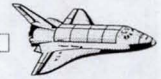


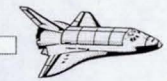
RCC NDE Update

Jose M. Hernandez

NASA - Johnson Space Center

March 9, 2004

Development NDE RCC Inspection Systems

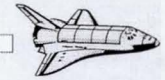


Took a two-phase approach:

- **Phase 1:** Quantitatively determine viability of each technique based on existing manufacturer acceptability testing capabilities and LESS localize convective oxidation NDE criteria. (Initially given 3 months > Took 7 months)
  - Held a TIM May 8-9 at KSC
  - Both long and near term technologies were identified
  - Near term defined as ability to field technique <= 10 months (i.e. focused on mature technologies)
  - Everything else categorized as advanced NDE techniques
  - Held 2nd TIM November 20-21 at Sandia National Laboratories
  - Reached consensus on technologies to pursue

- **Phase 2:** Develop selected techniques into "turn-key" systems. (12 months)
  - Are presently at the initial stage of phase 2

Results of 2nd TIM

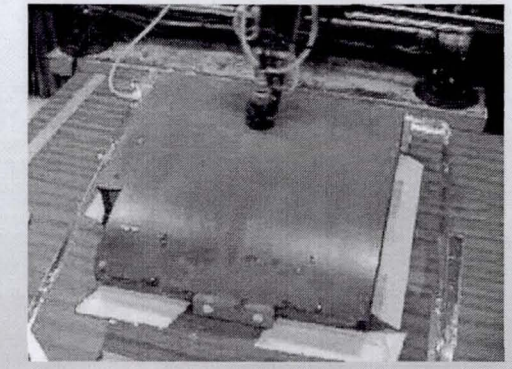


Selected the four most promising in-situ techniques with <12 months total development time

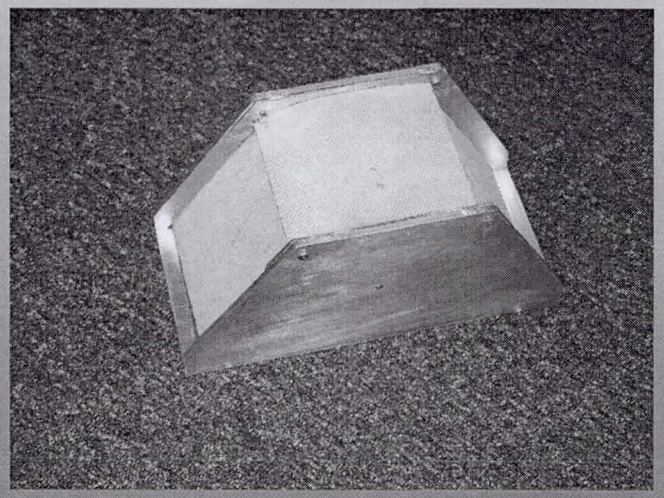
Short Term <12 months	Thermography	Radiography
	Contact Ultrasonics	Non-contact Ultrasonics*
	Eddy Current	Shearography *
	* Not Selected	
Long Term >12 months	Micro-Power Impulse Radar*	MRI*
	Thermal Conductivity Msmts.*	Tera-Hertz Imaging*
	Digital Radiography	Back Scatter X-ray
	Limited Angle CT	Guided Wave Ultrasonics
	X-ray transmission msmts. *	3-D microwave*
	Health Monitoring Sensors*	Remote Acoustic Impact Doppler*
	Phased Array Ultrasonics	Ultrasonic Spectroscopy*

RCC Validation Test Specimen Set

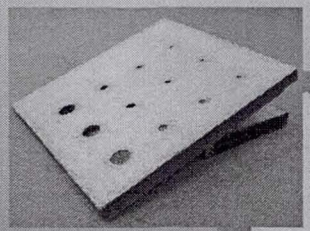
- Boeing disks w/ arc jet exposure
- 0.25" th. central section (coating)
- 0.44" th. edge section (no coating)
- 8L post impact – 4 panel round robin
- 0.25" th. section with natural flaws (coating)
- 8L "blind specimen" (Bill's Box)
- Uncoated "blind specimen" (Sam's Box)
- Complete RCC panel (manuf. reject)
- Various other pieces

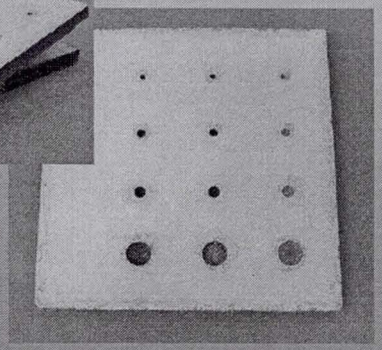


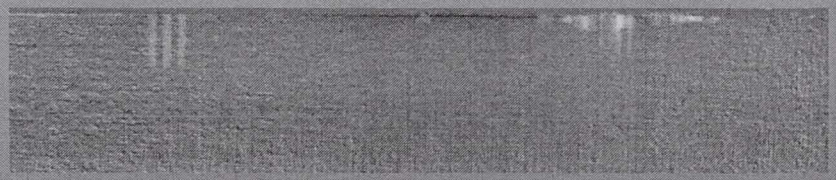
RCC Blind Test Box (Bill's Box)



RCC Blind Test Box (Sam's Box)



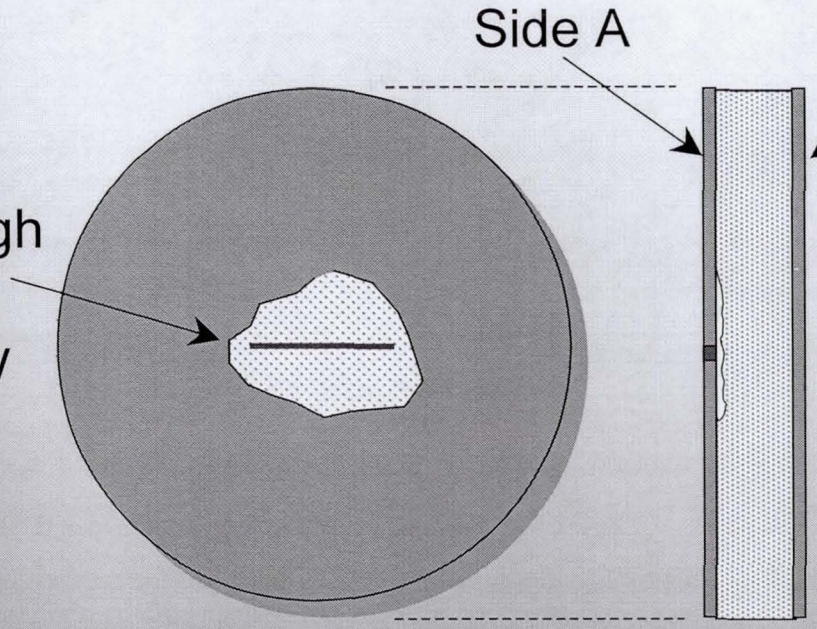




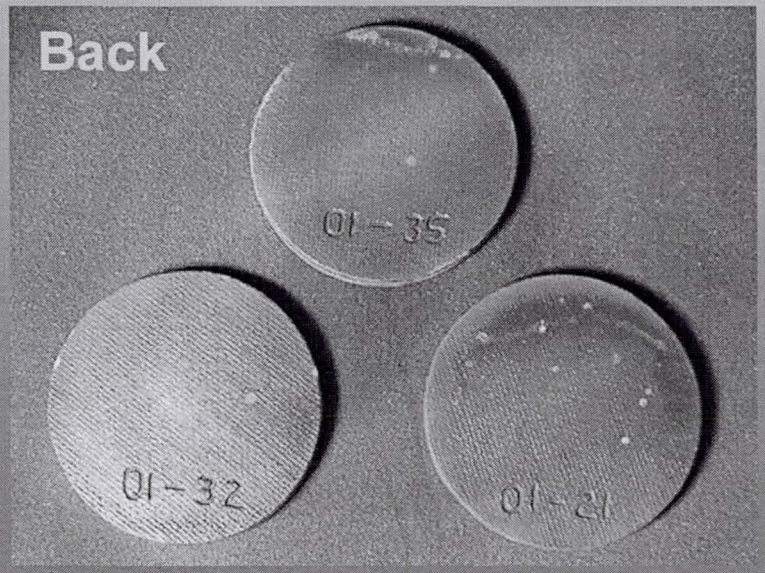
X-ray Test Specimen

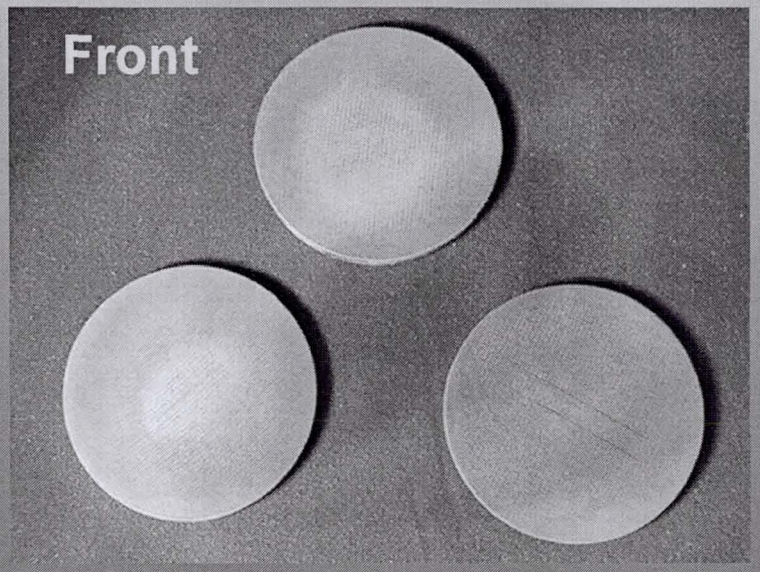
0.44" RCC Panel

RCC Puck Samples



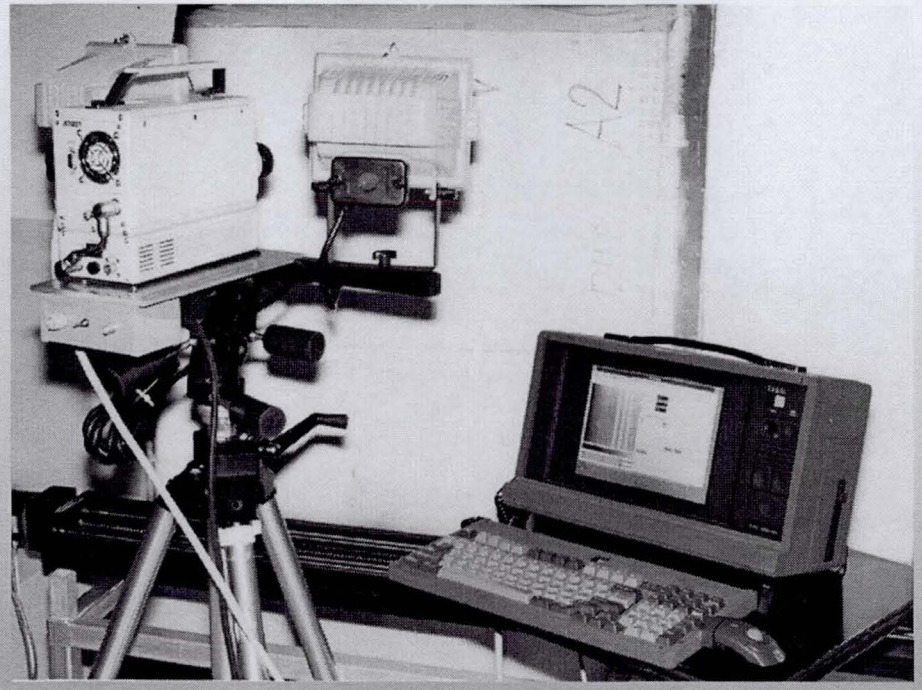
- **Inspection from Side A Simulates Nearside (Surface) Flaw Detection**
- **Inspection from Side B Simulates Backside (Deep) Flaw Detection**



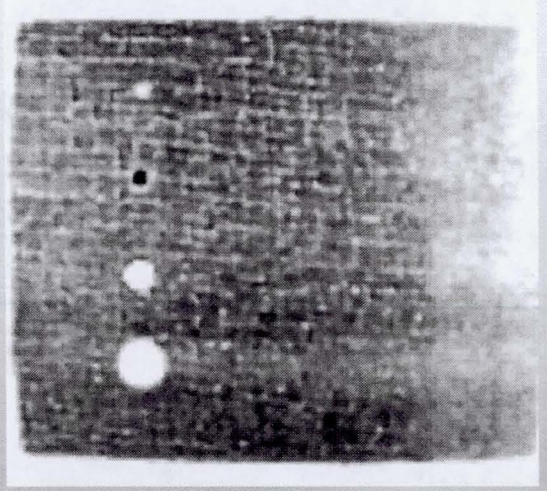


Thermographic Inspection of RCC

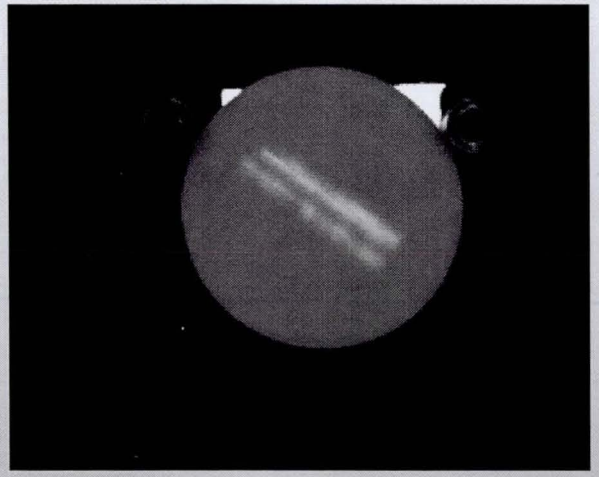
- Principal Advantage:
  - -No physical contact with RCC required
- Expected Detection Capabilities:
  - -Delaminations
  - -Large Voids
  - -Significant Porosity
  - -Microcracking
- Primary Limitation:
  - -Detectability of small deep flaws – flaws smaller than their depth
- Estimation for time of inspection on vehicle:
  - -2 hours per panel



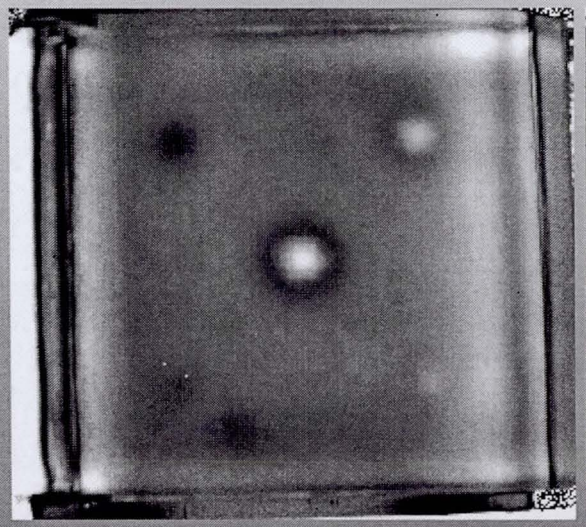
Thermography Inspections



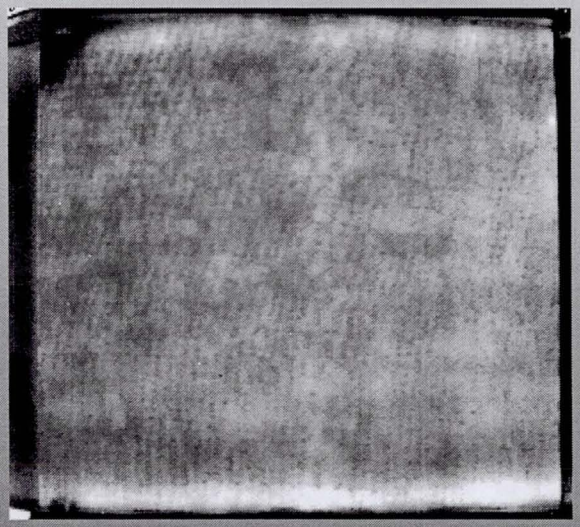
Thermography Data after 0.1 sec



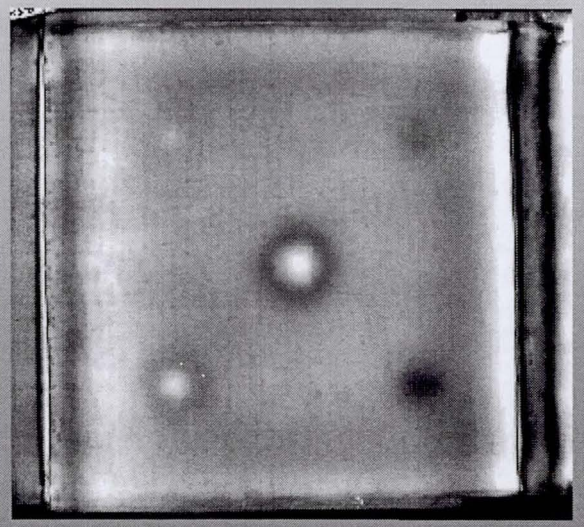
RCC Puck Sample



Panel 2



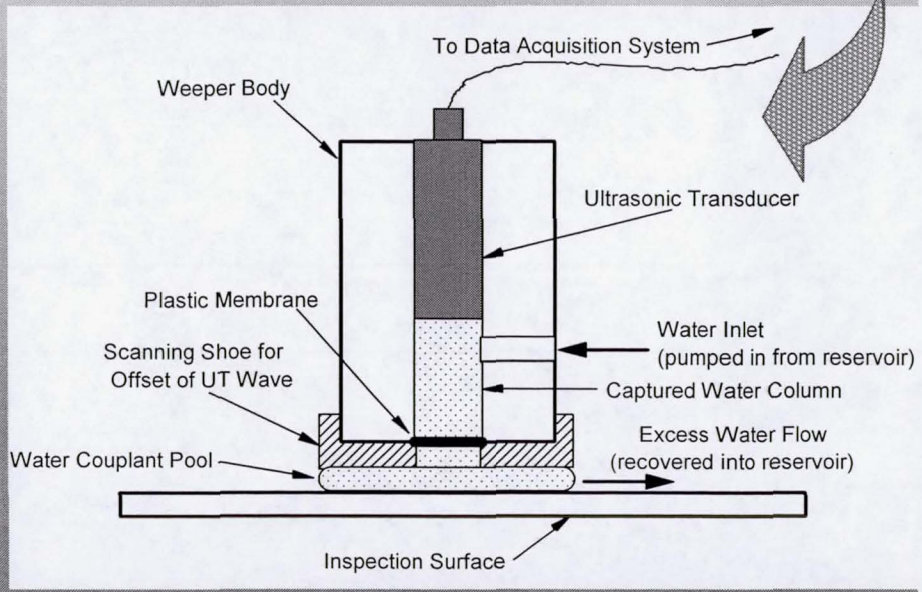
Panel 3 (no indications)



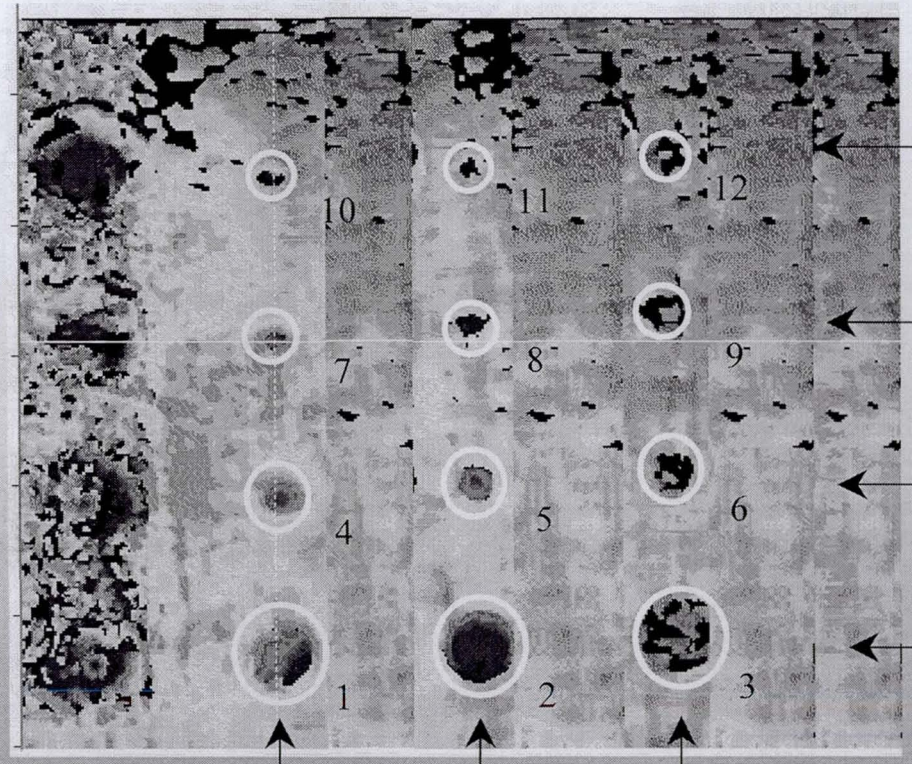
Panel 4

Ultrasonic Inspection of RCC

- Principal Advantage:
  - -Inspections performed from one side.
  - - Pulse-Echo technique seems most promising
- Expected Detection Capabilities:
  - -Sensitive to near-surface variations
  - -Interply delaminations
  - -Impact damage
  - -Voids
  - -Subsurface oxidation
  - -Disbonds at the Si-C to C-C interface
  - -UT niche: penetration for deep flaw detection
- Primary Limitation:
  - - Structure thickness & energy level excitation;
  - - Attenuation & near-surface signal clarity;
  - - Flaw size & depth sensitivity.
  - - Need well characterized cal standards
- Estimation for time of inspection on vehicle:
  - - 4 hours per panel

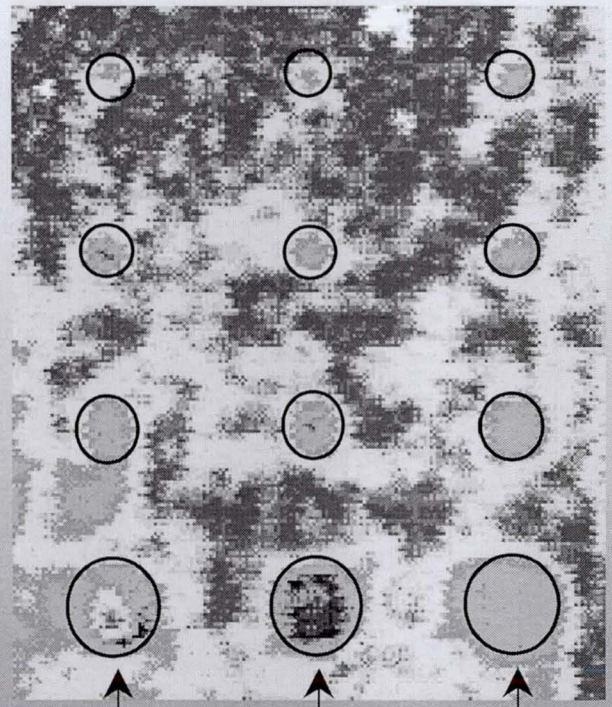


UT - 0.24” & 0.44” Panel with Coating



0.24” Thickness Sample

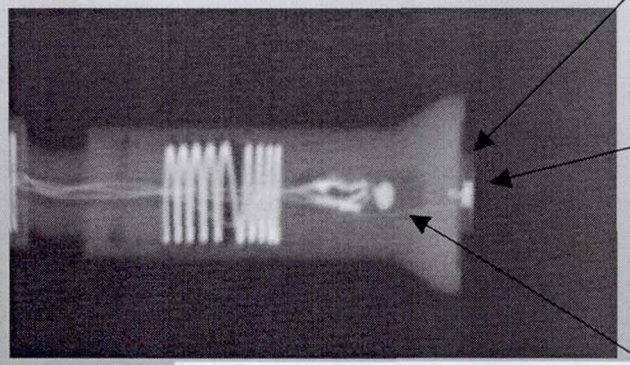
P-E UT Optimum Coupling



0.44” Thickness Sample

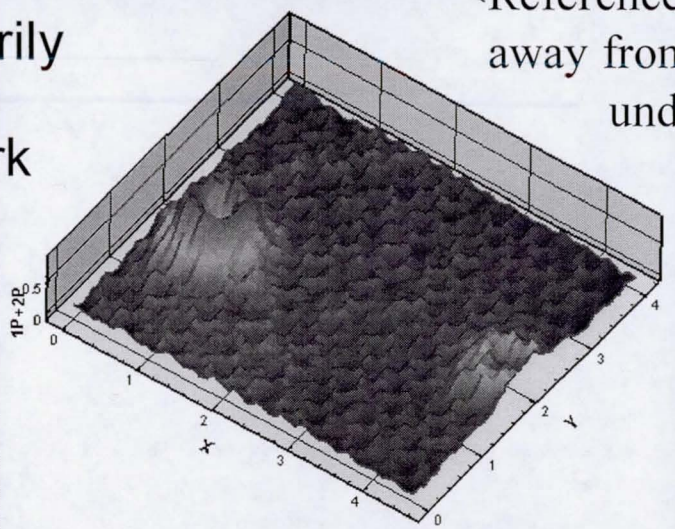
Eddy Current Inspection of RCC

- 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.



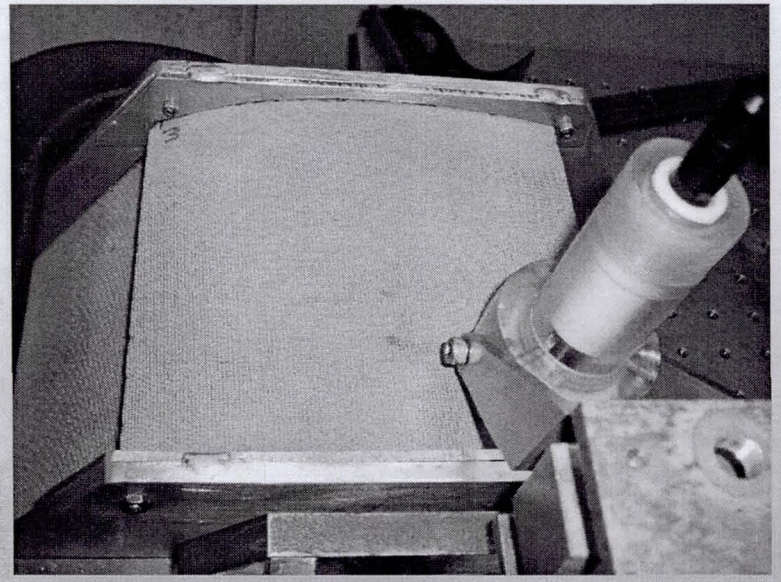
- Expected Detection Capabilities:
  -SiC coating thickness measurements
  -localized mass loss due to oxidation

- 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.

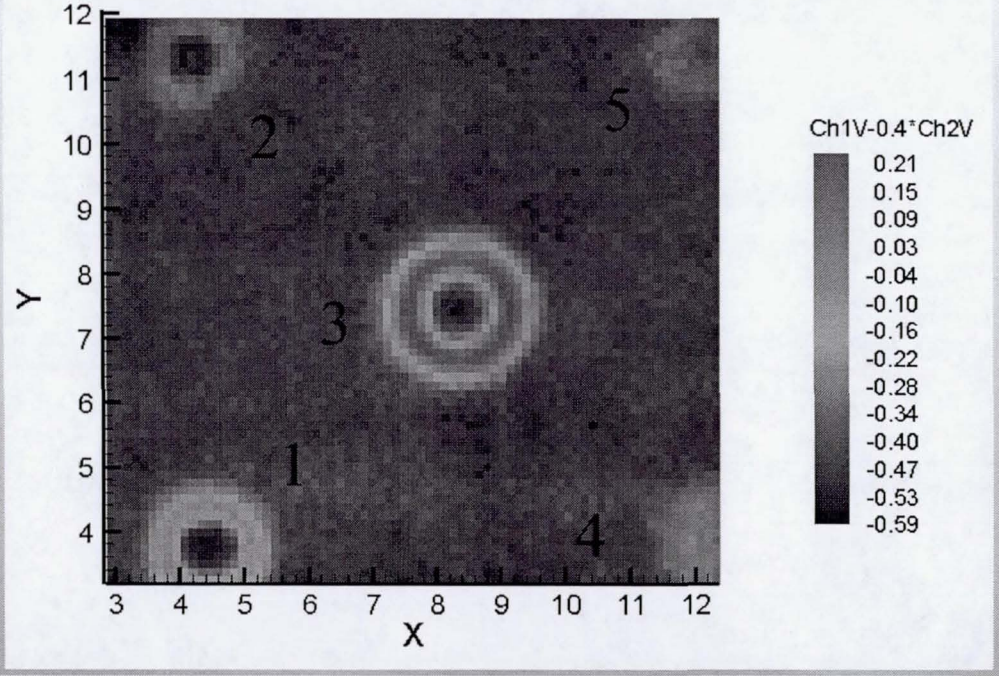


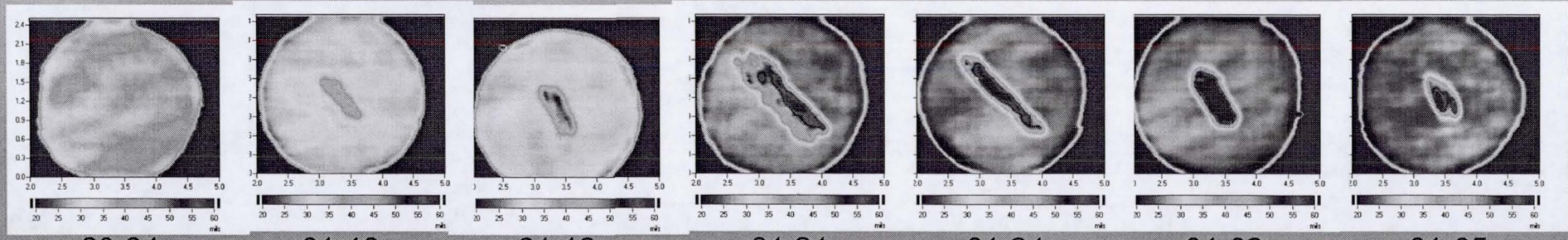
- Estimation for time of inspection on vehicle:
  - 4 hours per panel

Eddy Current of RCC Samples



Sam's Box





03-24 01-13 01-18 01-21 01-24 01-32 01-35

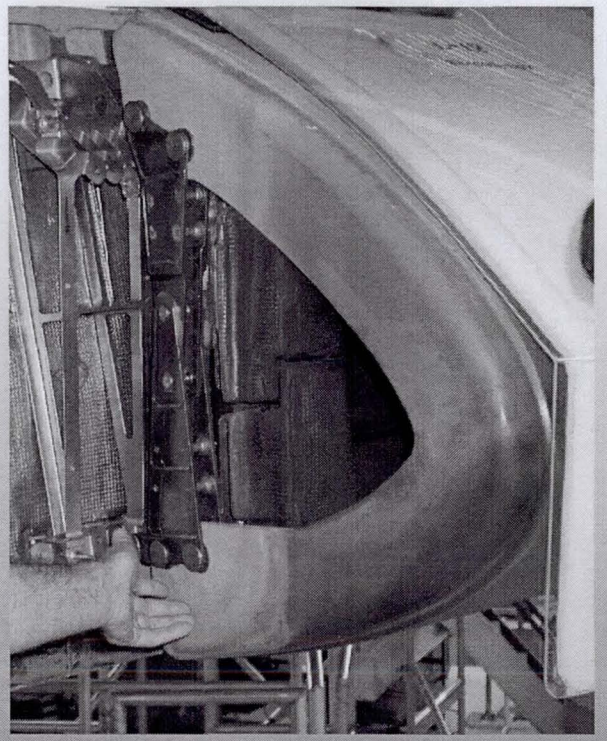
Boeing Puck Samples

Radiographic Inspection of RCC

- Principal Advantage:
  - Inspections performed from outer, exposed surfaces will provide high resolution imaging capability through the entire structure including subsurface structures

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

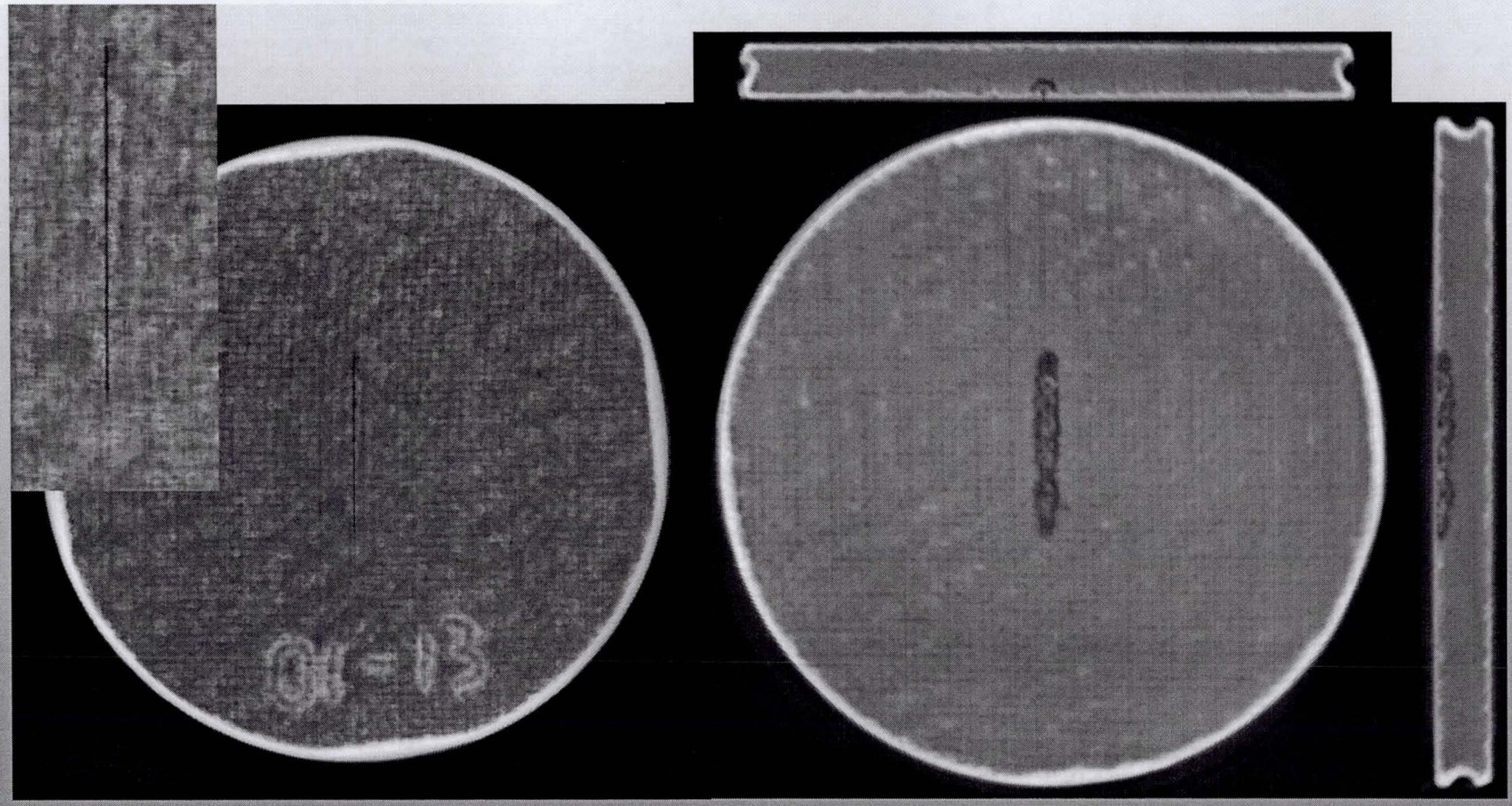
- Primary Limitation:
  -The RCC panels have an inherently high degree of local density variations. Differentiating natural variations or structural features from flaws will be the main challenge (digital image analysis may overcome this limitation).



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

Radiographic Oxidation Samples

Enlarged X-ray Image



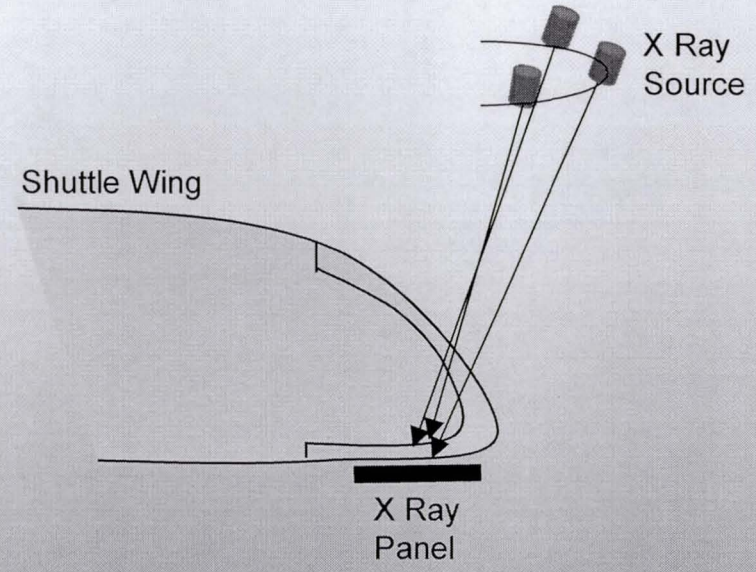
X-Ray Image

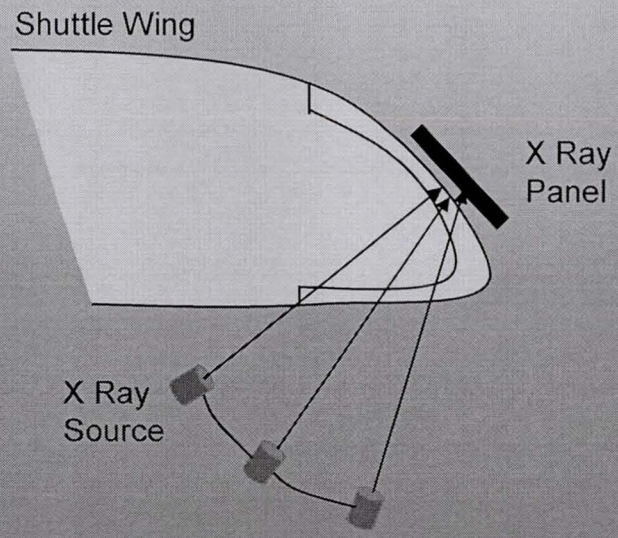
CT Images

Preliminary System Design

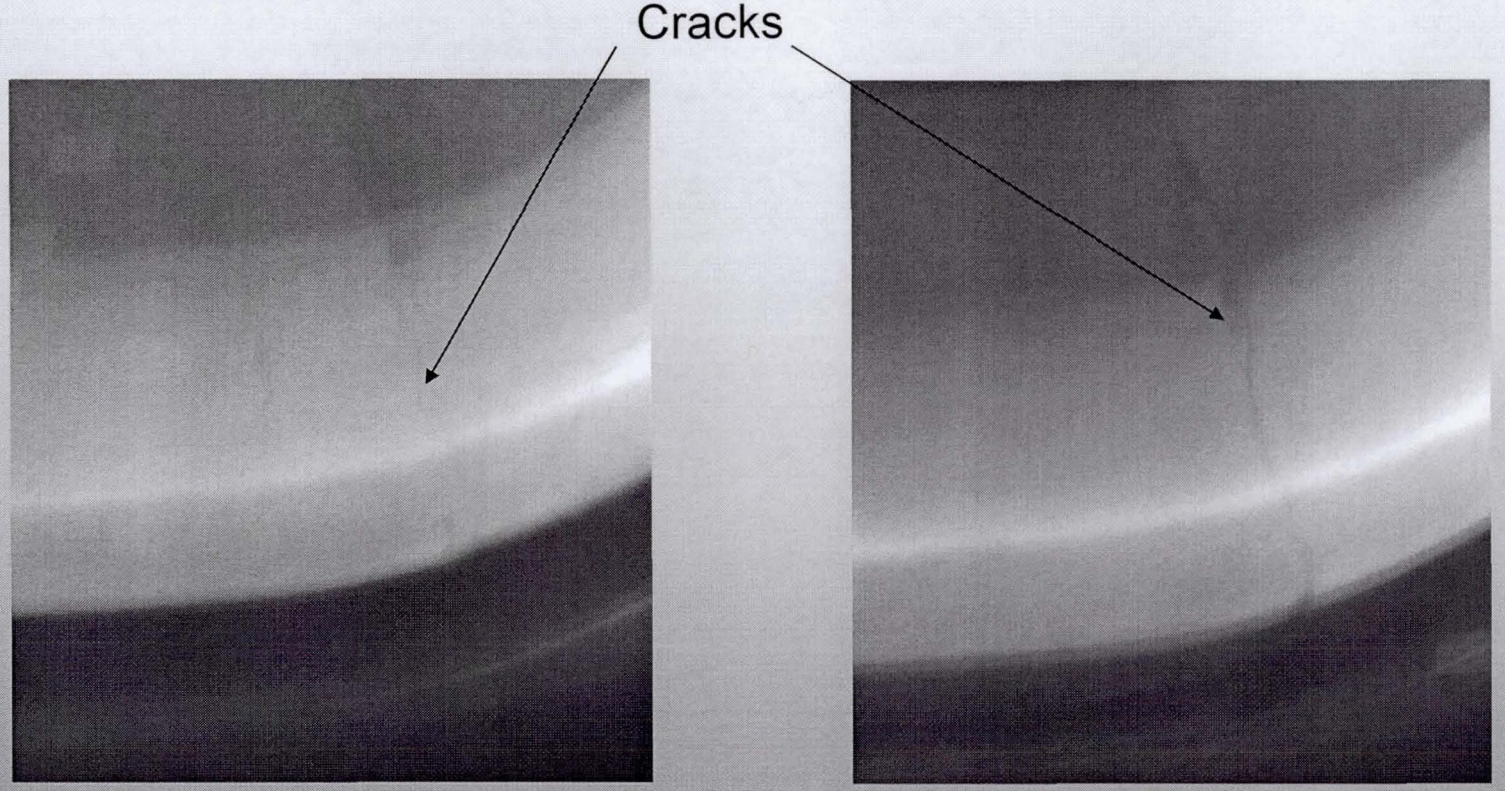
Preliminary technique for Radiographic inspection.

In addition to the positions shown, the x-ray source may need to be moved in and out of plane





Volumetric Imaging Results



View of outer rim section.

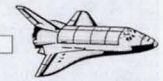
View of inner rim section.

Vertical views for different slices (exactly 0.230 in. apart) show distinct cracks in each rim section.

Capabilities of Chosen Techniques

Technique	Physical Contact Req'd	Deep Delams	Cracks	Large Voids	Sig. Porosity	Local Mass Loss	Impact Damage	Coat Msmt	Inspect Stem Fastener Area
Thermal		X	X	X	X	X	X		
UT	X	X	X	X	X	X	X		
Eddy Current	X		X		X			X	
X-ray	X		X		X		X		X

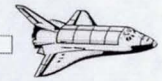
Detection Requirements



The LESS PRT has stipulated the following flaw detection requirements:

- **Tubular voids > 0.05" diameter and 3" in length**
- **Coating damage**
- **Delams – TBD**
- **Backside damage – TBD**
- **Cracks - TBD**

Inspection Process



Though the inspection process has not been developed, one can envision a process similar to the following:

Level I Inspection

- Visual
- Tactile
- Thermography – exposed acreage
- Ultrasoun/Eddy – exposed acreage
- X-ray – T-seal flange, lugs & rib areas

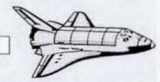
Level II Inspection

- Eddy Current (coating thickness)
- X-ray

Level III Inspection

- Panel removal
- Two-side inspection using above techniques
- Computed tomography (CT) scans

Other Areas Needing Attention



- Advanced NDE techniques show promise
  - Phased array UT, Guided Wave UT, EM Acoustic transducers, segmented and laser systems
- Developing RCC standards
  - Boeing has initiated development of generic standards
  - Need to develop technique specific standards
  - Need to agree on a robust validation process for each technique
- Data storage, reduction and analysis
- Systems integration and fielding of inspection systems
- Developing a viable inspection procedure that minimizes disruption of Orbiter processing activities