Development of New Ground Inspection Techniques for the Inspection of Orbiter RCC Components

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Improved Ground Inspection Techniques

- Five new ground inspection techniques are currently under development
- Other more advance techniques are also being pursued
- Using national nondestructive evaluation (NDE) expertise to ensure best technologies and techniques are developed

Techniques Being Developed

Thermography

Ultrasonics

Radiography

Shearography

Eddy Current

Other Longer Term Techniques Being Considered

- Micro-Power Impulse Radar
- Thermal Conductivity Msmts.
- Digital Radiography
- Limited Angle CT
- X-ray transmission Msmts.
- Remote Acoustic
- Ultrasonic Spectroscopy
- Bruisable Paint
- Tera-Hertz Imaging
- Back Scatter X-ray
- Microwave
- 3-D microwave
- Impact Doppler
- Magnetic Resonance Imaging (MRI)

Advantages of New Techniques

- Ability to detect subsurface degradation or damage not visible to the eye
- Techniques will not only compliment each other but will have some overlap detection capabilities
- More in depth inspection techniques also being developed for analysis of post screening regions of interest
- Results in a quantitative health monitoring program of all Orbiter RCC components

Background Information

Thermographic Inspection of RCC

- Principal Advantage:
  -No physical contact with RCC required

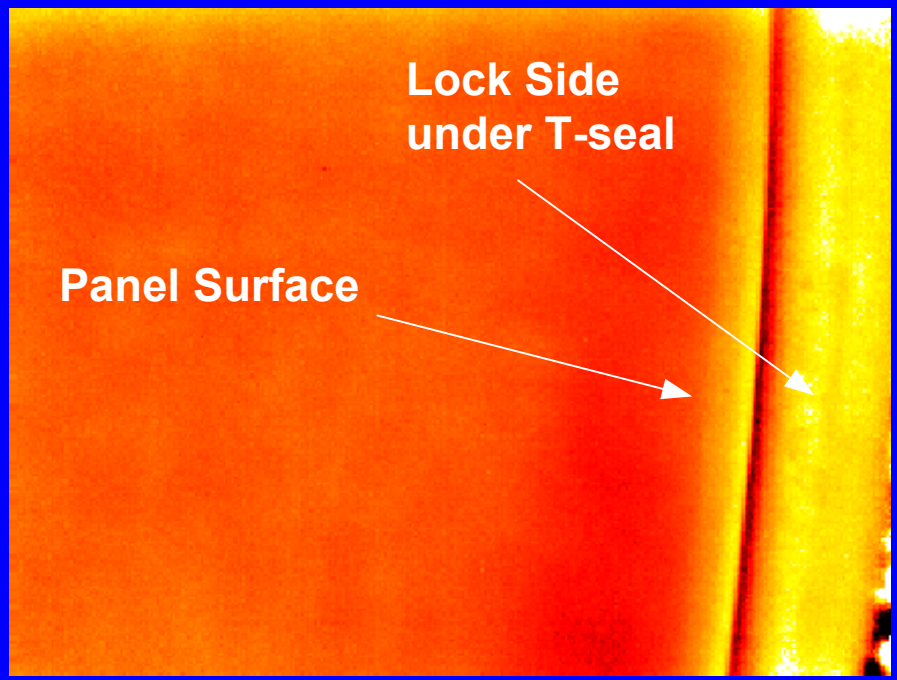
- Expected Detection Capabilities:
  -Delaminations
  -Large Voids
  -Significant Porosity
  -Localized Mass Loss

- Primary Limitation:
  -Detectability of small deep flaws - flaws smaller than their
  depth

- Estimation for time of inspection on vehicle:
  -2 hours per main panel

Thermography Inspections

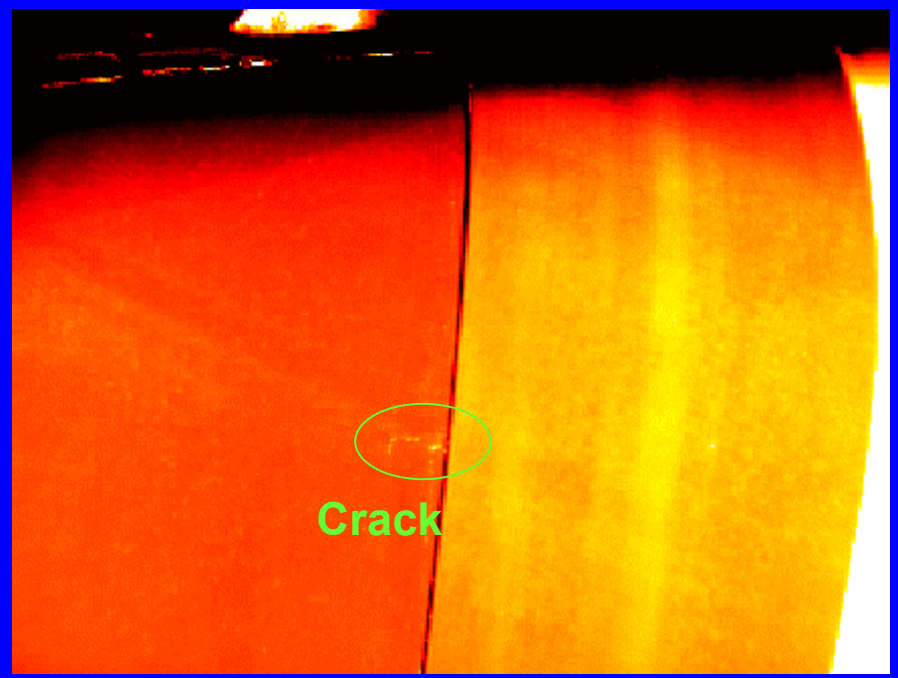
OV-103 6L Pre Impact



Thermal Image of the location of the crack

Outboard
(W/out T-seal)

OV-103 6L Post Impact



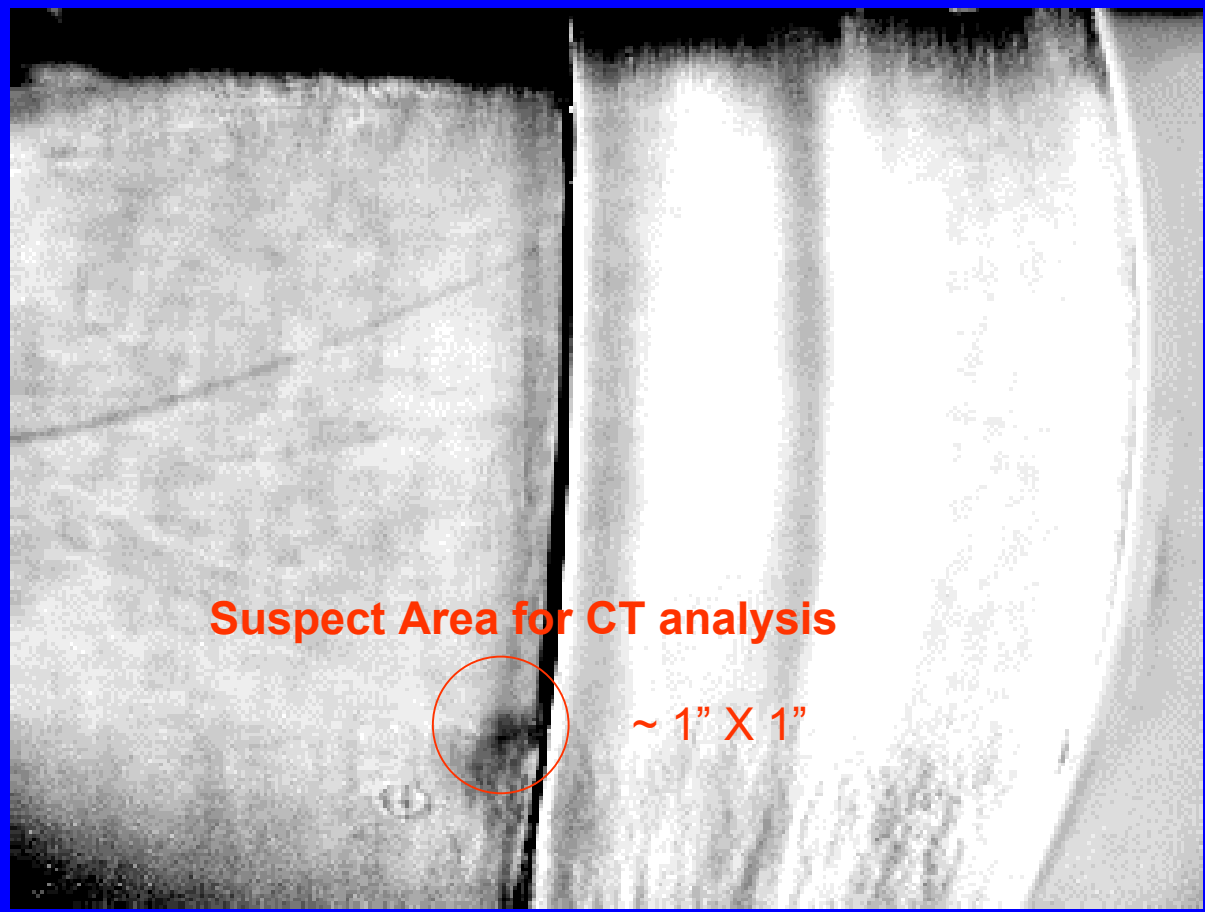
Thermal Image of the crack through the part

Outboard
(W/ T-seal)

OV-103 6L Post Impact

Thermography Inspections

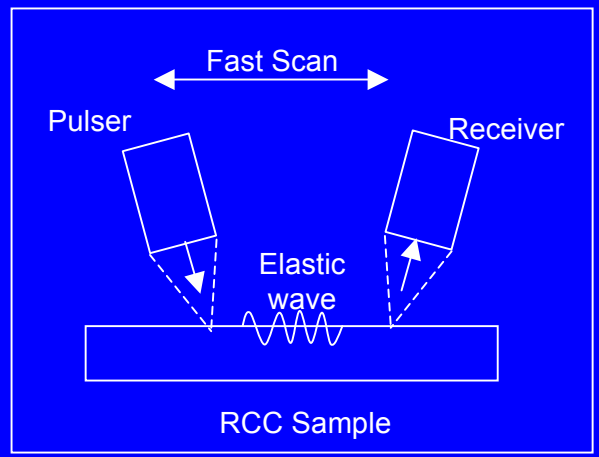
PCA Analysis of thermal data



Ultrasonic Inspection of RCC

- Principal Advantage:
  -Inspections performed from one-sided outer, exposed surfaces. Can utilize various UT techniques (air coupled, laser-based, MIA, Resonance, Pulse-Echo, Pitch-Catch)
  - Air-coupled and laser-based systems are non-contact
  - Very sensitive to material property changes (primarily elastic properties)

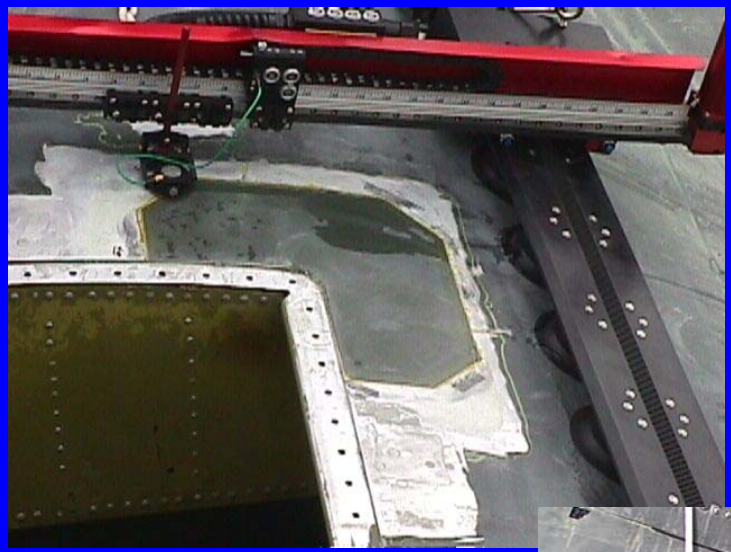
- Expected Detection Capabilities:
  -Sensitive to near-surface variations
  -Interply delaminations
  -Impact damage
  -Voids
  -Subsurface oxidation
  -Disbonds at the Si-C to C-C interface
  -local porosity changes



- Primary Limitation:
  - Thickness of structure and energy level excitation are primary limiting factors; attenuation & near-surface signal clarity are key concerns; need to study S/N ratios; flaw size & depth sensitivity TBD.
  - Need well characterized calibration standards

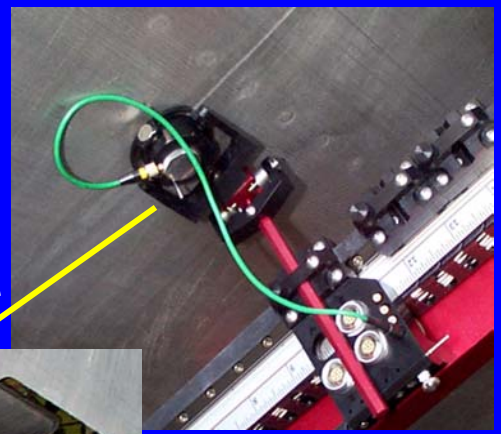
- Estimation for time of inspection on vehicle:
  - 4 hours per panel

Ultrasonic Scanning Systems



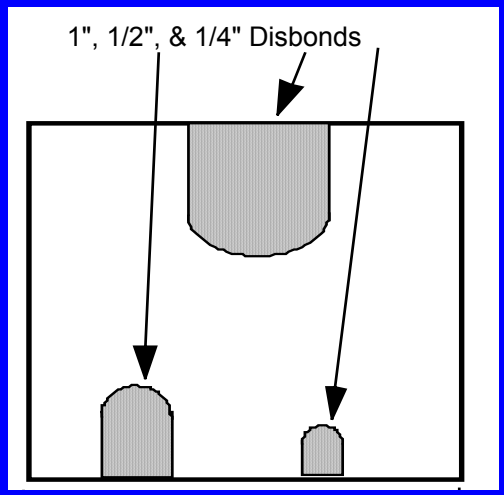
MAUS System

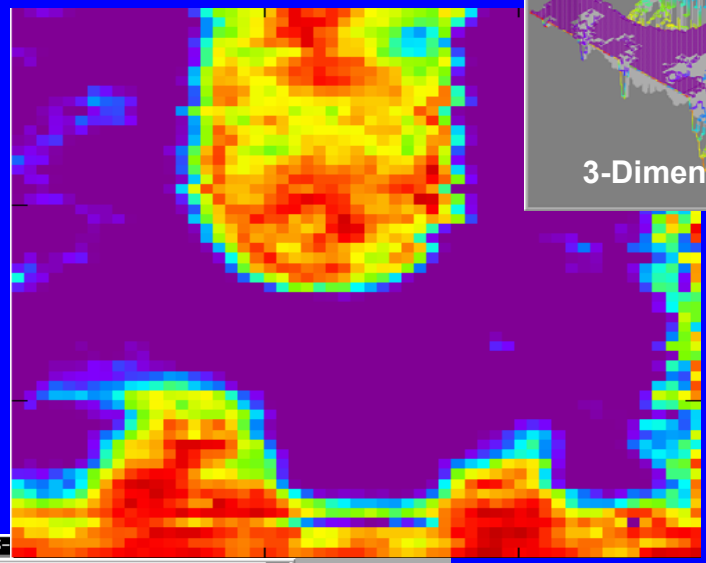
- Resonance
- MIA
- Pulse-echo
- Pitch-catch
- Eddy current

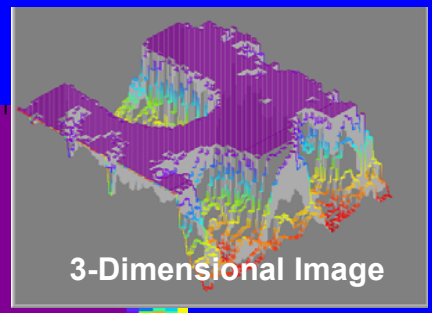


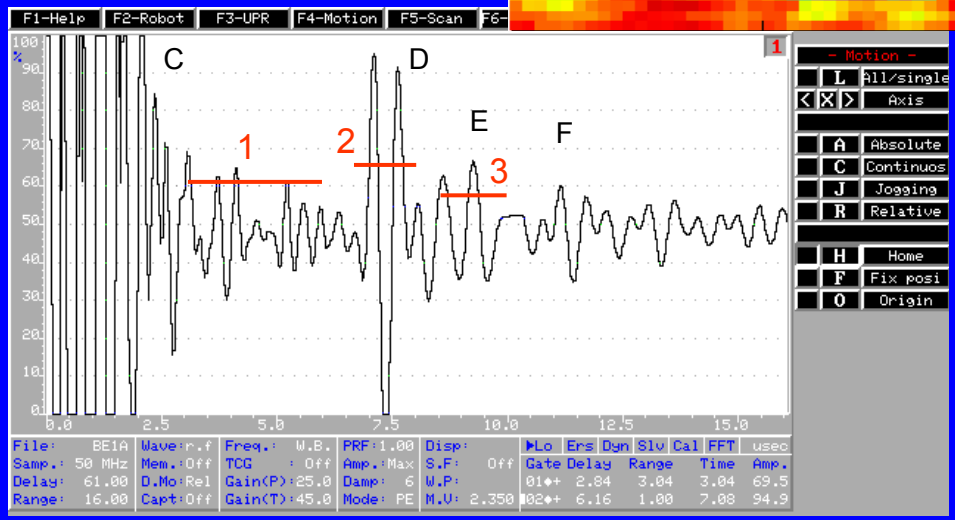
Interchangeable tracks allow for continuous scanning

C-Scan of 72 Ply Composite with Engineered Flaws



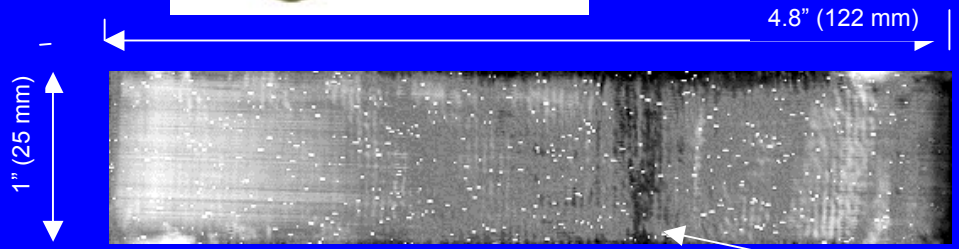




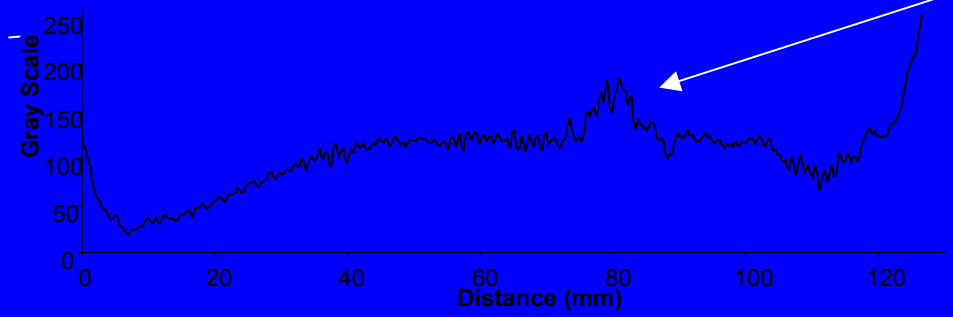


Initial Results: Crack Detection

RCC material with cracked SiC Reaction Layer



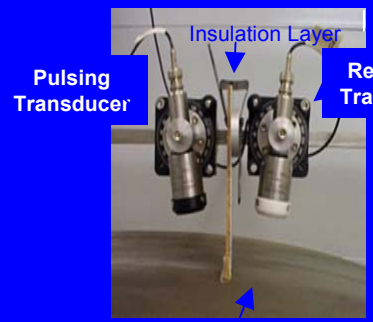
One-sided air-coupled ultrasound C-scan



Crack in SiC Layer

Data Acquisition
One-sided Air-UT Schematic

400 kHz Focused PZT Transducers
10° insertion angle
Distance between transducer faces – 1 7/8"(45mm)



Eddy Current Inspection of RCC

- Principal Advantage:
  -Inspections performed from outer, exposed surfaces utilizing a multi-frequency mode that should allow for the measurement of SiC coating thicknesses and the detection of localized carbon-carbon mass loss due to carbon oxidation.

- Expected Detection Capabilities:
  -SiC coating thickness measurements
  -localized mass loss due to oxidation

- Primary Limitation:
  -Detectability of deep flaws a limitation – Primarily a surface and near-surface inspection tool though preliminary work shows defects >0.25” deep can be detected.

- Estimation for time of inspection on vehicle:
  - 4 hours per panel

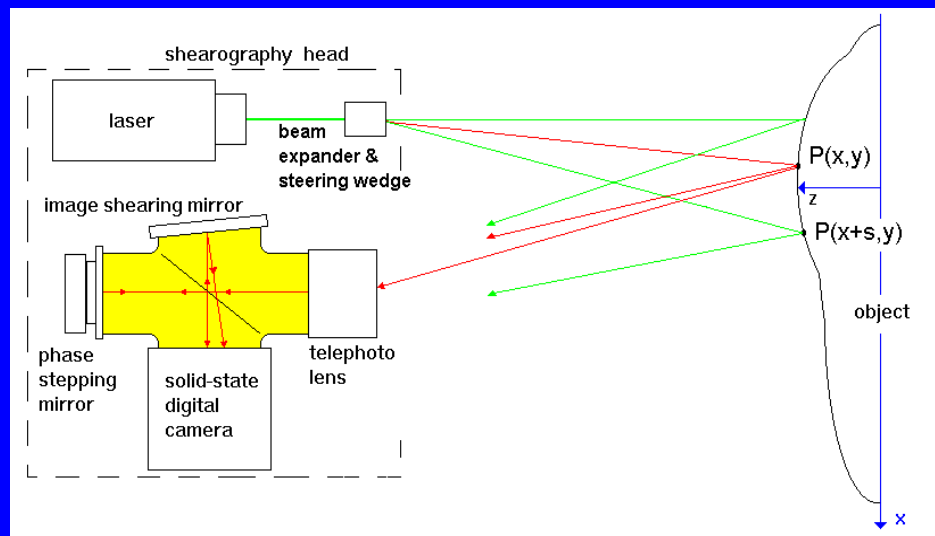
Eddy Current Inspection of RCC

- Resolution will likely be driven by presence of shallow flaws in areas of relatively large SiC thickness variations
- Sensitivity should allow us to detect 0.1” diameter and 0.005” depth material loss flaws due to oxidation in carbon-carbon at SiC carbon-carbon interface along outer surface of RCC laminate
- Integration of Eddy Current probes with MAUS scanning system has been demonstrated to produce scan rates of 36 sqft/hour.
- System will be designed to simultaneously measure SiC coating thickness and detect areas of mass loss due to carbon oxidation.

MAUS IV Flexible Track

Shearography Inspection of RCC

- Panel is stressed with sound, vibration, or heat to cause motion of defect
- Shearography camera measures deformation of surface towards the camera
- Defect can be mapped on surface
- Mounting system to isolate camera from vibration is needed
- Mounting system for piezoelectric shaker must be perfected and demonstrated not to cause damage



Shearography Inspection of RCC

- Principal Advantage:
  -Inspects a large area quickly, 12 to 24 square inches every time

- Expected Detection Capabilities:
  -Demonstrated capability of detecting down to 0.125” defect just below the SiC
  reaction layer
  -Demonstrated capability of detecting down to 0.5” defect 0.18” below the surface

- Primary Limitation:
  -Detectability of deep flaws a limitation – Primarily a surface and near-surface inspection tool though preliminary work shows defects >0.25” deep can be detected.

- Estimation for time of inspection on vehicle:
  -2 hours per panel

Radiographic Inspection of RCC

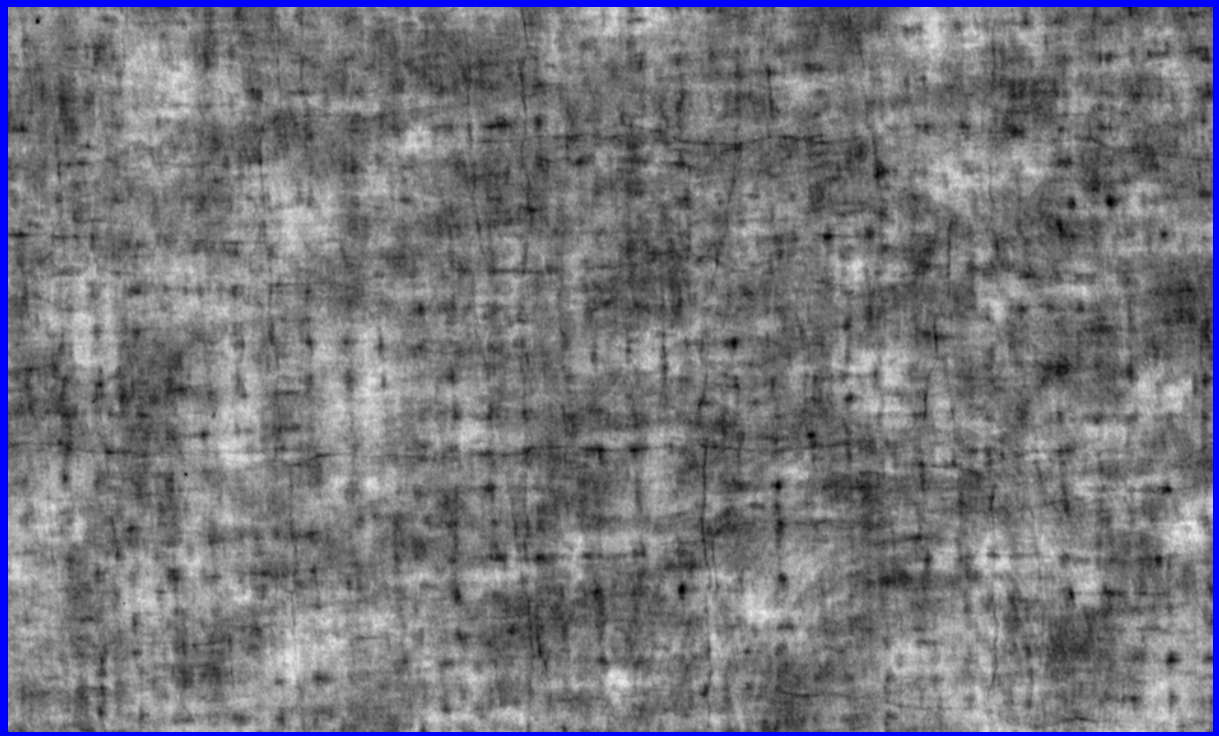
- Principal Advantage
  - Inspections performed from outer, exposed surfaces will provide high resolution imaging capability (digitized films and direct digital imaging) through the entire structure, providing images of surface structures as well as subsurface structures (i.e. connection points).

- Expected Detection Capabilities:
  -Large Voids
  -Mass Loss (when compared to previous images)
  -Cracks oriented parallel to the x-ray beam

- Primary Limitation:
  -The RCC panels have an inherently high degree of local density variations. Differentiating natural variations or structural features from flaws will be the main challenge (digital image analysis may overcome this limitation).

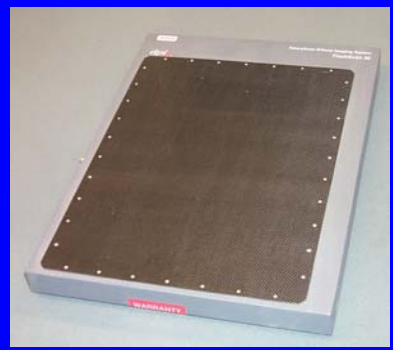
- Estimation for time of inspection on vehicle:
  - 2 hours per panel with additional time for post image analysis

Radiographic Inspection of RCC



Digitized Film Radiographic image of 0.75” x 1.25” RCC. Note natural density variations and craze cracks.

Portable X-ray Machine



Near Film Quality Portable Digital X-ray Imaging Device

Standards

Material Defect Reference Standards Are Crucial For NDE

- Used to determine the threshold detectability limits of each technique
  - Defect Size
  - Defect Depth
  - Defect Type
- Used to develop the probability of detection
- Used to certify the inspectors

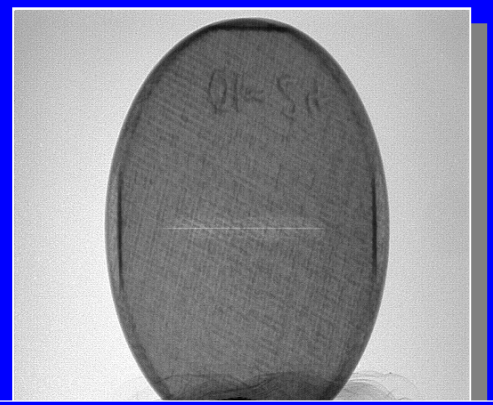
Boeing is currently on contract to develop NDE material reference Standards

Localized Oxidation Standards

- Plasma Arc Jet Test Facility at NASA JSC
- Specific sample configuration required to fit within the test holder
- Half of specimens will have simulated (machined 0.006” diameter) craze cracks through SiC coating to enhance localized oxidation and simulate the mass loss associated with anomalous coating loss found on flight hardware
- Several hours of conditioning required for measurable mass loss
  - Craze crack samples conditioned at 2800°F, 0.05 atm for 2 or 4 hours
  - Undamaged samples conditioned at 2800°F, 0.05 atm for 4 to 8 hours (longer durations required to achieve measurable mass loss)

Undamaged Specimen

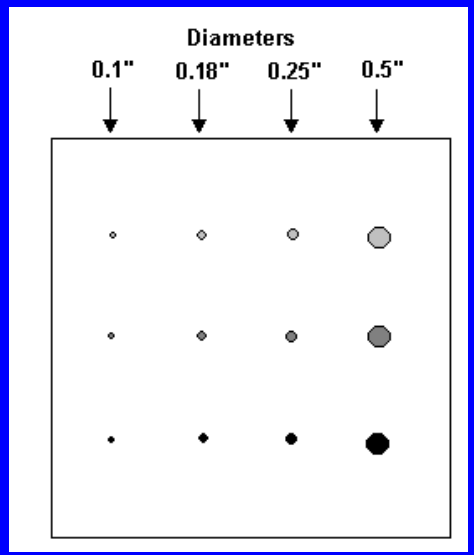
Arc Jet with Craze Crack

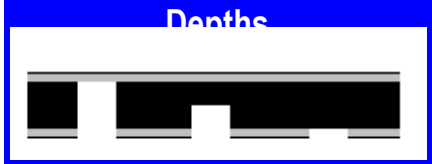


X-ray Image with Craze Crack

Flat Bottom Hole Standards

- Simulate circular delaminations within the C-C substrate
- For single-sided techniques
- Machine flat bottom holes to various diameters and depths
- Performed previously on scrap material for thermography demonstration





Drilled Slot and Disbonded Delam Standards

- To simulate internal defects for through transmission or double-sided NDE techniques, both sides must be defect-free