

Pulse-Echo Phased Array Ultrasonic Inspection of Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)

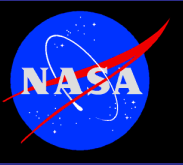
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2010 Review of Progress in Quantitative Nondestructive Evaluation

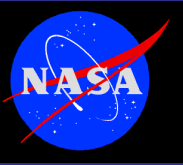
San Diego, CA

July 19-23, 2010



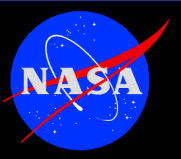
Overview

- Background for this work
- Description of the PRSEUS concept
- Ultrasonic array approach
- Results

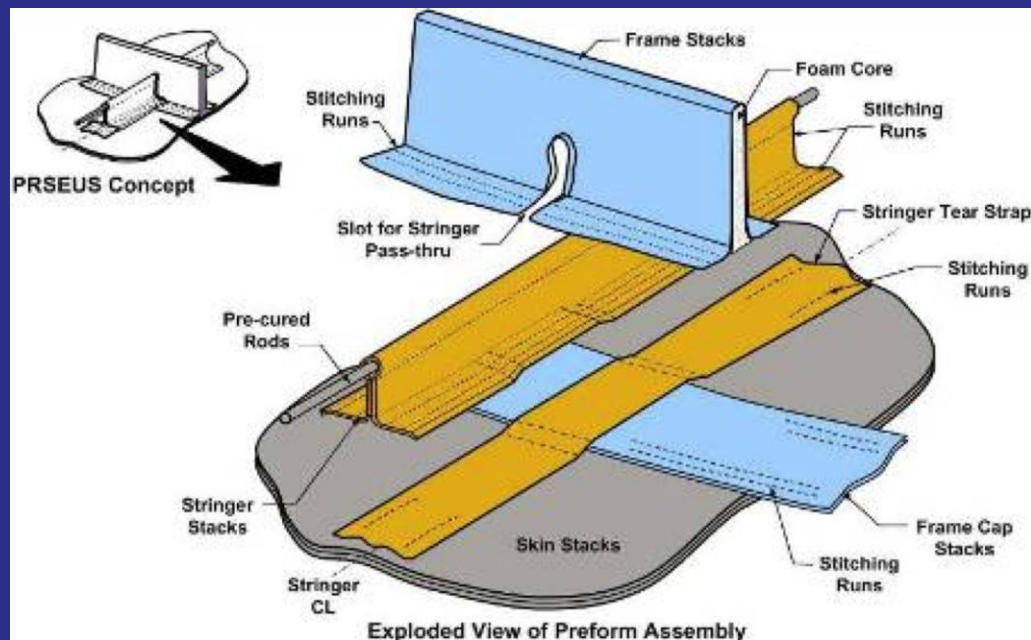


Background

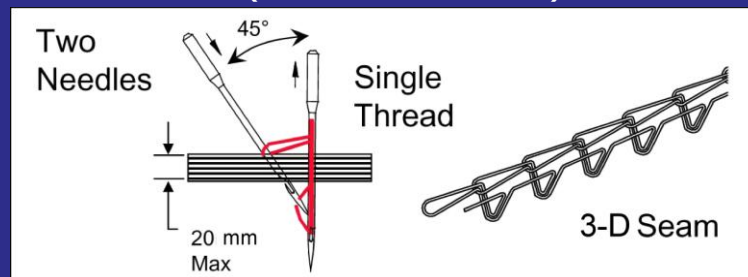
- PRSEUS concept under development by NASA and Boeing under Subsonic Fixed Wing (SFW) activities
- PRSEUS was offered for consideration by Advanced Composites Technology (ACT) Project as a candidate structural concept for large booster application
 - Multi-Center NDE team was charged with ranking the “inspectability” of the various structural concepts
 - None of the team members had any experience with PRSEUS, but with earlier stitched and out-of-autoclave cases
- This work combined NDE support for SFW test and hands-on input for ACT concept assessment
- PRSEUS now under Environmentally Responsible Aviation (ERA) Project



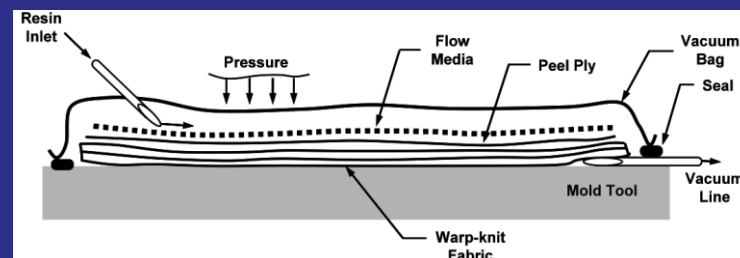
Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)



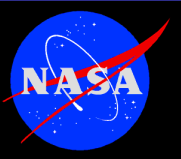
Single-Sided Stitching (Vectran fibers)



CAPRI (Controlled Atmospheric Pressure Resin Infusion)

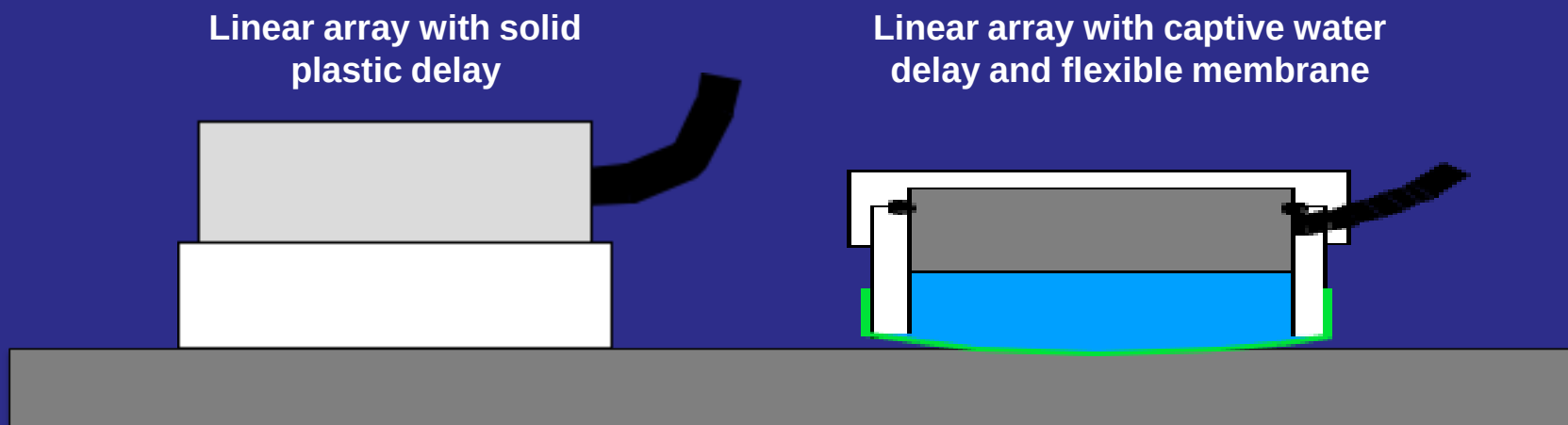


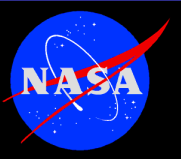
- Rod improves stiffening
- Stitching enables fail-safe design
- Self-supporting pre-form reduces tooling



Ultrasonic Array Approach

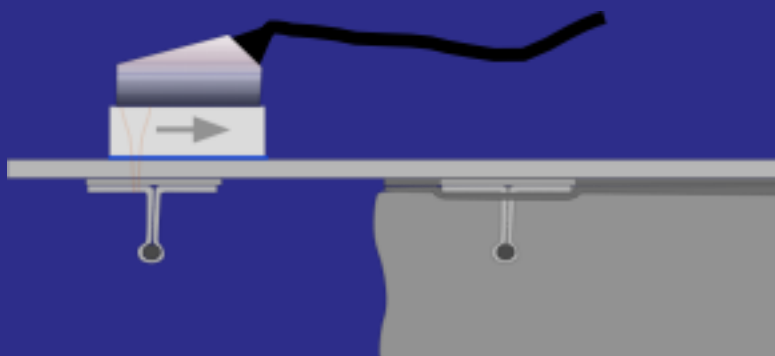
- Flat skin surface of PRSEUS panel provided good interface with solid plastic delay wedge using water as couplant
- Solid wedge was not adequate after installation of gages/wiring
- For other NASA projects we developed a similar probe with immersion array in a captive column of water with flexible membrane and water couplant
- Captive water column with flexible membrane could maintain better coupling near gages and wires

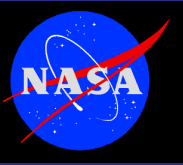




Ultrasonic Measurements

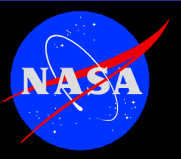
- Linear phased-array probe (10 MHz, 64 elements each 10mm X 1 mm) mounted on plastic delay or captive water probe
- Beam focused just under surface of composite
- 16-element aperture scanned electronically to yield 49 lines per sweep
- Two-dimension manual scanner with encoder output to instrument





Mechanical Test Sequence

- Baseline **NDE**
- Impact: 45 ft lb using a 25 lb drop weight impactor with a 1 inch diameter spherical tup
- Impact **NDE**
- Static compression load to 137,000 lb (design limit load)
- Static load **NDE**
- Cycled 20 times to approximately 96,000 lb
- Cyclic load **NDE**
- Static compression load to failure at 200,000 lb.



Ultrasonic A-Scan Analysis

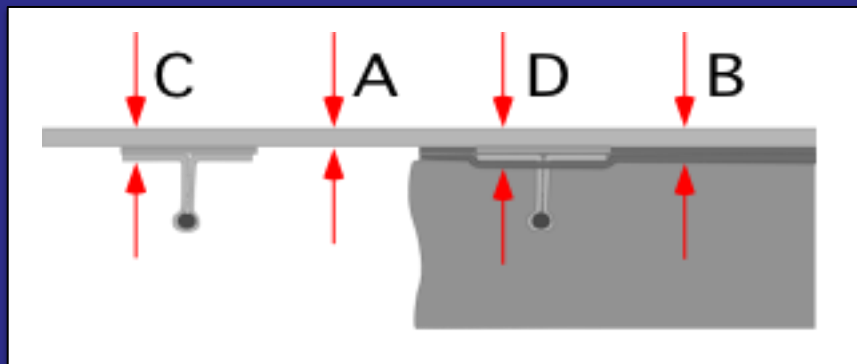
Four distinct round-trip echo delays:

A: Skin layer only

C: Stringer flange layer over skin layer

B: Frame flange layer over skin layer

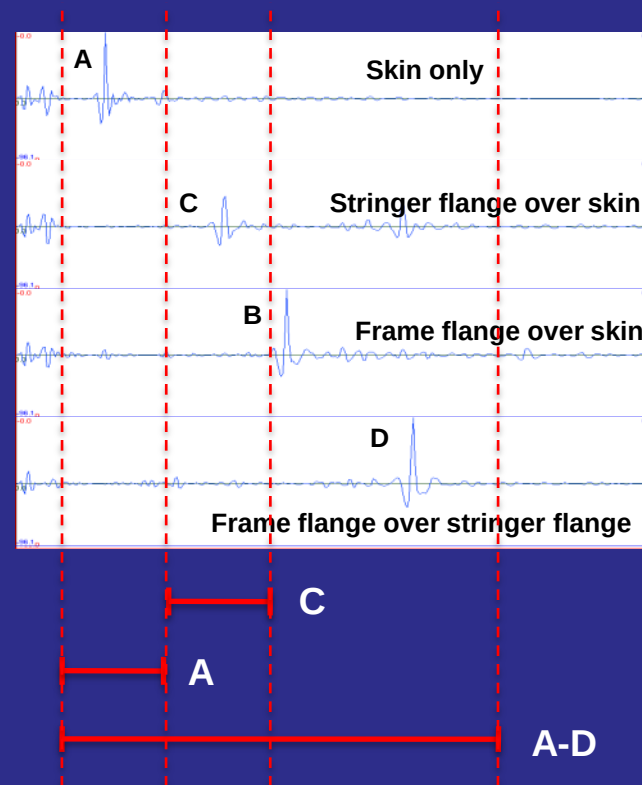
D: Frame flange layer over stringer flange and skin layer

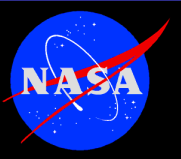


Gate C: Only echoes from stringer flange

Gate A: Only echoes from skin

Gate A-D: Echoes from all surfaces



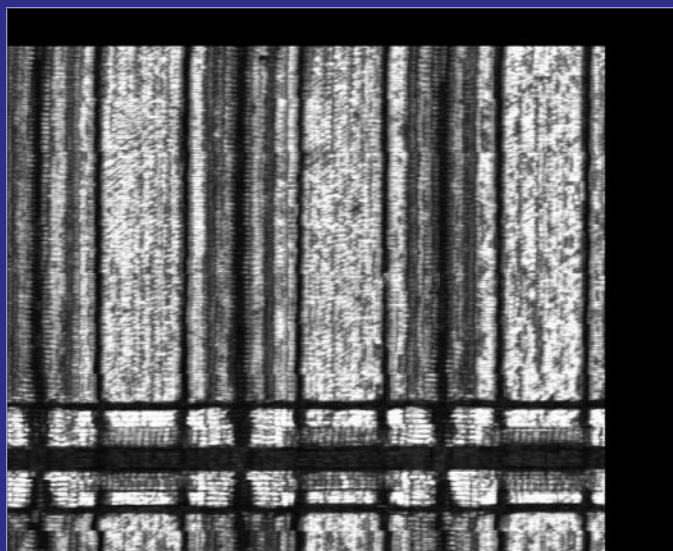


Ultrasonic C-Scan Analysis: Gate A-D

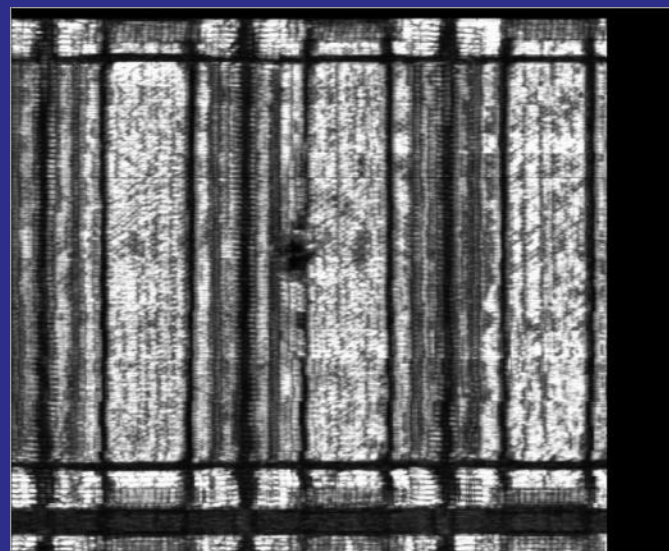
Images showing highest signal from any depth, before impact and after impact

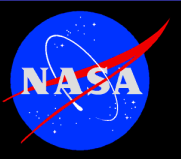
Dark region in center of IMPACT image represents signal loss due to localized damage caused by impact

BASELINE



IMPACT





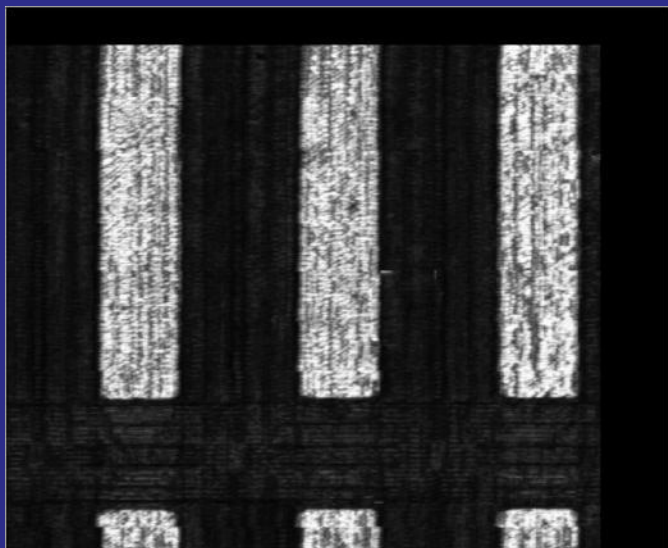
Ultrasonic C-Scan Analysis: Gate A

Images showing highest signal from depth corresponding to back of skin, before impact and after impact

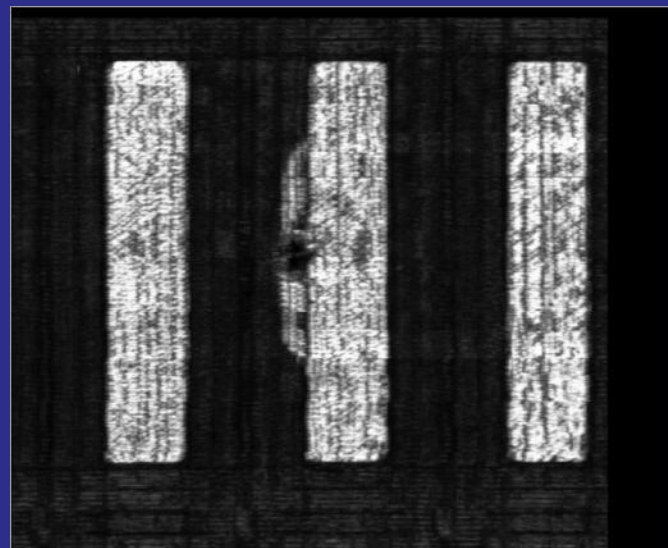
Dark region in center of IMPACT image represents signal loss due to localized damage caused by impact

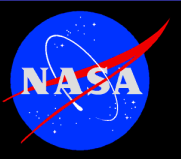
Bright area extending to left of free skin is reflected sound from delamination between skin layers and stringer flange layers

BASELINE



IMPACT



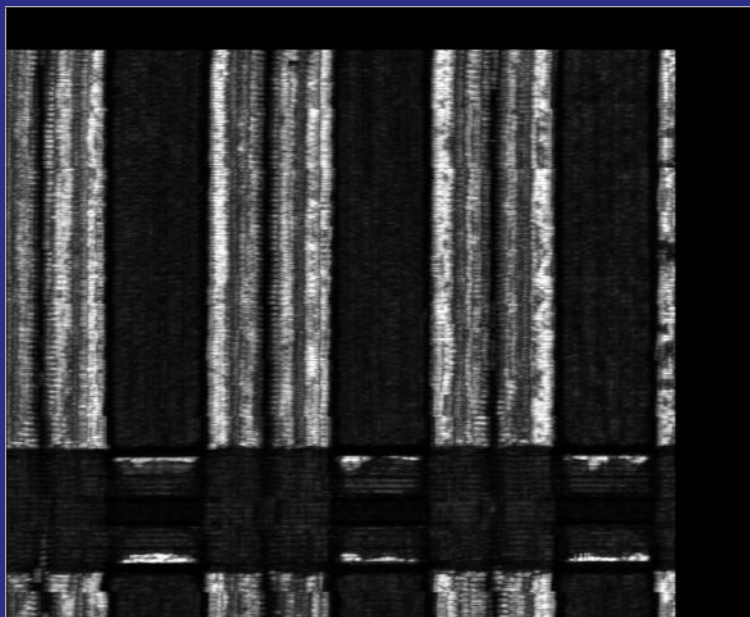


Ultrasonic C-Scan Analysis: Gate C

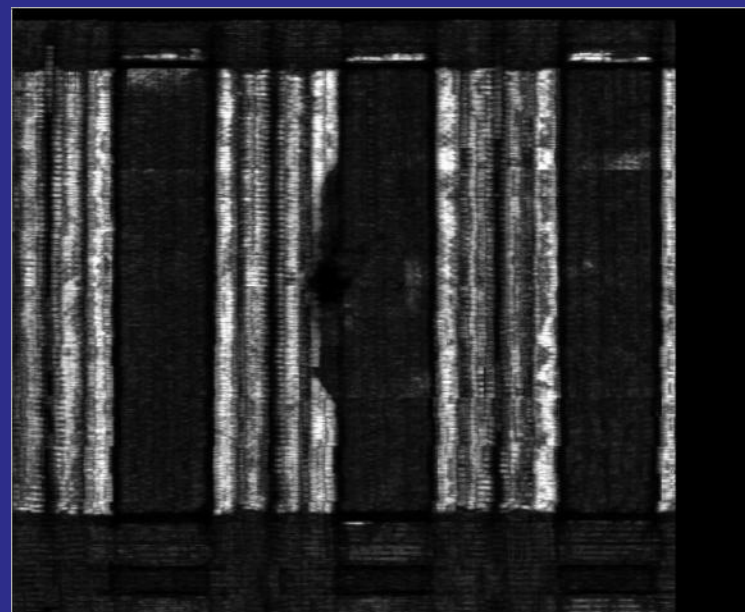
Images showing highest signal from depth corresponding to back of stringer flange, before impact and after impact

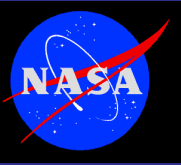
Darkened region in center of IMPACT image represents signal loss due to shadowing by delamination between skin and flange layers

BASELINE

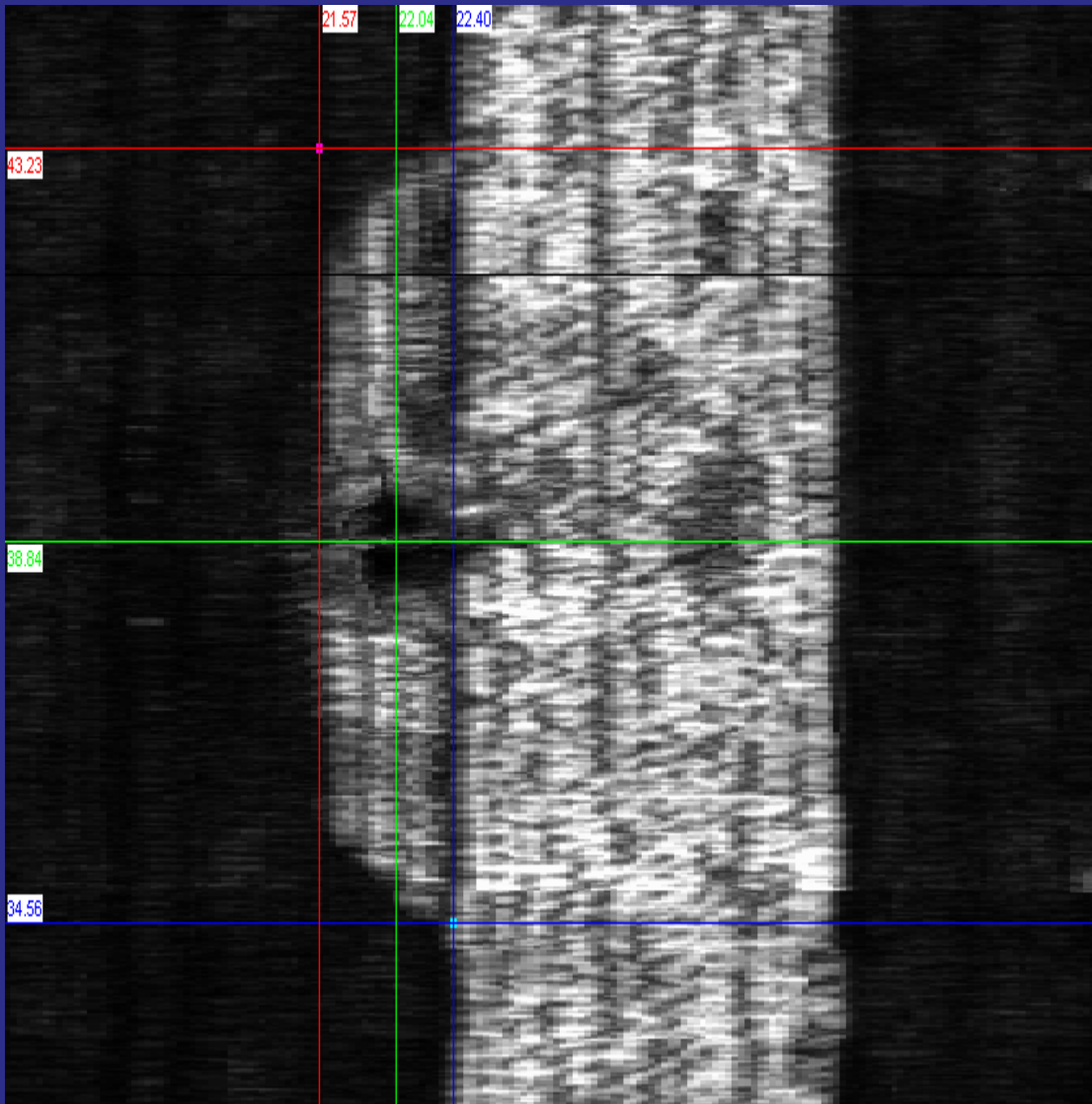


IMPACT



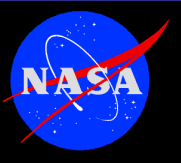


Ultrasonic C-Scan Analysis: Delam Size

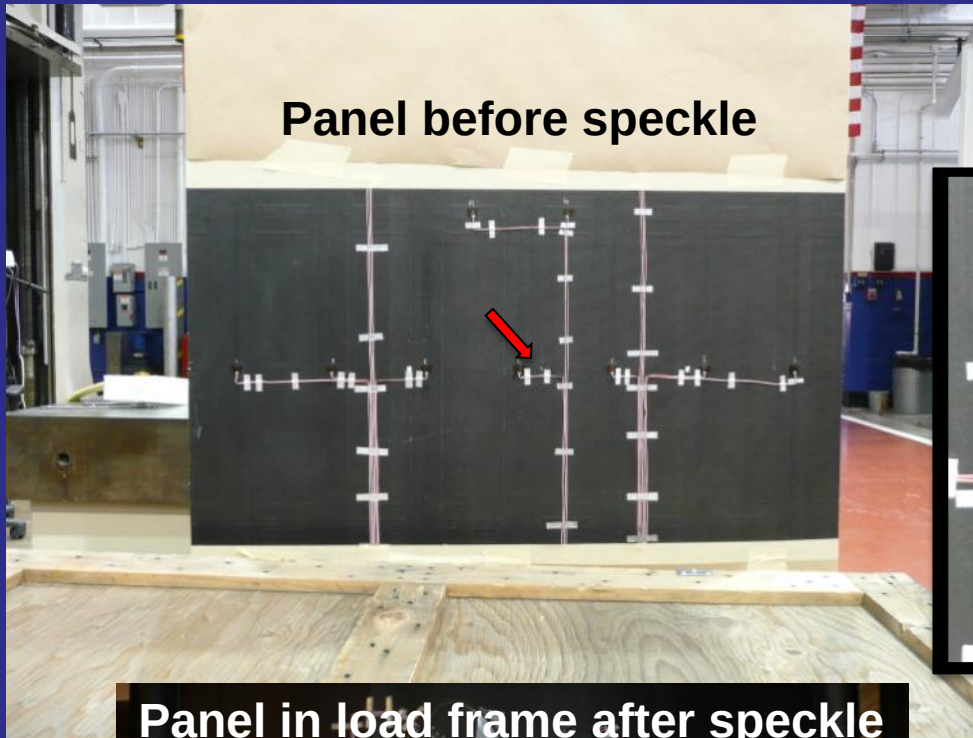


**Delamination extends
4.39" above and 4.28"
below the impact center**

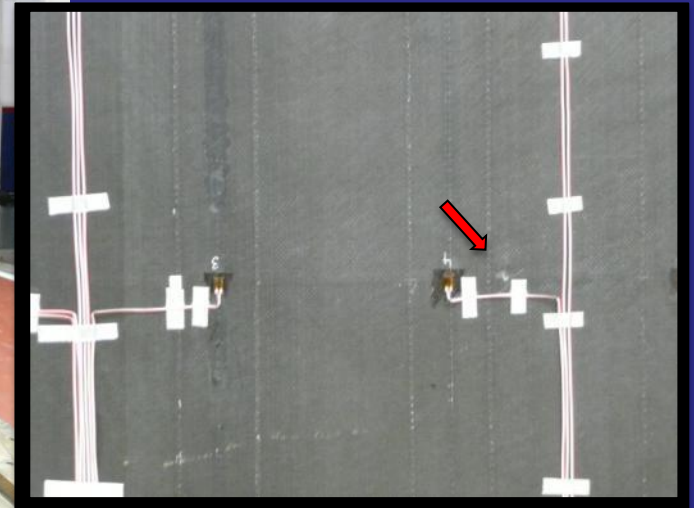
**Lateral dimension of
delamination is
constrained to 0.83" by
row of stitches in flange**



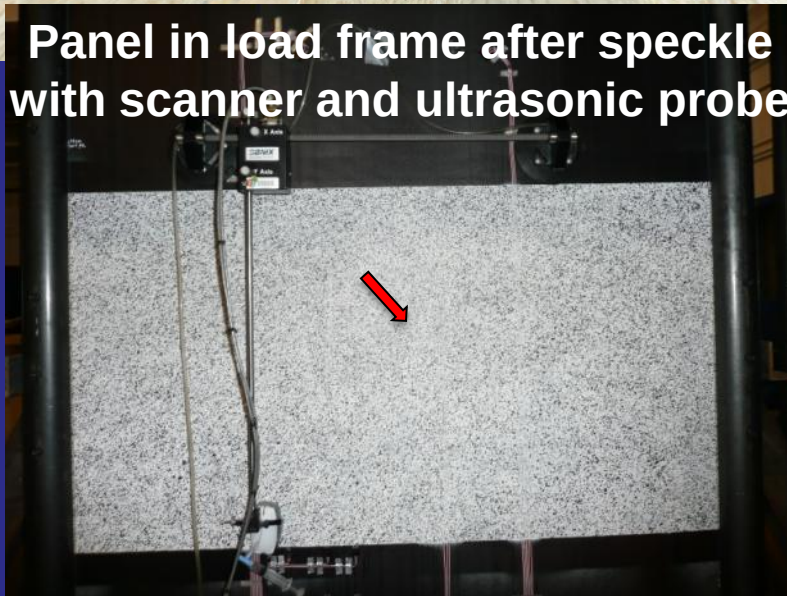
Panel before speckle



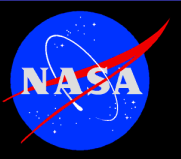
Close-up of impact area



**Panel in load frame after speckle
with scanner and ultrasonic probe**

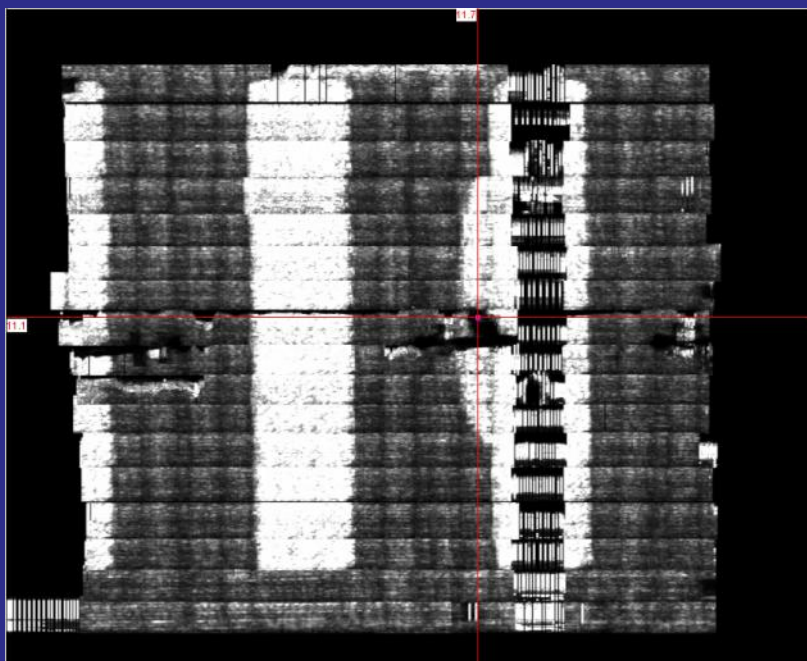


**Red arrow points to
impact site**

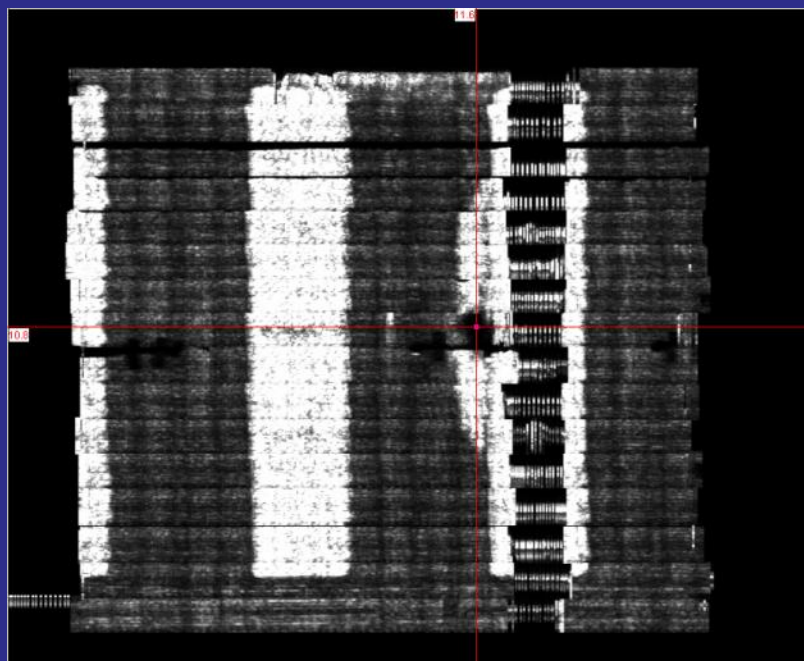


Ultrasonic C-Scan Analysis: Gate A

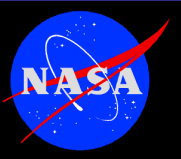
Post-Static Load



Post-Cyclic Load

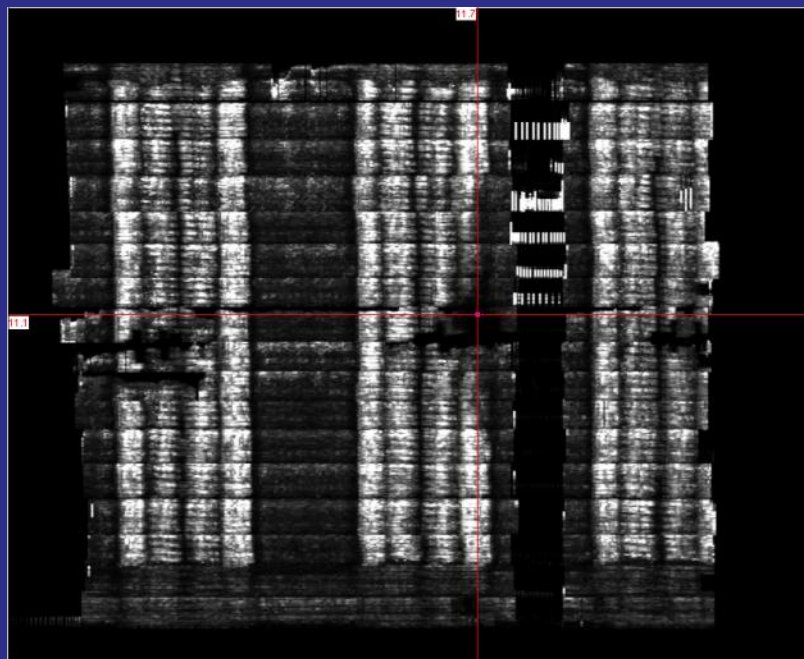


- Delamination showed no growth during either static loading or cyclic loading
- Captive water column with flexible membrane provided good coupling over the gages and near wires (some slipping of probe in scanner grip)

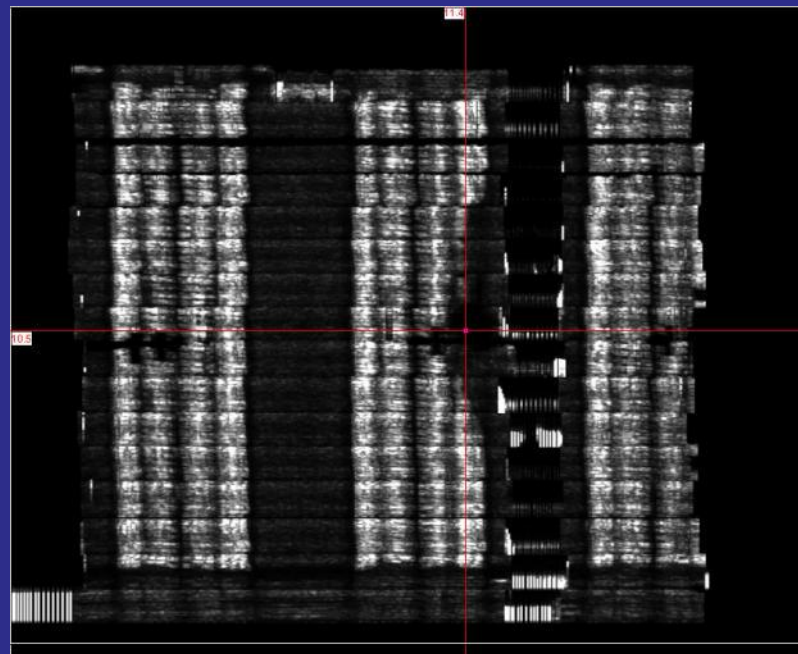


Ultrasonic C-Scan Analysis: Gate C

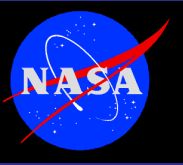
Post-Static Load



Post-Cyclic Load



- **Delamination showed no growth during either static loading or cyclic loading**
- **Captive water column with flexible membrane provided good coupling over the gages and near wires (some slipping of probe in scanner grip)**



Summary

Subsonic Fixed Wing/Environmentally Responsible Aviation

- Ultrasonic NDE showed that impact damage in PRSEUS is arrested and constrained by stitching during impact and subsequent static and cyclic loading

Advanced Composites Technology

- Pulse-echo ultrasonics works very well in PRSEUS
- Out-of-autoclave processing and stitching do not produce unmanageable ultrasonic attenuation

Aircraft Aging and Durability/Composite Crew Module

- Ultrasonic array probe with captive water column and flexible membrane works well on surface with gages and wires