Computed Tomography Scanning of a 1-meter Demonstration Heatshield For Extreme Entry Environments

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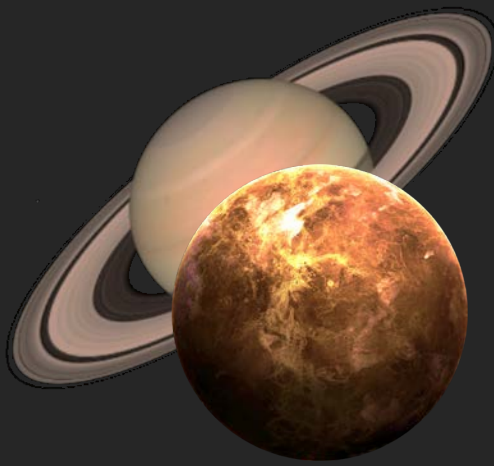
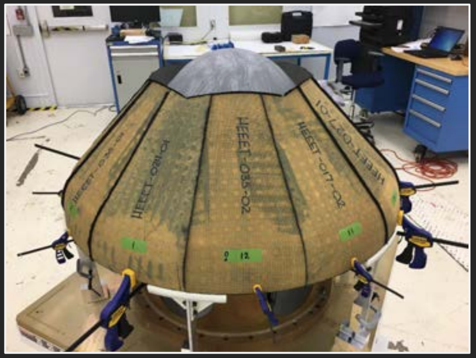
HEEET Overview

- **Heatshield for Extreme Entry Environments Technology**



- **Project Goal: Mature HEEET TPS system to TRL 6 to support NASA SMD robotic entry missions**
  - Target missions include Venus Lander and Saturn Probes
  - HEEET Material is dual-layer, 3D woven with carbon yarns
  - Capable of withstanding extreme entry environments:
    - **Peak Heat-Fluxes up to 5000 W/cm^2; Peak Pressures up to 5 atm**
  - System is scalable with application to 1-3 meter probes

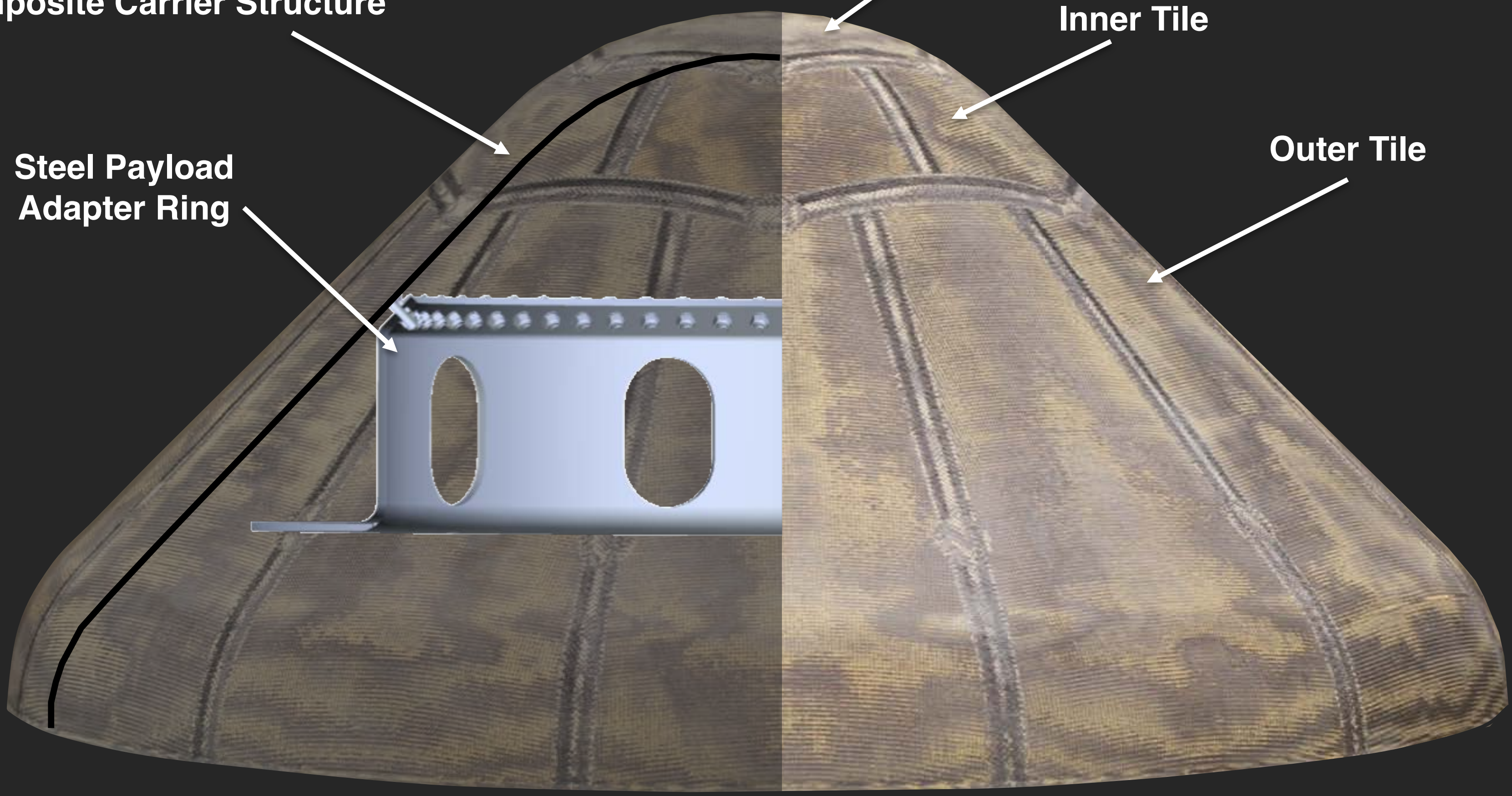
- **Key deliverable of HEEET Project is a 1-meter, flight-relevant Engineering Test Unit (ETU):**
  - ETU build demonstrates manufacturing and integration processes
  - Environmental testing demonstrates structural performance at scale



Detailed discussion of the HEEET Project today at 2:54pm by Don Ellerby:

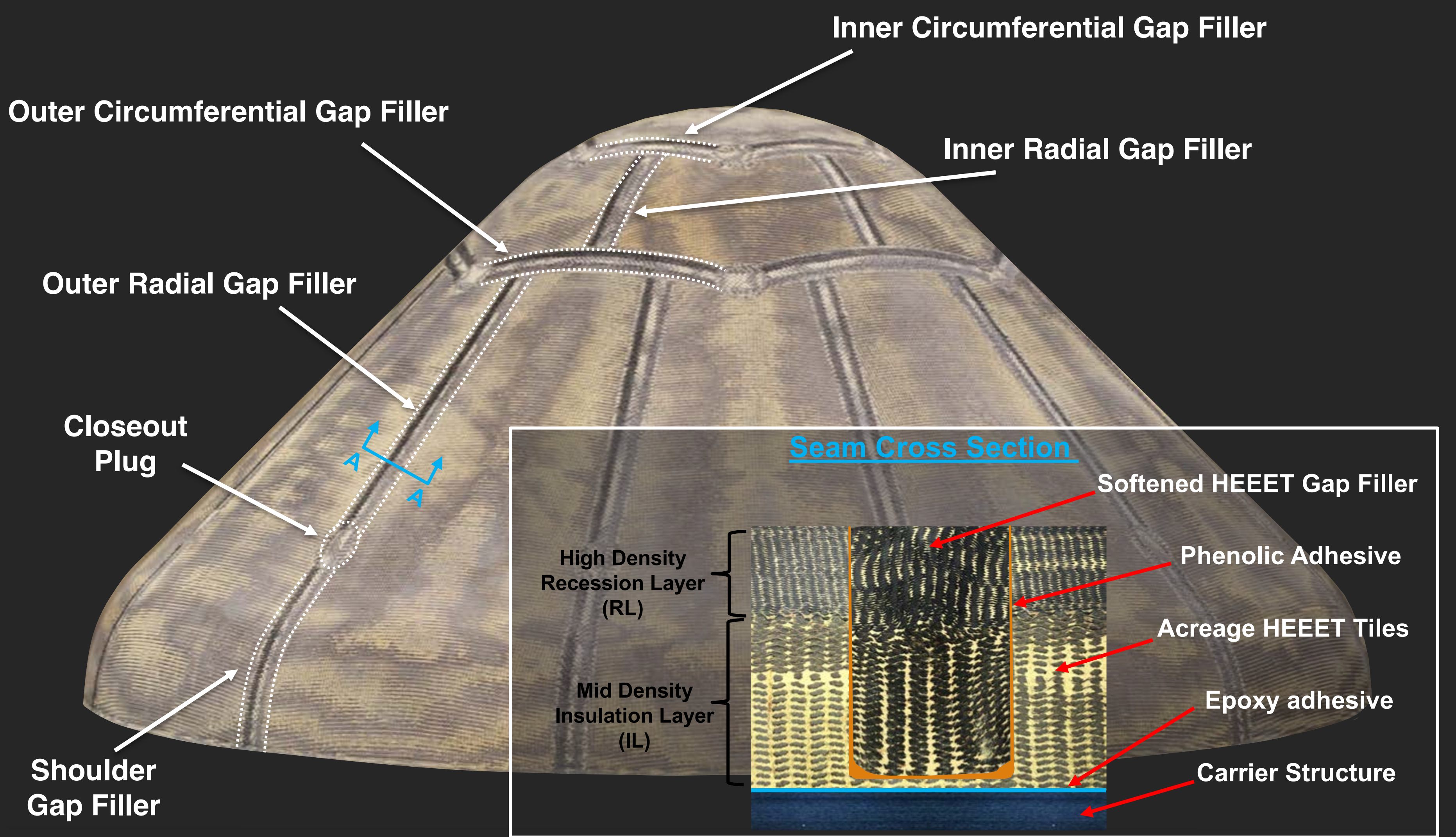
Overview of heatshield for extreme entry environment technology (HEEET) project

ETU Anatomy



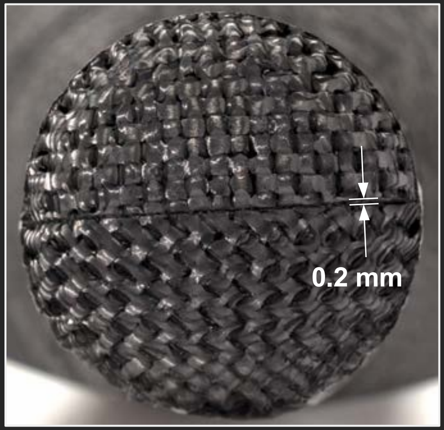
Nosecap
Composite Carrier Structure
Inner Tile
Outer Tile
Steel Payload
Adapter Ring

ETU Seam Anatomy

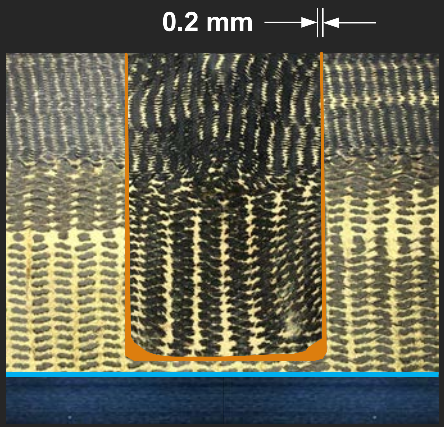


Need for CT Scanning

- **Extreme environments = extreme requirements**
  - No tiled TPS has ever been qualified for similar conditions
  - Arcjet tests show that narrow adhesive seams are necessary
    - Seams are ~200 μm
    - 5-10x thinner than other tiled heatshields
  - Adhesive system used is a phenolic film (not RTV)
    - Robust aerothermally; Unforgiving in integration due to high viscosity
- **Verification of integration success achieved with CT:**
  - Primary Objective: Identify defects in critical adhesive seams
  - Narrow bondline drives the inspection requirements
    - Reconstructed voxel size required ~100 μm
- **Pre-Test versus post-test scan comparisons**
  - CT scan allows for characterization of the ETU state prior to testing
  - Post-Test scans will find defects introduced from testing
- **Alternative NDE methods evaluated in parallel to CT**
  - HEEET properties introduce challenges for NDE methods

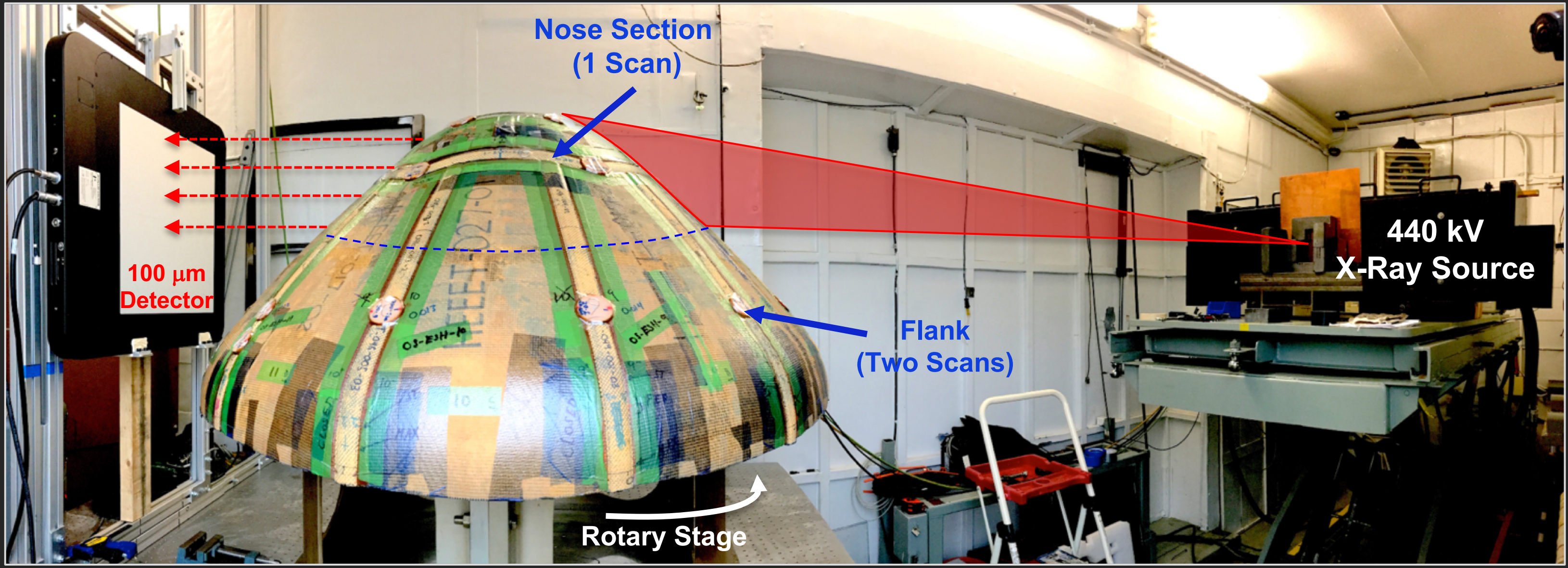


Post-Test model with thin adhesive seam

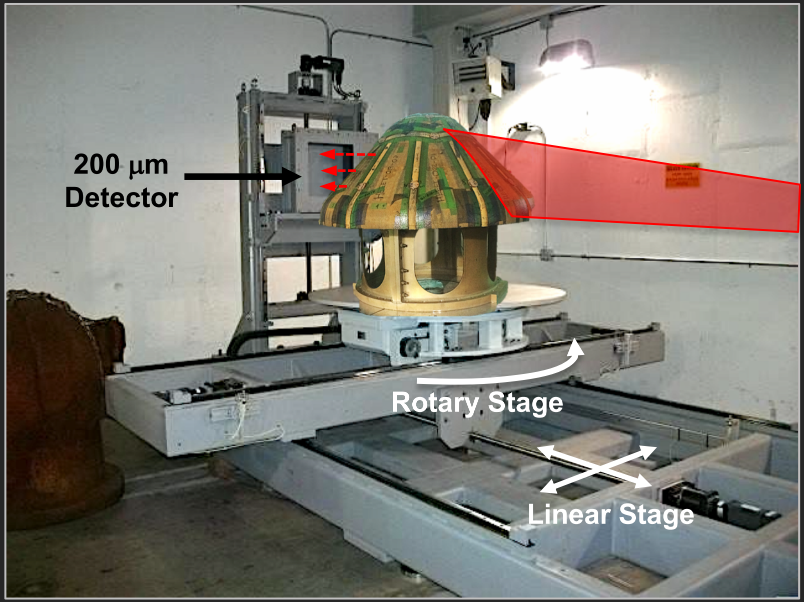


ETU CT Scanning With VJ Technologies

440 kV Setup
VJ Technologies

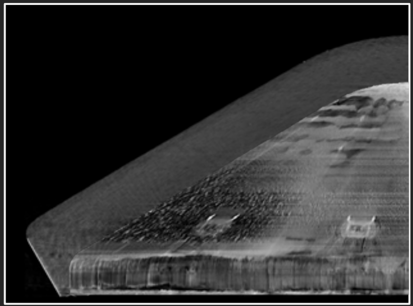


9 MeV Setup
VJ Technologies

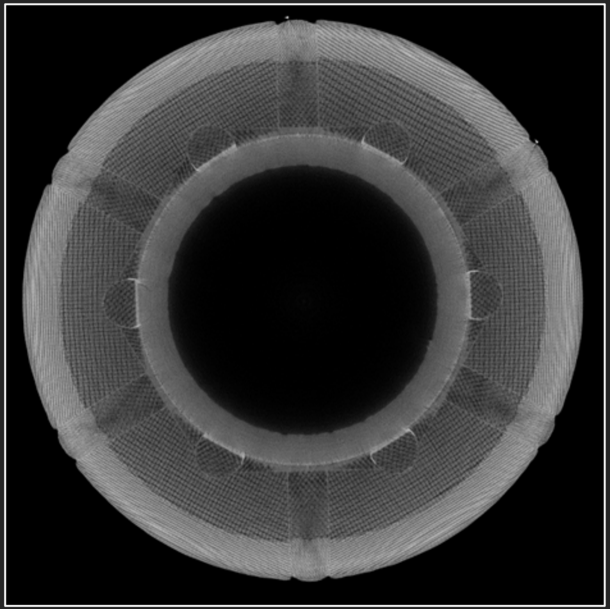


CT Scan Quality

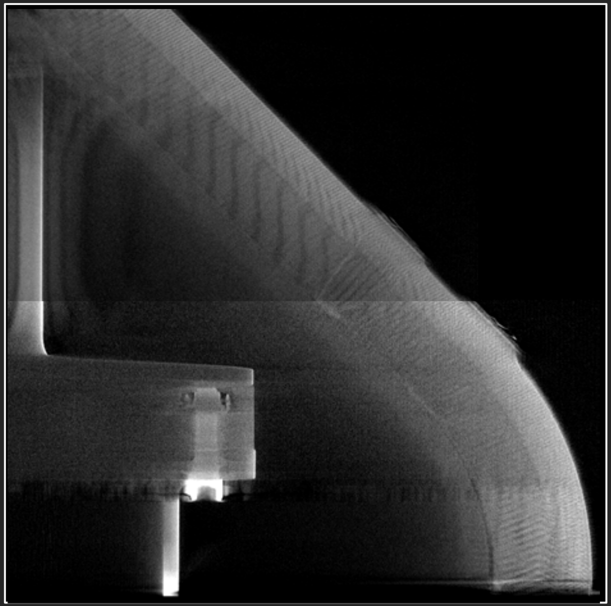
- **Stardust is the only flight probe to be fully CT scanned (post-flight only)**
- **Several factors make the HEEET ETU inspection more difficult:**
  - Stainless steel ring: noise, trade between noise reduction and contrast/resolution
  - Density of HEEET (>3x PICA) and 0.3” laminate aeroshell are highly attenuating
  - Contrast difficulties due to similar material compositions
  - Practical considerations: 40 hours per scan, large data volumes
- **Scans of nose region met requirements**
  - Sufficient resolution and scan quality to inspect phenolic adhesive
- **High energy scans of flank are sufficient to rule out any gross defects**
  - Steel ring required we trade between resolution and scan quality



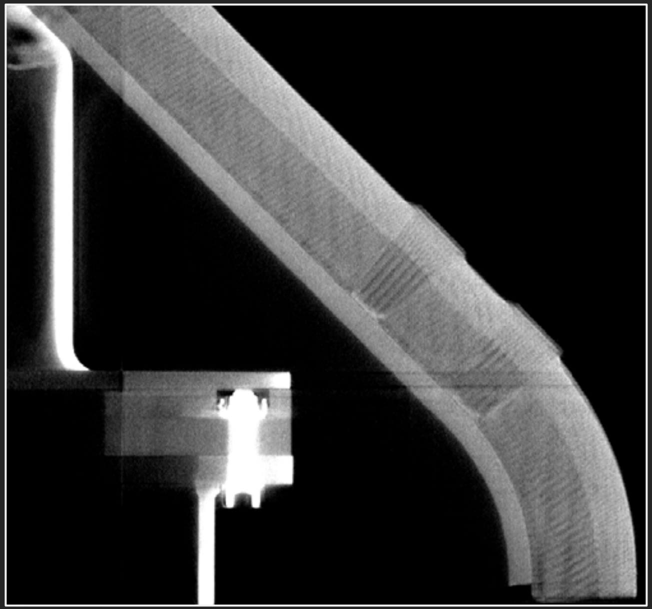
Stardust Post-Flight
(NASA / LLNL)



Nose Region: 440 kV, 100 μm
Sufficient resolution and quality



Flank: 440 kV, 100 μm
High resolution, extreme noise



Flank: 9 MeV, 165 μm
Lower resolution, reduced noise

Defects in Phenolic Adhesive

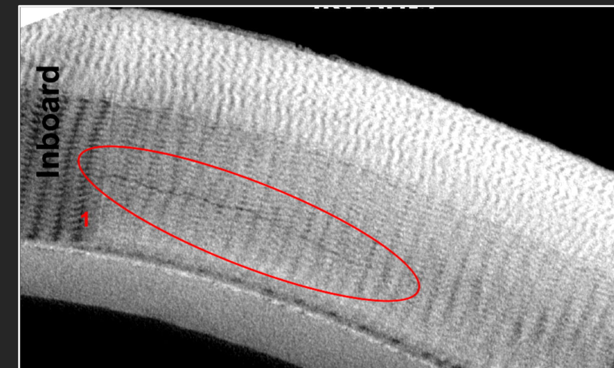
- **Hairline cracks in the phenolic adhesive**
  - Found in insulation layer
  - Not an aerothermal concern

- **Local adhesive debonds**
  - Found at recession/ insulation layer transition
  - Debonds extending into RL would likely be repaired on flight vehicle
  - Repair technique demonstrated on ETU

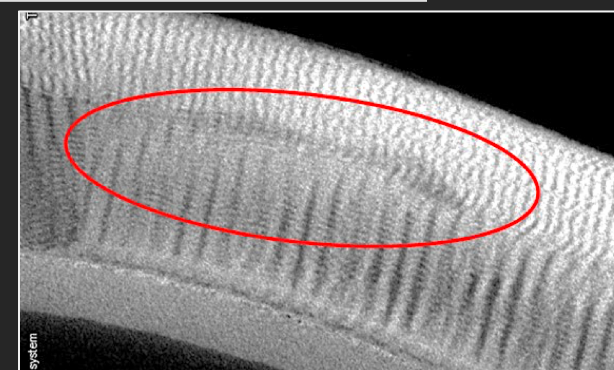
- **Risk to ETU testing from defects is low**
  - Theromostructural articles had minor defects
  - Testing revealed no premature failures
  - Correlated analysis of defects shows that ETU test objectives will not be affected

- **Confidently moving forward into ETU testing without repair of any defects**

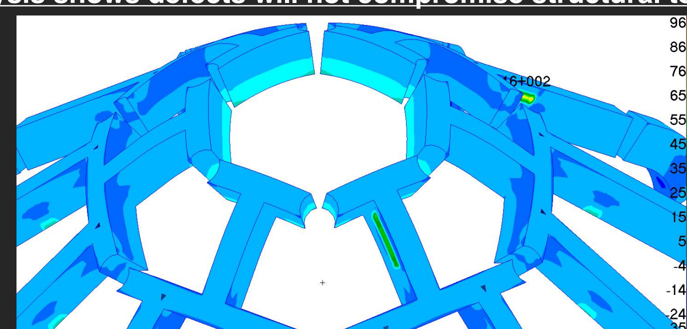
Defect Type: Hairline Cracks in Phenolic



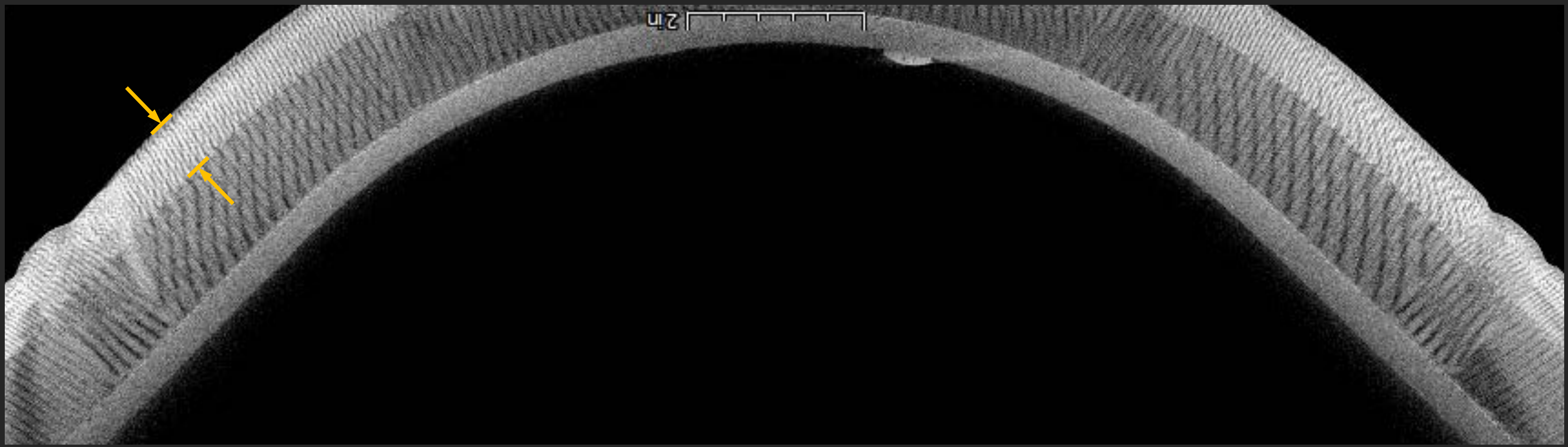
Defect Type: Adhesive Wrinkles and Debonds



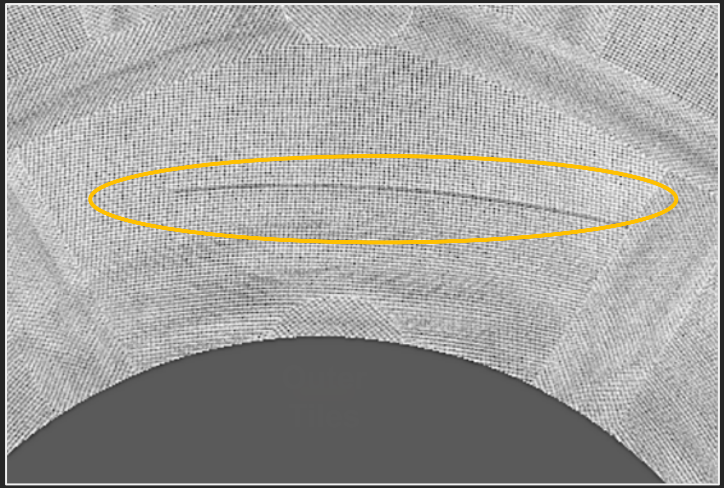
Analysis shows defects will not compromise structural testing



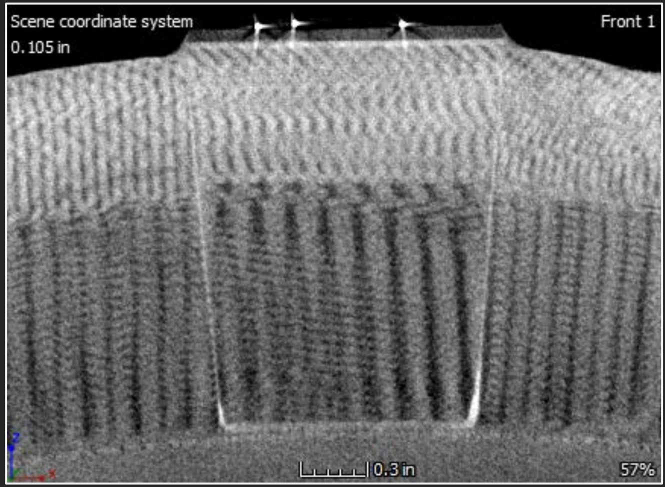
Other Insights from CT Data



Recession layer thickness measurements



Missing fibers



Adhesive pools under closeout plugs

Consolidated epoxy base bond

Conclusions

- **HEEET Project designed and manufactured a 1-m ETU**
  - CT scanning employed to verify manufacturing success
- **CT scanning method developed with industry met threshold requirements for verifying manufacturing success**
  - Minor defects detected in nose region
- **After inspection and analysis ETU Testing is moving forward**
  - Defects are not anticipated to affect test performance
  - Post test scans of the upper portion will characterize effects of testing
- **Despite challenges, state of the art advanced for for 1-m probes**
  - Use of carbon ring in flight vehicles will improve scan quality
  - For larger probes, alternative CT scan methodology may be necessary
- **CT scanning provides wealth of information valuable to missions**

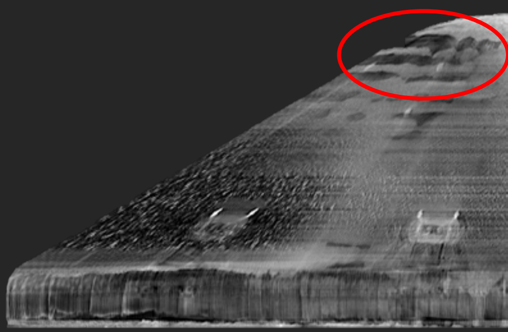
Questions?

Backup

CT Scanning of Entry Probes

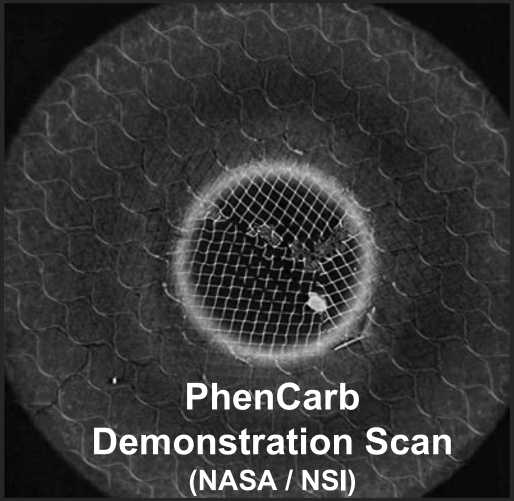
- **1- Meter probes have been CT scanned previously**
  - Stardust post-flight (NASA/LLNL)
  - NASA ARC development effort (North Star Imaging)

- **NASA Discovery and New Frontiers mission calls incentivize pre- and post-flight CT scanning for Earth return probes**



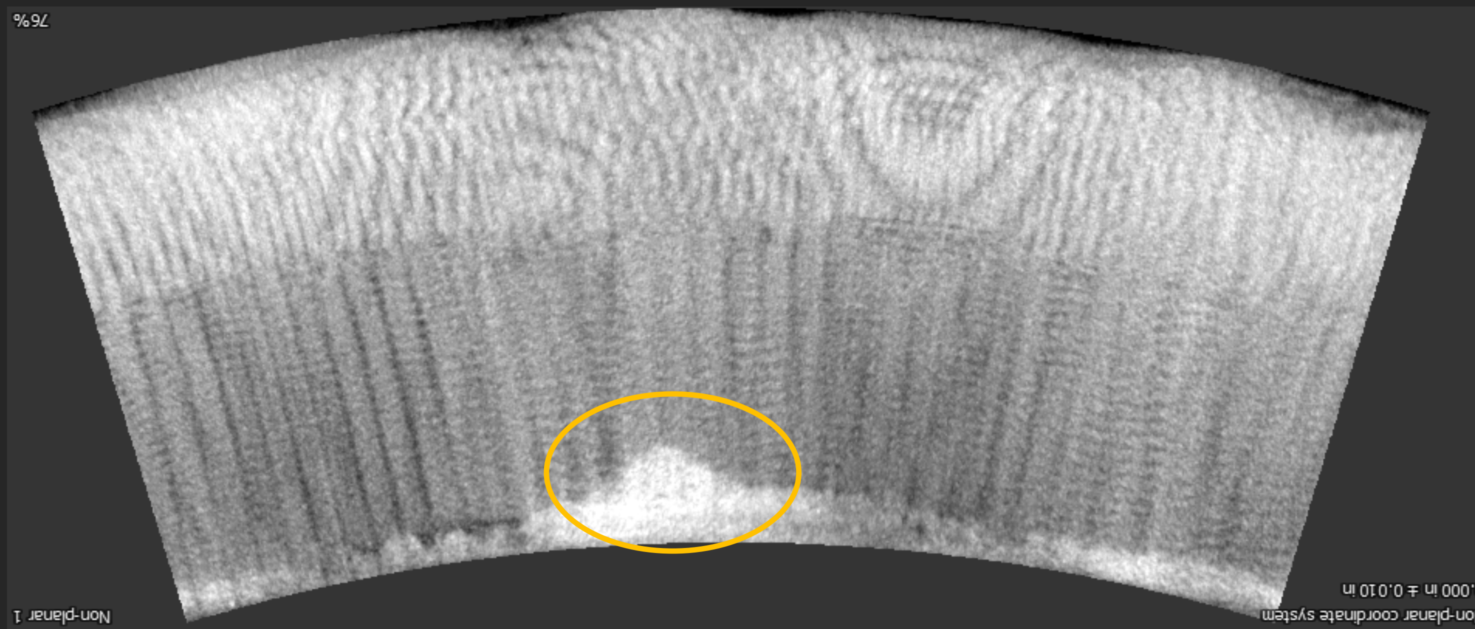
Stardust Post-Flight Adhesive Debonds
(NASA / LLNL)

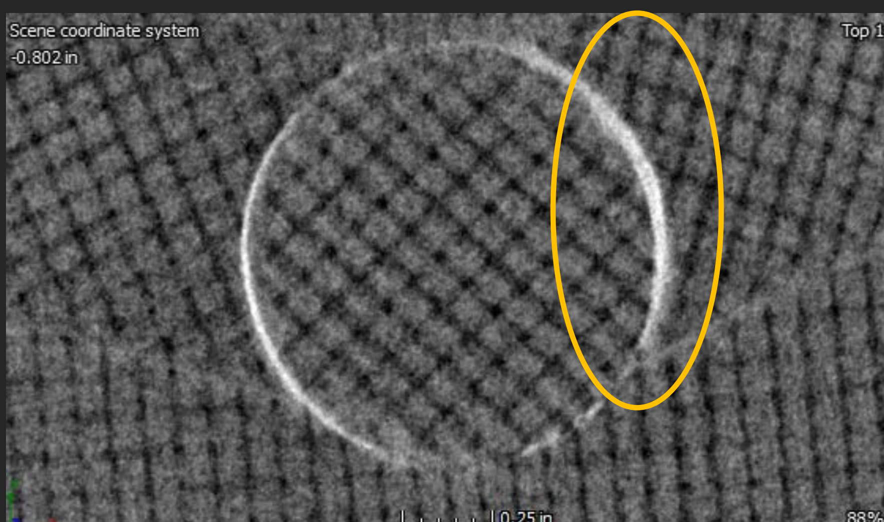
Stardust Post-Flight CT Scan Slice
(NASA / LLNL)

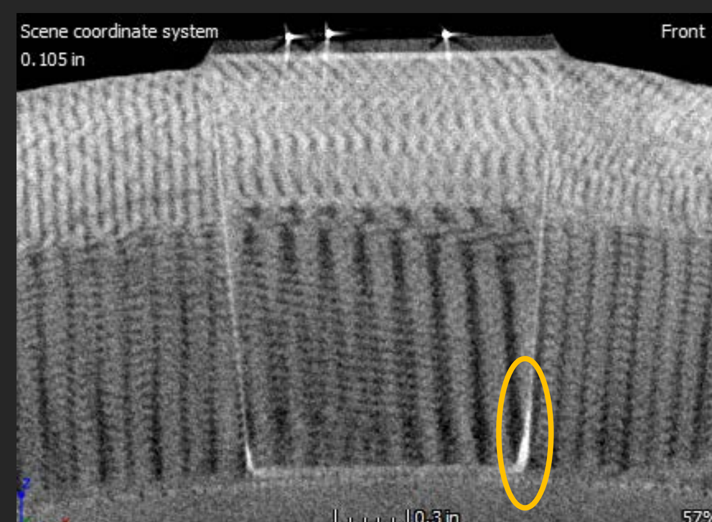


PhenCarb Demonstration Scan
(NASA / NSI)

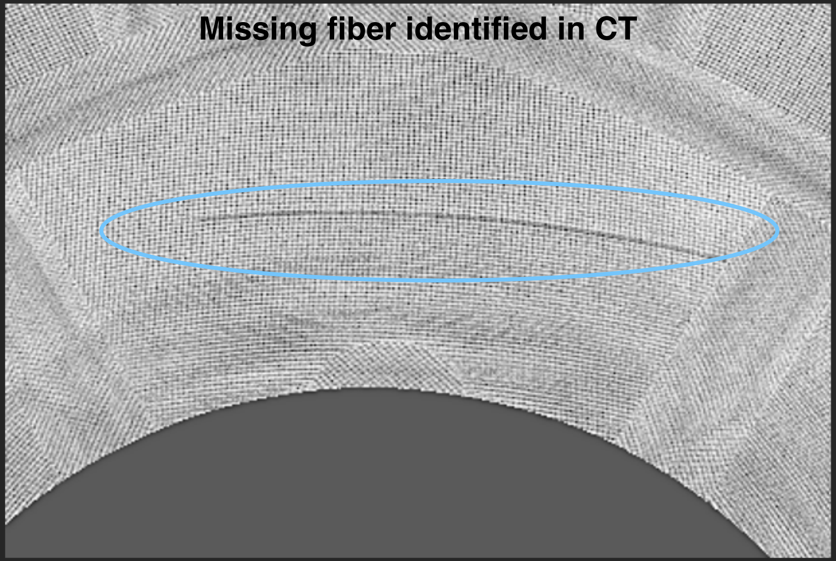
Closeout Plug Adhesive

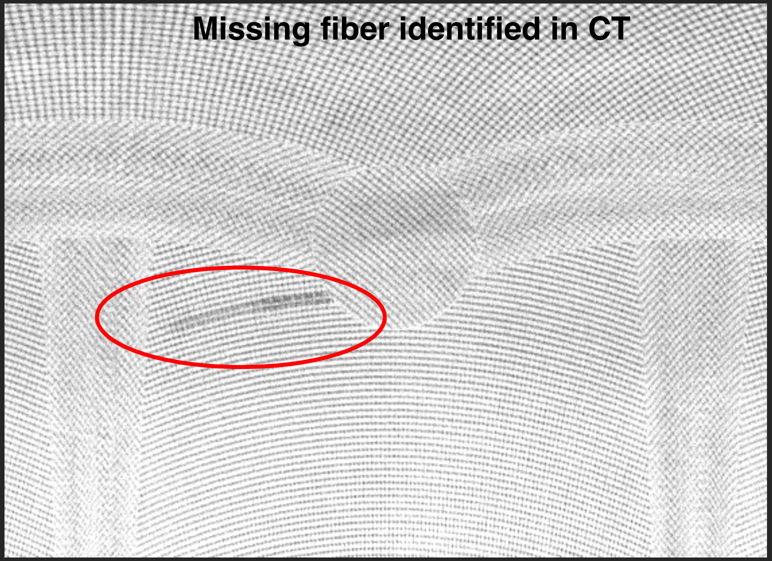






Missing Fibers





Missing fibers near surface after final machining


3D


19%
2 in
-1.481 in
Alignment to Clipping plane 1
Top 1

The Weave

HEEET Weave is a Layer-to-layer (L2L) weave that has ***2 distinct portions integrally woven together***:

- Recession Resistant Layer - Fine weave placed at top to optimize ablation performance, ~100 connections per in^2 between layers
- Insulating Layer - Coarse weave below ablation layer to reduce density, reduce thermal conductivity, increased weaving efficiency and lower cost

- Portions of the warp fiber run in Z direction
- Ties one layer to a layer below
- Limits thermal conduction through thickness
- Moderate z-strength

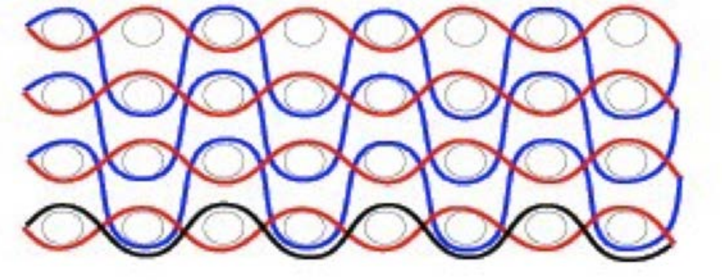


Figure 1 - Layer-to-Layer

CT Scan Parameter Trades

- ***Given the material composition and the shape of the HEEET shield the challenge for CT scanning require a choice amongst three competing performance goals:***
- ***High spatial resolution – the parameters and methods required to obtain spatial resolution in the 0.1 mm range***
- ***Sufficient transmission signal for the entire shield - configuring a scan with an effective-energy adequate to provide signal over the changing lengths in the HEEET shield***
- ***Robust photon statistics to result in a per-voxel signal-to-noise that will enable the detection of small features in the adhesive layer and in the TPS to inspect for shield integrity and to guide possible repairs.***