

# Process Compensated Resonance Testing CF6-80A 1<sup>st</sup> Stage HPT Blade

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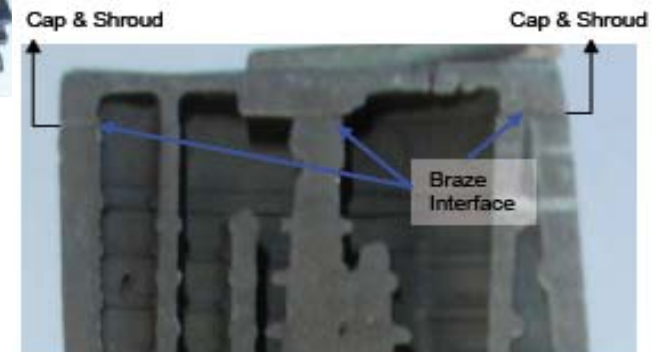
**Vibrant**



**DELTA** 

# OUTLINE OF PRESENTATION

- Background/History
- Area Of Interest
- PCRT Overview
- PCRT correlation to braze quality
- PCRT vs Other NDT
- Other Applications
- Summary



# BACKGROUND/HISTORY

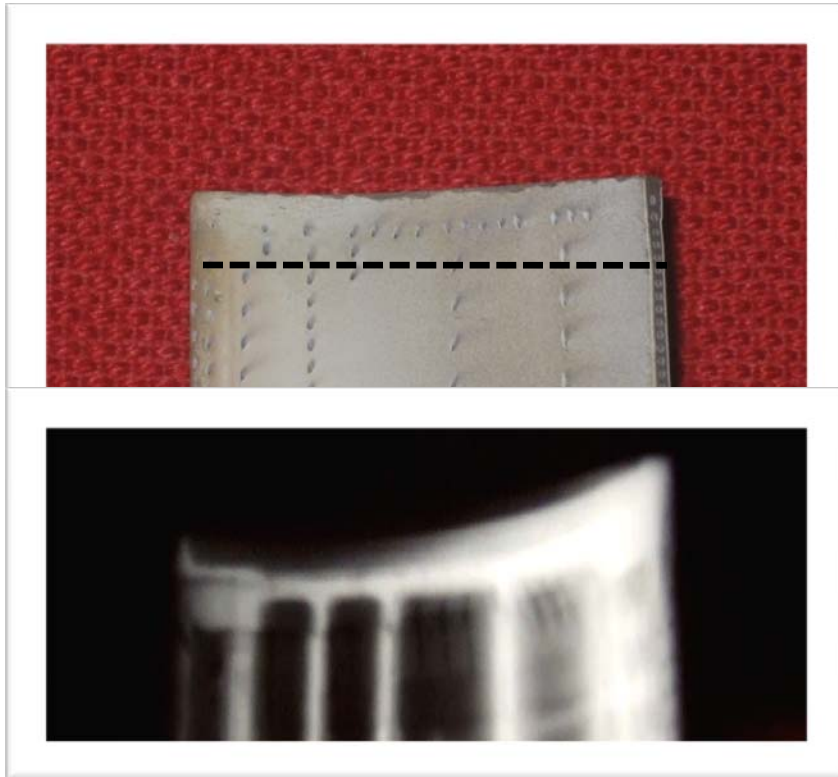


## CF6-80A 1<sup>st</sup> Stage HPT Blade

- Brazed end-caps
- No Standard NDT method inspection available
  - Repair and Overhaul X-ray and FPI methods prove to be inconclusive in detecting braze interface cracking.
  - Blades returned as serviceable are still considered suspect.
- New part number replaces brazed tip cap blades with cast blade (including cap)
- Failure results in loss of HPT blades and damage to downstream components

**CF6-80A 1 Stage HPT Blades are suspected of containing hidden defects**

# AREA OF INTEREST



## CF6-80A 1<sup>st</sup> Stage HPT Blade

- 5 Failures attributed to brazed tip cap liberation – EXPENSIVE!
- 20+ unscheduled engine removals – EXPENSIVE!
- Delta reliability initiative = pull all blades with > 10,000 hrs and scrap/quarantine
- Estimate premature removal of 1500 blades with an average of 50% of life still remaining – EXPENSIVE!
- Blade potentially reclaimed if inspection technique examines braze integrity
  - Blades which fail inspection could be repaired

**CF6-80A 1st Stage HPT Blades have caused pain**

# PCRT OVERVIEW

## Process Compensated Resonance Testing with Vibrant Corporation fixed nest

- No requirement to coating strip or surface prep
- Eliminates structural integrity suspicions
- Eliminates acceptance of hidden structural defects
- Eliminates corrosion concern in Engineering
- Improves inspection methodology and reliability

### Status

- Part inspection in progress, algorithm developed
- Comparing PCRT to:
  - X-ray (current process)
  - Visual/FPI (current process)
  - Computed Tomography
  - Mechanical testing
- Data required for reclamation is low
  - Delta instituted rule, not FAA
  - Supplemental to OEM manuals



**PCRT can be used to reclaim CF6-80 T1 blades = significant savings**

# PCRT OVERVIEW

**PCRT System** uses resonance spectra and complex algorithms to correctly sort acceptable from unacceptable parts

**Resonant Frequencies** determined by dimensions and material properties of “whole part”

$$f_r \sim \sqrt{k/m}$$

$f_r$  = resonant frequency

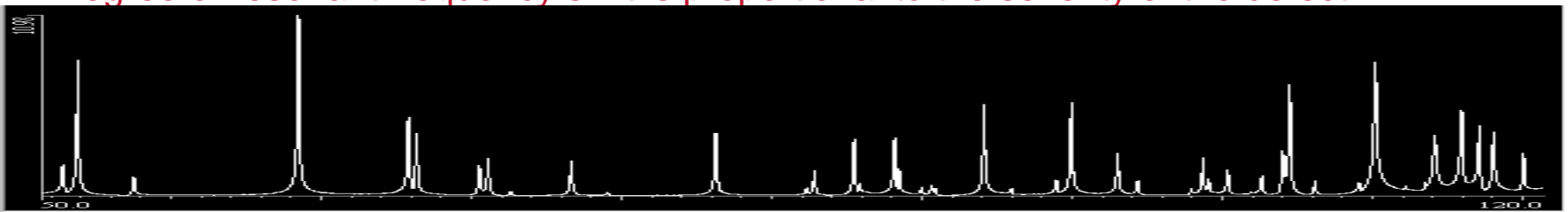
$k$  = stiffness (elastic properties e.g., Young’s Modulus)

$m$  = mass (dimensions, density)

**Structural Defect** = Strength reduction caused by degraded material properties or dimensional variation

e.g., a crack reduces stiffness and lowers the resonant frequency

Degree of resonant frequency shift is proportional to the severity of the defect



**Resonance Spectra**

**Use of PCRT can significantly reduce inspection time**

# PCRT OVERVIEW

**Simple resonance analysis** is insufficient for defect detection since unacceptable and acceptable patterns are interlaced

**PCRT calculations** MTS (Mahalanobis-Taguchi System) characterizes acceptable parts & variation and a Bias score characterizes unacceptable parts

## PCRT System Hardware

- Simple part interface, PZT transducers
- Precision spectrum analyzer & signal generator

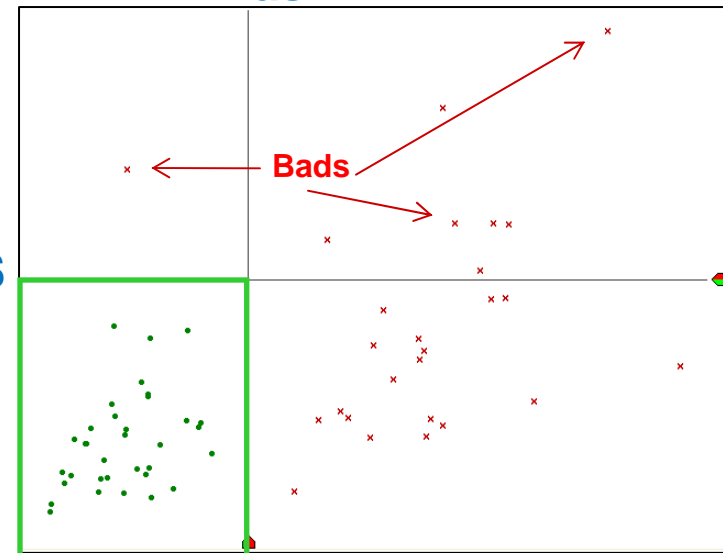
## PCRT System Software

- PC computing power
- Statistical analysis with Mahalanobis-Taguchi
- Vibrational pattern recognition algorithms
- Digital storage of spectra

## PCRT Strengths

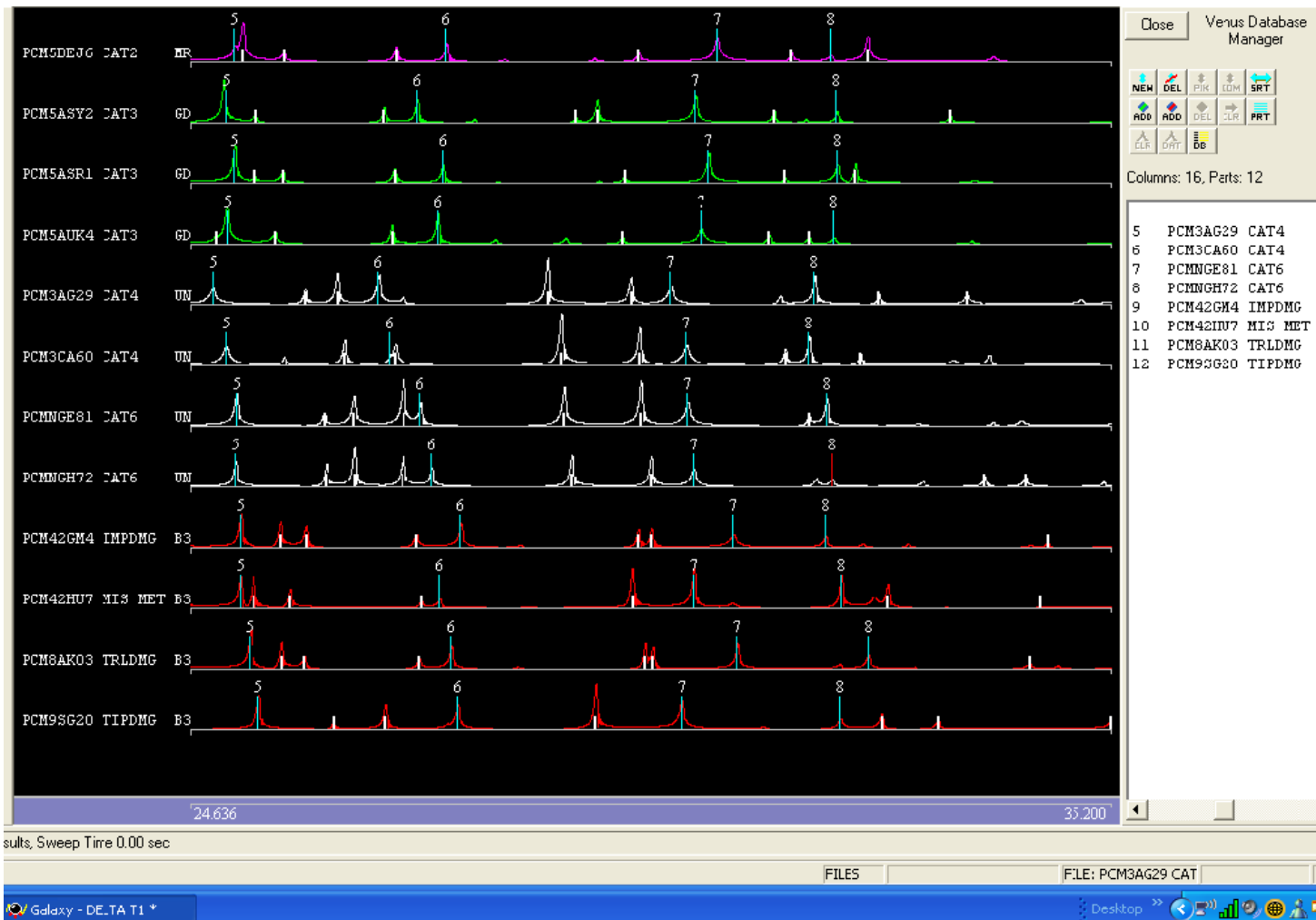
- Rigid, Hard Components
- Characterizing Mature, Well-Controlled Manufacturing Processes
- Sorting for Structural Integrity with a Single, Whole Body Test for Multiple Defects
- Digital Historical Record of Resonant Spectra for Life-of-Part Surveillance
- Elimination of Operator Error

MTS



**Use of PCRT can significantly increase inspection confidence**

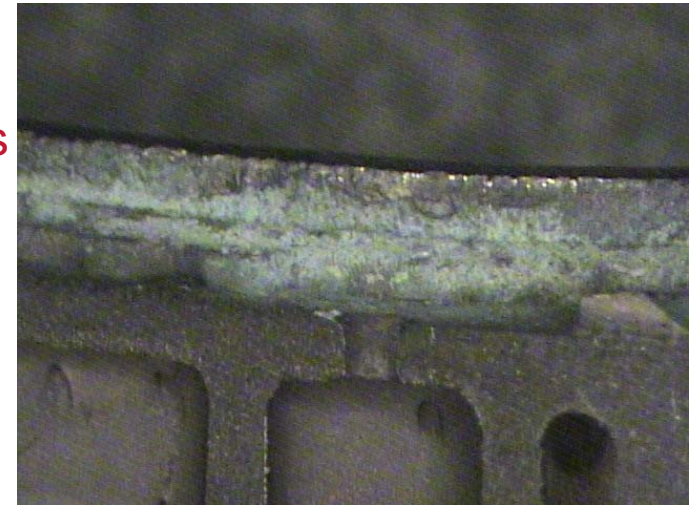
# PCRT OVERVIEW



**The power of PCRT is the advanced software behind it**

# PCRT RESULTS – BRAZE QUALITY

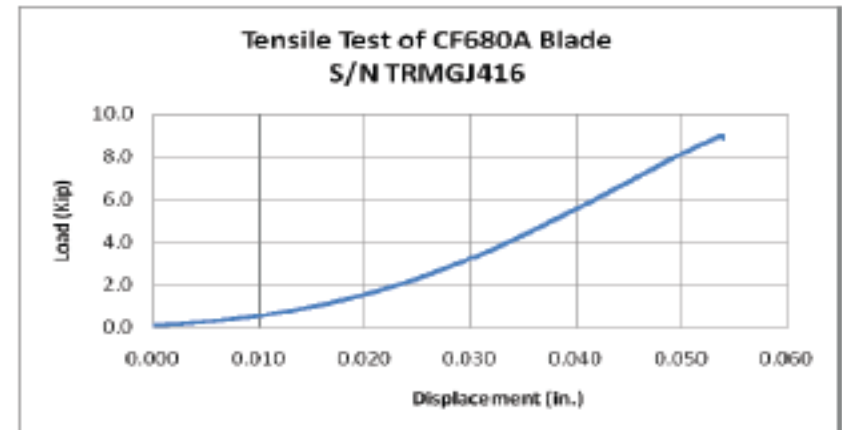
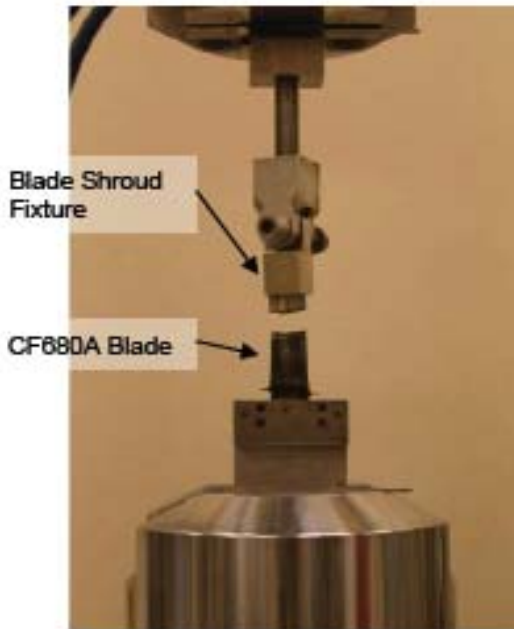
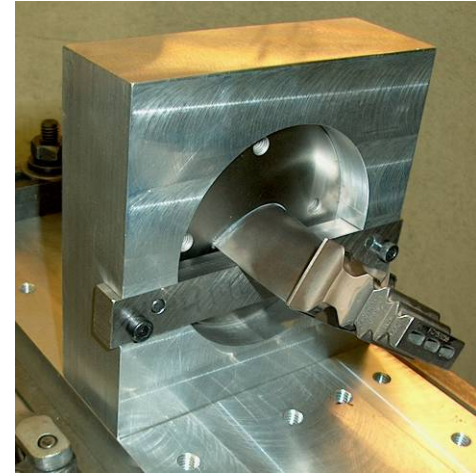
- 325 blades scanned with PCRT
  - Sort developed based on braze quality
- Typical Failure details:
  - Braze interface under the cap breaks down from fatigue or inadequate diffusion
  - Because the cap contact is limited to the leading edge, cavity one, and the internal partitions, the cracking almost always propagates toward the leading edge
- Blades identified with PCRT as suspect
- 30 blades sent to Sandia National Labs for CT scans
- X-ray performed at Chromalloy
  - Level III examined, compared to PCRT results
- Visual for LE cracking performed by two Level IIIs
- 10 blades exhibit cracking from CT scans



**PCRT results correlate well with other techniques**

# PCRT CORRELATION TO BRAZE STRENGTH

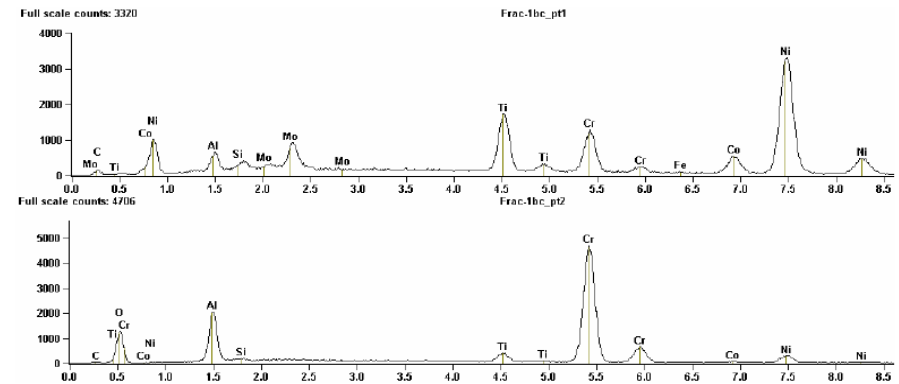
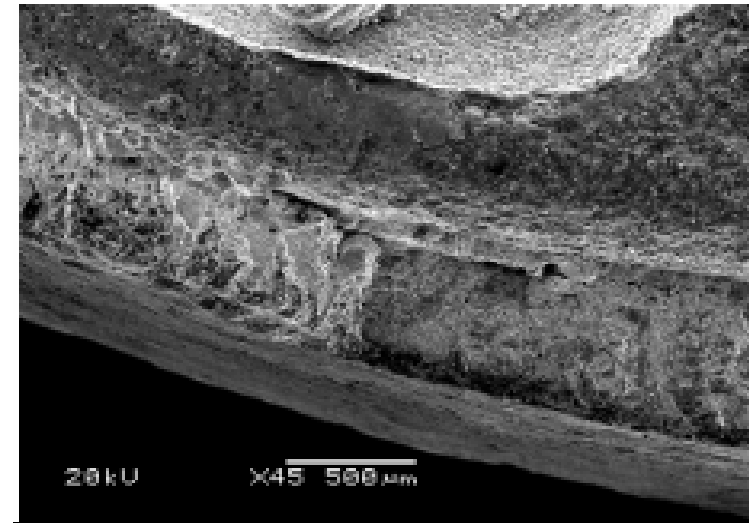
- DESTRUCTIVE TESTING AT FAA-AANC
  - Torsional test
    - Twist, fail at highest stress point
  - Tensile test
    - Laser welded fixture to cap



**PCRT results correlate well with destructive testing**

# PCRT CORRELATION WITH BRAZE DEFECT

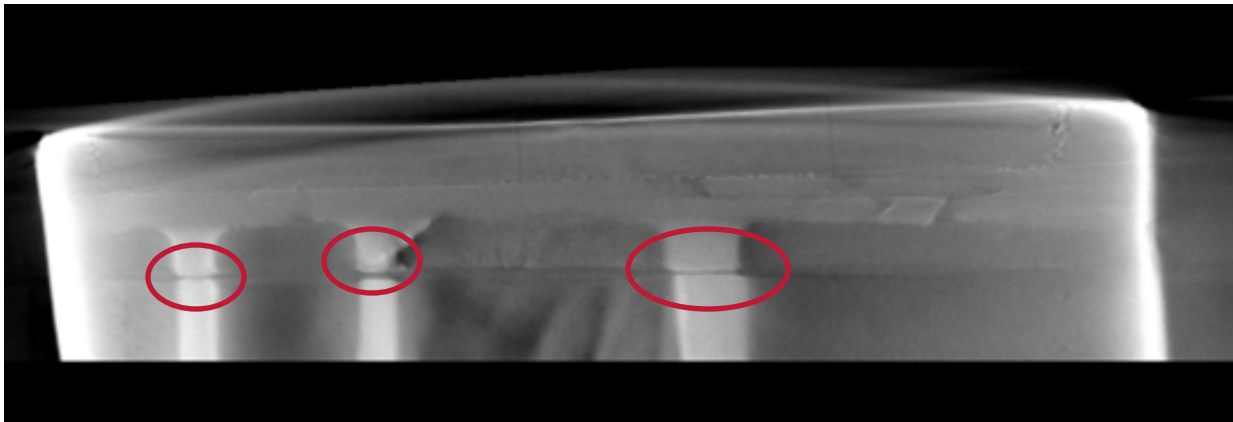
- Fractography at Sandia National Labs
  - SEM confirms braze defect
  - Elemental compositions via Energy Dispersive Spectroscopy (EDS)



**PCRT results correlate well with fractography**

# PCRT VS OTHER NDT TECHNIQUES

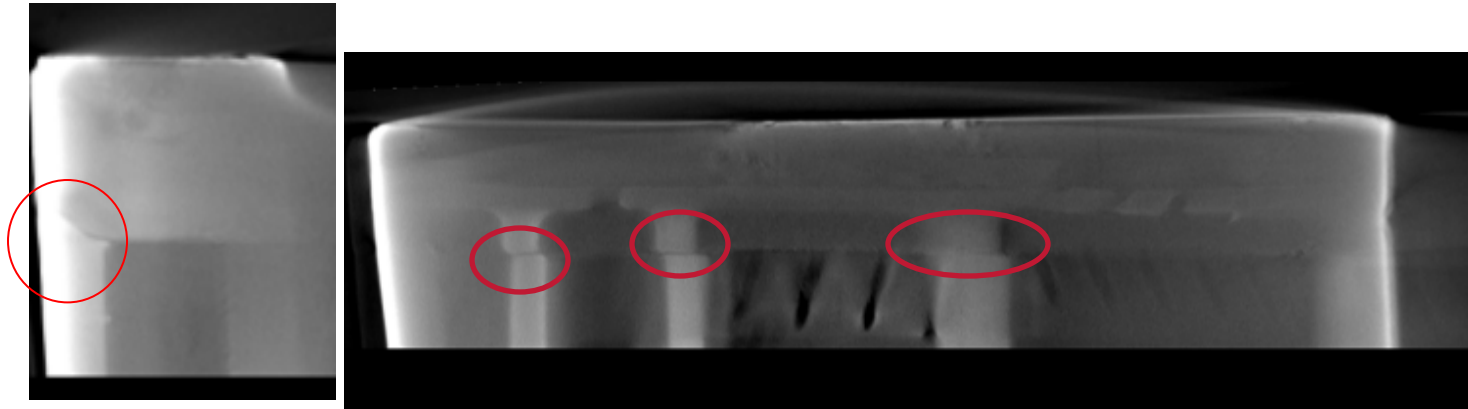
- CT scans at FAA-AANC
- X-ray at Chromalloy
  - Reject criteria for a brazed tip cap gap is as follows:
    - (a) A gap of .005 inch is permitted between the tip cap and blade ribs 3, 5, & 7. A gap of .010 inch is permitted between the tip cap and rib 1 of the blade.
    - (b) Braze alloy must not flow into cavities beyond .100 inch from the bottom of the tip cap. Braze is not permitted around the trailing edge pin fins which are more than .050 inch from the bottom of the tip cap



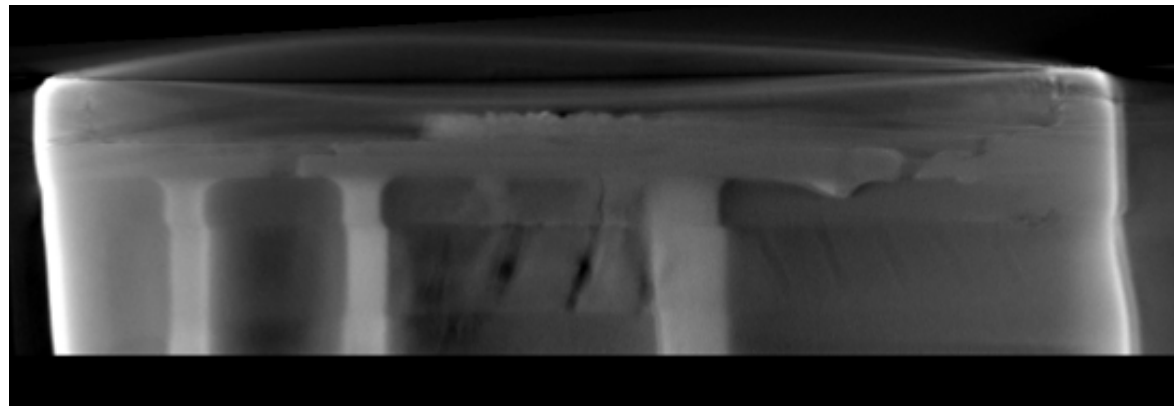
Unacceptable

**PCRT results correlate well with more expensive techniques**

# PCRT VS OTHER NDT TECHNIQUES



Unacceptable – crack at LE, 0.005” gap mid-web



Acceptable – no indication of gap

**PCRT results correlate well with more expensive techniques**

# PCRT GOODNESS

- The Bottom Line
  - \$5800 per blade from GE!
- Approximately 1500 blades quarantined

*If 50% of blades are salvageable = \$4,350,000 cost avoidance  
Not counting \$\$ saved by preventing future failures and UERs*

- DL is the only airline with PCRT technology for turbine blades
- Can be applied to numerous components for a variety of uses
- No operator interpretation required

## Status

- Several projects being conducted with very positive results and potential savings
- Potential PMA component conformance correlation
- Ability to monitor the induced stress of a component at each service interval

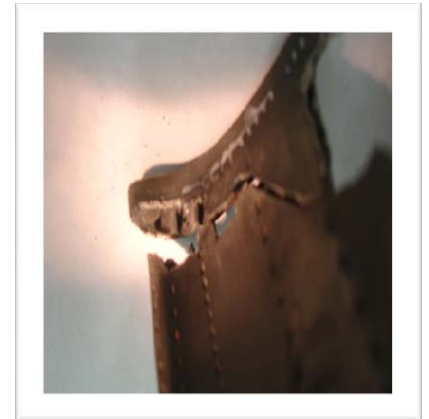


**PCRT can provide cost savings and improve reliability simultaneously**

# SUMMARY

Implementation of Process Compensated Resonance Testing provides:

- Significant cost savings potential for Delta
  1. Reduces need to purchase new blades
  2. Saves money on determining which blades to repair
  3. Use of technology on other applications – domino theory
  4. Validating PCRT through use of CT, X-ray, inspections plus mechanical testing
- Insourcing potential
- Not your father's vibrational testing
  - Powerful software and engineering rigor



**PCRT has potential to change the inspection world**