

## **Large Scale Shearography Inspection of the Space Shuttle External Fuel Tank**

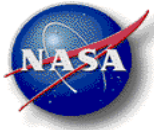
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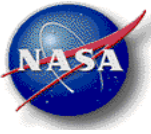


## Background: External Propellant Tank

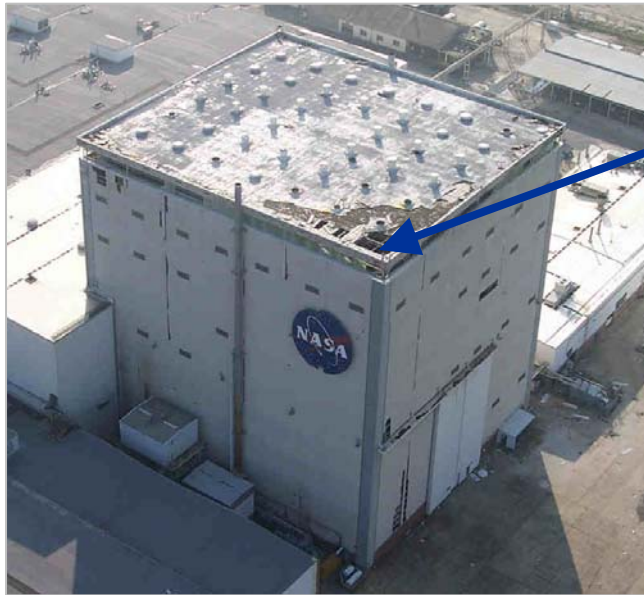


- **External Propellant Tank (ET) Background**
  - ET holds cryogenic liquid hydrogen and oxygen fuel for shuttle main engines
  - Polyurethane foam insulation prevents cryogenic fuel from boiling as well as ice formation
  - Aero loads during launch can produce foam debris potentially damaging the shuttle orbiter
  - After the Columbia accident, ET foam debris was identified as a likely cause of the orbiter wing damage
  - Several NDE methods including shearography were developed for foam inspection to minimize debris damage to orbiter





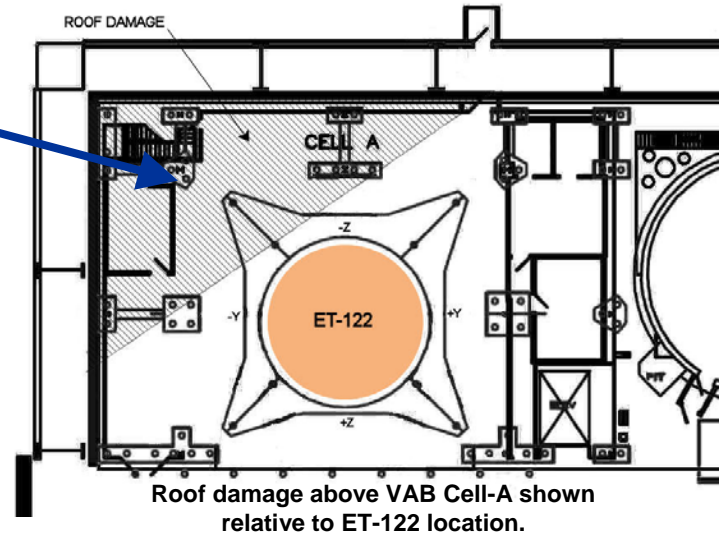
# ET-122 Background - Hurricane Katrina



Hole in Roof  
(not directly over ET-122)



ET-122 in Cell A after Katrina



LO2 Tank Ogive Damage

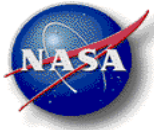


Roof Debris on Access Platform Near Intertank Access Door (-Z Quadrant)



Intertank Damage



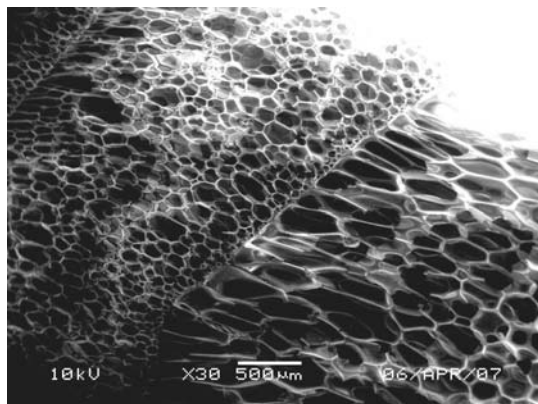


## ET-122 Restoration Thermal Protection System Assessment

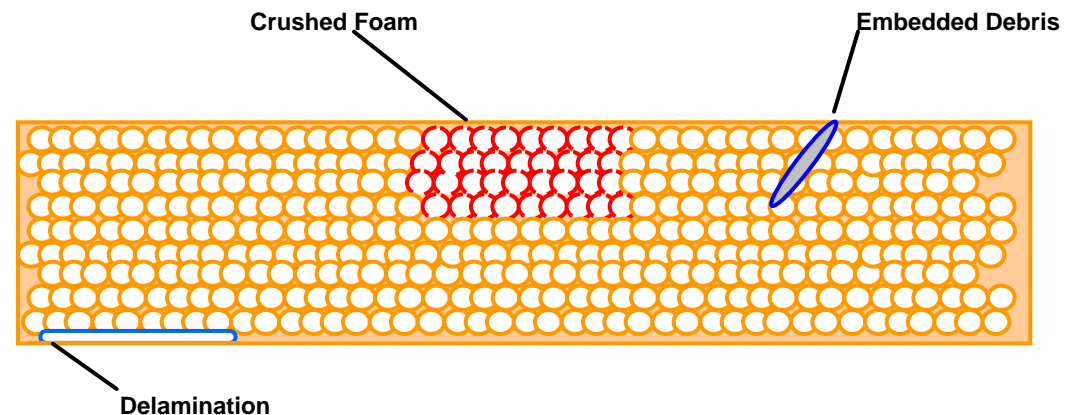


- **Objective**

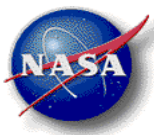
- Perform Shearography to inspect for non-visible damage including:
  - Crushed foam
  - Delaminations
  - Embedded debris
- Provide a screening test that could be confirmed with follow up visual and tactile inspections



**SEM Photomicrograph of  
Intact Foam Cells**



**Three Types of Damage Assessed with Shearography Inspection**



# ET-122 Restoration Shearography Assessment



## Method Description

- Shearography (Shearing Holography) is an inspection technique that detects minute changes of shape of a part due to heat, vacuum or another form of agitation.
- The system measures the interference pattern generated by two sheared laser speckle images before and after loading.
- The result of the interference pattern is a measure of the change in out of plane surface slope which can be directly related to the local stiffness of the structure under test.

## Equipment

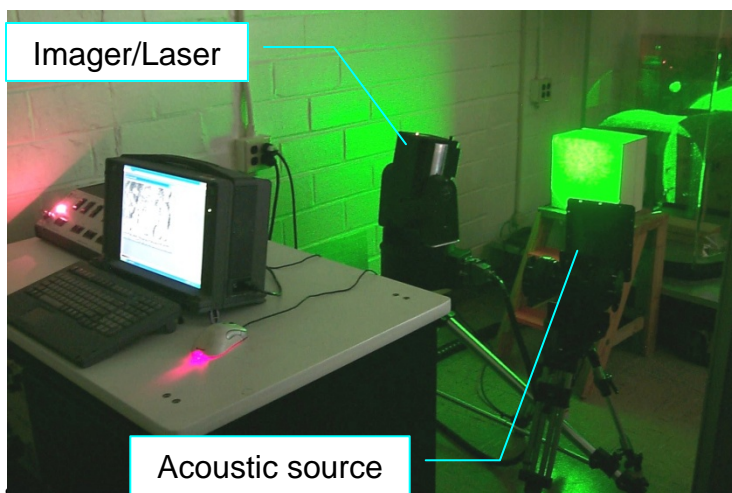
- A Laser Technologies Inc. Model 5100 shearographic system along with heat lamps, vacuum, acoustic and vibration sources for structural excitation

## Advantages

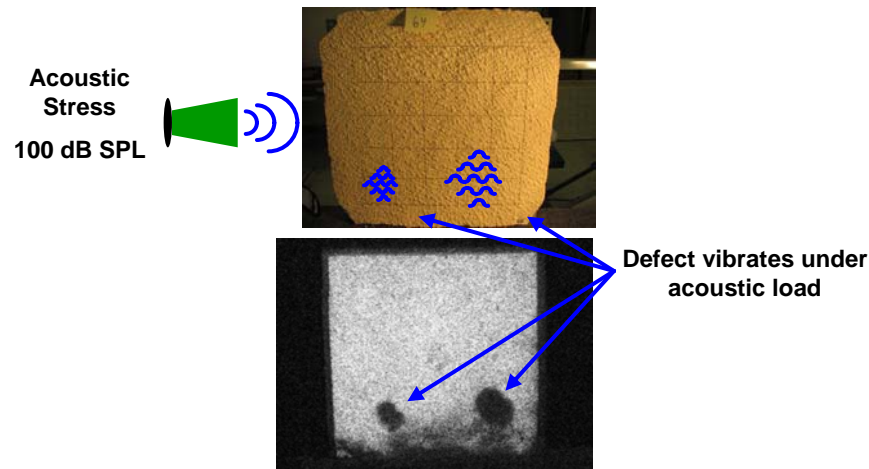
- Useful in detecting and sizing voids, delaminations, contamination, cracks, material inconsistencies in coatings and paints, insulation layers, and polymer or elastomer based structural materials
- The shearographic method images a large area (up to several square feet) of the part under test providing a rapid, near real time, inspection.

## Limitations

- The part under test must have a matte, light colored, surface that will reflect the laser speckle without glare.
- The test article must be stable and not move during the acquisition time.
- The interpretation on the images requires some training and is not as intuitive as other imaging techniques.



ASNT Spring Comm. 2016





# ET-122 Restoration Shearography Assessment

- **Background – Shearography System**



Sound Meter

Camera/Laser

Tank inspection fixture  
Bldg 420



Data acquisition and  
system control cart

**Test Procedure:**  
QTI-N-044 Drafted  
“Shearographic Inspection of  
the External Tank”

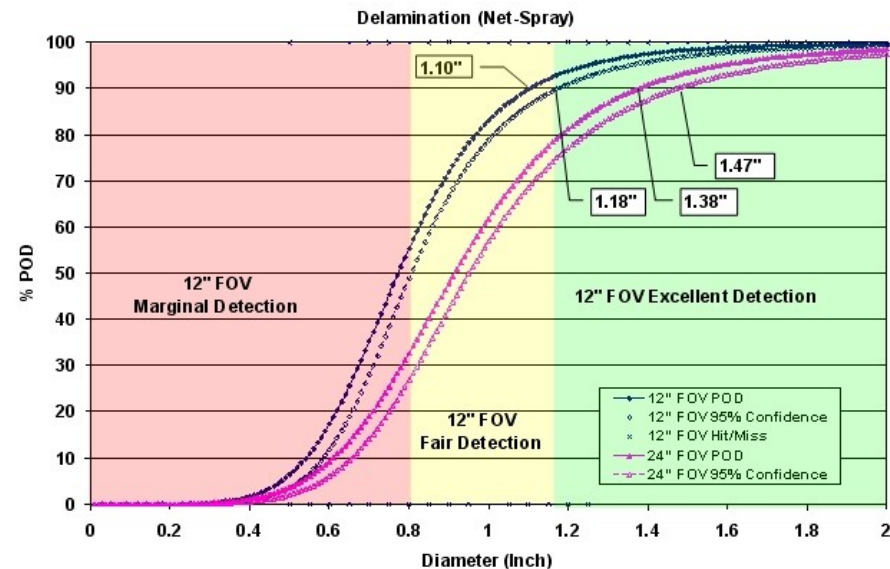
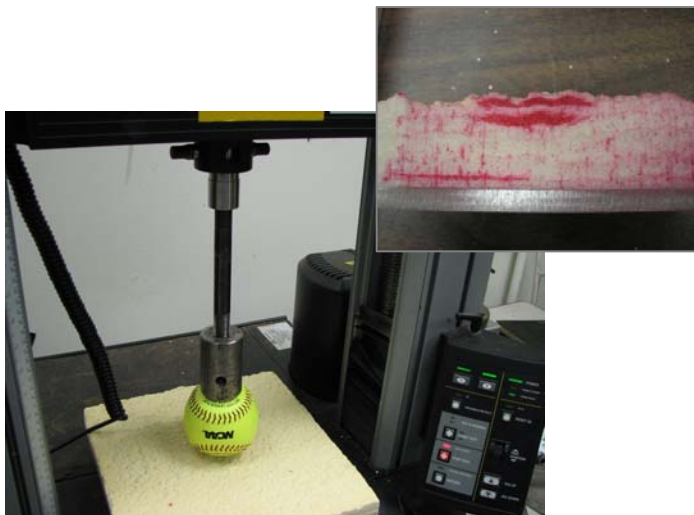


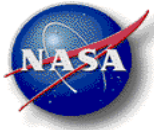
# ET-122 Restoration Shearography Assessment



## • Background - POD Summary

- POD Test Plan was developed following the guidelines of MIL-HNBK-1823
- Multiple inspectors participated in study
- 100 defects and 300 blanks were used to evaluate detection and false call rates
- POD studies completed for non-visible crush damage and delaminations
- Worst case POD value for shearography on net spray foam:
  - Crushed foam is 0.43" deep
  - Delamination 1.18" diameter
- False positive rate established
  - No false positive results at or above critical flaw size
- MSFC FCB reviewed and concurred with shearography POD for detection of crush damage and delaminations





## ET-122 Restoration Thermal Protection System Assessment

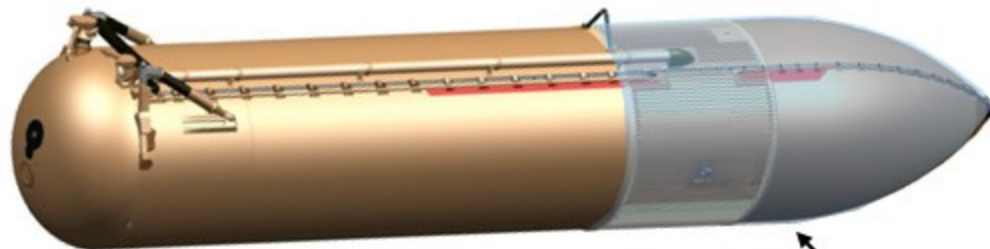


- **Issues**

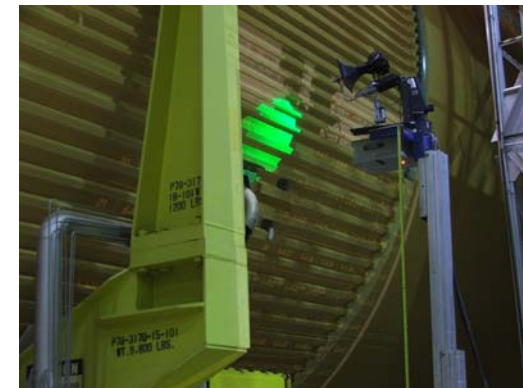
- Large inspection area
- Accurate positioning of inspection grid
- Access to +Z ogive region
- Detection threshold for embedded concrete



Scissors lifts and stands provide access to all inspection regions except +Z, or top, of tank

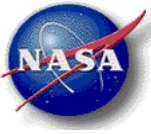


Inspection area encompassing  
~3100 square feet



Difficult geometries such as stringers and carrier support arm require angled shots

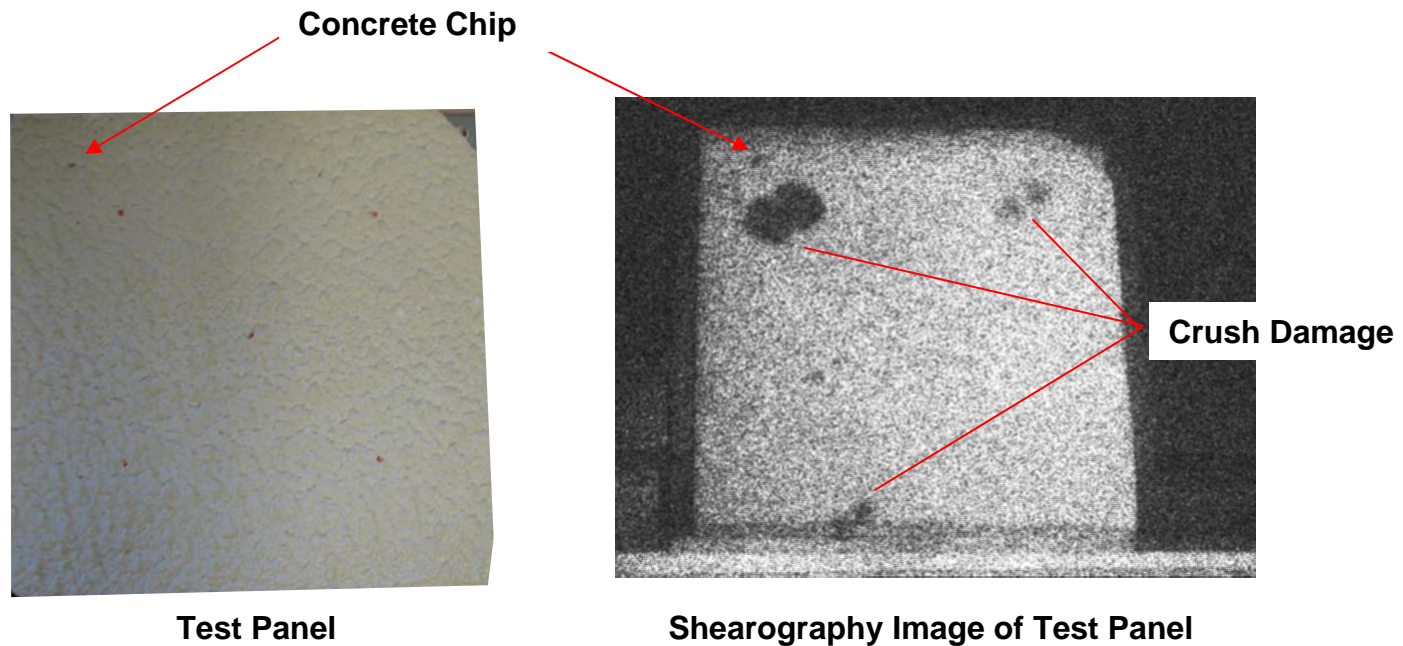


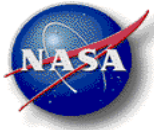


## ET-122 Restoration Shearography Assessment



- **Shearography on Acreage with Crush Damage and Embedded Concrete**
  - Test panel with net spray NCFI
  - Simple geometry allows optimal inspection
  - Test article contained 1/8" concrete chip embedded in foam plus crush damage
  - One foot field of view to detect 1/8" concrete chip
  - Smaller concrete chips were not reliably detected

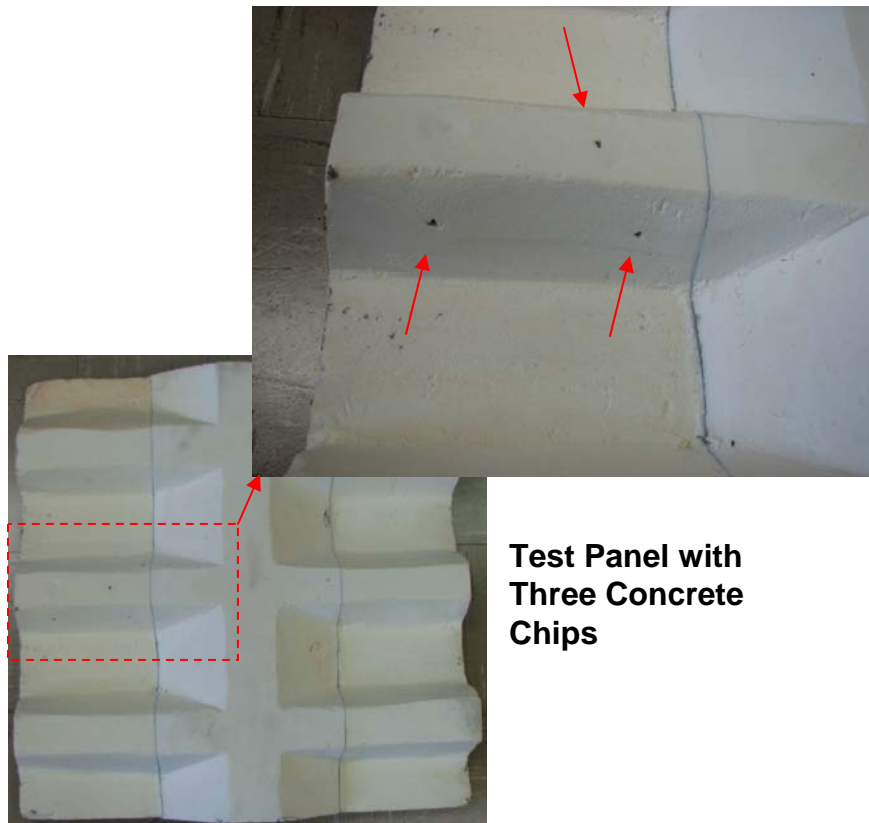




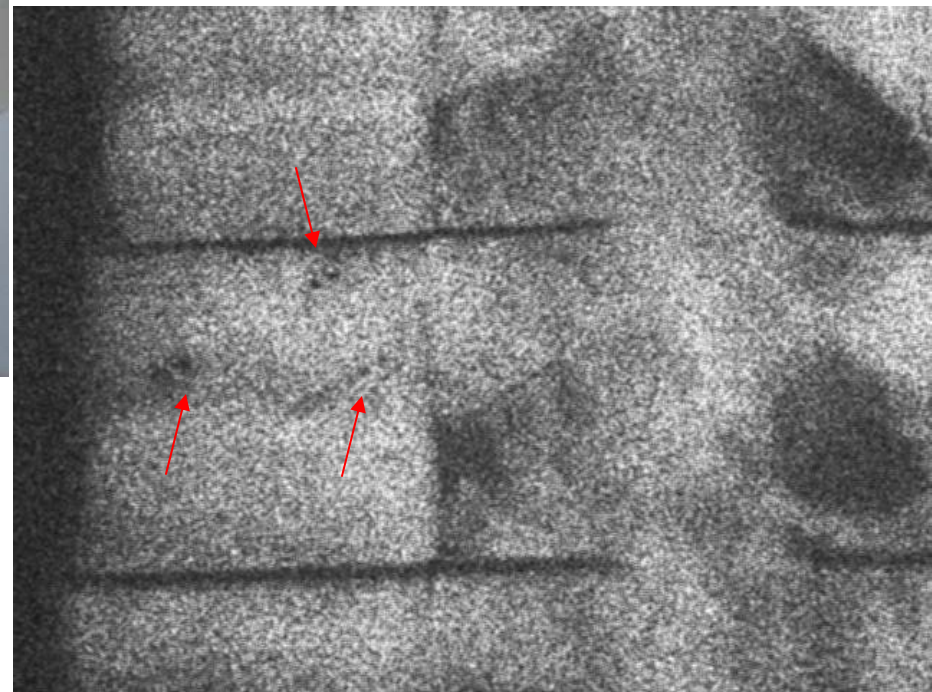
## ET-122 Restoration Shearography Assessment

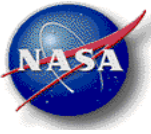


- **Shearography on Stringers with Embedded Concrete**
  - Stringer geometry introduces difficulties
  - Test article is approx. stringer geometry with approx. 1/8" concrete chips embedded
  - At approx. 30° off normal, concrete chips are detected on top and side of stringer
  - Stringer inspections will require two shots, at  $\pm 30^\circ$  to capture tops and sides of stringers



**Test Panel with  
Three Concrete  
Chips**



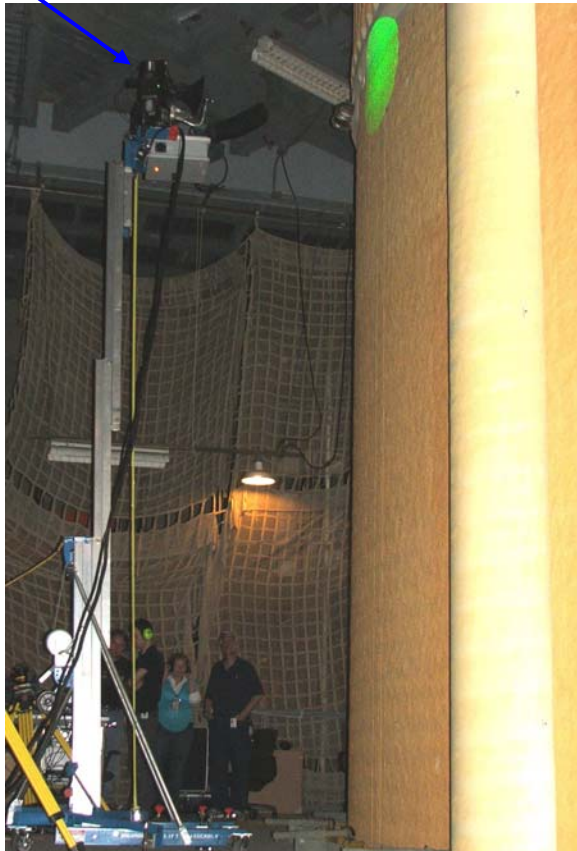


# ET-122 Restoration Shearography Assessment



- **Shearography System Positioning Fixtures**

Shearography System

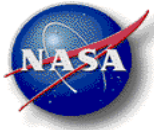


**SLA-22 Shearography fixture at KSC  
(VAB Check-out Cell)**

Shearography System



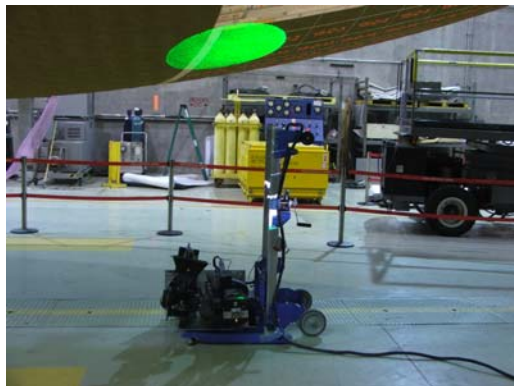
**Acreage Shearography fixture at  
MAF (Bldg 420)**



## ET-122 Restoration Shearography Assessment



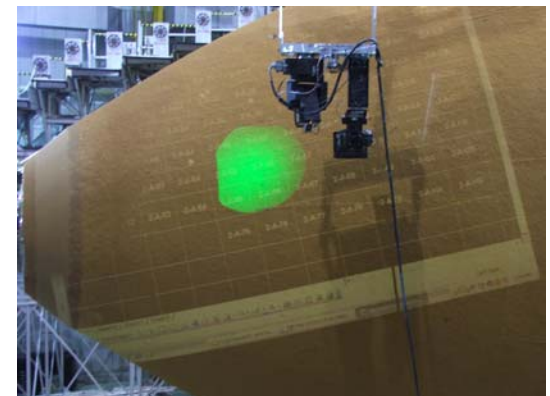
- ***Shearography Inspections Were Performed in Three configurations***
  - -Z region: modified Genie Lift tool adapted for shearography camera
  - Region below +Y and -Y: SLA tool (another modified Genie Lift model)
  - Region above +Y and -Y: Crane mounted tool



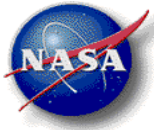
**-Z Inspection**



**-Y and +Y  
Inspection**



**+Z Inspection**



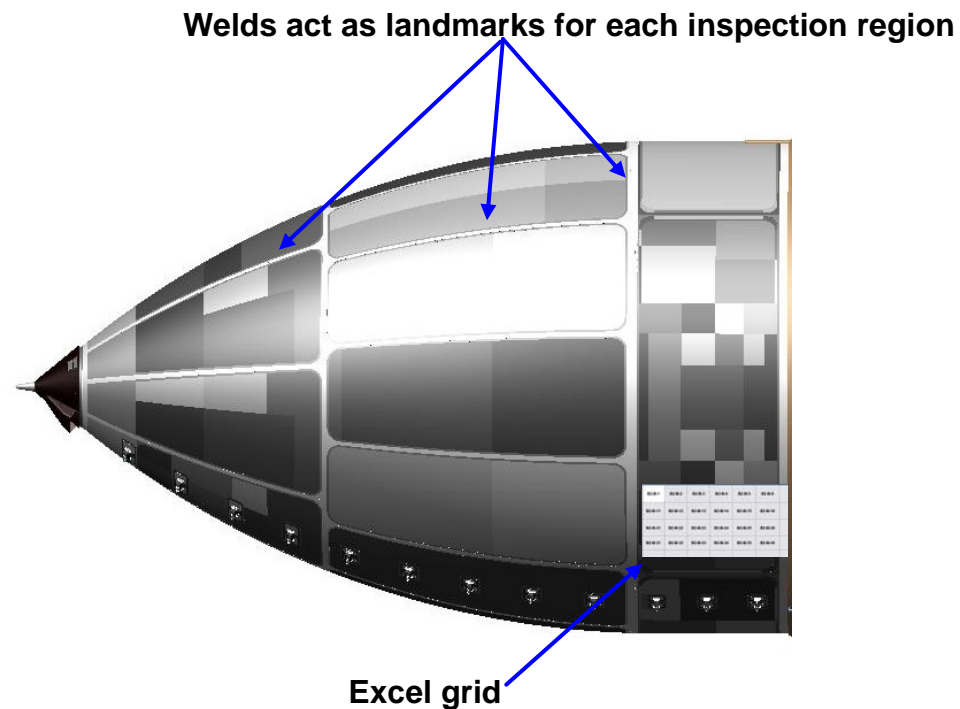
## ET-122 Restoration Shearography Assessment

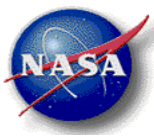


- ***Shearography Inspection Approach***

- Inspection Layout

- Regions were identified by ogive, barrel, or inter tank panel
- Inspections were performed by panel to work with manageable sizes
- An LCD projector was used to project an Excel worksheet onto the panel
- The Excel grid was adjusted to provide 12" cells





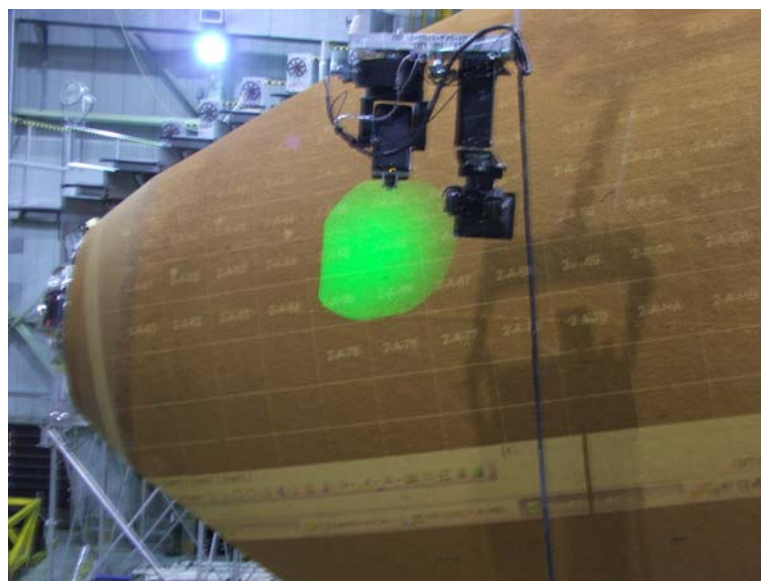
## ET-122 Restoration Shearography Assessment



- **Shearography Inspection Approach**

- Defect Identification

- Defects were identified with the worksheet cell number
- Defect locations were marked on the tank with permanent marker
- Defects were marked at the time they were identified, using the live view of the shearography camera to provide accurate location



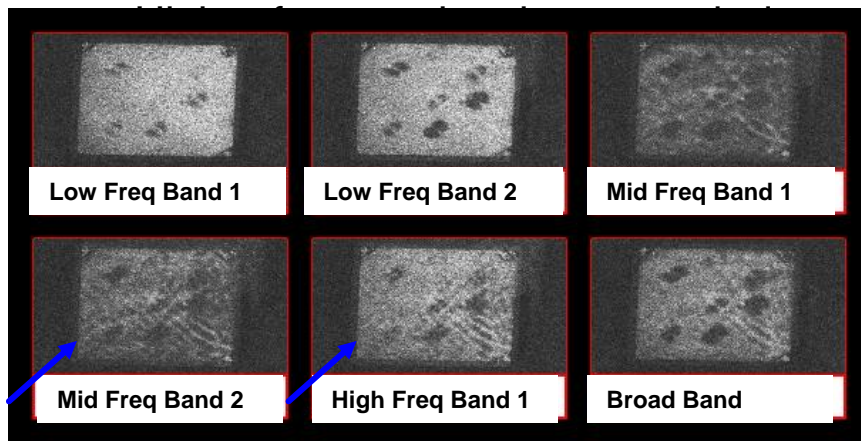


## ET-122 Restoration Shearography Assessment

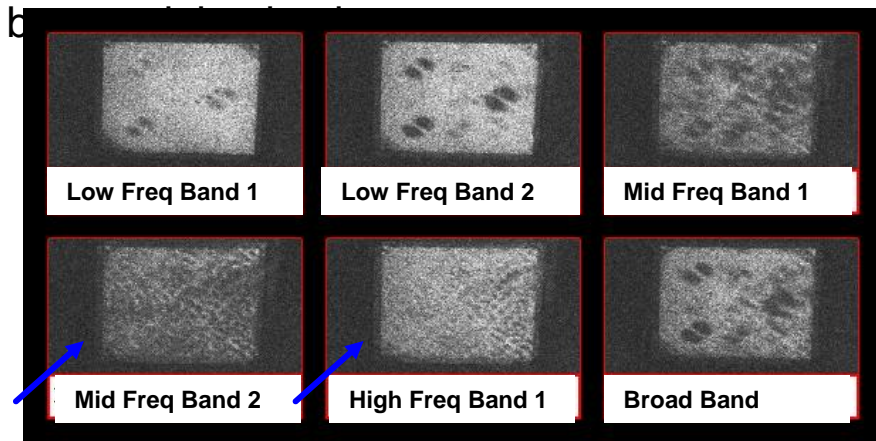


- **Shearography Acoustic Stressing Technique**

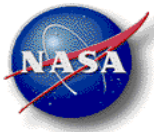
- Band limited white noise in the audio frequency range
- Intensity  $105 \pm 5\text{dB}$  at part
- Frequency bands are established to distinguish deeper delaminations from near surface crush damage



**Crush Damage Test Panel**  
Response in the mid to high frequency range



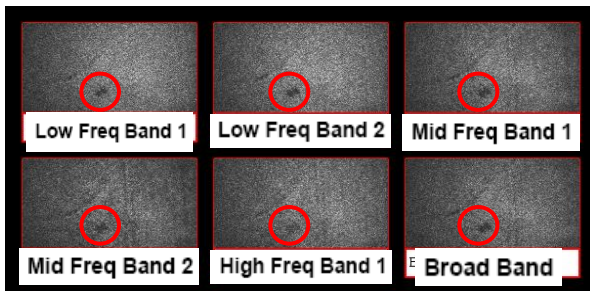
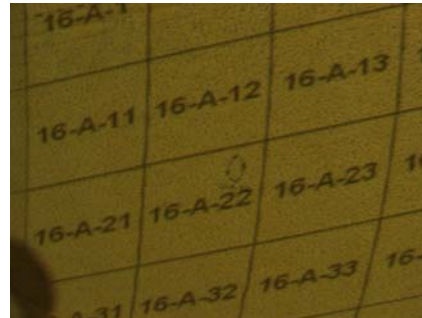
**Delamination Test Panel**  
No response in the mid to high frequency range



# ET-122 Restoration Shearography Assessment

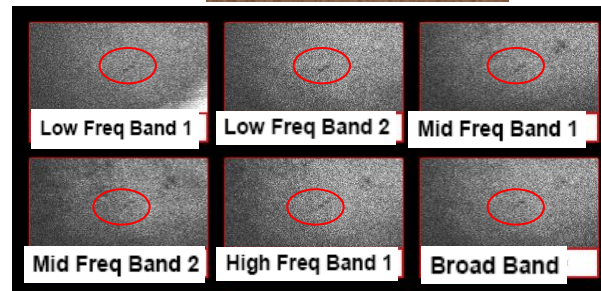


- **Shearography Results - Examples**



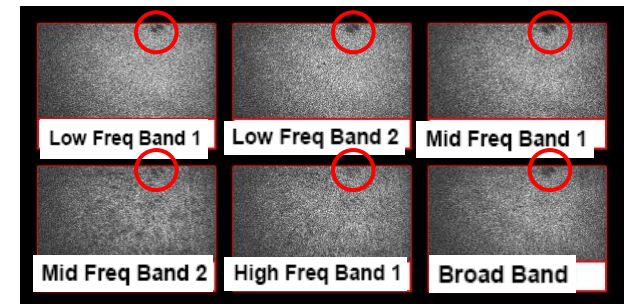
### **Visible Indication**

Strong Shearography response and damage was visibly evident



### **Non-visible Indication**

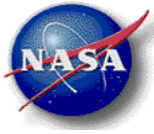
Strong Shearography response but no visible damage on tank



### **Embedded Concrete Chip**

Strong Shearography response, small but visible damage on tank



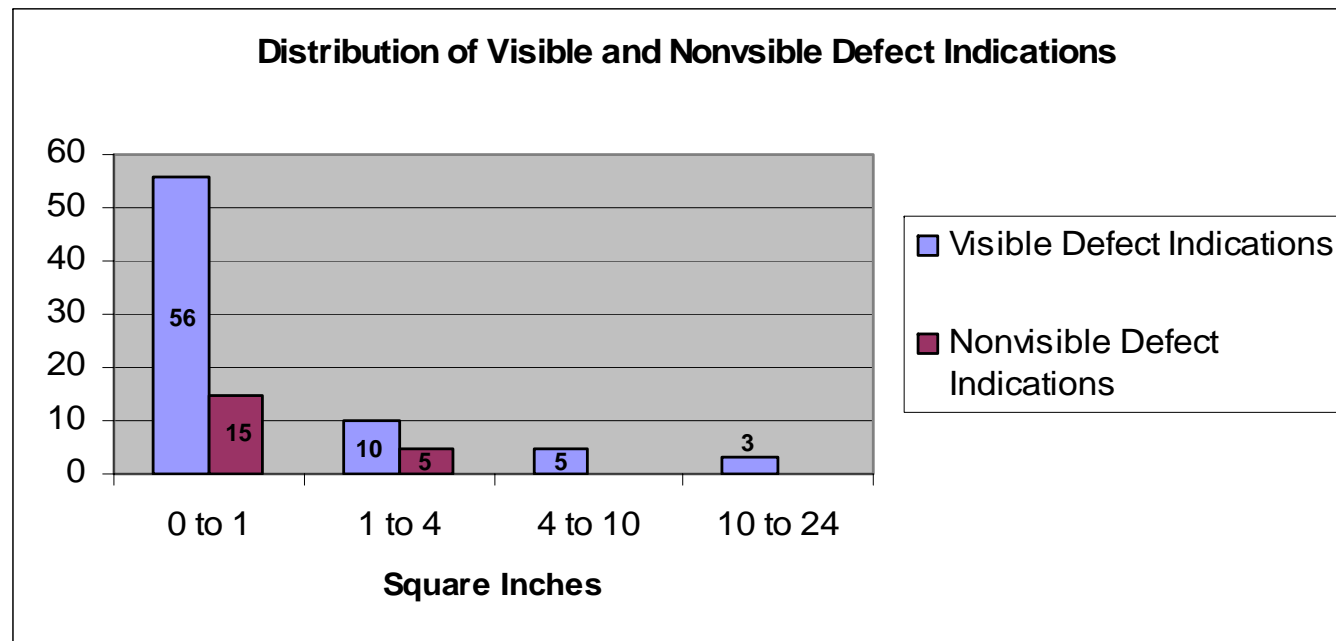


## ET-122 Restoration Shearography Assessment

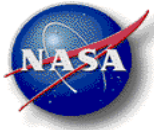


- **Shearography Results**

- 95 total defect indications
- 74 indications involved visible TPS damage
- 21 indications exhibited no visible damage
- Two occurrences of embedded concrete chips were detected



**Distribution of Defect Indications by Size**



## ET-122 Restoration Shearography Assessment

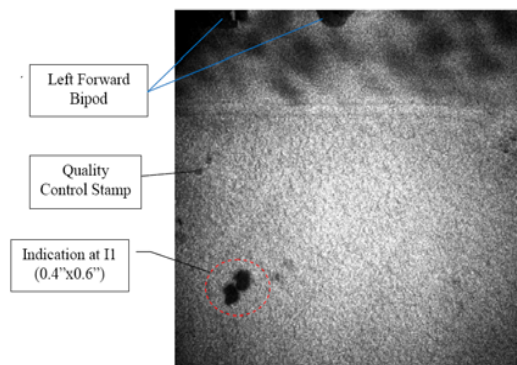


### • Additional Results

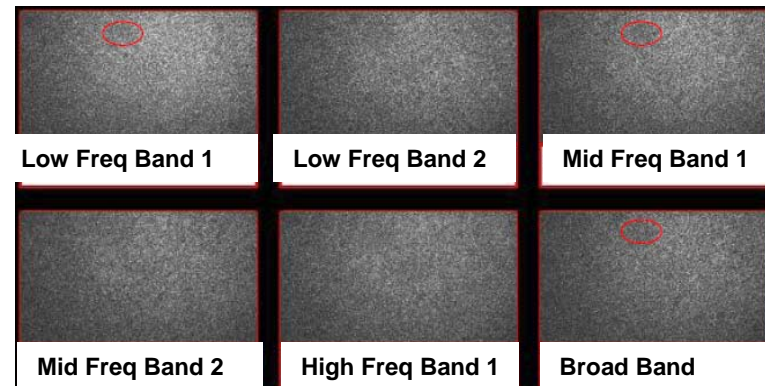
- Of 95 total defect indications:
  - 94 were crush damage
  - 1 was a possible delamination
  - 1 was a possible crack
- No visible defects exhibited additional nonvisible damage
- Follow on visual, tactile, and destructive test did not confirm any of the 21 nonvisible indications as actual foam damage
- Inspections were intentionally conservative since no experience base was available for debris damaged foam



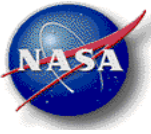
Contamination adjacent to visible impact damage was determined by shearography not to be actual foam damage



Distinct crush damage indication from recent ET135 inspection



Many ET122 indications were faint and not distinct in all frequency bands



## ET-122 Restoration Shearography Assessment



- **Conclusions**

- Shearography was successfully used to inspect the damaged region of ET122 for nonvisible damage
- The shearography inspection was extensive covering over 3100 square feet of foam and lasting 9 months
- Most foam damage was visible and shearography results confirmed that foam damage in visibly impacted regions did not extend outside the area with visible damage
- Of the 21 nonvisible defect indications detected with shearography, none were determined to be actual foam damage
- Inspections were intentionally conservative since no experience base was available for debris damaged foam
- Shearography results were used in conjunction with tactile and visual inspection to support the acceptance of the foam application allowing the tank to move forward for refurbishment