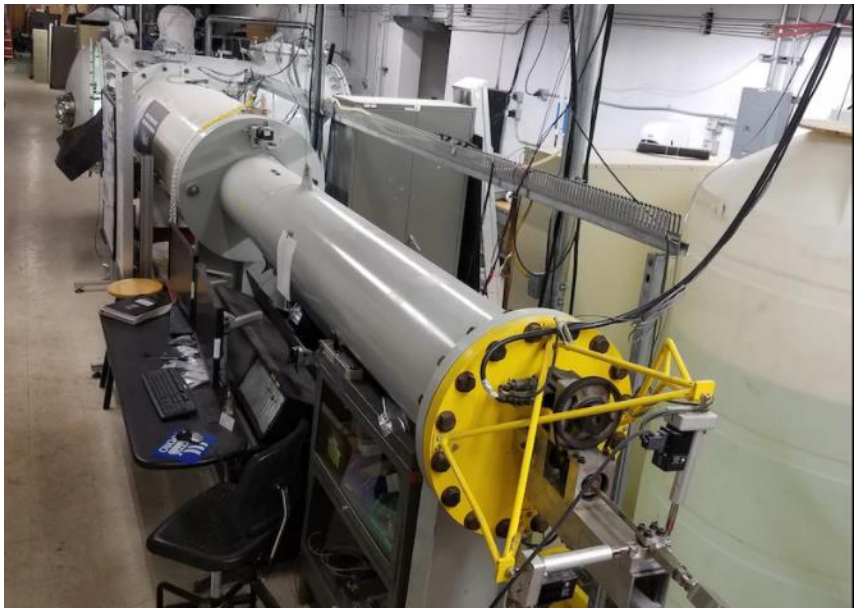


Uncoated Blade Specimen

BlackGold® Coated Blade Specimen

Phase II – Fluid Erosion Tests

- **UDRI conducting fluid erosion tests using Supersonic Rain Erosion (SuRE) test rig at AFRL in Dayton**
  - 30 specimens: 3 rails X 10 specimens
- **SuRE test conditions**
  - Representative fluid droplet size and LE impact speeds



Specimens for AFRL Test

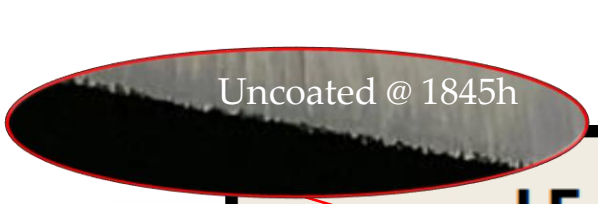
	Rail 1	Rail 2	Rail 3
1	TS1	TS2	TS3
2	TS4	TS5	TS6
3	TS7	TS8	TS9
4	TS10	TS11	TS12
5	TS13	TS14	TS15
6	TS16	TS17	TS18
7	TS19	TS20	TS21
8	TS22	TS23	TS24
9	TS25	TS26	TS27
10	TS28	TS29	TS30

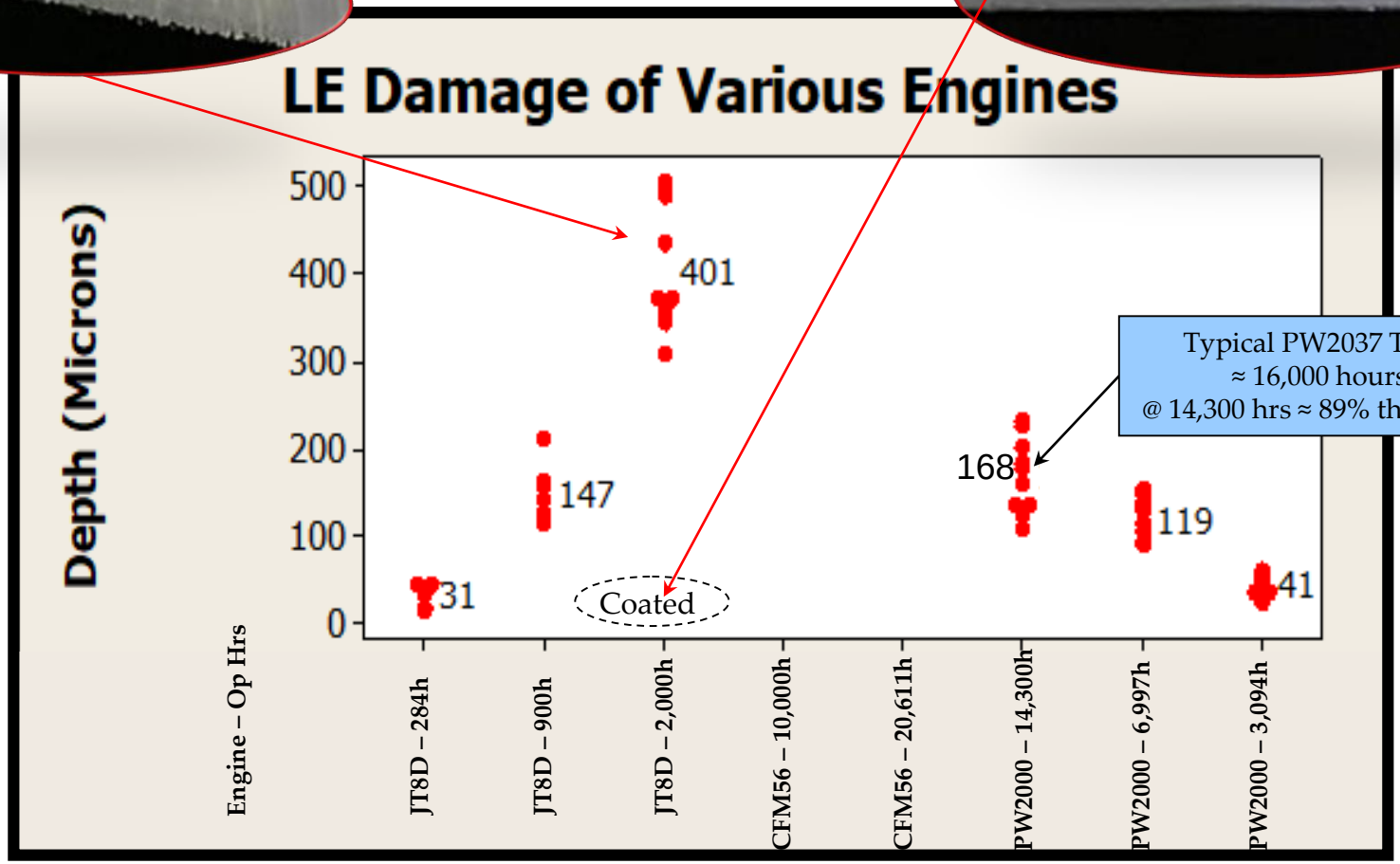
Phase III - Certification

PW2000 selected for initial certification

Major Alteration
Type Certificate E17NE Rev 15

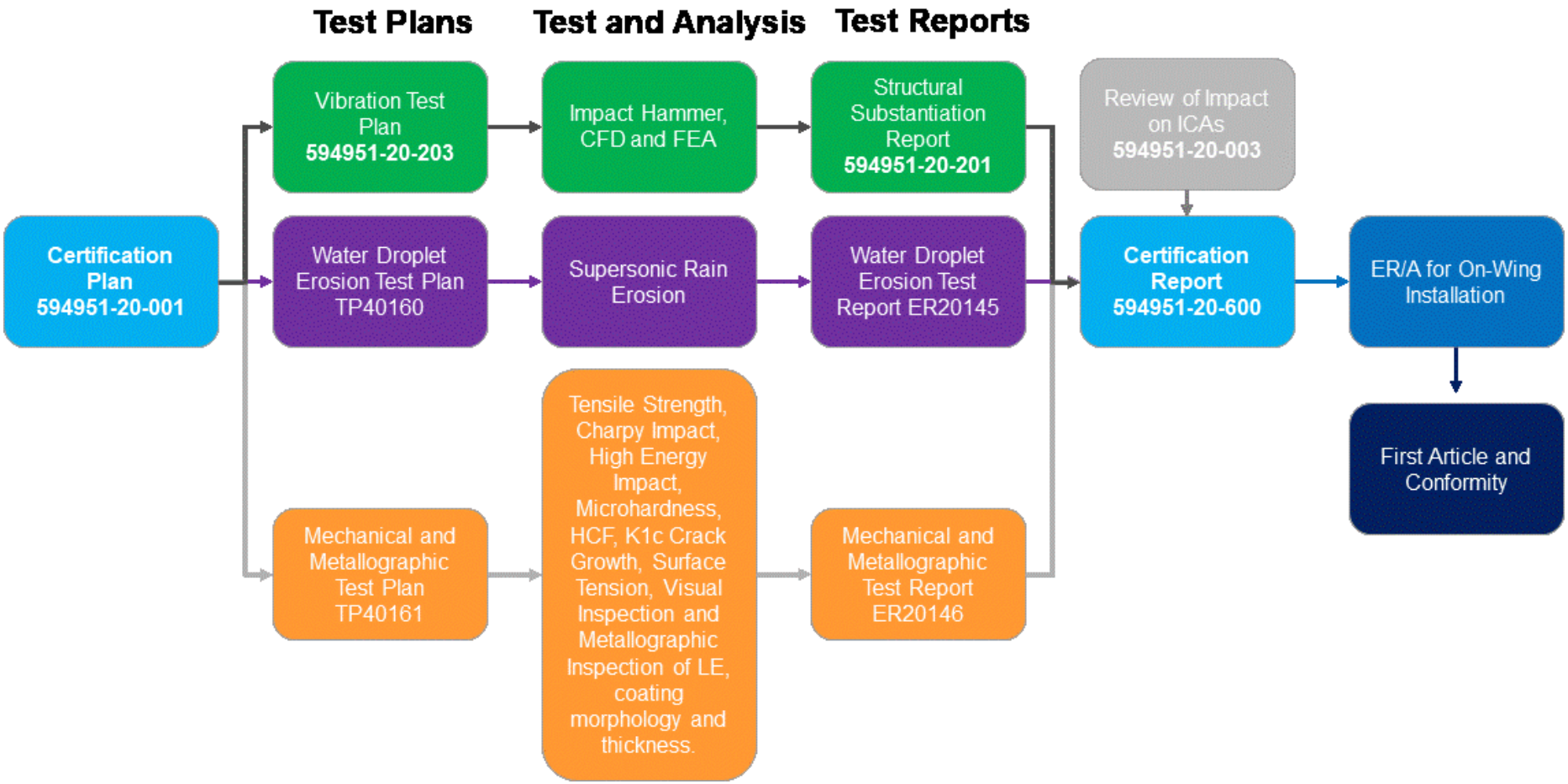
WHY?





Phase III – PW2000 Certification

Certification Overview



Future Work

Data Collection

- Measure pit depths on repliset molds from 12 different engines
  - Populate data collection matrix and plot
- Correlate LE laser measuring tool with repliset data on JT8D blade
- Continue LE condition data collection as a function of time-since-overhaul

AFRL Fluid Erosion Test

- Confirm test date at AFRL SuRE's facility in January 2022
- Manufacture test fixture (3 x 10 racks)
- Issue Purchase Order to conduct test
- Coat test specimens from different TF 1st stage engine blades

PW2000 Certification

- Defining Certification & Test Plans

Thank You

DELTA TechOps

GKN AEROSPACE

MDS COATING

AMERICA'S PHENIX
AEROSPACE CONSULTANTS for the Americas