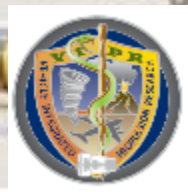




Vehicle Integrated Propulsion Research (VIPR) III Volcanic Ash Environment (VAE) Preliminary Visual and Teardown Observations



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Slides containing PW data generated under NASA Space
Act Agreement for approval for public release
Pgs 8, 9, 10, 11, 12, 13,14, 15, 16,17, 18, 19, 20, 22, 23, 24

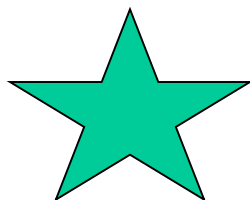


Slides containing PW data generated under Air Force
Contract for release by Air Force
Pgs 28, 29, 30, 31



NASA/Air Force Data provided for context of presentation
Pgs 1, 4, 5, 6, 25

Entire presentation will be cleared by NASA and Air Force for Public Release



Volcanic Ash Environment

EXPERIMENT SUMMARY



VIPR III Volcanic Ash Environment



Motivation	Fleet grounded
Prediction	<ul style="list-style-type: none">• <u>DEGRADATION</u> WITHIN <u>1HR @ LOW</u>;• <u>EGT EXCEEDANCE</u> @ <u>3HR HIGH</u>
Approach	<ul style="list-style-type: none">• Fed small ash amounts → installed engine → low & high feed rate
Experiment	<ul style="list-style-type: none">• Used best practices for on-wing test → Fleet vehicle & engine
Benefit	<ul style="list-style-type: none">• <i>May</i> assist in safe flying protocols & engine monitoring
Actual	<ul style="list-style-type: none">• 10 hours → Measurable degradation• (7 hours low and 3 hours high)• 14 hours → Engine had several degrees of margin remaining
Why	<ul style="list-style-type: none">• Conservative thresholds set to protect vehicle/engine asset• Real-world test needed on relevant equipment





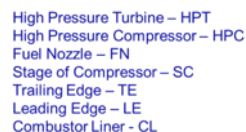
Summary of Run Schedule

Water Wash						
Ash Run 1 Low Rate						
Ash Run 2 Low Rate						
Ash Run 3 Low Rate						
Ash Run 4 High Rate						
Ash Run 5 High Rate						
	14-Jul	28-Jul	29-Jul	31-Jul	4-Aug	5-Aug



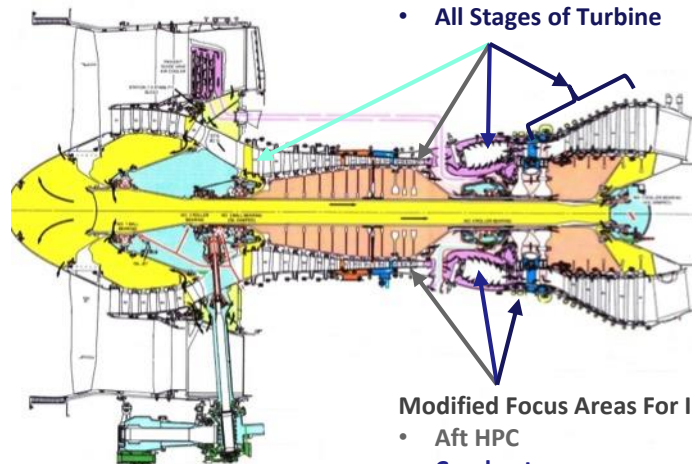
NOTES

- **LOW RATE IS A TARGET CONCENTRATION**
 - $\sim 1\text{MG/M}^3 \approx .11 \text{ GM/SEC FEED RATE}$
- **HIGH RATE IS A TARGET CONCENTRATION**
 - $\sim 10\text{MG/M}^3 \approx 1.1 \text{ GM/SEC FEED RATE}$
- **BASELINE ENGINE INSPECTION**
 - INDUSTRY AND GOVERNMENT EVALUATIONS
 - FORWARD AND AFT COMPRESSOR
 - ENTIRE TURBINE WAS SELECTED
- **FINDINGS**
 - AFT COMPRESSOR, BURNER SECTION & FORWARD TURBINE
 - MOST CRITICAL
 - CONTROL LINES (PB/P4.9)



Original Focus Areas For Inspection

- Forward Compressor
- Aft Compressor
- **Combustor**
- **All Stages of Turbine**




Modified Focus Areas For Inspection

- Aft HPC
- **Compressor**
- **Forward Stage of HPT**





Volcanic Ash Delivery

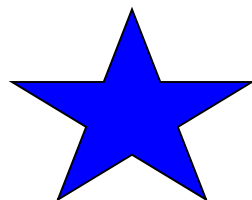


Date	Target Rate	Ash Flow Duration	Initial Ash Wt	Ash out during auger prime	Ash added during test	Ash augered out post-test	Actual Rate	Total Ash Delivered
	g/sec	minutes	g	g	g	g	g/sec	wt
28-Jul-15	0.1	90	2991	40	0	2221	0.14	730
29-Jul-15	0.1	68	3014	39	0	2426	0.13	549
31-Jul-15	0.1	269	2967	35	1000	1776	0.13	2156
4-Aug-15	1	175	2998	57	8977	901	1.05	11017
5-Aug-15	1	235	3001	64	12449	921	1.03	14465
All Tests Sum:	N/A	837	N/A	N/A	N/A	N/A		28917

✓

✓





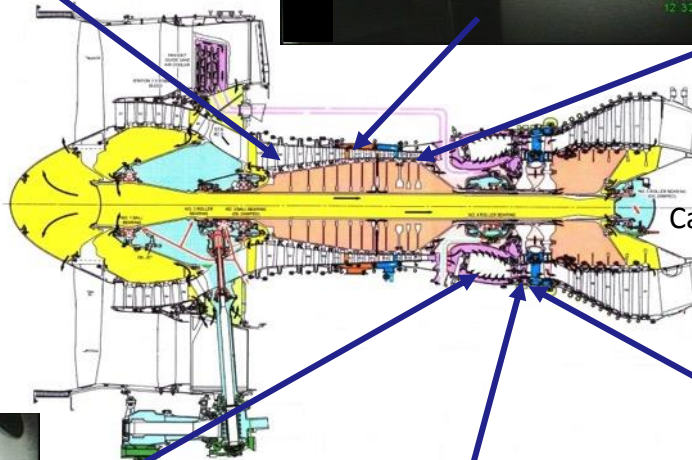
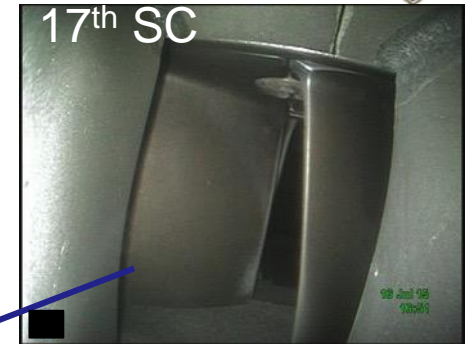
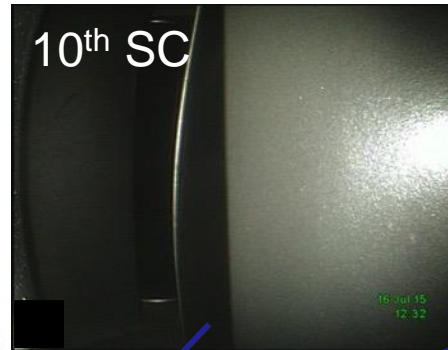
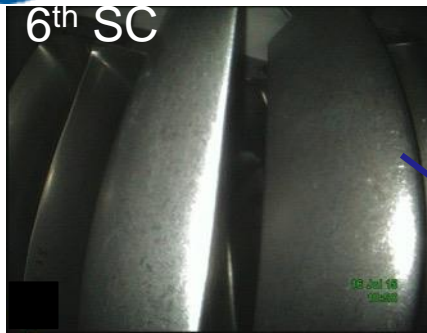
5 Days of Engine Tests

ENGINE ASH INGESTION OBSERVATIONS

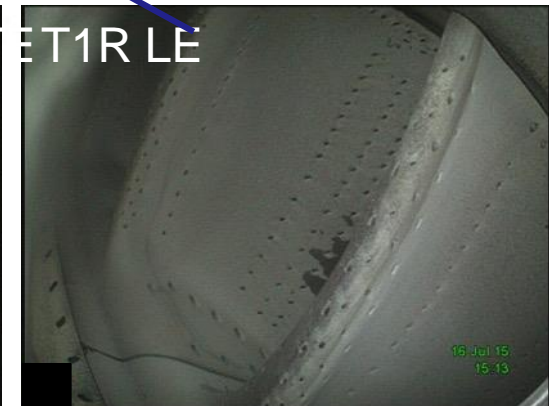
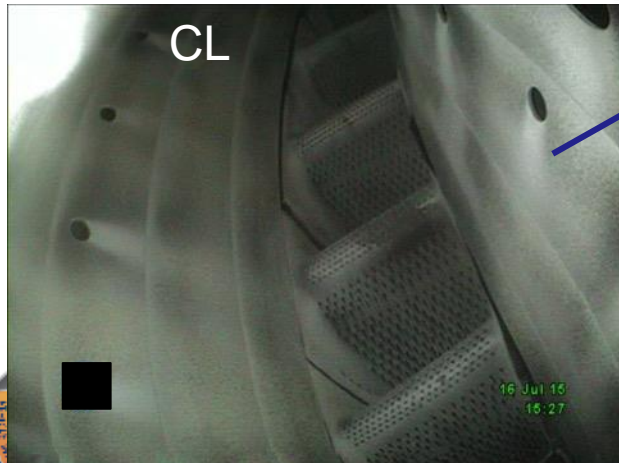




Baseline – Post Water Wash 14 July 2015



Whiteish coating →
Calcium Carbonate Used During Prior Research





Baseline – Post Water Wash 14 July 2015

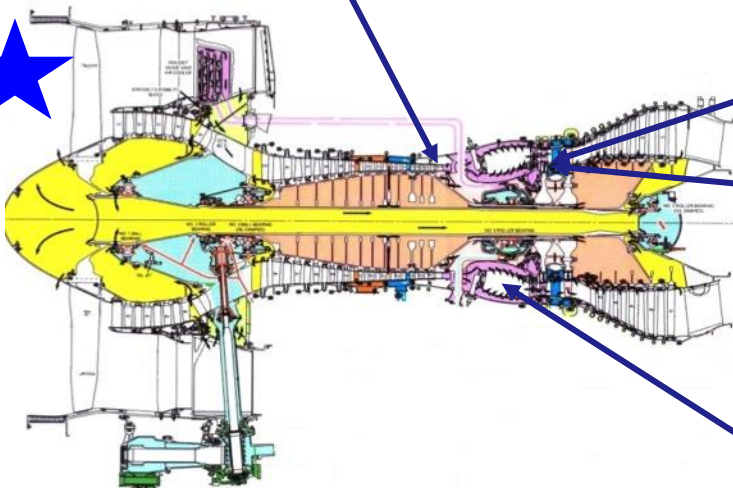


- No issues with blades or vanes
- TBC intact
- No blade distress
- Darker areas on blades potentially soot from shutdown
- No appearance of coating or alloy burning





Run 1 Low Ash Rate 28 July 2015



Distribution A. Approved for public release: distribution unlimited





Run 1 Low Ash Rate 28 July 2015

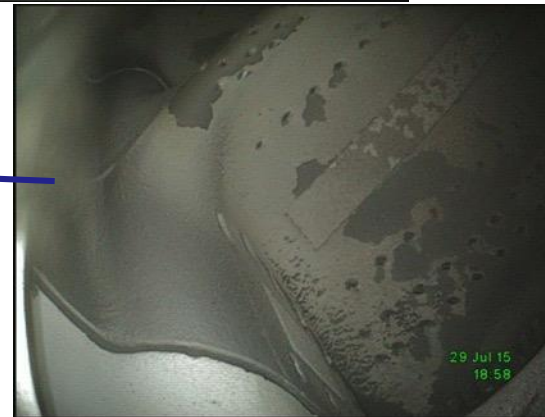
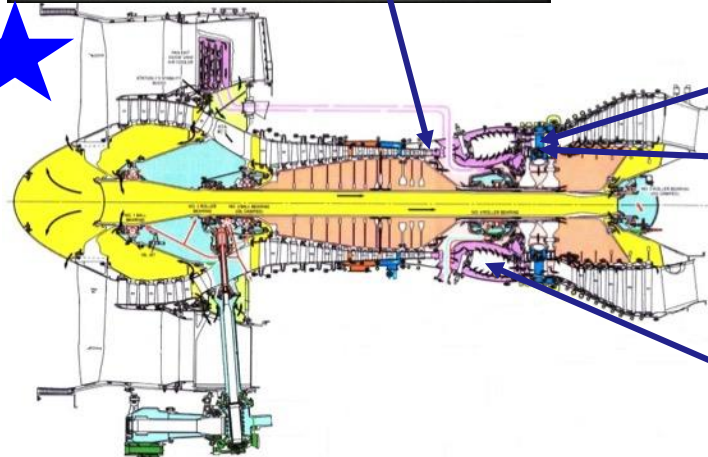
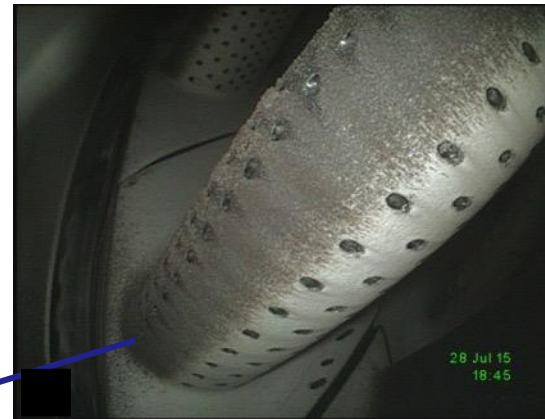


- No evidence of ash accumulation on turbine parts
- Slight plugging of cooling holes in first stage turbine vane
- Cooling air still flowing, not a concern to continue running
- Mild ash accumulation on 10th stage bleed cap
- HPC very clean, no obvious wear or discoloration





Run 2 Low Ash Rate 29 July 2015





Run 2 Low Ash Rate 29 July 2015

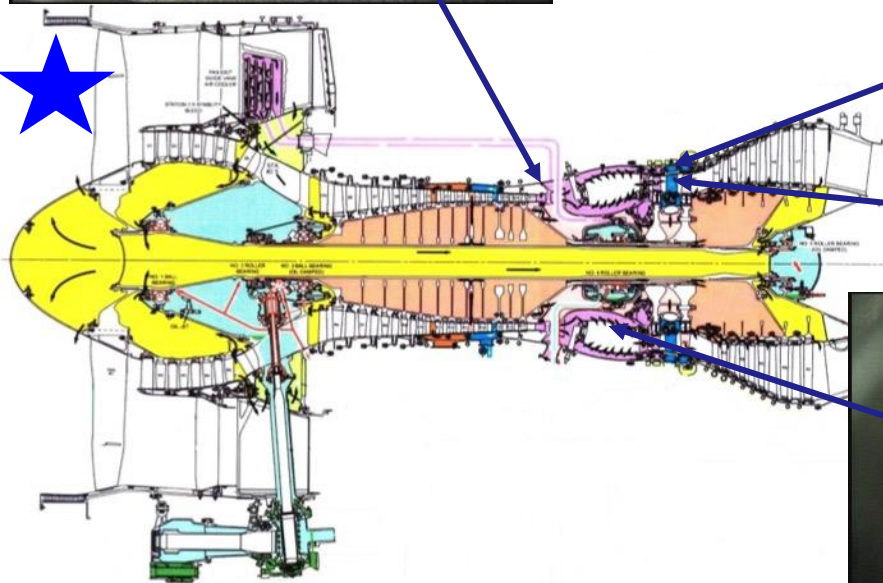


- Slight ash seen on first vane leading edge
- No ash seen on gauge point area of 1st vane
- No ash seen on first blade
- 1st blade outer edge seal leading edge region
 - *May have small ash particles*





Run 3 Low Ash Rate 31 July 2015



Distribution A. Approved for public release: distribution unlimited



Run 3 Low Ash Rate 31 July 2015

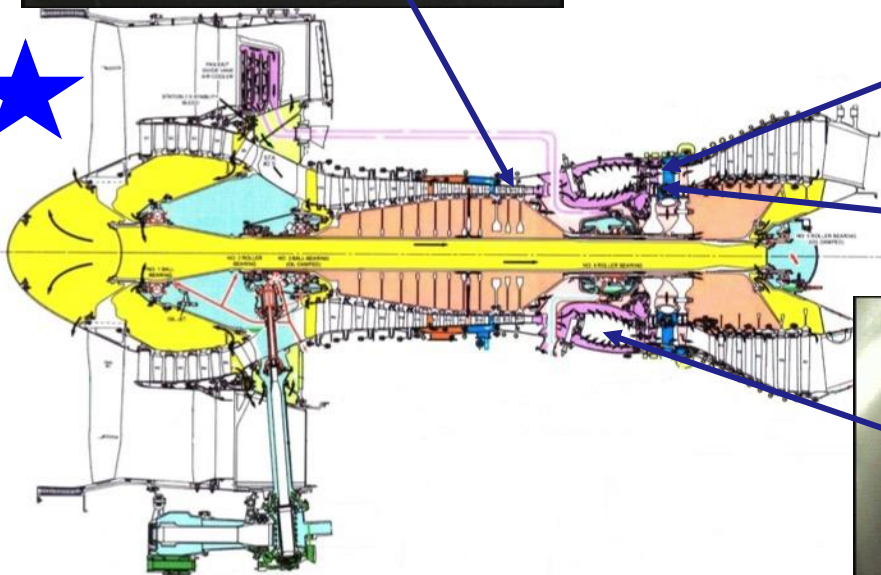


- **More build up**
 - 1st vanes leading edge and forward pressure side
- **Aft pressure side gauge area (A4)**
 - No built up thus -not reducing the gauge area
- ★ • **1st blades**
 - Still show very little effect of the ash
- **Shedding material starting to show up in combustor area**
- **Other areas around the fuel nozzle show some very local ash accumulation**
- **Turbine ash accumulation in is still very low**
 - Not expected to impact the durability or ability to continue to high rate





Run 4 High Ash Rate 4 August 2015



Distribution A. Approved for public release: distribution unlimited



Run 4 High Ash Rate 4 August 2015

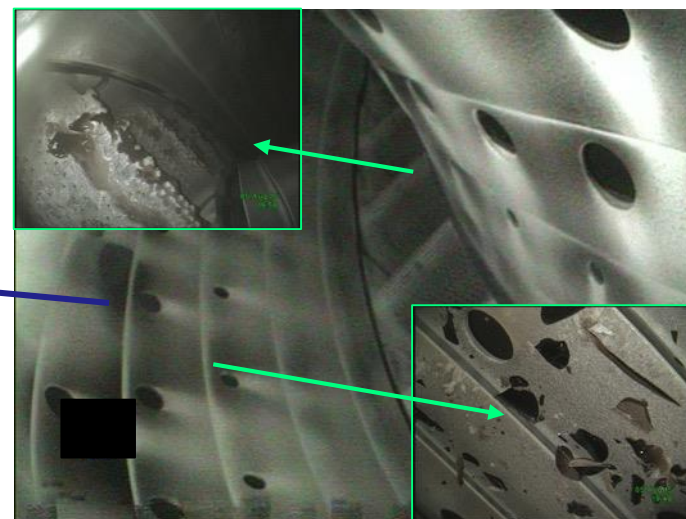
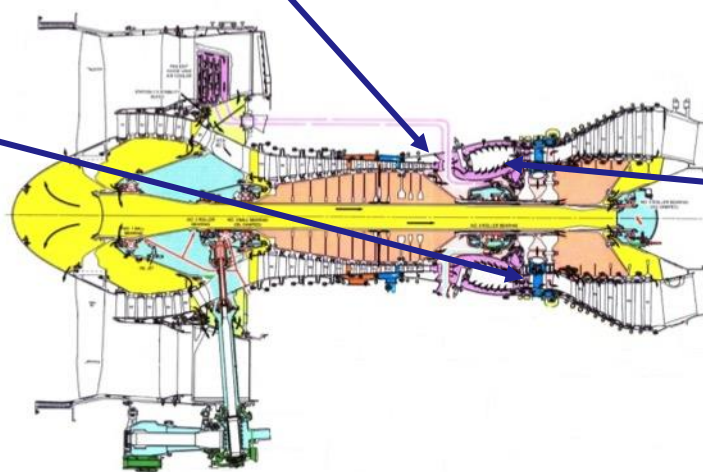
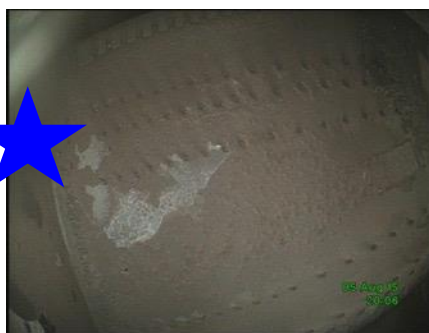
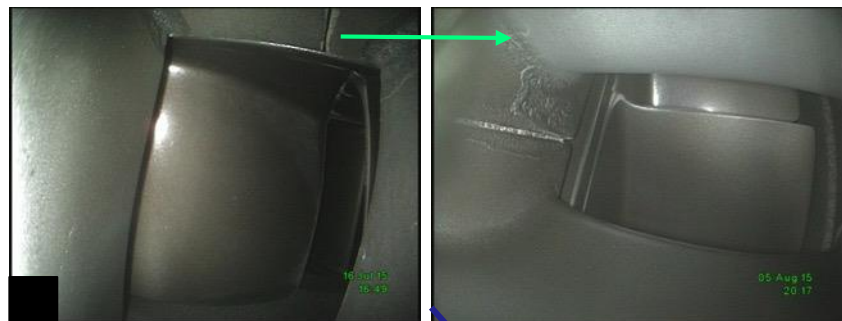


- **1st stage turbine vanes**
 - Build up appears to be glassified ash as expected
 - Gauge point region -still not significantly closed down
- **Combustor and turbine**
 - Show large thin flakes of ash shedding
- **1st blades still are relatively clean**
 - No concerns
- **Recommend**
 - Continue running at this point





Run 5 High Ash Rate 5 August 15



Distribution A. Approved for public release: distribution unlimited

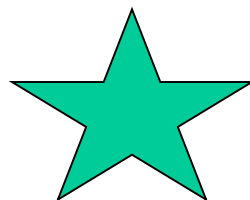


Run 5 High Ash Rate 5 August 15



- **1st vane**
 - Build up and shedding looks similar to the 1st high rate run day
 - Gauge area (A4) still not built up.
- **Combustor looks similar to first high run day**
- **New boroscope finding on last day**
 - Slight build up on some 1st blade leading edges
 - Assume it's ash, but does not look “glassified”
 - Disassembly will be required to tell if it's ash or not





Summary by Engine Module

ENGINE ASH INGESTION OBSERVATIONS





Summary – Combustor Degradation

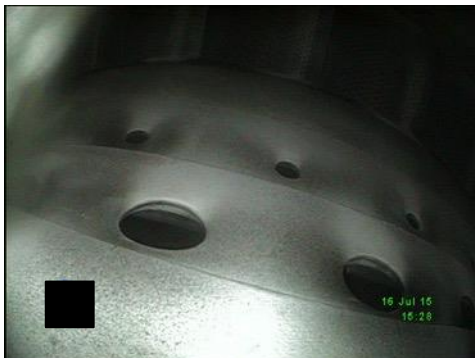


Run 1

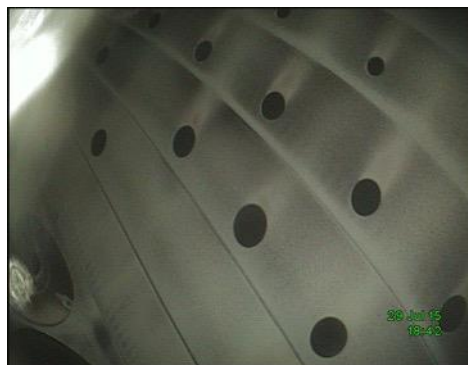
Run 2

Run 3

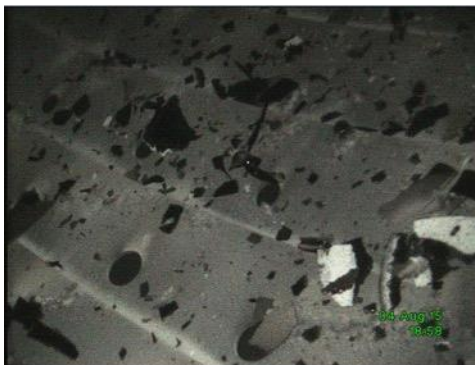
Post Water
Wash



Low
Concentration



High
Concentration



Distribution A. Approved for public release: distribution unlimited





Summary – First Stage Turbine Vane Degradation



Run 1

Run 2

Run 3

Post Water
Wash



Low
Concentration



High
Concentration



Distribution A. Approved for public release: distribution unlimited



Summary – 1st Stage Turbine Rotor Degradation

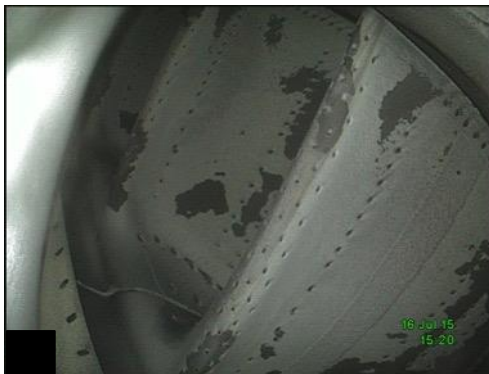


Run 1

Run 2

Run 3

Post Water
Wash



Low
Concentration

High
Concentration



Distribution A. Approved for public release: distribution unlimited



Volcanic Ash Experiment



- **VIPRIII is only one data point**
 - *Very important for modern high-performance turbine engines*



Particulate Feed Rates Do Matter





Volcanic Ash Experiment

Consideration In Follow-on Testing



Operational/Environmental

- On-wing or in test stand
- Type – F117 or other
- Volcano/ash and mixture (gas or foam) type
 - Pacific NW vs SW-CONUS vs Asia vs Iceland vs standard model ash
- Non-vis/vis ash concentrations for fly/no fly decision
- Known validated/monitored performance conditions





Post VAE Engine Teardown

ENGINE ASH INGESTION OBSERVATIONS



Initial Teardown Observations



- **Fan/Fan Case**

- No indication of ash buildup in fan bypass, transitions, joints, or interfaces
- Fan blade leading edges had slight change in roughness and rounding
- Spinner components and fan exit guide vanes did not have any visible erosion



- **Low Pressure Compressor**

- Not disassembled during the period of the initial teardown report
- 1st stage LPC appeared to have surface finish changes between blade platforms
- 5th stage LPC contained blades with trailing edge tip distress and polishing
- Ash accumulation on outer side of flanges





Initial Teardown Observations



- **High Pressure Compressor**

- All blades and stator vane assemblies were “polished” on the outer $\frac{1}{4}$ - $\frac{1}{3}$ span
- 8th stage HPC wear at leading edge tips
- 11th stage HPC wear at trailing edge tips
- *Variable stator segments (6th- 10th stages) were “stiff”, normally smooth when turning by hand
- Blade Outer Air Seals (BOAS) intact for forward stators (6th – 10th stages)
- Blue tinting appearing on metal disk stages 10-17, with heaviest notes on 14th and 15th
- HPC exit stators contain leading edge distress extending radially outwards

* Reported as atypical





Initial Teardown Observations



- **Combustor**

- Inner and outer combustor liner intact with no evidence of distress
 - Ash accumulation on inner and outer liner surfaces with additional build up in the outer cavity between the burner and diffuser case
 - Inner liner had a light tan ash deposits aft of the cooling holes
- *Green tint on outside wall of outer basket, increasing further aft
- Combustor was more difficult to remove than typical
- Glass-like deposits found at 6 o'clock position when engine held horizontal

* Reported as atypical





Initial Teardown Observations



- **Combustor (cont'd)**
 - Fuel nozzle air holes had significant ash build up but did not appear to obstruct air flow





Initial Teardown Observations



- **High Pressure Turbine**

- 1st Stage Vane Assemblies

- Ash deposits of various transformations accumulated on most of the vanes and varied in thickness, reflectivity, color and coverage
 - Shedding appeared to have occurred multiple times at some locations
 - Some deposits were estimated to be 7- 10 mm thick
 - Some of the heavier deposits completely covered leading edge cooling holes, preventing flow
 - Trailing edge surface accumulation was notably different in texture and color compared to leading edge buildup





Initial Teardown Observations



- **High Pressure Turbine (cont'd)**
 - 1st Stage Vane Assemblies
 - Cooling circuit inner flow path appeared to be clear of ash
 - 1st Stage Blades
 - Majority of leading edge of blades had sporadic blockage of cooling holes
 - Leading edges of blades exhibit mechanical impact erosion and some appear to have divots





Initial Teardown Observations



- **High Pressure Turbine Continued**

- 1st Stage Blades Continued

- The pressure side of the blades a matte tan color was evident



- Various levels TBC spallation and removal observed throughout blades
 - Ash accumulation found in cooling passage at root but did not show plugging
 - Platform cooling holes were not plugged
 - Typical wear on outer edge BOAS





Initial Teardown Observations



- **High Pressure Turbine Continued**

- 2nd Stage Vane Assemblies

- No visual evidence of cooling flow blockage on vane and inner cooling flow path circuit is clean

- Few vanes had TBC missing

- 2nd Stage Blades

- Blades were normal, unremarkable
 - Loose ash found on blades and blade roots
 - Heavy ash content found below the platform
 - Coating material on BOAS missing in blade path

