Development of Non Destructive Evaluation Techniques for the In-Situ Inspection of the Orbiter's Thermal Protection System

José M. Hernández
NASA – Johnson Space Center
Houston, Texas

One of the Columbia Accident Investigation Board's (CAIB) recommendation is to develop and implement an inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon (RCC) system components that make part of the Space Shuttle's thermal protection system. This presentation focuses on the efforts to leverage non-destructive evaluation (NDE) expertise from academia, private industry, and government agencies resulting in the design of a comprehensive health monitoring program for RCC components. The different NDE techniques that were considered are presented along with the chosen techniques and preliminary inspection results of RCC materials.

IEEE Symposium
Guadalajara, Mexico

Jose M. Hernandez
NASA - Johnson Space Center

April 2, 2004

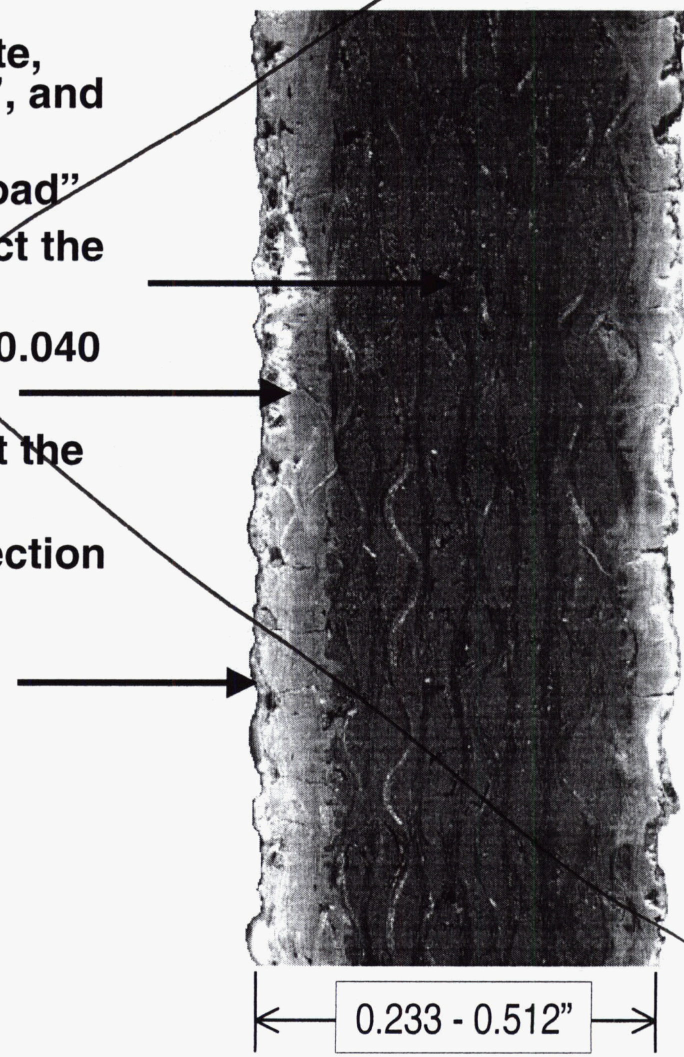
Introduction

Objective

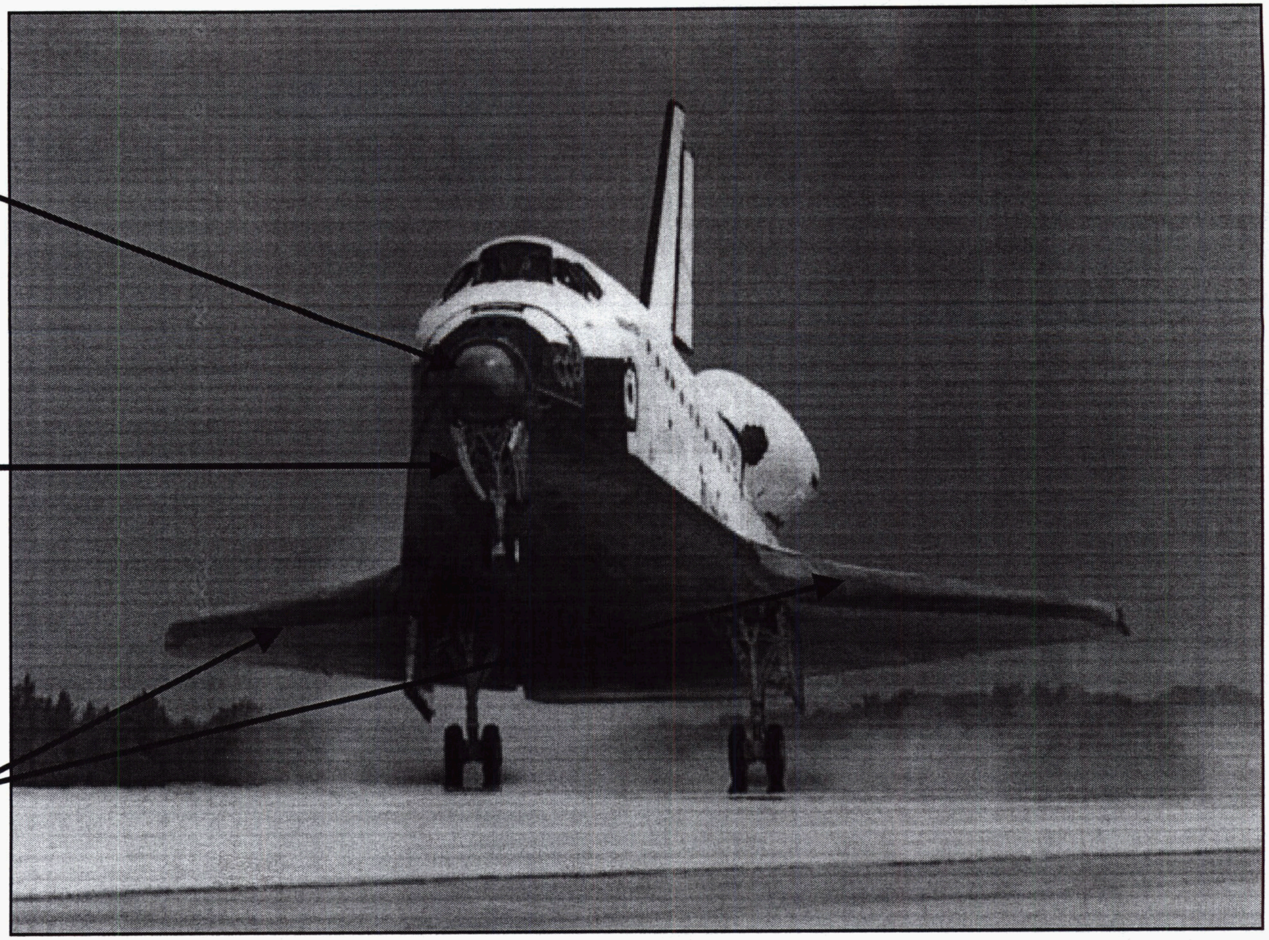
Enhance NASA's approach to the development of a comprehensive NDE program for the in-situ health monitoring of Space Shuttle Orbiter RCC components.

Reinforced Carbon-Carbon (RCC)

- RCC is composed of Carbon substrate, Silicon Carbide conversion “coating”, and a Type A sealant
  - Carbon Substrate – “Carry the Load”
  - Silicon Carbide Coating – “Protect the Carbon”
    - In-situ coating – outer 0.020-0.040 inch “converted” to SiC.
  - TEOS and Type A – “Help Protect the Carbon”
    - TEOS provides internal protection against porosity within the laminate.



Space Shuttle Reinforced Carbon-Carbon (RCC) Components



Nose Cap, Chin Panel, and Seals

Forward External Tank Attachment "Arrowhead" Plate

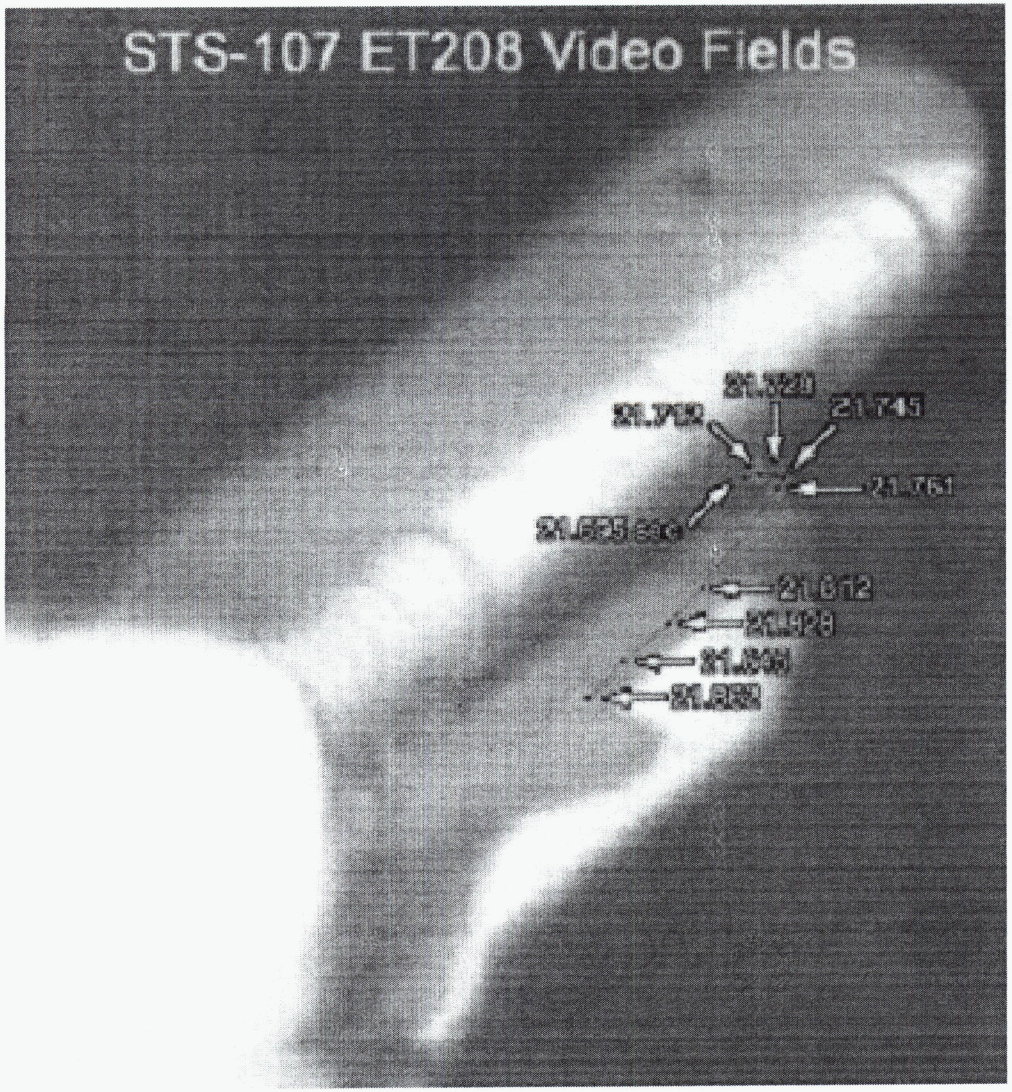
Wing Leading Edge Panels and Tee Seals

Detection Requirements

The Shuttle program has stipulated inspection techniques be able to detect the following flaws:

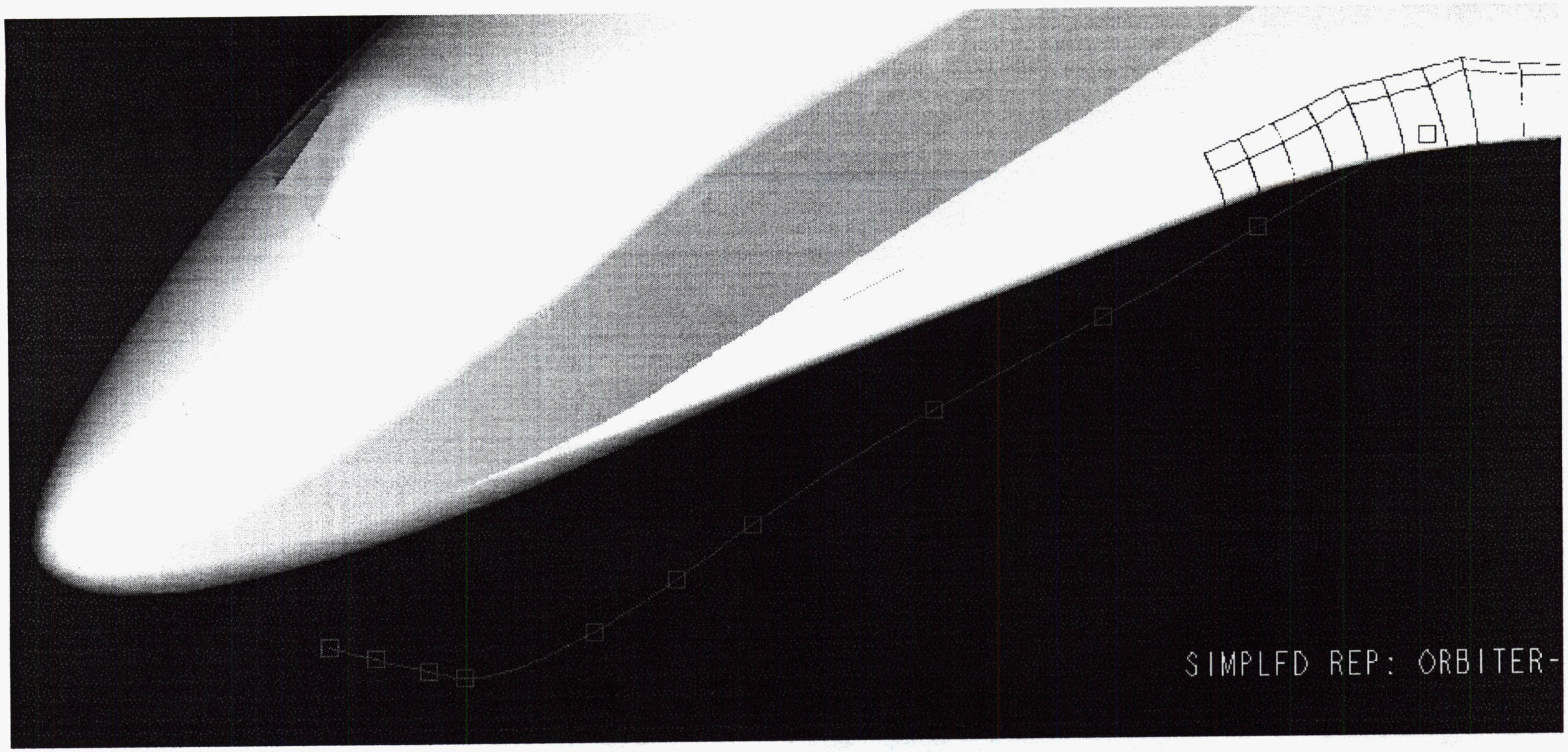
- Tubular voids
- Coating damage
- Delaminations
- Backside damage
- Cracks

Columbia Accident Investigation



- T+81 sec after launch of STS-107 a piece of debris was noted to come off the external tank (ET) and impact the LH wing of the Shuttle
- Analysis during the flight identified a zone where the debris had the potential to impact
  - MLG Door, Wing, RCC and Carrier Panel
- Tasks were initiated to better understand foam projectile impacts on potential impact zones and develop improved in-situ NDE inspection techniques

Ascent Debris Position based on Photographic Analysis



Development NDE RCC Inspection Systems

Took a two-phase approach:

- **Phase 1:** Quantitatively determine viability of most promising non-destructive evaluation (NDE) techniques:
  - ➢Held a Technical Integration Meeting with NDE community at KSC (May 2003)
  - ➢Both long and near term technologies were identified
  - ➢Near term defined as ability to field technique <= 12 months (i.e. focused on mature technologies)
  - ➢Everything else categorized as advanced NDE techniques
  - ➢Held 2nd Technical Integration Meeting (November 2003)
  - ➢Reached consensus on which techniques to pursue

- **Phase 2:** Develop selected techniques into "turn-key" systems. (12 months)
  - ➢Presently implementing phase 2

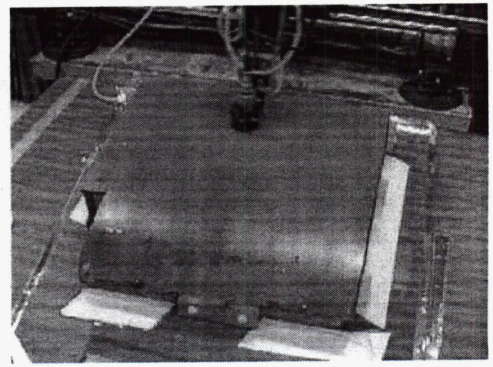
Results of Feasibility Studies

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

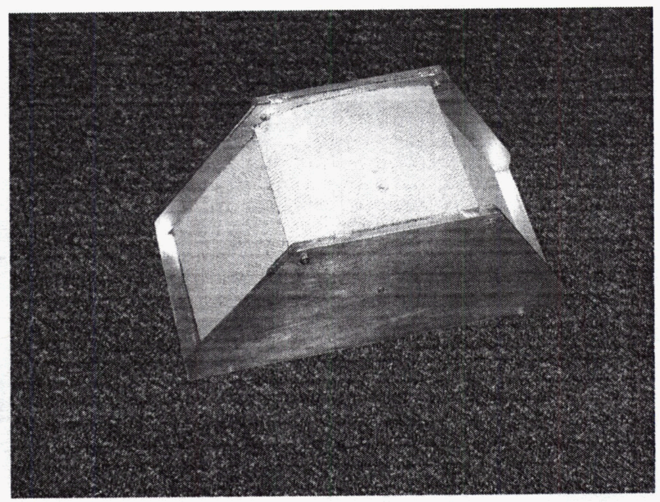
Short Term <12 months	**Thermography** **Contact Ultrasonics** **Eddy Current**	**Radiography** **Non-contact Ultrasonics*** **Shearography ***
	*** Not Selected**	
Long Term >12 months	**Micro-Power Impulse Radar*** **Thermal Conductivity Msmts.*** **Digital Radiography** **Limited Angle CT** **X-ray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

RCC Validation Test Specimen Set

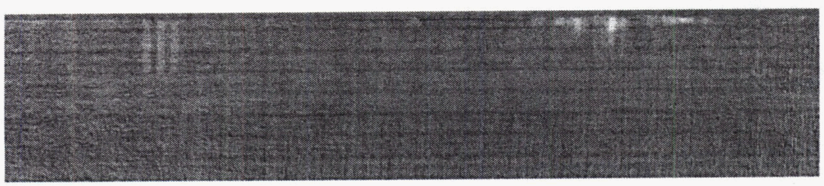
- Boeing disks w/ arc jet exposure
- 0.25” th. central section (coating)
- 0.44” th. edge section (no coating)
- 8L post impact – 4 panel round robin
- 0.25” th. section with natural flaws (coating)
- 8L “blind specimen” (Bill’s Box)
- Uncoated “blind specimen” (Sam’s Box)
- Complete RCC panel (manuf.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



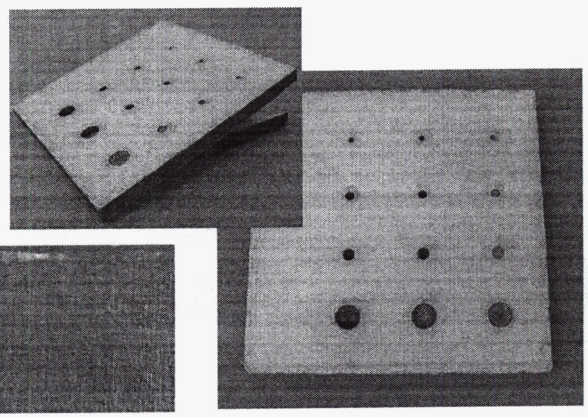
RCC Blind Test Box (**Bill’s Box**)



RCC Blind Test Box (Sam’s Box)



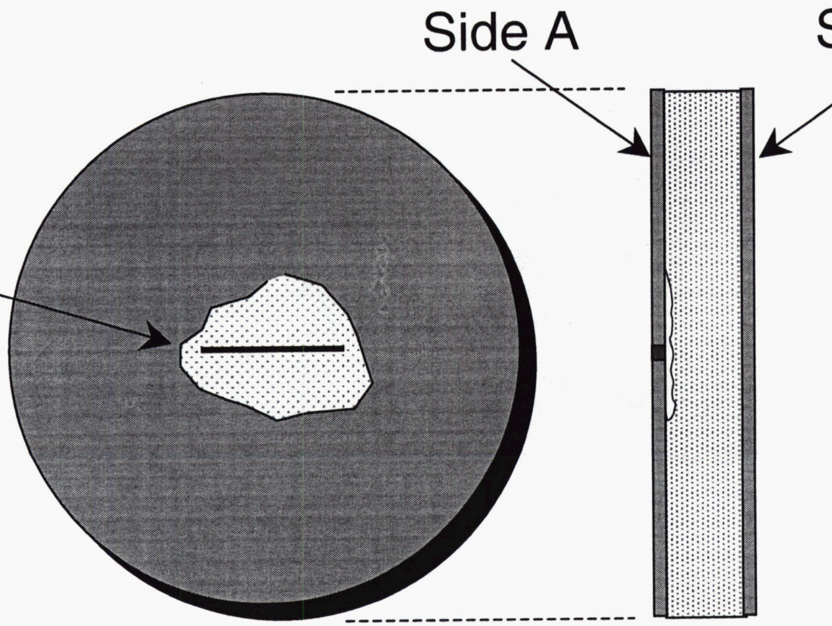
X-ray Test Specimen



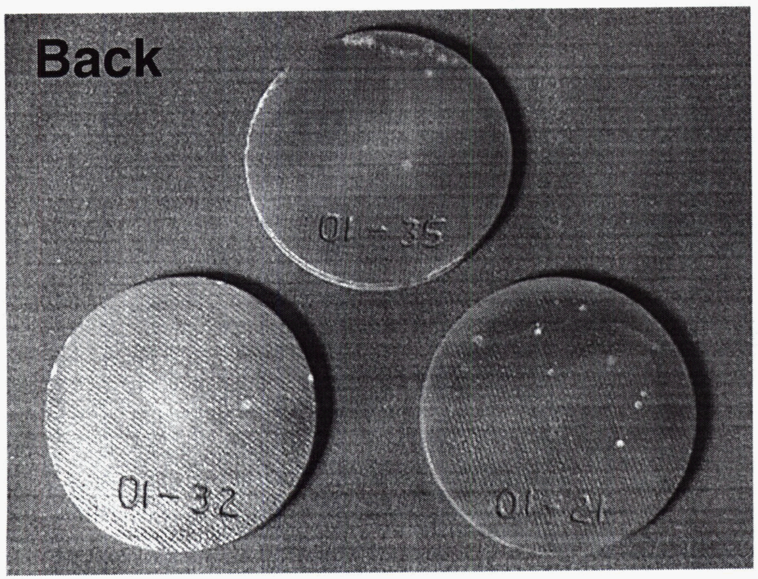
0.44” RCC Panel

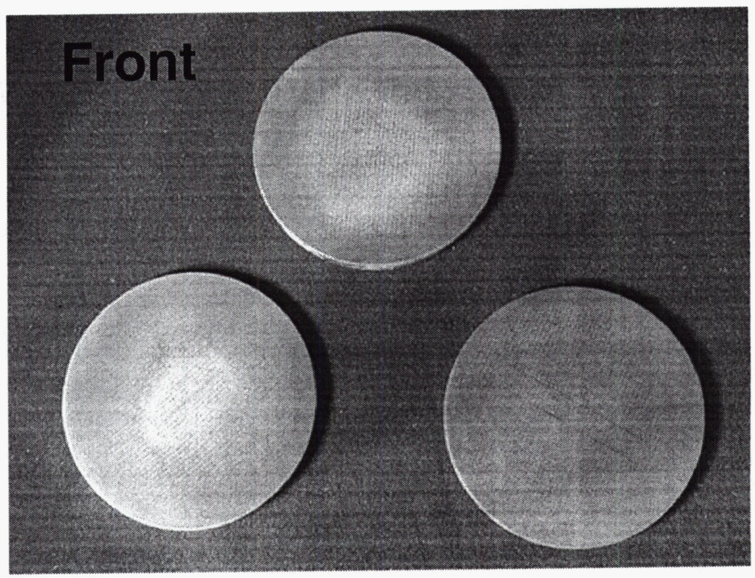
RCC Puck Samples

Crack through Si-C layer followed by arc-jet exposure

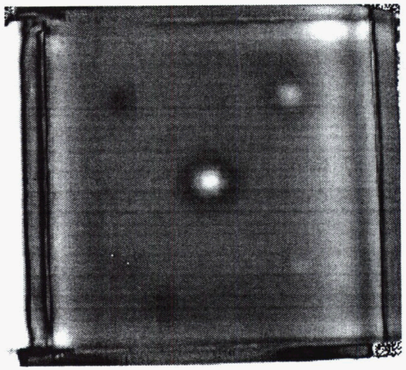


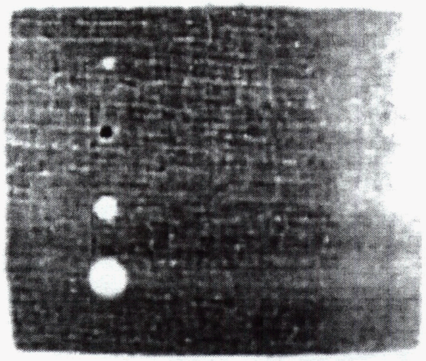
- **Inspection from Side A Simulates Nearside (Surface) Flaw Detection**
- **Inspection from Side B Simulates Backside (Deep) Flaw Detection**

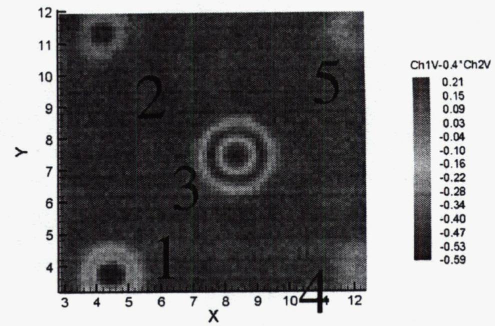


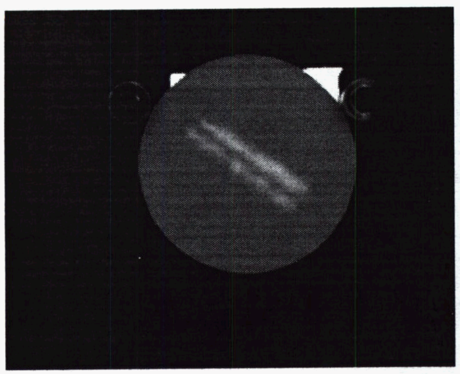


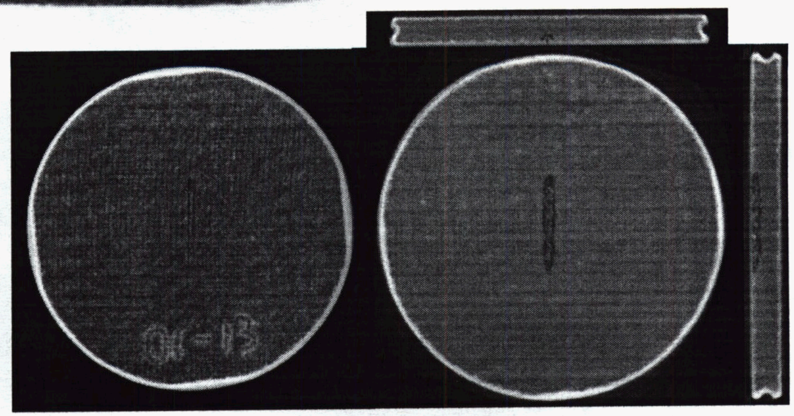
NDE Results of Various RCC Samples

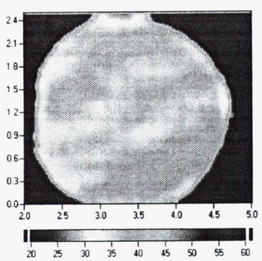




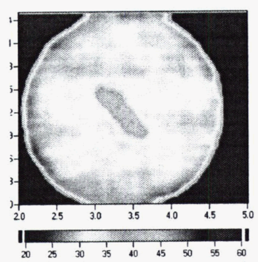




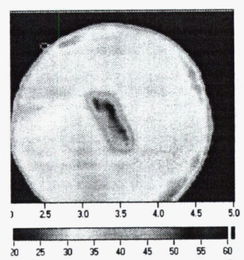




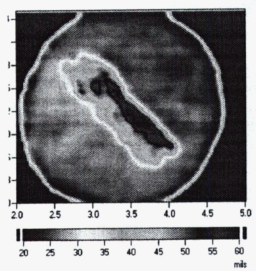
03-24



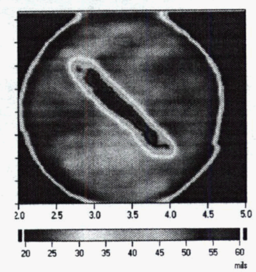
01-13



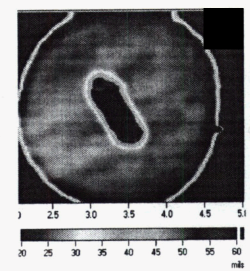
01-18



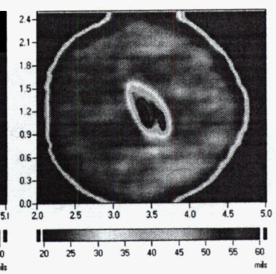
01-21



01-24

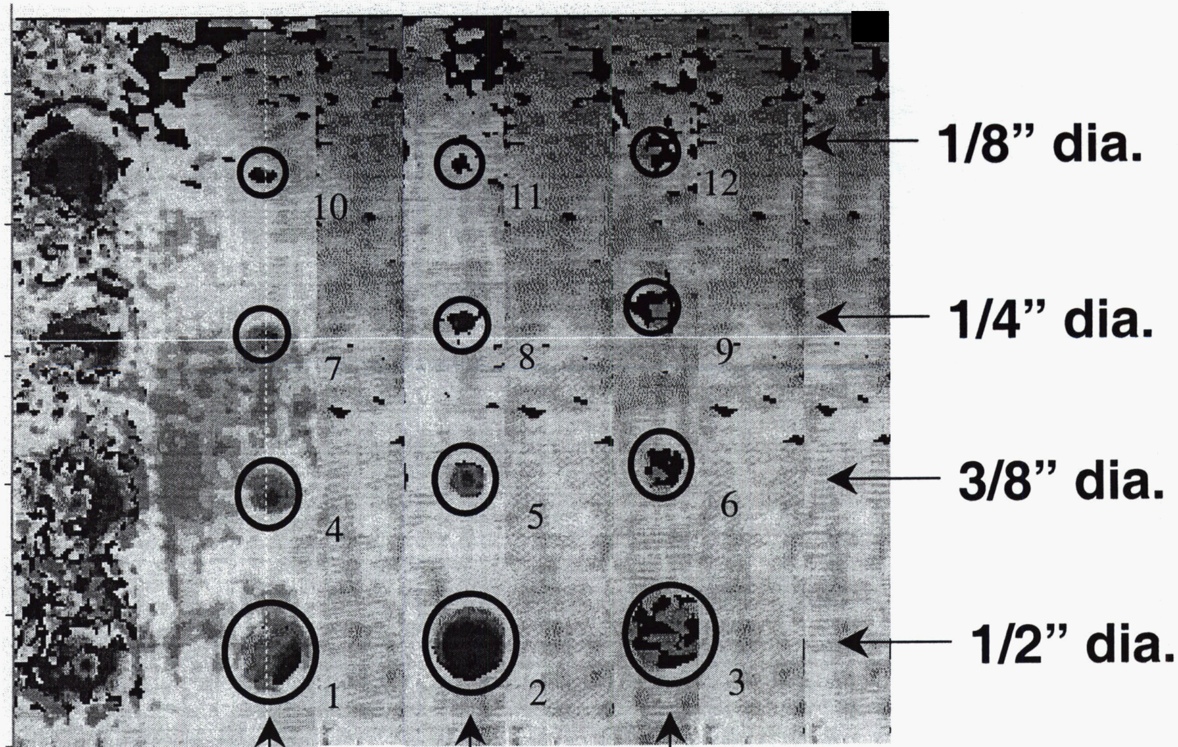


01-32



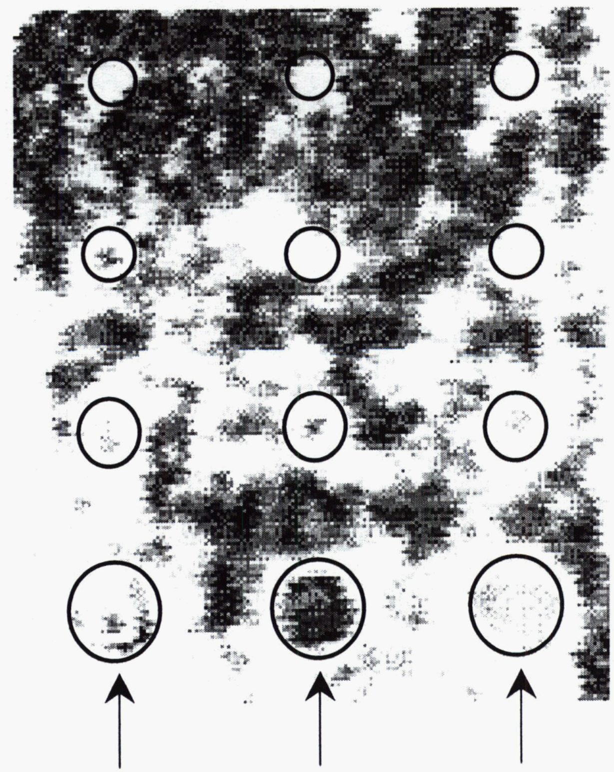
01-35

UT - 0.24" & 0.44" Panel with Coating



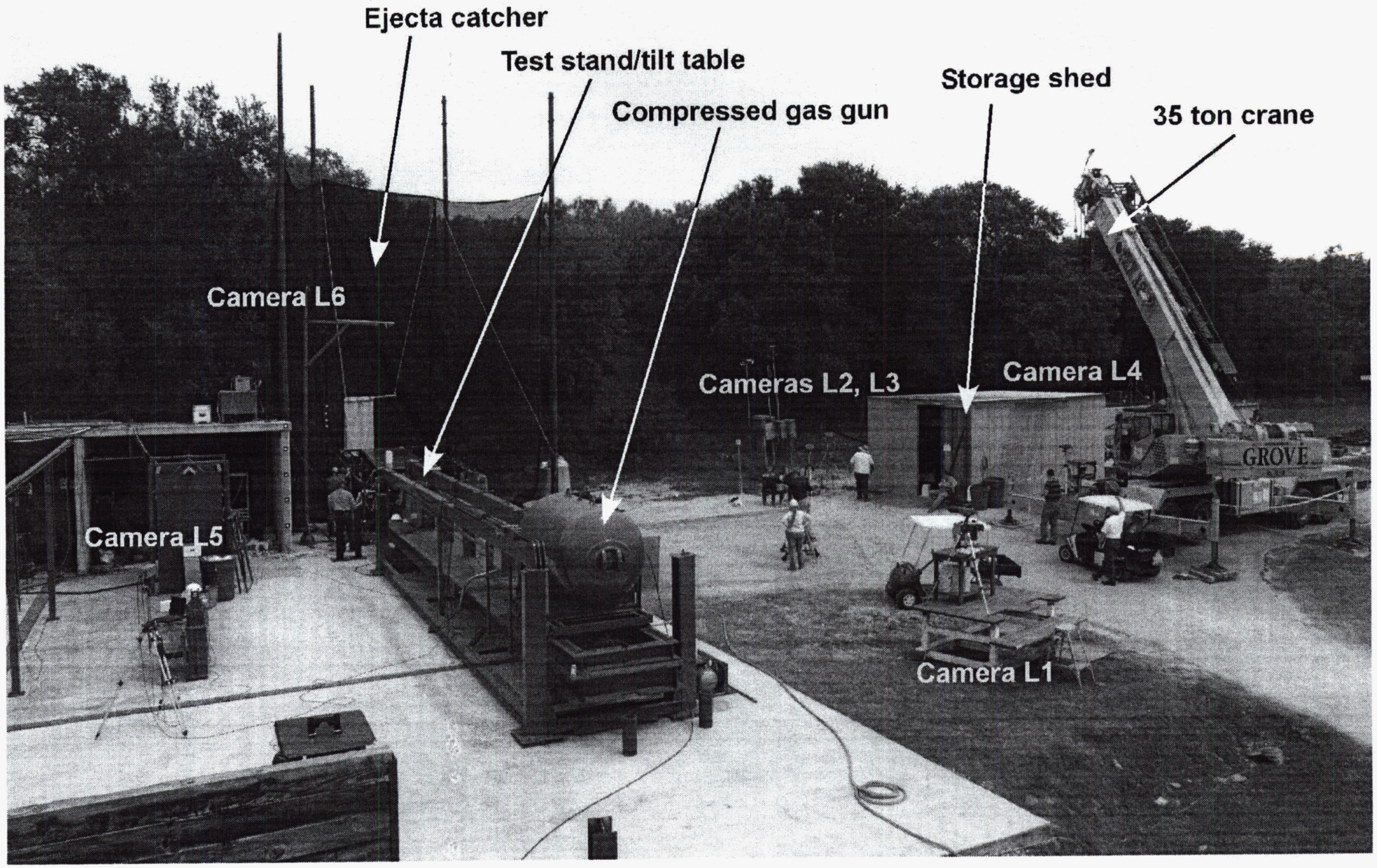
0.24" Thickness Sample

P-E UT Optimum Coupling



0.44" Thickness Sample

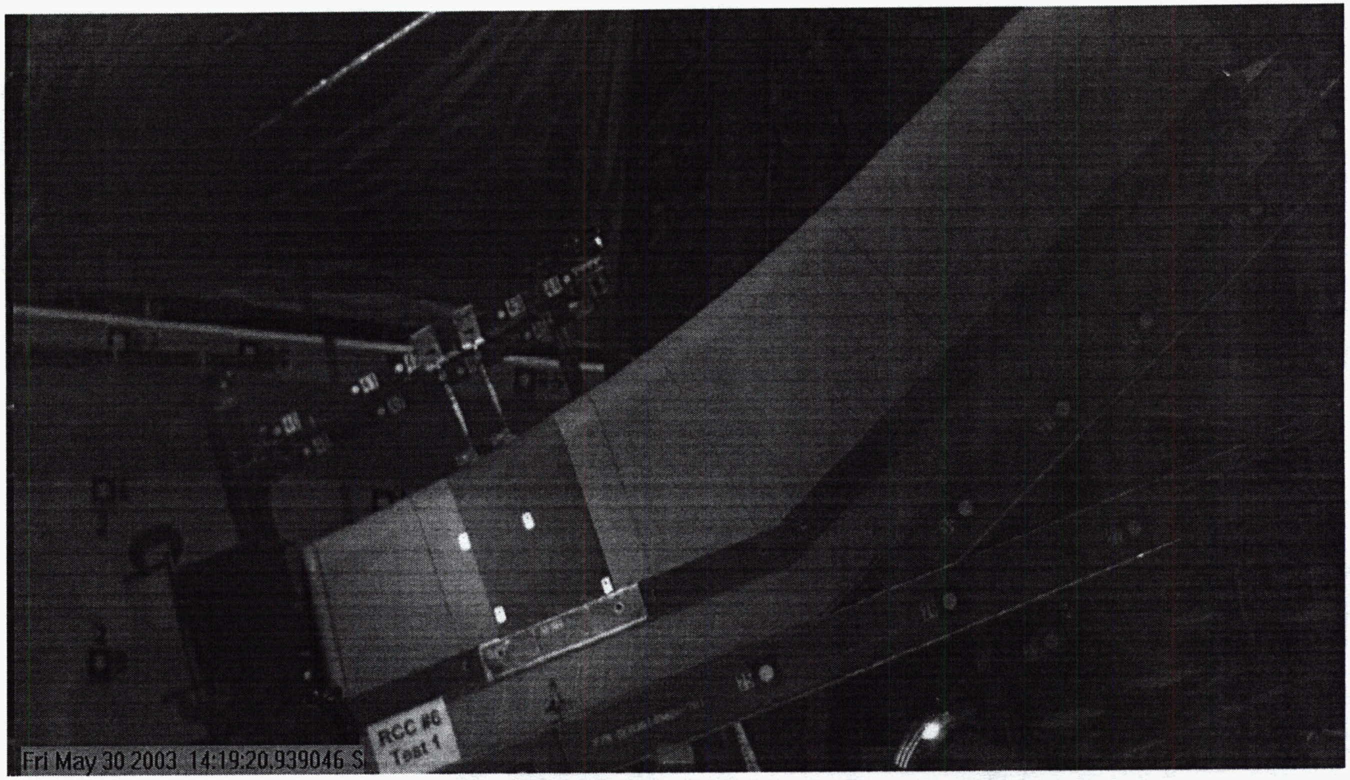
Took Advantage of Foam Impact Tests conducted at SwRI

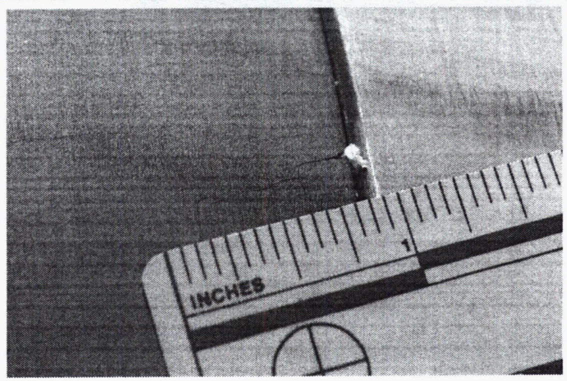


RCC testing in support of the Investigation

Two full scale RCC panel tests were conducted during the Investigation

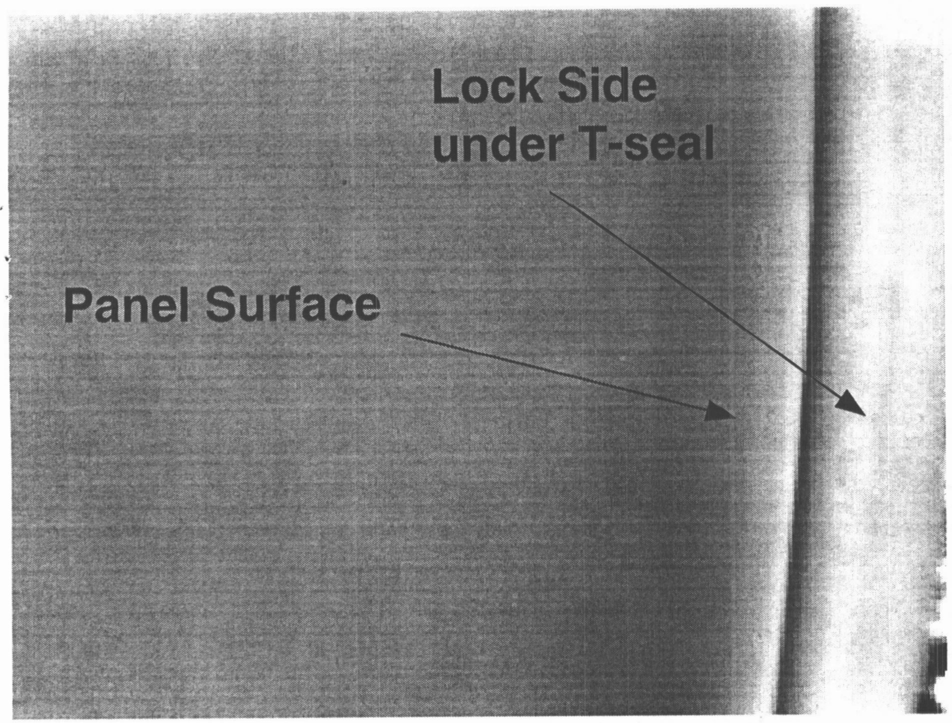
- Panel 6
  - Material: BX 250 foam
  - Dimensions: 5.63" x 11.56" x 21.38"
  - Mass: 763.8 g (1.68 lb)
  - Actual launch velocity: 768 ft/sec
  - CG angle of impact: 20.6°
  - 5½" long through thickness crack
  - Located on the lock side approximately 6" below the stagnation
  - Transverses the entire rib width, extends through the lock side channel and onto panel lower face.
  - Approximate 3/4" crack on the lower face
  - T-seal crack 2.5" long on rib





Thermography Inspections

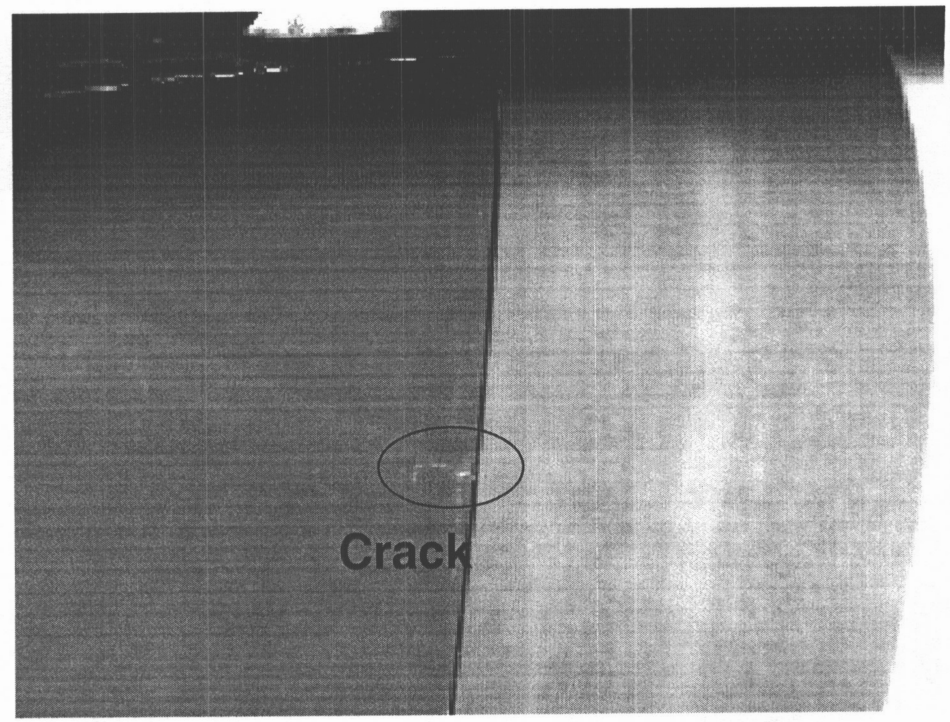
OV-103 6L Pre Impact



Thermal Image of the location of the crack

Outboard
(W/out T-seal)

OV-103 6L Post Impact

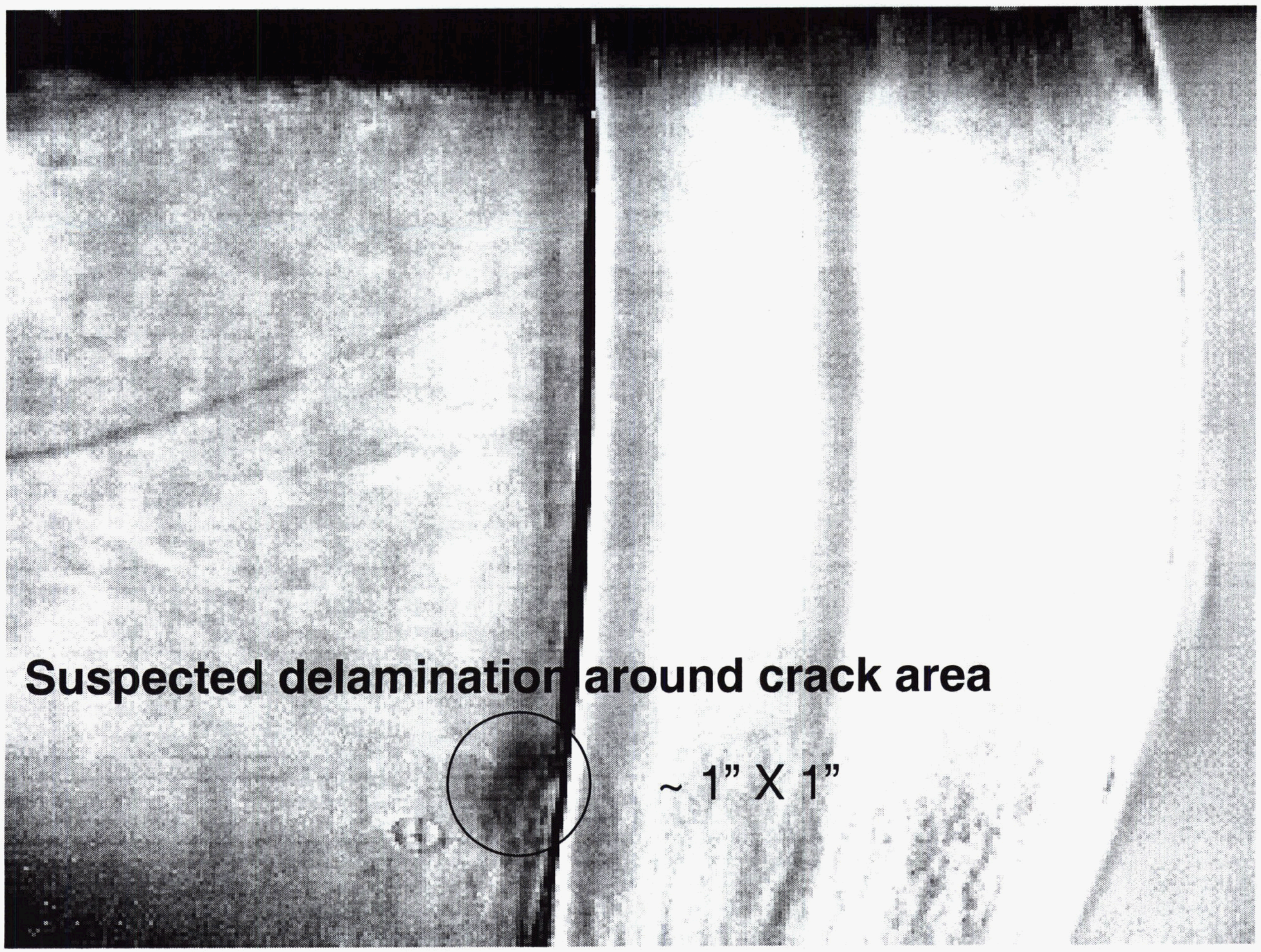


Thermal Image of the crack through the part

Outboard
(W/ T-seal)

OV-103 6L Post Impact

PCA Analysis of thermal data



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