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)

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Approved for Public Release

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

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 July 2020**

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

[4] Computational Fluid Dynamics

Schedule (High Level)

- **Phase I – Data Gathering**
  - Blade Condition Analysis on inducted engines
  - Engine Test
  - CFD Analysis

COMPLETE PHASE I REPORT SUBMITTED

- **Phase II - IIA – Coating Optimization Tests**
  - Conduct tests at AFRL Supersonic Rain Erosion (SuRE) Rig

COMPLETE PHASE II REPORT SUBMITTED

- **Phase III – Flight Certification Tests**
  - Certification Plan
  - Test Plan
  - Metallographic Analysis
  - Mechanical Testing & Frequency Analysis
  - Impact Tests
  - Instructions for Continued Airworthiness (ICA) analysis

COMPLETE PHASE III REPORT COMPLETE

- **Phase IV – Flight Service Evaluation – Install On-wing April thru July 2018**
  - 500 hours: **Jun - Sep 2018**
  - 1000 hours: **Aug - Nov 2018**
  - 3000 hours: **Apr - July 2019**
  - 6000 hours: **Apr - July 2020**

Estimated engine inspection interval

1st Engine Installed April 2018

Risk Assessment Matrix

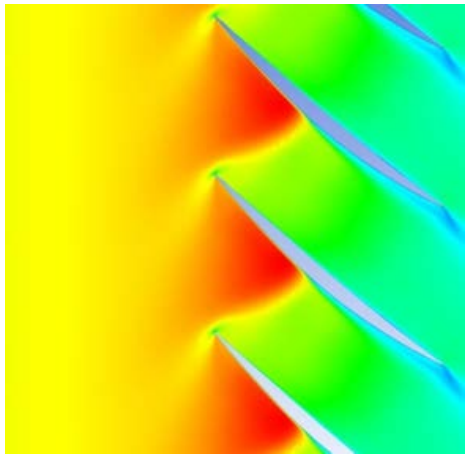
Task	Technical Risk	Schedule Risk	Budget Risk
Phase III - Flight Certification Tests			
Tooling Design & Fab	LOW	LOW	LOW
Weight Analysis	LOW	LOW	LOW
Metallographic Analysis	LOW	LOW	LOW
Frequency Analysis	LOW	LOW	LOW
Stress Analysis	LOW	LOW	LOW
Campbell Diagram	LOW	LOW	LOW
High Cycle Fatigue	LOW	LOW	LOW
Mechanical Property Tests	LOW	LOW	LOW
Impact Tests	LOW	LOW	LOW
Weld Repair Analysis	MEDIUM	LOW	LOW
Phase IV - Flight Demos			
Aircraft # 1	MEDIUM	LOW	LOW
Aircraft # 2	MEDIUM	LOW	LOW
Aircraft # 3	MEDIUM	LOW	LOW
Aircraft # 4	MEDIUM	LOW	LOW

- **Phase II / IIA component level technical results encouraging.**
- **Simulated operational conditions with loaded samples, representative impact speeds and water droplet size.**
- **LE condition of uncoated test specimen similar to LE of an operational blade**
- **Uncoated blades initial breach @ 3 passes.**
- **Coated blade initial breach @ 23+ passes.**
- **Potential to increase by 8X or greater via Flight Demonstration?**

Phase I – Data, Test & Simulate

Blade Condition Analysis

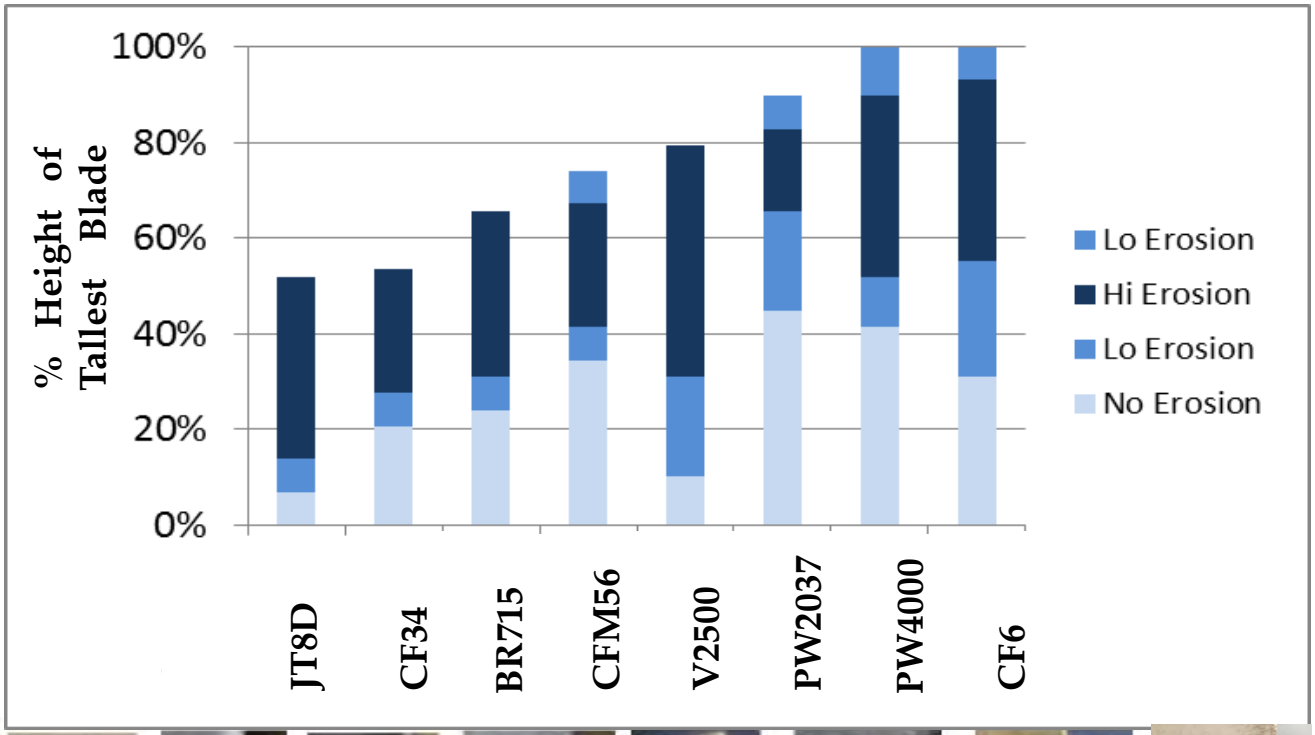
Engine Test Data

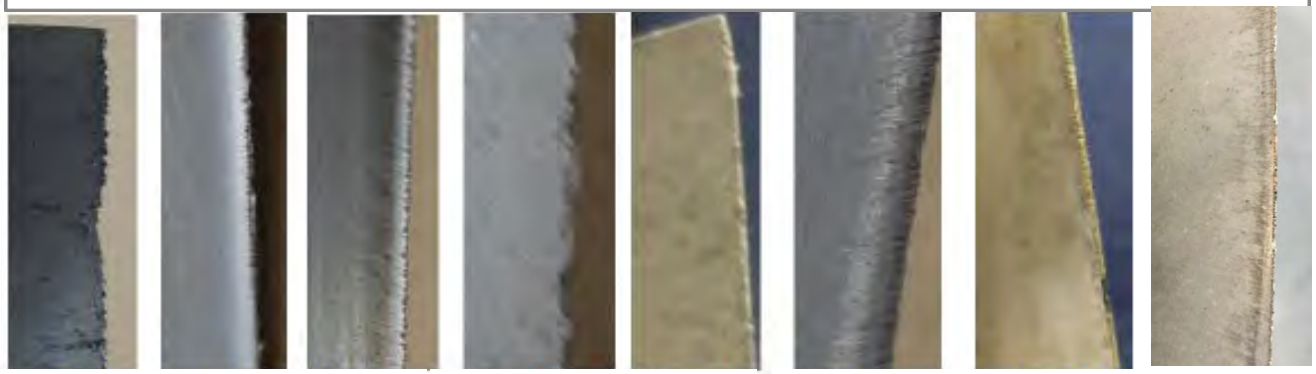


CFD Analysis

- 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

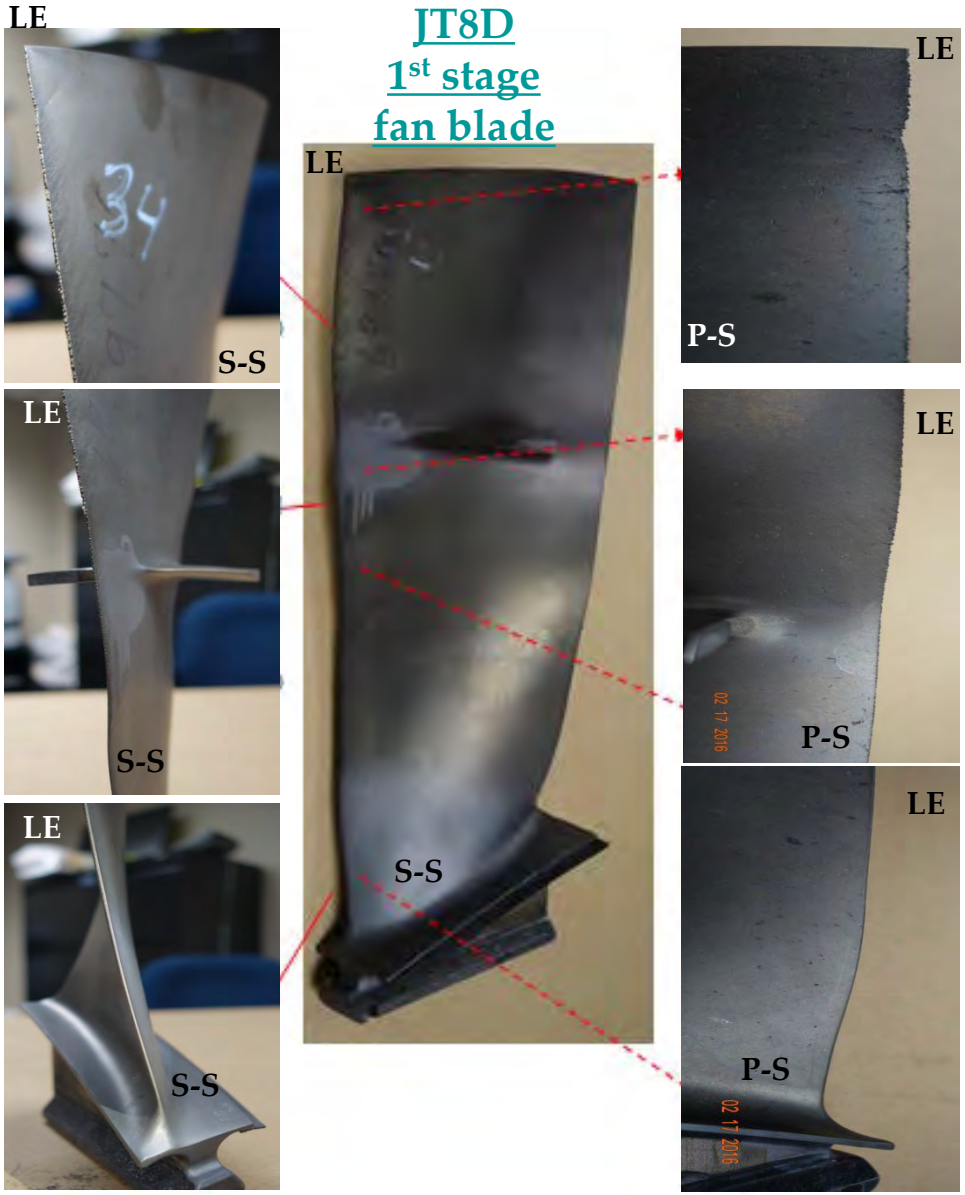
Phase I – Blade Condition Analysis

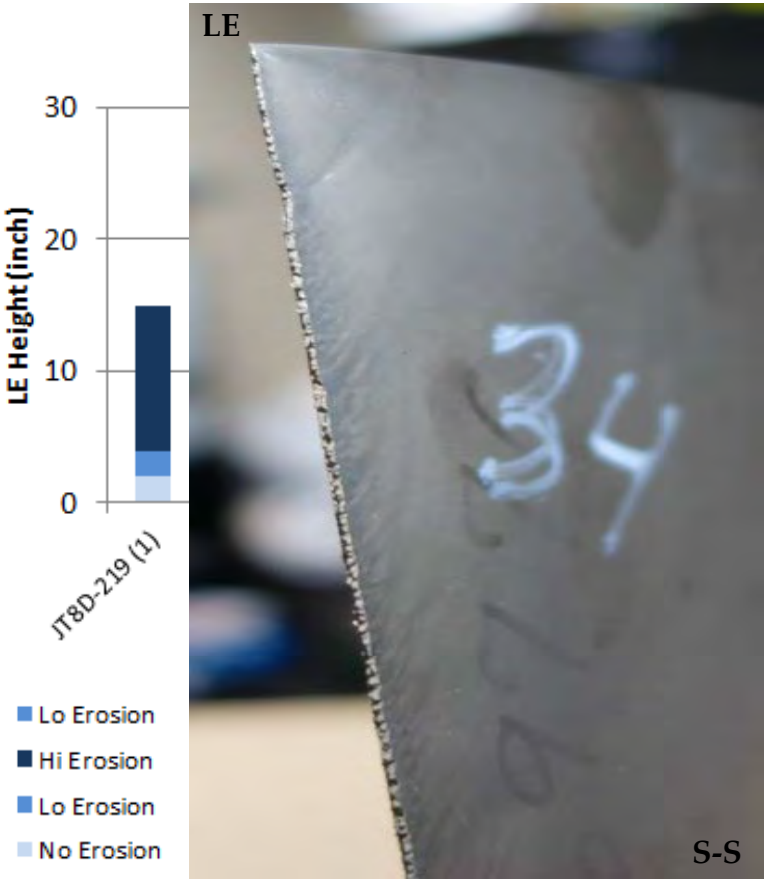




JT8D CF34 BR715 CFM56 V2500 PW2037 PW4000 CF6

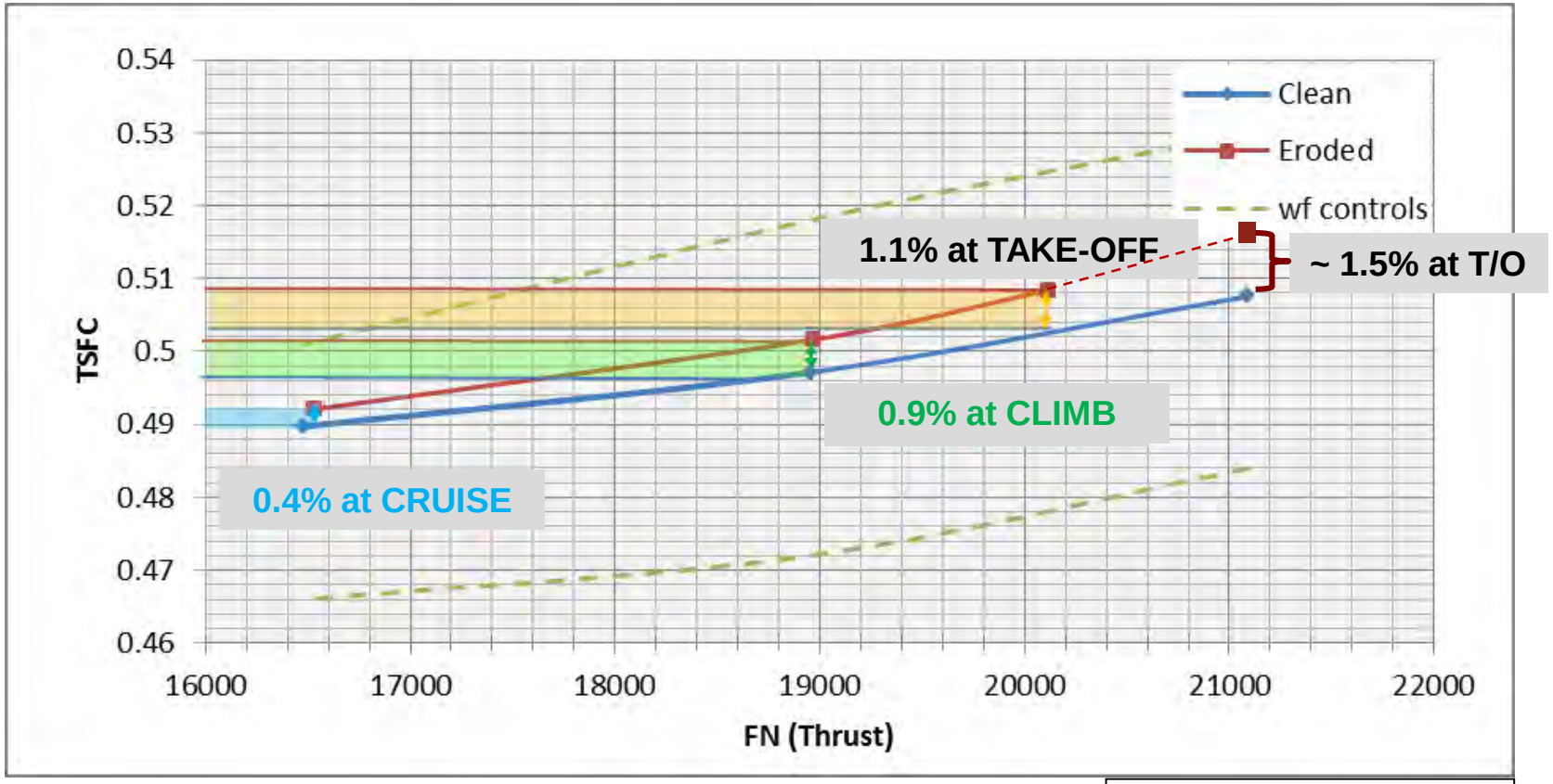
Phase I – Blade Condition Analysis





Phase I – Engine Test

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

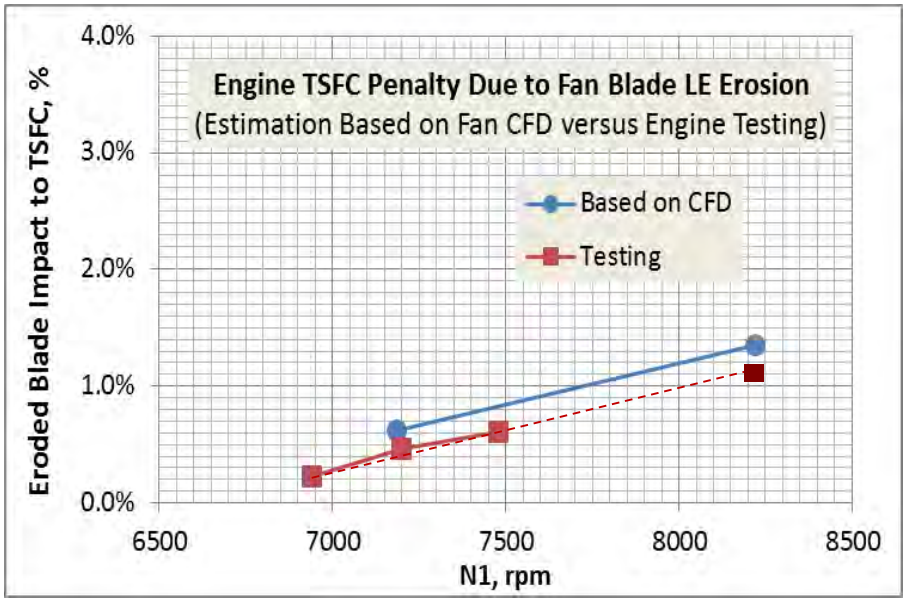


Clean = repaired, serviceable fan blades

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

Phase I – CFD Analysis

Engine Test Data vs CFD Analysis TSFC



TSFC comparison
Engine Test Data and CFD Analysis

Flight Condition	CFD (TSFC)	Engine Test (TSFC)
Fan Design Speed for Take-Off	1.35%	1.12%*
Max Continuous Thrust for Cruise	0.62%	0.40%

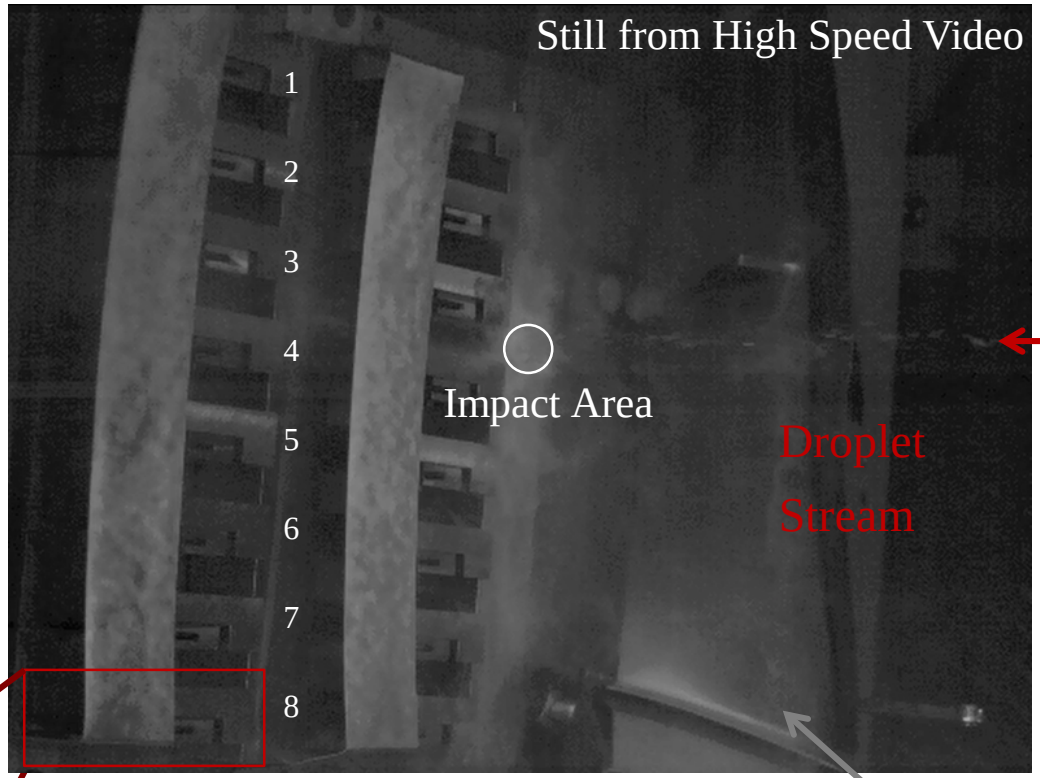
* Extrapolated values from test cell data

Phase II – Fluid Erosion Test

@ AFRL – Supersonic Rain Erosion (SuRE) Rig

Specimen Preparation

Specimen Tooling



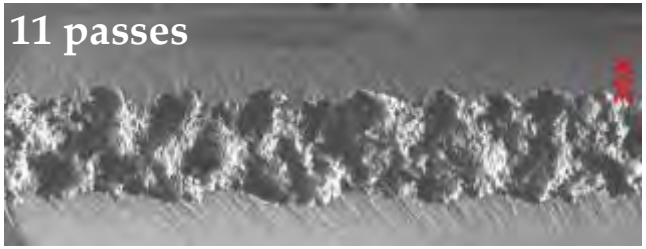
Uncoated Blade Specimen

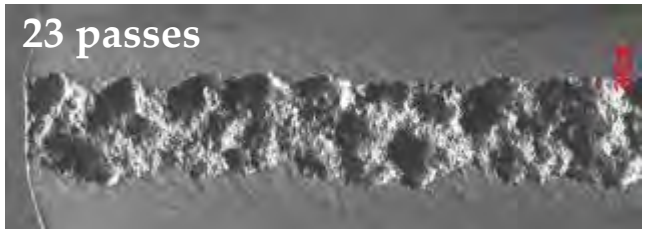
BlackGold® Coated Blade Specimen

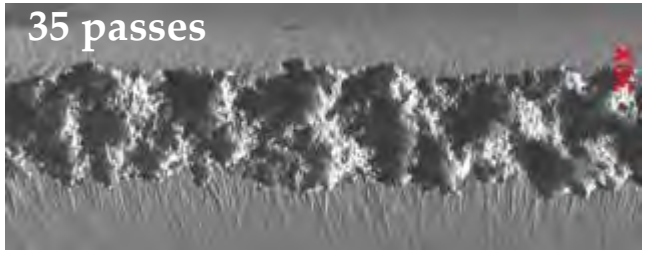
Coated Blade

Phase IIA – Test Results

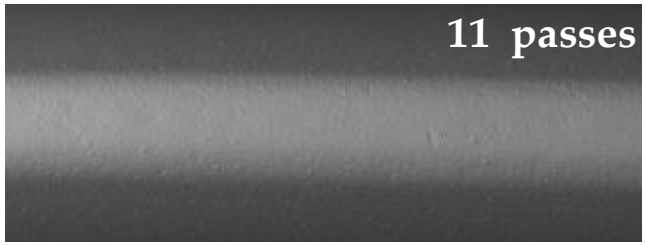
Uncoated PW2037

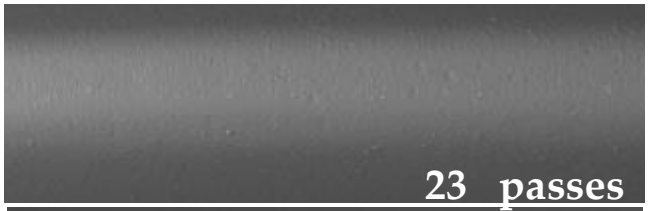


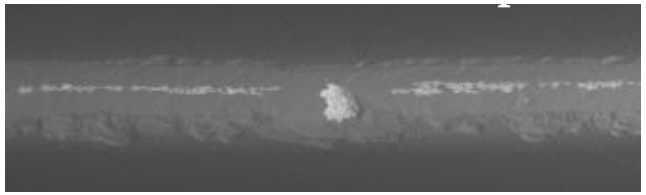


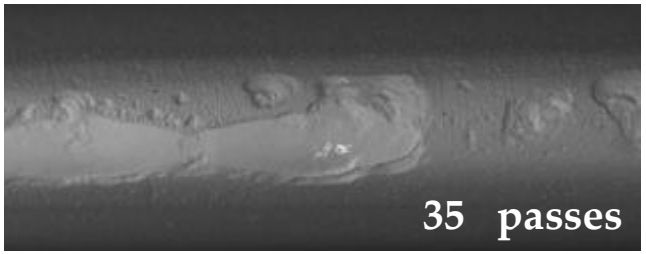


BlackGold® Coated PW2037



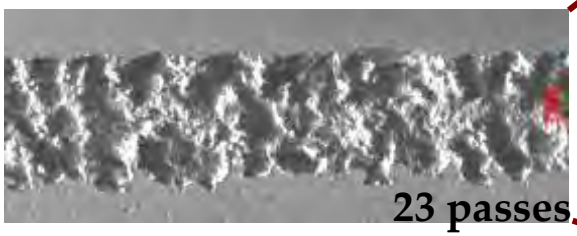


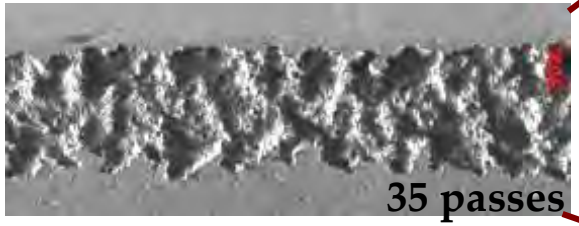




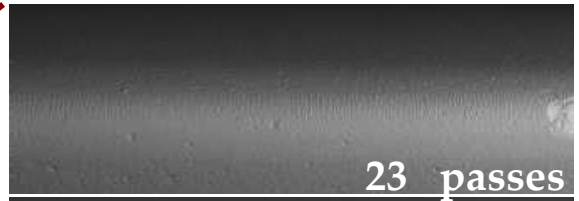
Phase IIA – Test Results

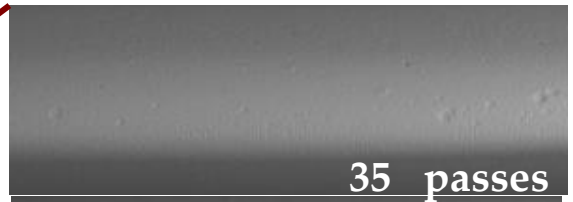
Uncoated CF6





BlackGold® Coated CF6

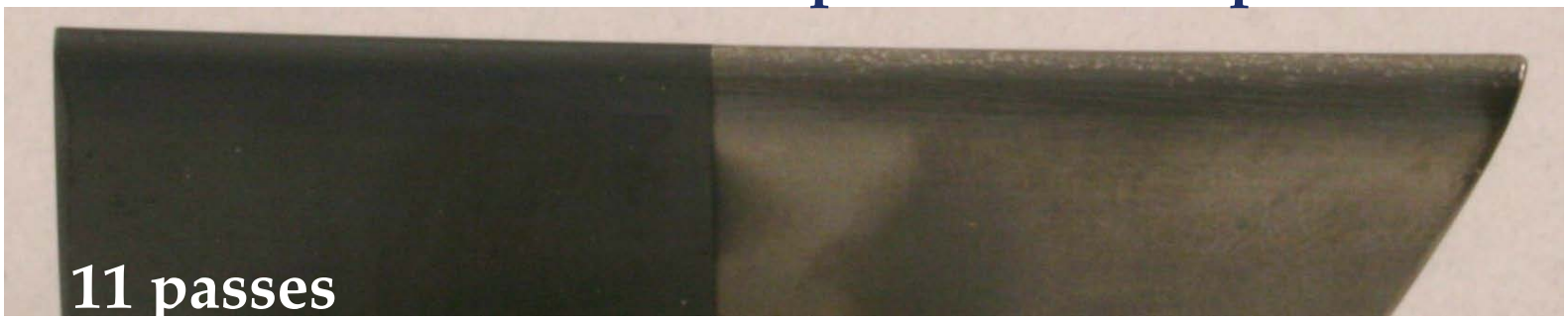


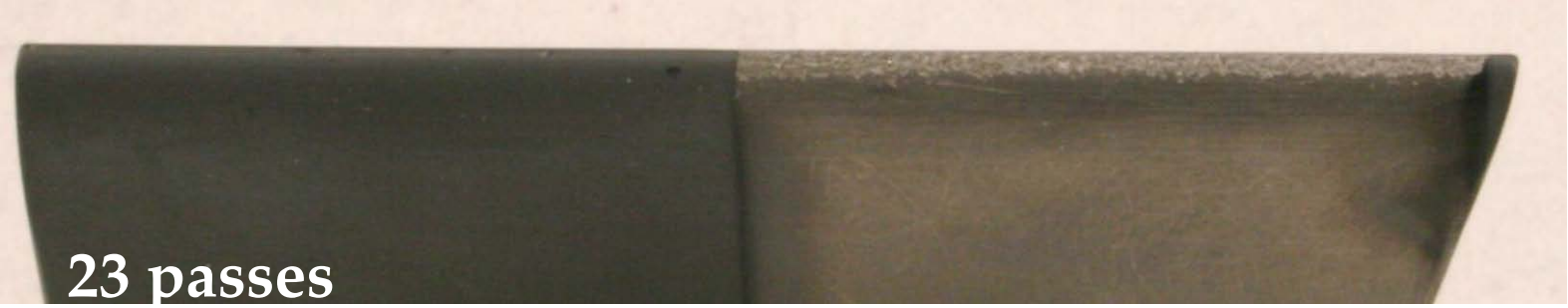


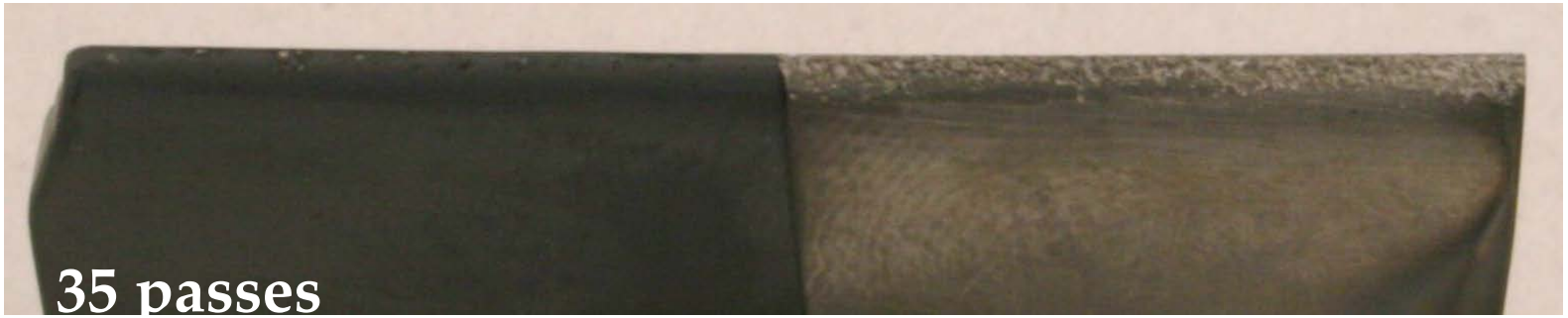
- No visible damage to the substrate even after 35 passes

Phase IIA – Test Results

Fluid Erosion Comparison Ti Strips







Fluid Erosion Tests @ AFRL

Conclusion

- AFRL's SuRE rig test closely reproduced damage observed on PW2000 and CF6 field blades
- BlackGold® coating provided protection
  - Projected improvement of ≈ 8X based on first breach point observed on uncoated (3 passes) and coated (23 passes) test specimens

PW2000 Uncoated 35 passes

≈ 300 μm pit depth

PW2000 Field part ≈ 5,000 cycles & 14,000 hours

≈ 300 μm pit depth

Similar depth damage

Phase III – Flight Cert Tests

Impact Test – Conducted at UDRI

BlackGold® Coating, Top View

Phase IV – Flight Demonstration

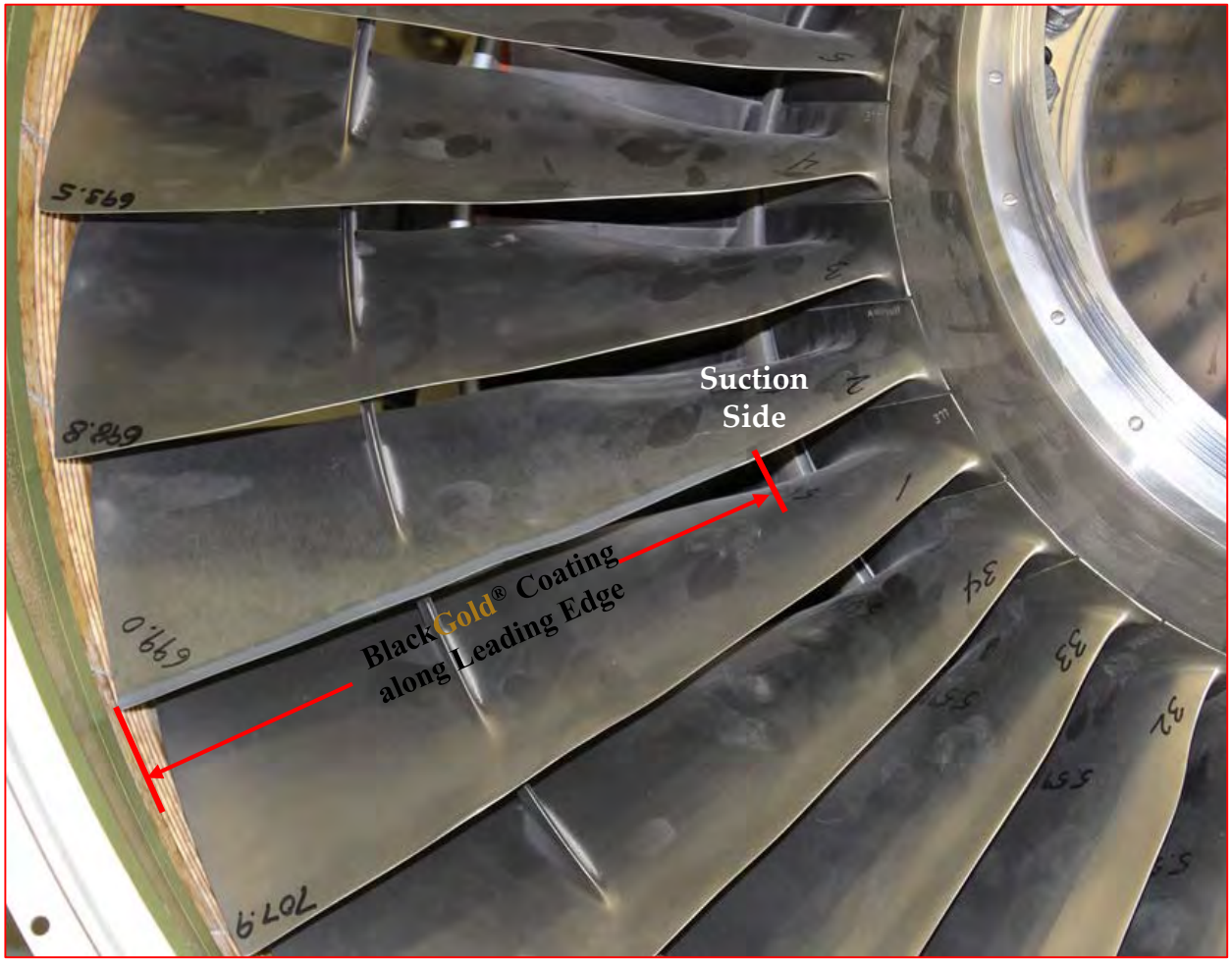
1st Coated Engine Installed

BlackGold® Coating
1st Stage Fan Blade Locations

Currently at 146 hours
≈ seven (7) hours per day

Phase IV – Flight Demonstration

1st Set of Coated Blades Installed – JT8D-219 Engine



Engine Set # 2

- passed test awaiting install

Engine Set # 3

- Assembled

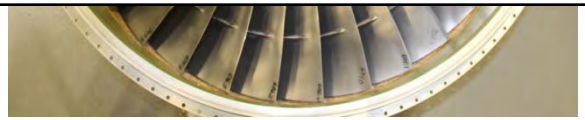
Engine Set # 4

- Ready for weight & balance

Phase IV – Flight Demonstration

CLEEN II Program Summary

for other engine types



DELTA TechOps

MDS Coating Technologies Corporation

AMERICA'S PHENIX

Aerospace Consultants for the Americas

THANK YOU