The Development of NDE Techniques for Payload Fairings and Other Composite Structures

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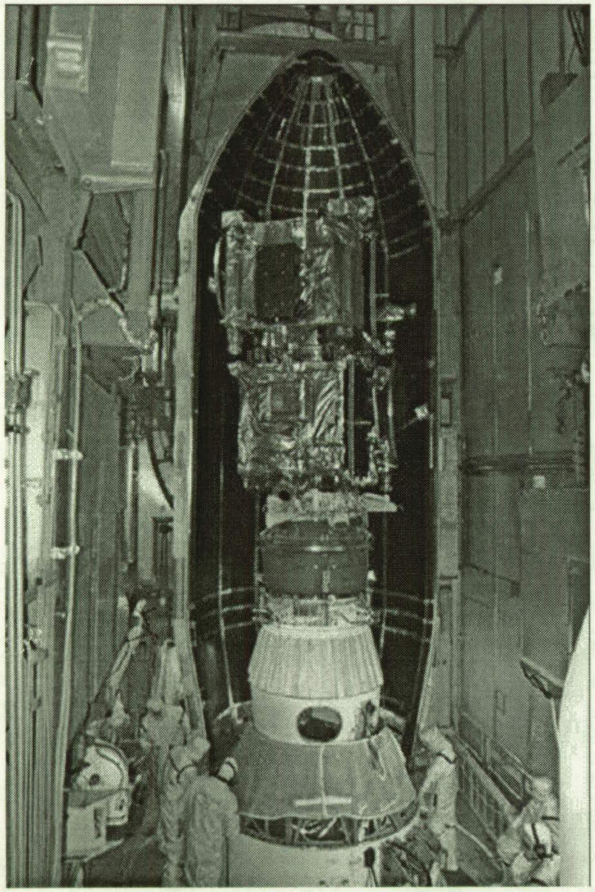
Objective

- Develop and demonstrate NDE techniques to assist in the fabrication and operational monitoring of expendable vehicle payload fairings and other composite structures.
  - Delta II fairing contains Rohacell foam core which enhances moisture uptake and thereby weakening.
  - Constellation is designing a variety of composite structures for Orion, Ares 1 and Ares V which will require NDE techniques.

Moisture in Delta II Fairing



STEREO on the Delta II booster with fairing.

- <u>Problem Statement</u>
- After manufacturing, the fairing structure is exposed to a varied environment which results in moisture exposure and diffusive absorption.
- The effect of moisture is to weaken the structure especially when the fairing is heated during ascent. This weakening increases the risk of structural failure under ascent loads.
- ULA uses a proprietary computer model WetLam to estimate moisture content in fairing at launch.

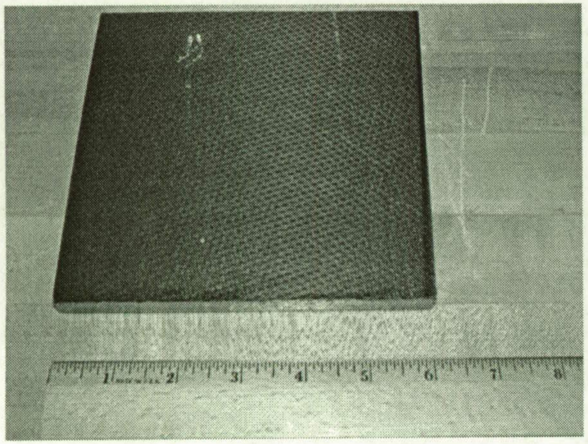
Two Paths Pursued - Measurement and Modeling

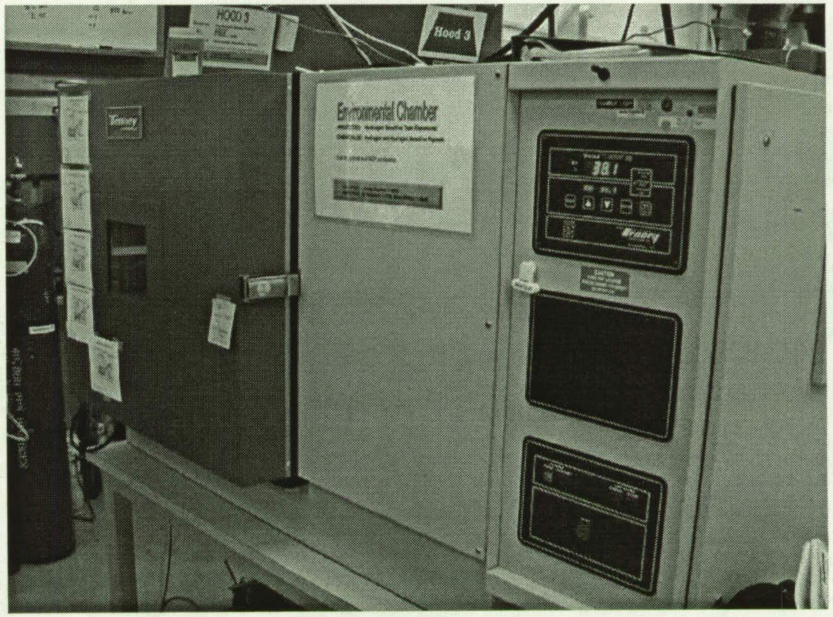
Measurement

- We reviewed several promising methods:
- Gravimetric approach (2004)
    - A witness sample follows the fairing and is weighed periodically to determine moisture uptake
- Neutron scattering
    - Vendors believe that carbon atoms will provide a strong signal, making it difficult to distinguish from water.
    - This is likely to require expensive development.
- Capacitance/ Impedance
    - Preliminary tests showed some promise but revealed challenges of calibration, repeatability, and sensor placement.
    - The method turned out to be less practical than originally thought:
        - The GEC faces are not electrically isolated from one another in an actual fairing, unlike our test samples.
        - While an embedded conductor in the foam core could make a capacitance measurement possible, it would require much more extensive analysis to determine impacts on the structural integrity and the manufacturing process.

Modeling

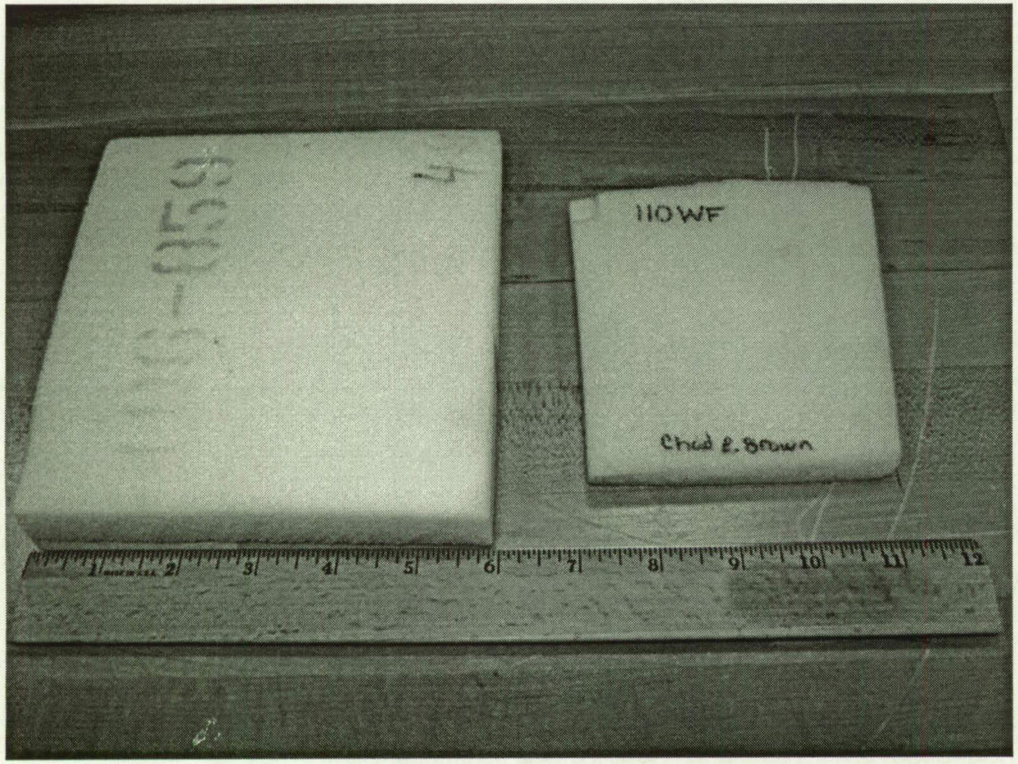
- Dried samples were inserted into an environmental chamber (fixed temperature and RH) and the mass was recorded versus time;
    - Rohacell foam core material of two different densities
    - A GEC facesheet with the glue still present on one side
    - A cutout from a fairing section was used with aluminum tape on the edges.
- The diffusivity was computed for each of the individual pieces.
- A multi-layer predictive model was developed based on finite difference methods.
- The model prediction and the data from the cutout were compared.
- A foam sample was vacuum dried at room temperature to determine the temperature dependence of the diffusivity.





Rohacell Foam Core Diffusivity

- Rohacell samples of different densities were tested (0.125 g/cc and 0.107 g/cc (110 WF)).
- The environmental chamber set points were 37.8°C & 85.0% RH.
- The data was fit to the following equations in Springer (p16) to find D_x



diffusivity correction for open sides:

$$\boxed{D_x = D\left(1+\frac{h}{l}+\frac{h}{w}\right)^{-2}}$$

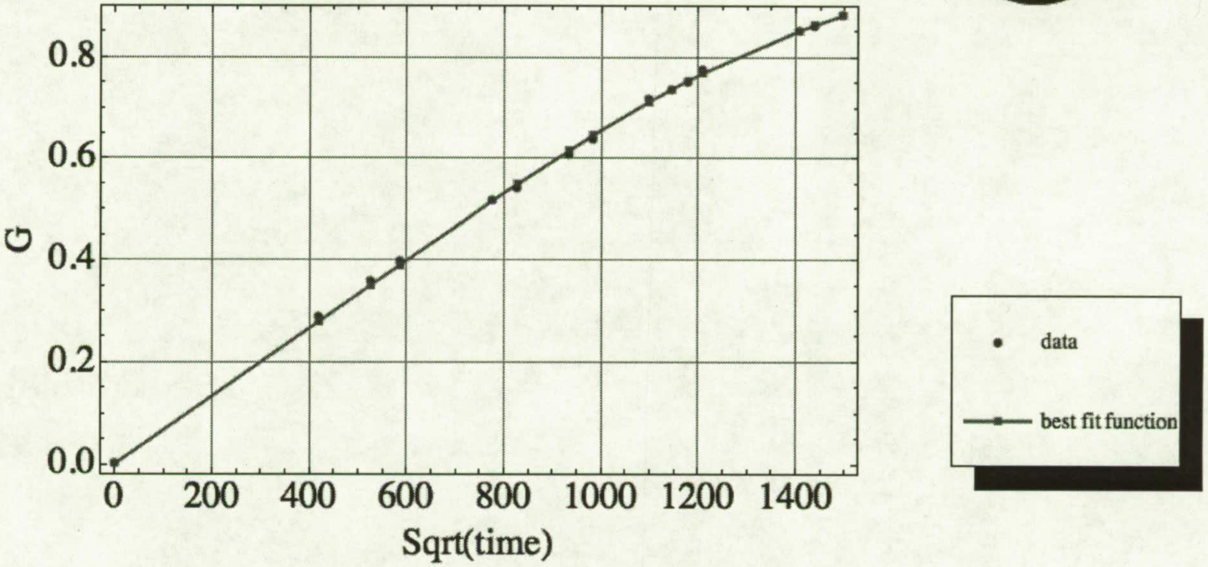
D - uncorrected diffusivity
h - thickness of sample in cm
l - length of sample in cm
w - width of sample in cm

$$\boxed{G=\frac{M-M_i}{M_m-M_i}=1-\tfrac{8}{\pi^2}\sum_{j=0}^{\infty}\frac{Exp[-(2j+1)^2\pi^2(D_x t/h^2)]}{(2j+1)^2}}$$

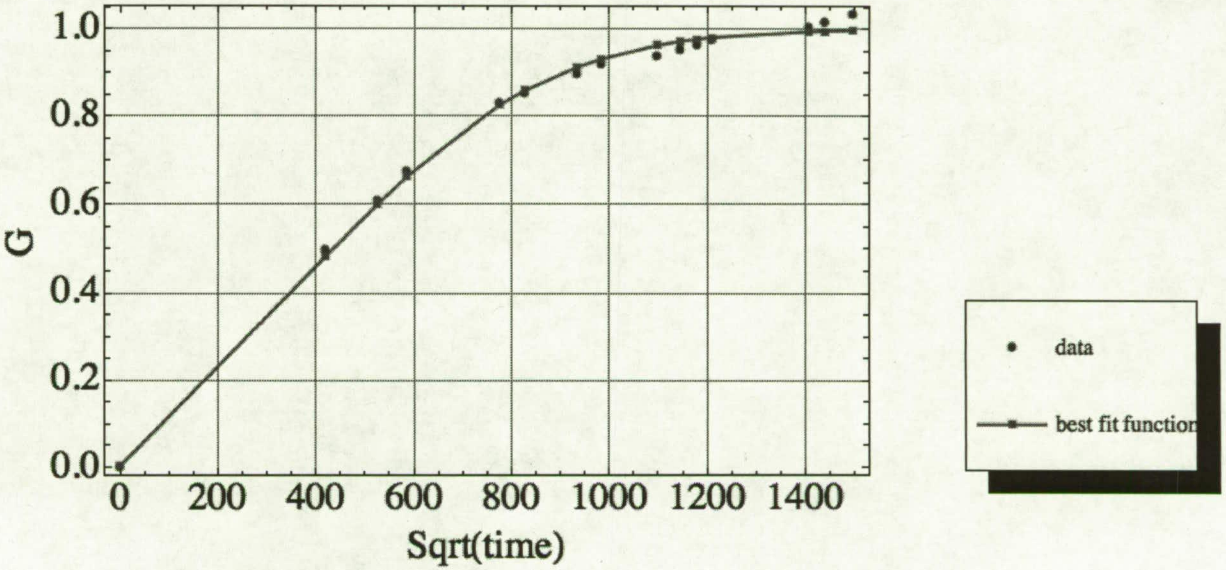
M - measured mass in g
M_i - initial mass in g
M_m - maximum mass in g
t - time in sec

Rohacell Foam Diffusivity

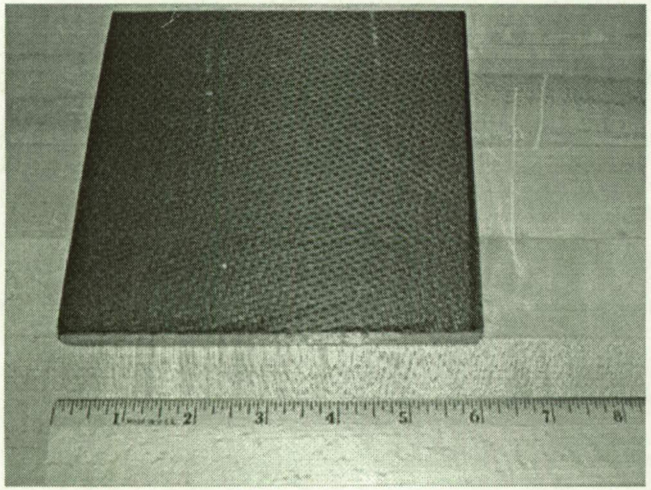
$D_x=2.0*10^{-7}cm^2/sec$
(thicker specimen)



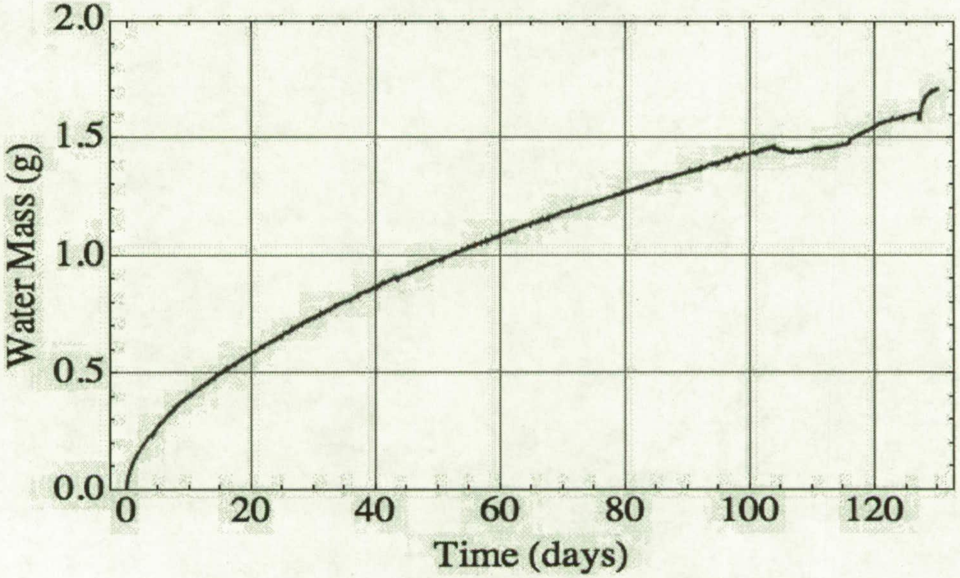
Delta II fairing core material
(110 WF)
$D_x=2.8*10^{-7} cm^2/sec$



Delta II Fairing Material Moisture Uptake



A sample of Fairing was dried and placed in an environmental chamber set at 37.8°C & 85.0% RH for approximately 130 days. The resulting change in mass plot versus time is shown below on the right.



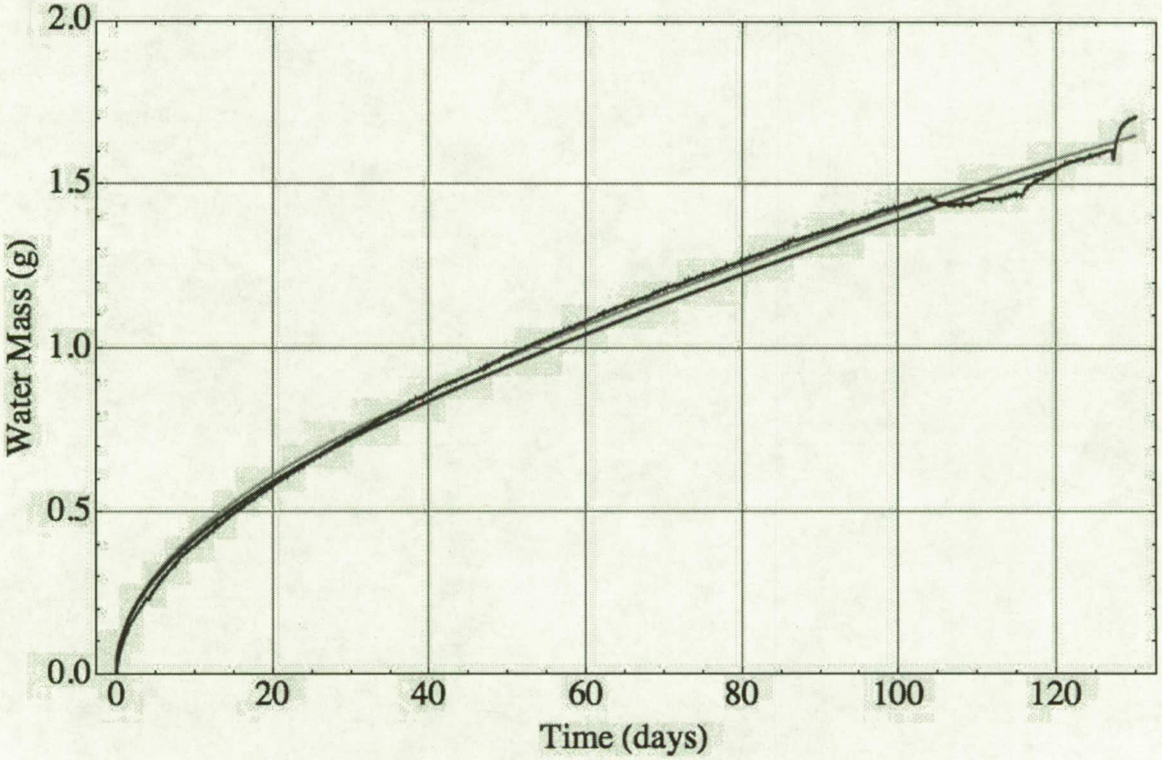
Moisture Uptake Computer Model

- We created an independent multi-layer moisture diffusion model based on finite-difference methods to compare with Wetlam (the ULA model)
- Our model assumes:
  - fixed temperature
  - fixed RH at outer boundaries
  - diffusion constant from ULA for GEC face sheet
  - KSC diffusion constant for the foam core
  - a and b parameters from ULA (c=a*phi^b)
  - no glue layer
- The values that were used to model the Delta II fairing material appear in the table below:

	Density (g/cc)	a	b	D (cm^2/sec)	Area (cm^2)	h (cm)
facesheet	1.61	1.45	1.65	$2.0*10^{-9}$	248	0.142
core	0.111	10.6	1.9	$2.8*10^{-7}$	248	1.27

Data vs. Models

- Our model agreed with the output of Wetlam to within rounding errors and to the data.



ULA model in green;

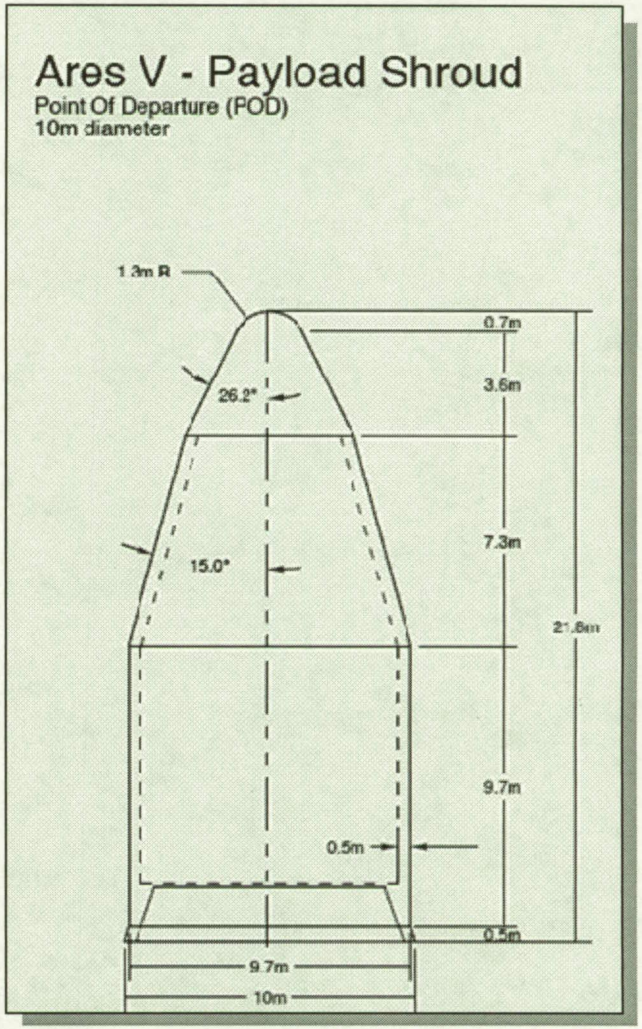
KSC model in red

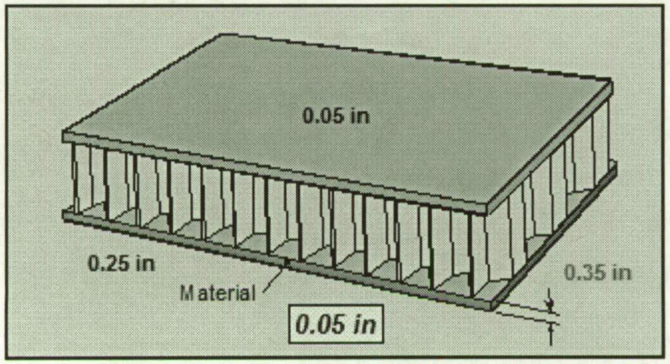
Delta II Results and Status

- We provided an independent verification of ULA's modeling approach to estimated moisture at launch.
- ULA has agreed to test gravimetric coupons from next fabricated fairing against model.

Ares V Payload Shroud

- Honeycomb Sandwich construction
  - IM7/977-2 face sheets
    - $[0/+45/-45/90]_s$ Quasi-Isotropic layup
    - Smeared into Equivalent Orthotropic properties
    - Only sized by total thickness – no layup optimization
  - Aluminum (Hexcel Al 5052) honeycomb core
    - 4 designs considered
    - including 4 wall thickness and two cell sizes
- Single "Access" petal with all penetrations
- Three non-penetrated petals
- Ring Frames at each angle change & base
- Simple analysis showed only a small effect from mid-panel rings; left for later trade.


Ares V - Payload Shroud
Point Of Departure (POD)
10m diameter



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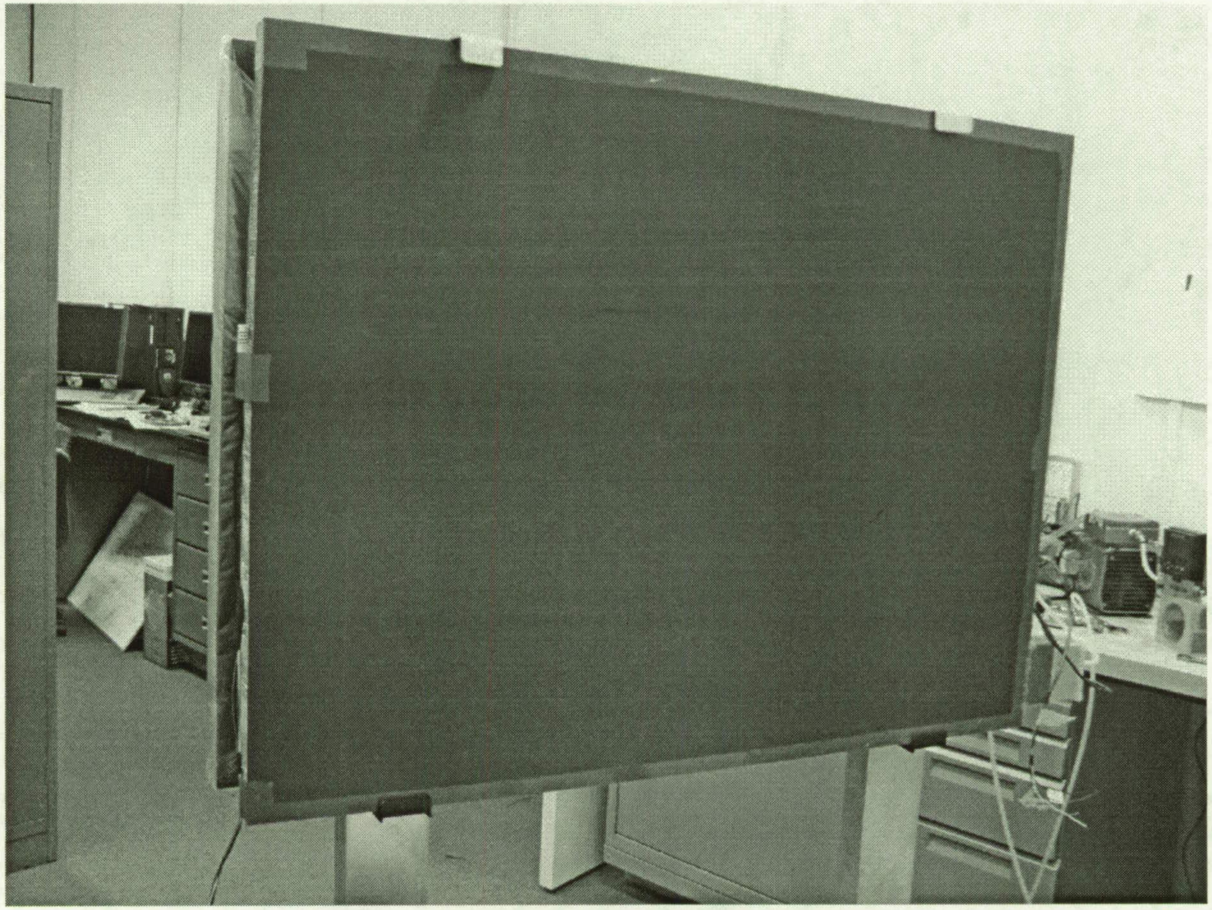
ATK Fairing Samples

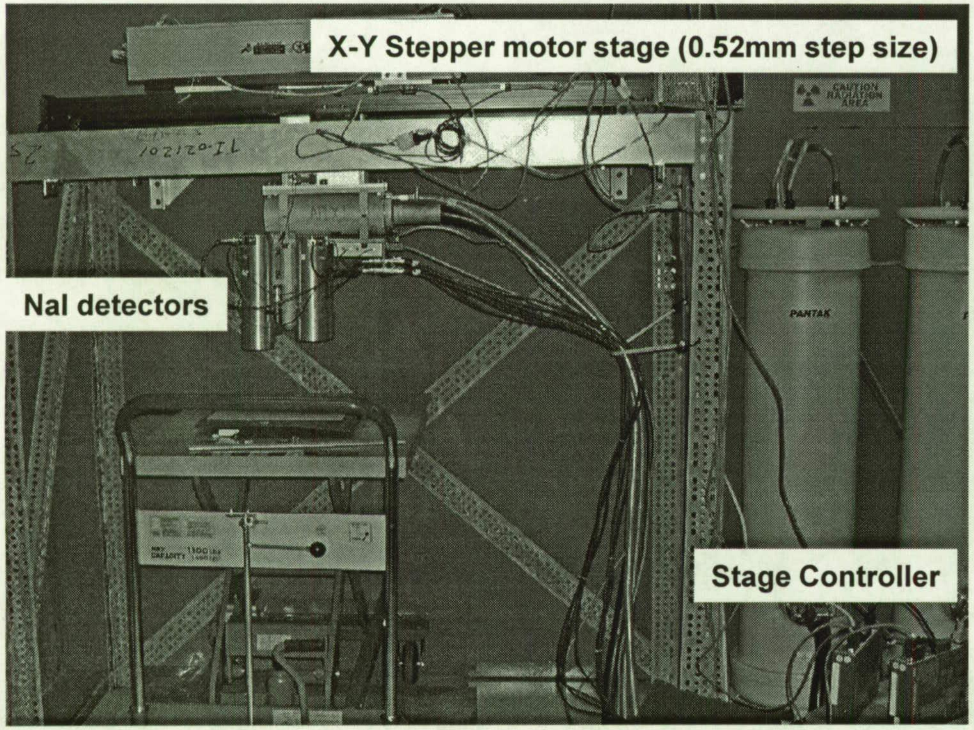
- We have begun testing a novel method to reduce moisture in perforated honeycomb sandwich structures.

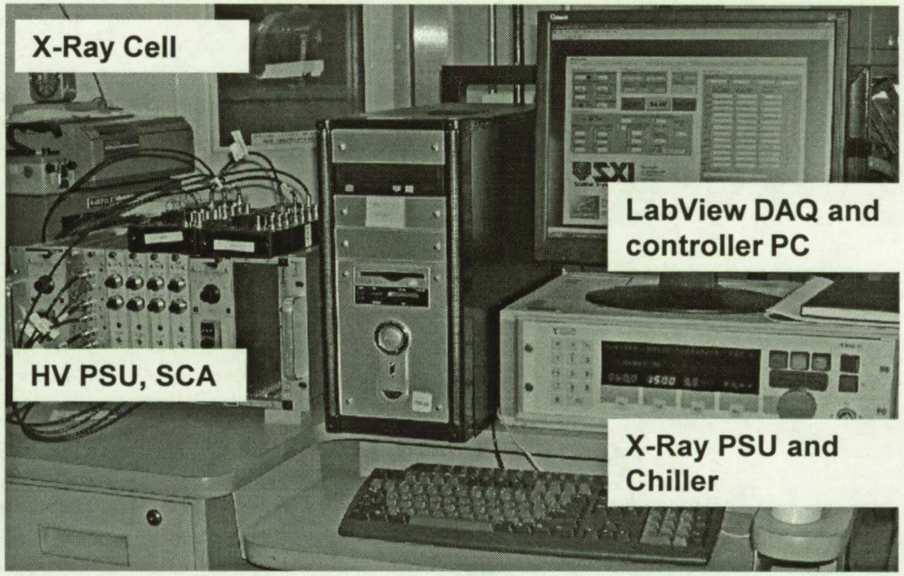


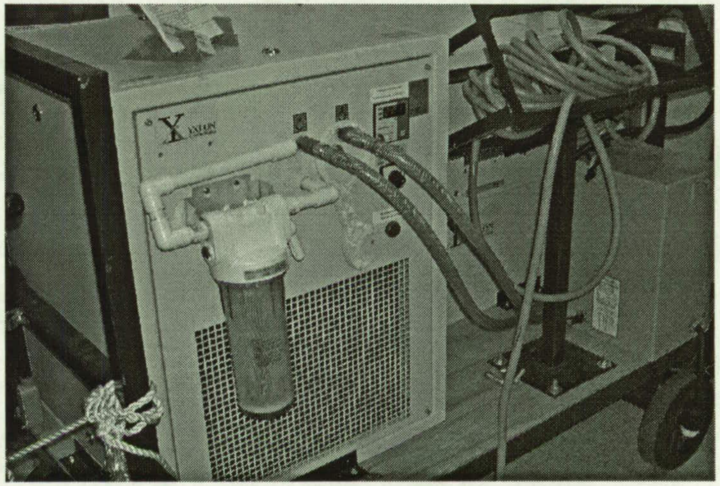
Orion Heat Shield

KSC has prototype LM heat shield with PICA tiles adhered to base-plate with RTV for evaluation of handling and NDE techniques and related NDE samples.

Backscatter X-Ray System

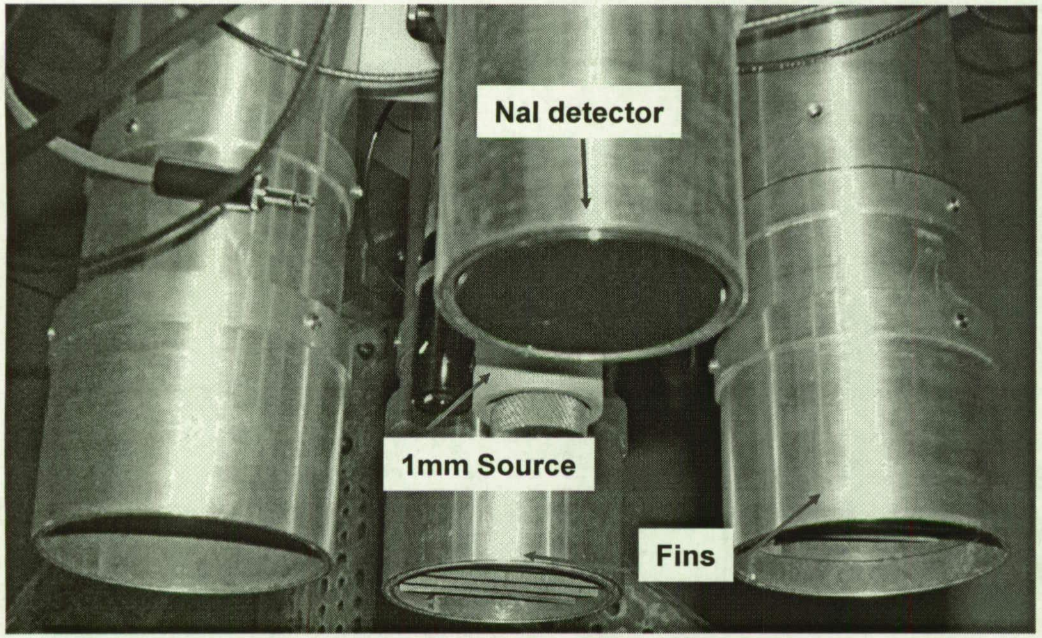


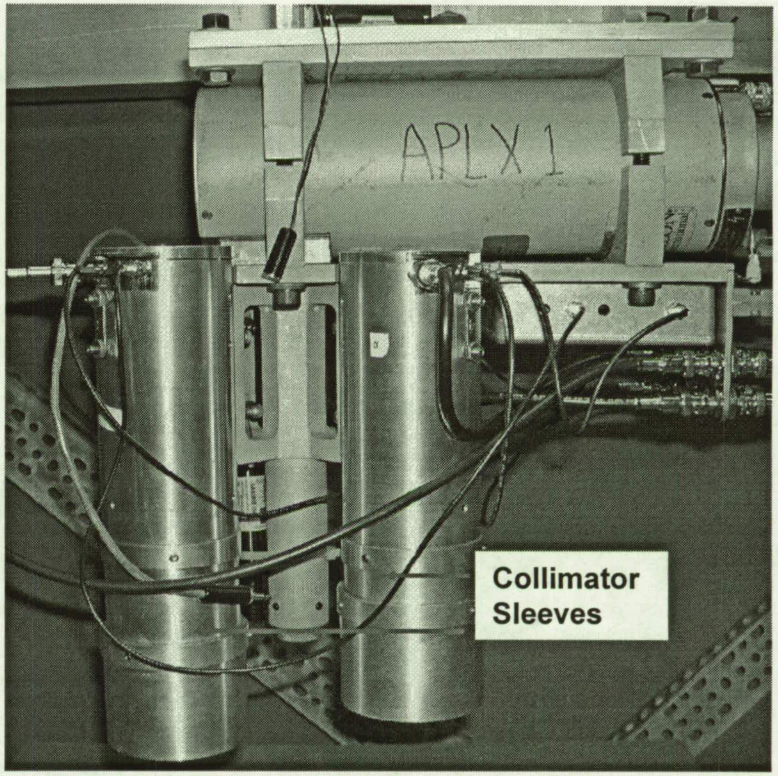




- Yxlon x-ray source
- Maximum settings 110kV 20mA
- Four NaI detectors
- 5.5mm spot size
- LabView stage control and DAQ

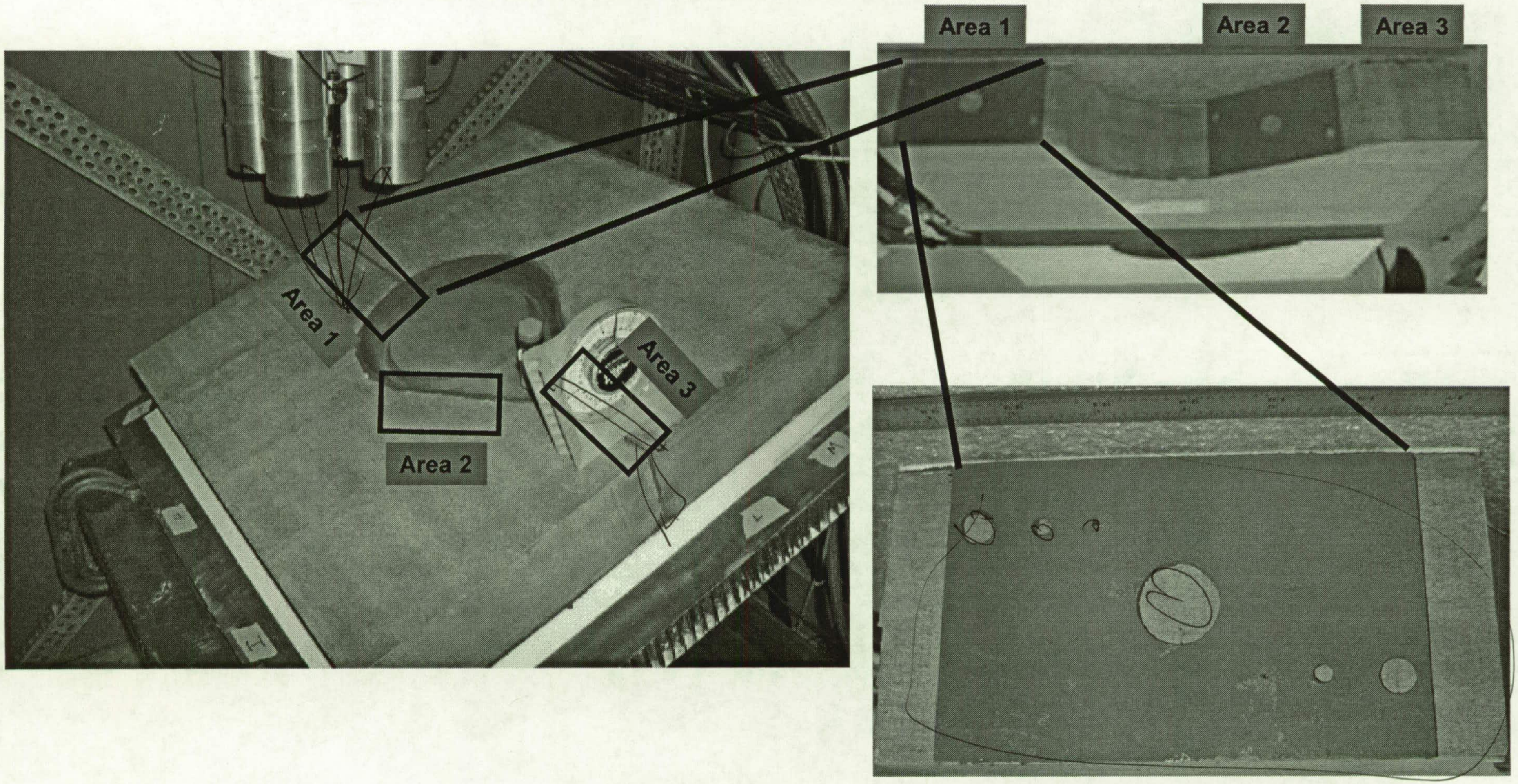
Backscatter X-Ray Head



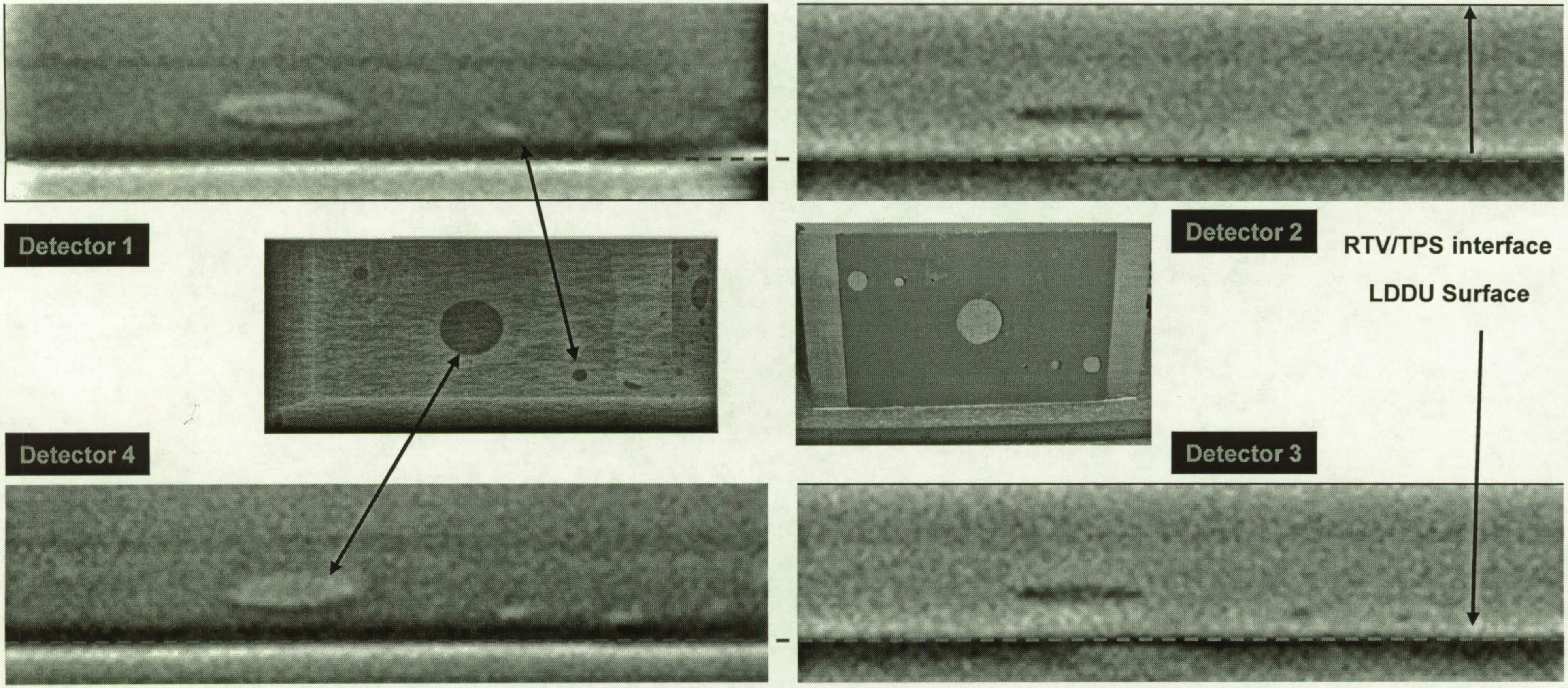


- **Spot size focused to 1mm with lead apertures**
- **Collimator sleeves have 60mm travel length**
- **Lead fins are inside collimator sleeves and can be rotated to block out primary backscatter x-ray signals**
- **The Source and the detectors raster across the imaging area of interest**

LDDU Regions of Interest



LDDU BSX Scan 11° Tilt



Detector 1

Detector 2

RTV/TPS interface

LDDU Surface

Detector 4

Detector 3

- **The 1in, the partially filled 0.5in and the 0.25in holes can be clearly seen by each detector**
- **The 0.25in hole on the near the TPS interface be seen by detector 4**

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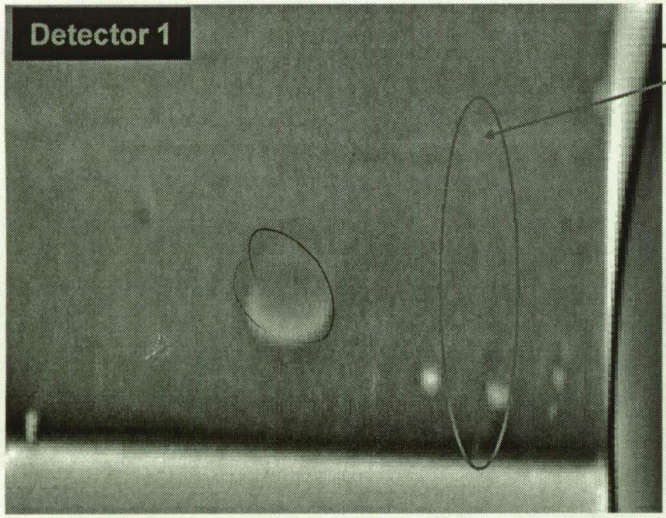
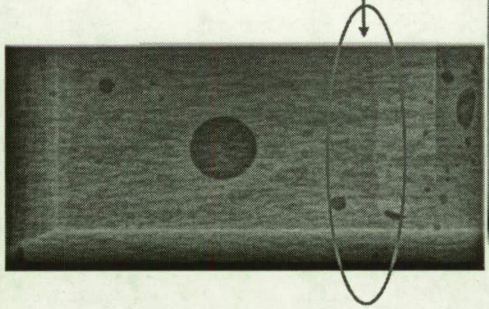
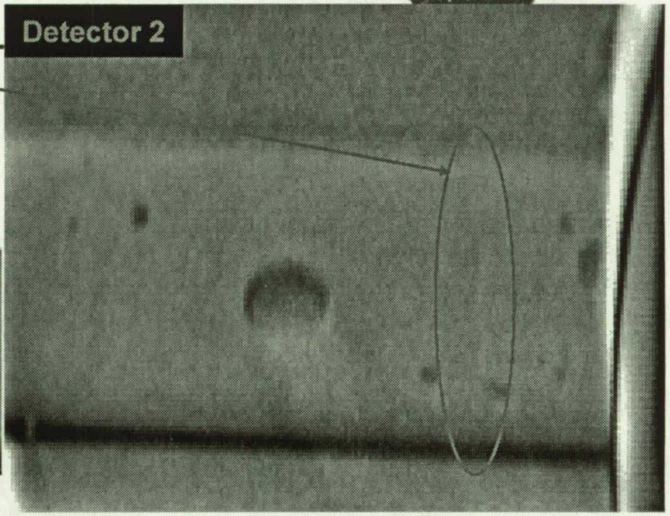
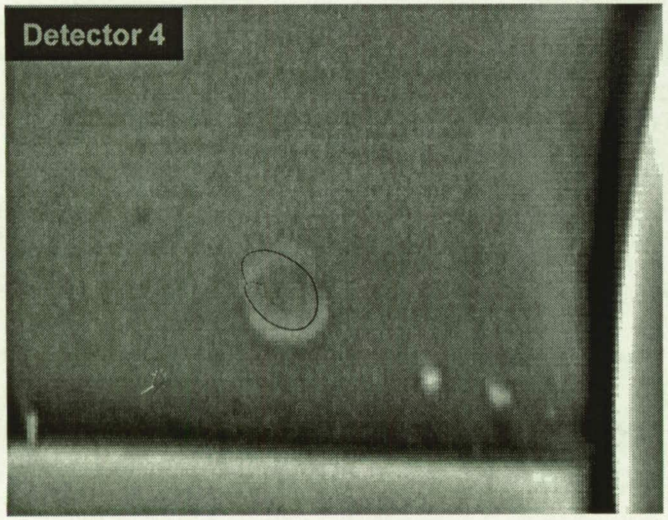
Scan 23° Tilt, FFT Filter

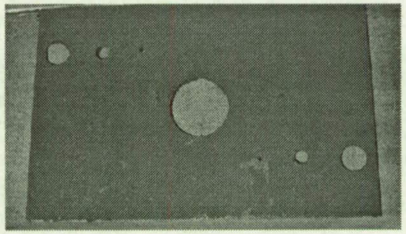


RTV cure mismatch interface

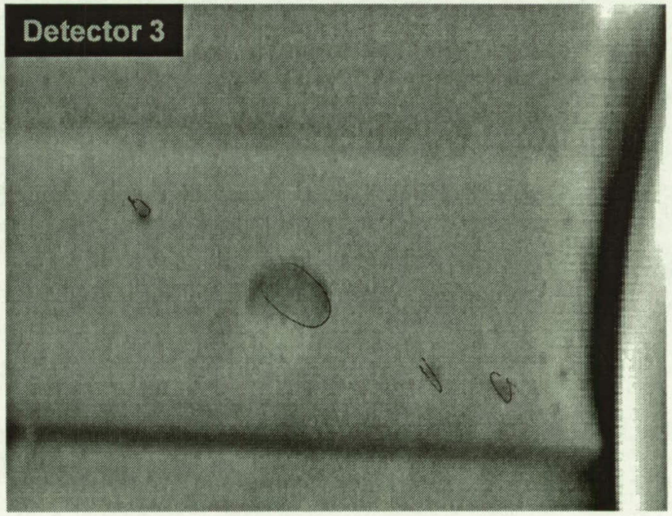








- **FFT bandpass filter and scaling is used enhance the voids in the image**



Summary

- We developed data and a moisture model to verify ULA approach to estimating moisture levels (therefore fairing strength) at launch.
- We have demonstrated a method to perform 1 sided X-ray of the PICA heat shield RTV seams. This angled method is applicable to a wide variety of materials.
- We acquired test panels of structures of interest to Constellation to perform drying and other tests.