Development of a Nondestructive Inspection (NDI) Approach based on Bolt Hole Ultrasonic Testing (BHUT) for complex, multi-layered Aircraft Structures

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Outline

- **Project Motivation/Approach**
- **BHUT Approach Principle**
- **BHUT Procedure Development for C-5 Contour Box Beam Fitting (CBBF)**

BHUT Inspection Development

AF Project F09650-03-D-001 5020 Task 2 (completed October 2007)

C-5 Contour Box Beam Fitting (CBBF) Structure

Background:

- Develop NDI approach to eliminate need for labor and cost intensive structure and fastener removal and to eliminate maintenance induced damage
- Address Off-Aircraft Inspection Verification Requirement

Products:

- NDI system including enhanced UT bolt hole probes supporting depot inspections
- Validated Bolt Hole Ultrasonic Inspection Procedure for C-5 CBBF
- Verification test articles for use in similar NDI or POD projects

Benefits:

- Advanced, cost-saving NDI inspection procedure for pressing inspection problems
- NDI equipment development enables the initiation of a transition programs
- Solution of complex structures has high potential to leverage similar solutions for other MDS
- Availability of test articles enables follow-up NDI verification efforts

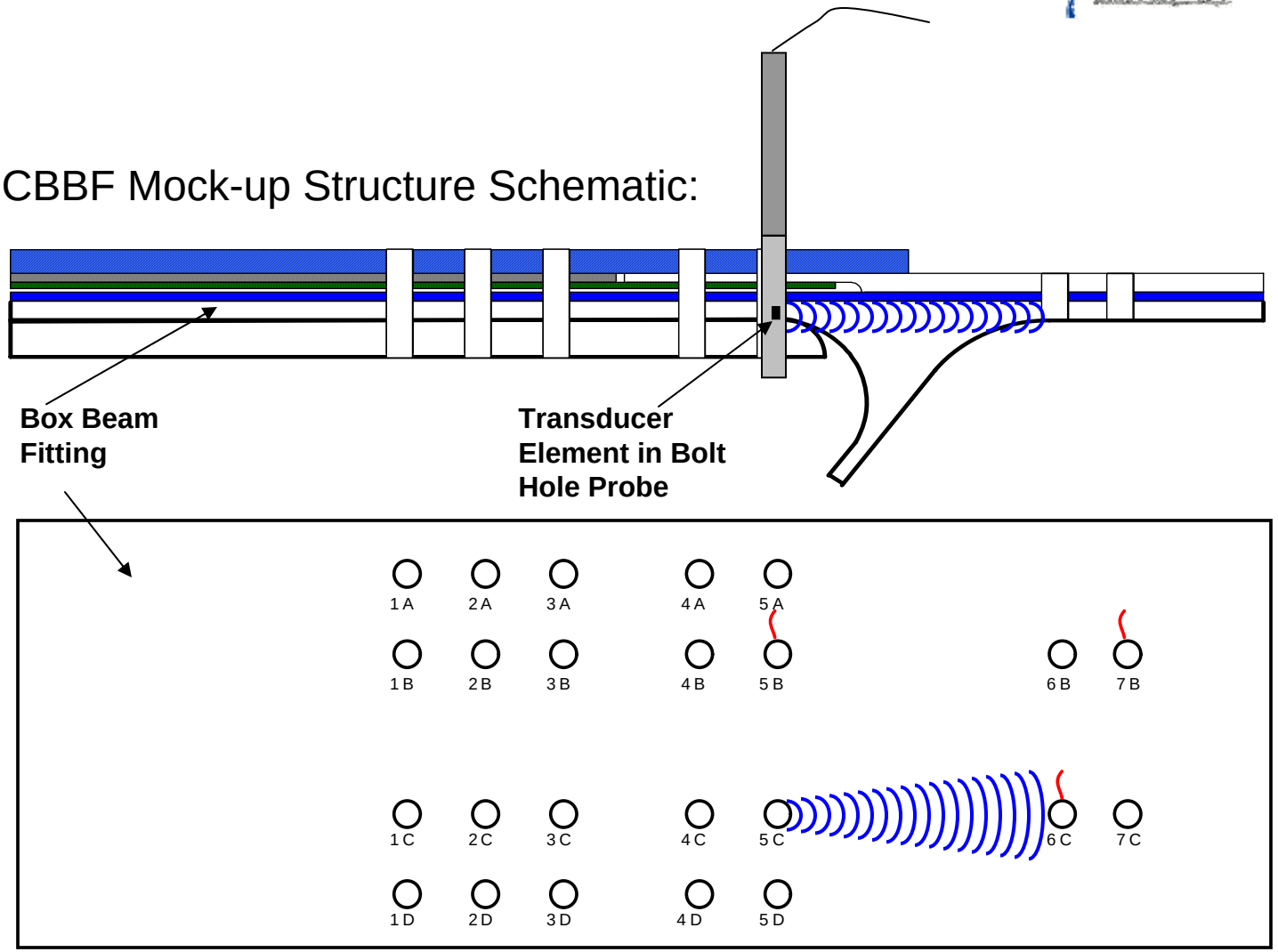
BHUT Technology Description

- Unlike BHEC, only selected fasteners need to be removed for inspection

- Probe, containing small rectangular transducer element, is inserted in opened bolt hole
  - Ultrasound is sent and received into and from each layer (pulse/echo set-up)
  - Sound can be coupled into each layer of interest by varying the probe insertion positioning the transducer at the correct depth
  - Transducer can detect various significant reflectors up to several inches distance including both material damage (cracks) and structural features (other bolt holes, edges, corners)

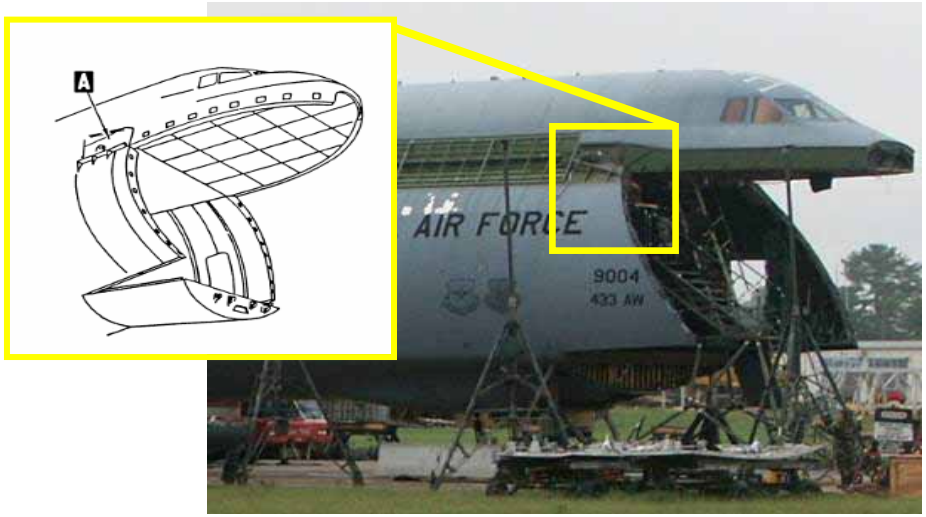
BHUT Technology Description

C-5 CBBF Mock-up Structure Schematic:



C-5 CBBF Application
Project Motivation

- At least 31 C-5As have known Cracks in Contour Box Beam Structure– Believed to be caused by a combination of stress fatigue and SCC
- Replacement recommended
- Until Replacement is complete, reliable NDI is necessary



Location of contour box beam fitting (CBBF) structure on C-5 aircraft

BHUT Development Approach

Technical Challenges:	Technical Approaches:
• Evaluate inspection task and determine crack detection requirements	• Analyze Failure Analysis and determine a_{NDI} for given inspection intervals
• Detection of cracks at various hard-to-reach locations; reduce structure disassembly	• Improve BHUT inspection equipment, particularly the probes, to meet inspection requirements
• Verification of inspection findings without extensive aircraft disassembly	• Develop off-aircraft verification testing procedure using aircraft simulating mock-up structures
• Development of inspection procedure usable for AF Level II UT inspectors	• Optimize procedure incorporating results from the verification testing as well as AF inspector feedback

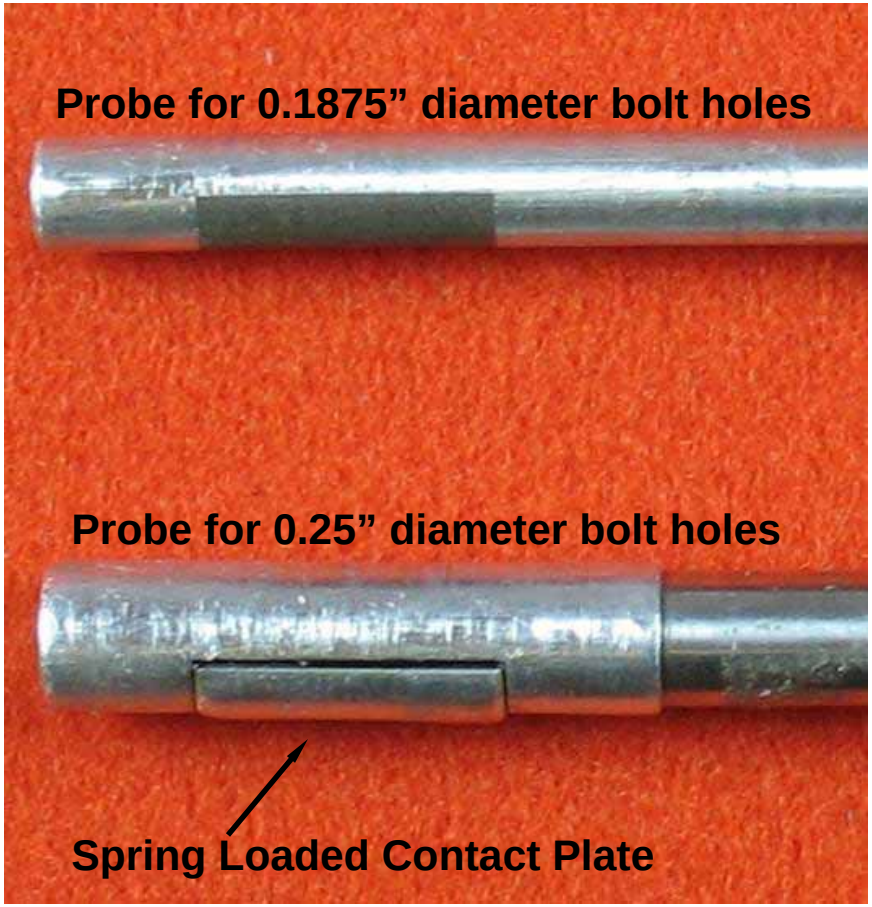
C-5 CBBF Application
Crack Detection Criteria

Crack Detection Criteria for C-5 CBBF Application:

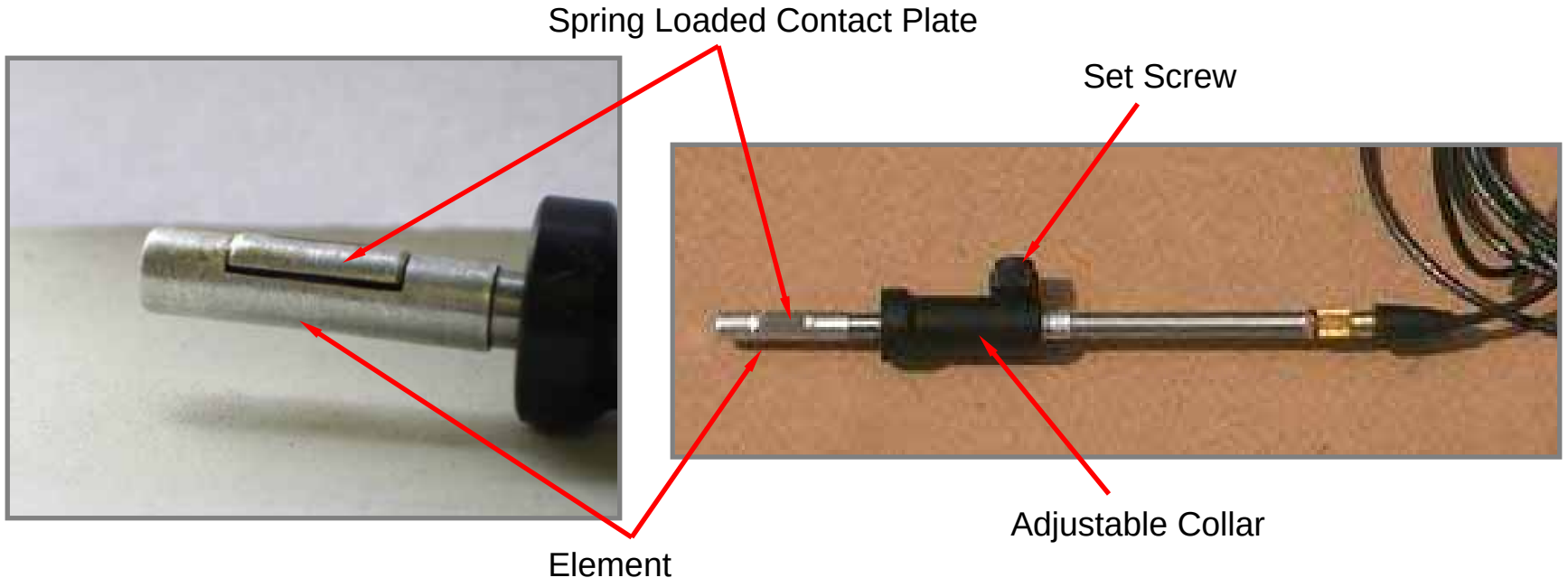
- Lockheed-Martin Failure Analysis Studies enabled determining what cracks need to be detected considering crack length, location and orientation in each layer of interest
- Three a_{NDI} crack lengths were determined:
  - 0.250” inches as a minimum detection requirement for the Box Beam Fitting
  - 0.090” fulfils the detection requirement for a minor ISO field inspection for both Y-Fitting and Titanium Safety Strap
  - Additional 0.060” for the Y-Fitting
- Orientation of all cracks is either aircraft forward or aft direction
- All cracks are considered through-thickness cracks

BHUT Probe Development

- Cylindrical probe diameter selected to fit bolt holes with diameters between 0.1875” and 0.25”
- Half-cylinder holding transducer element
- Transducer embedded in Al-alloy for optimized sound coupling to target structure
- Transducer with rectangular shape; long axis not larger than smallest target layer thickness
- Spring located at transducer back side to ensure optimal contact to bolt hole surface

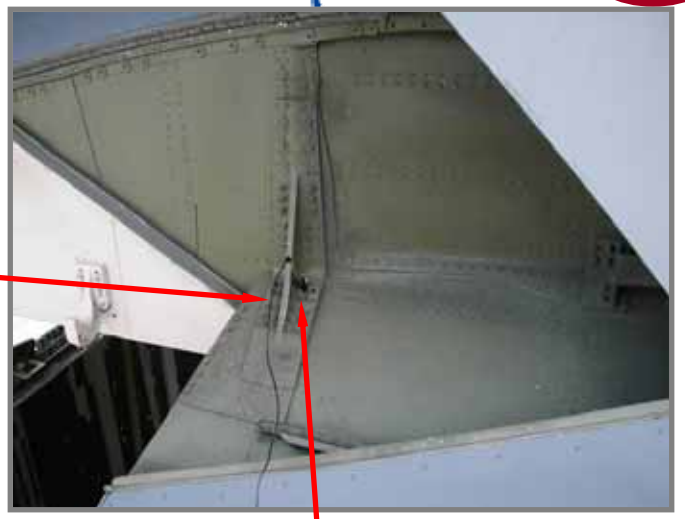


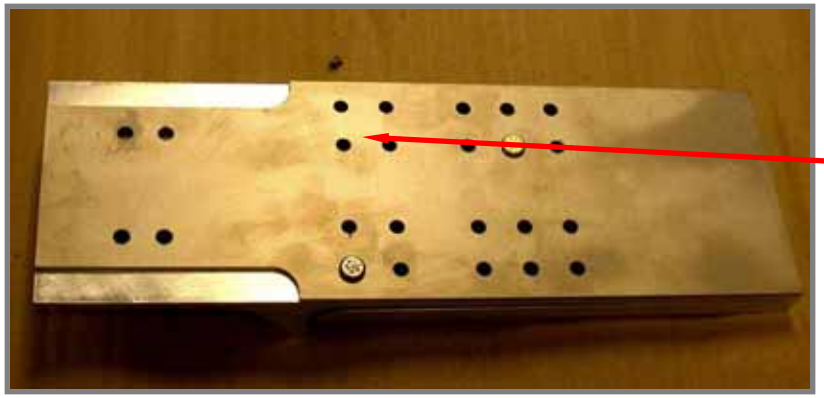
BHUT Probe Development

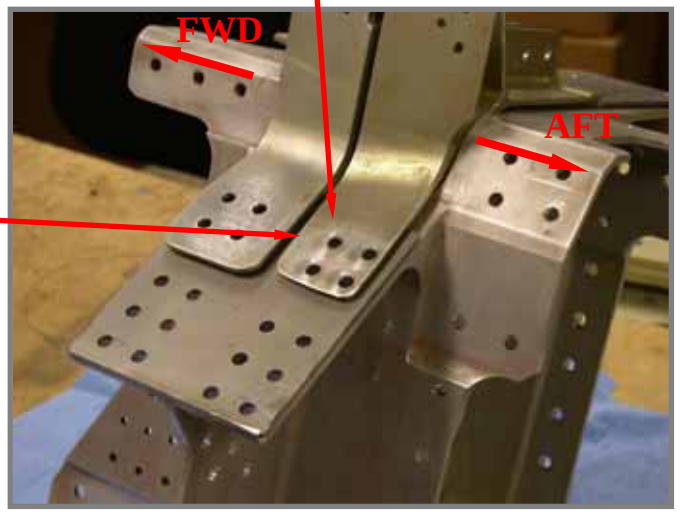


5 MHz, single element, straight beam

C-5 CBBF Application
Verification Testing







C-5 CBBF Application Verification Testing

C-5 CBBF structure removed from aircraft shown with ultrasonic probe

SKT fabricated C-5 CBBF "mock-up" structure shown with bore probe and USN-58L

- Test Article Mock-up Structure to simulate C-5 CBBF Structure, as on-aircraft verification of inspection results not an option
- Fatigue Cracks of critical length at critical locations were introduced in three layers of interest (Box Beam Fitting, Titanium Safety Strap and Y-Fitting)
- Mock-up Structure used for both Verification and Calibration

C-5 CBBF Application
Verification Testing

Bending Fatigue to introduce Crack in Radius

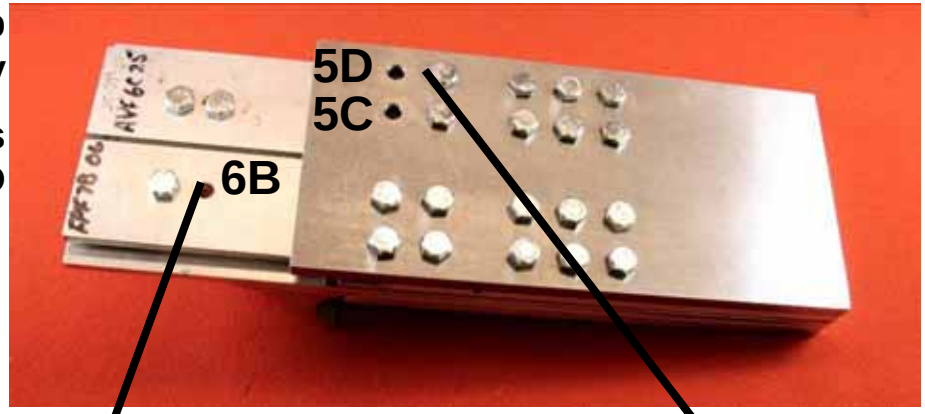
Fatigue Crack Introduction in Box Beam Fitting Specimens

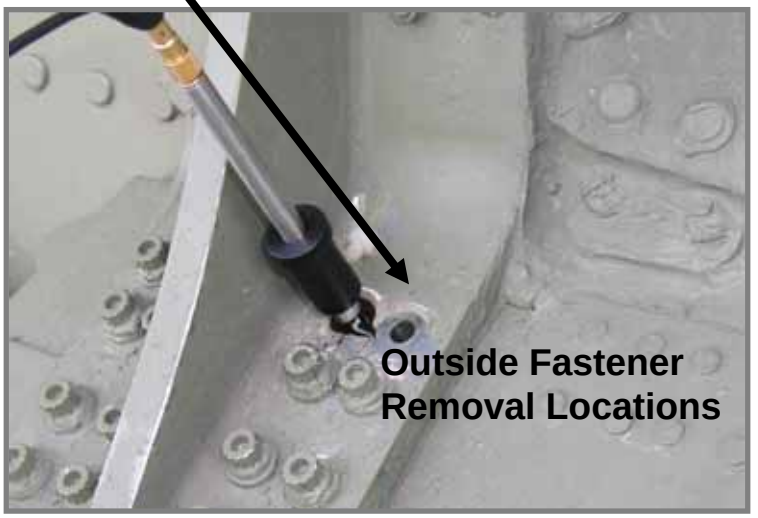
Controlled crack propagation experiments required the generation of only one crack per specimen

C-5 CBBF Application Verification Testing

C-5 CBBF Mock-up Structure Assembly

Inspection from Holes 6B, 5C, 5D

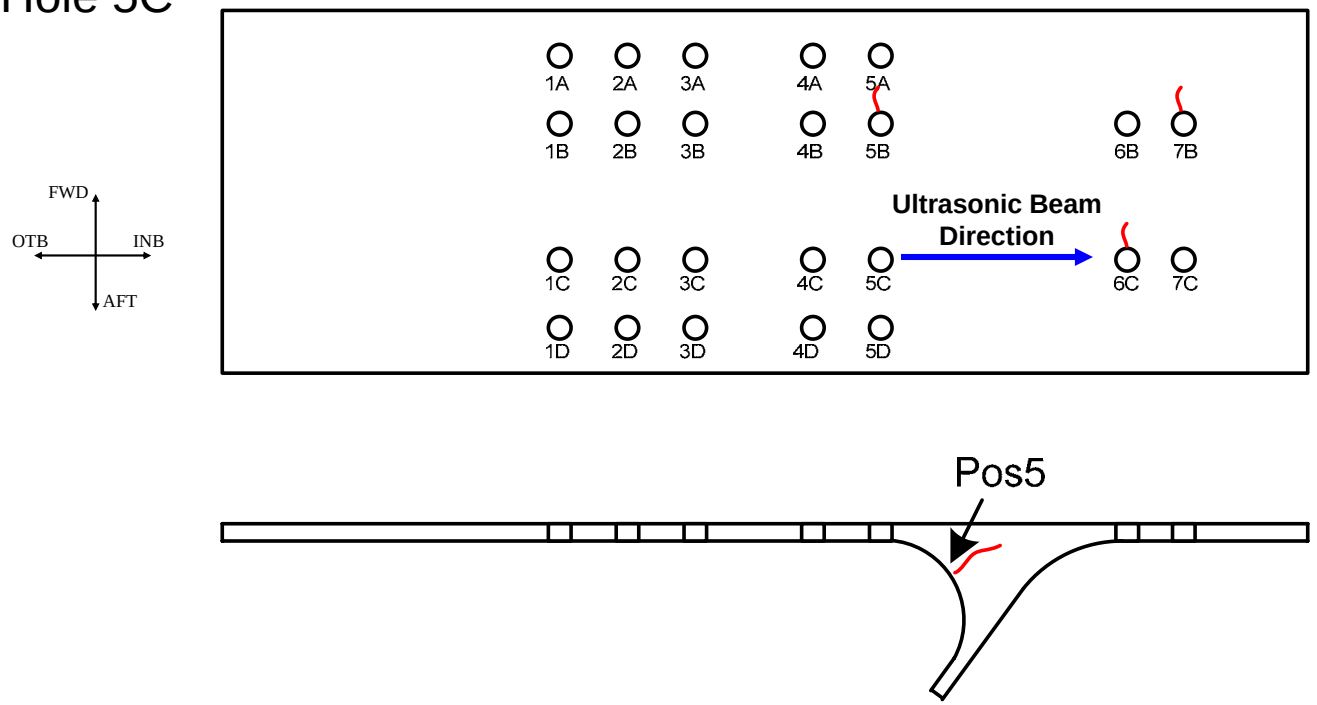




C-5 CBBF Application Verification Testing

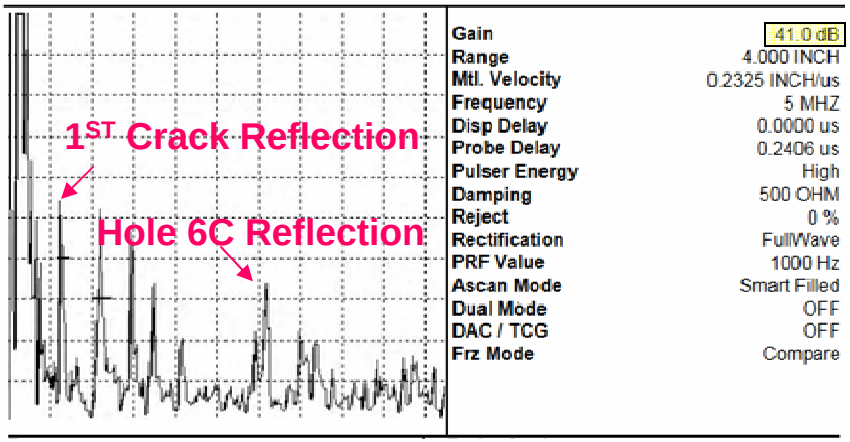
Verification Testing – Example 1:

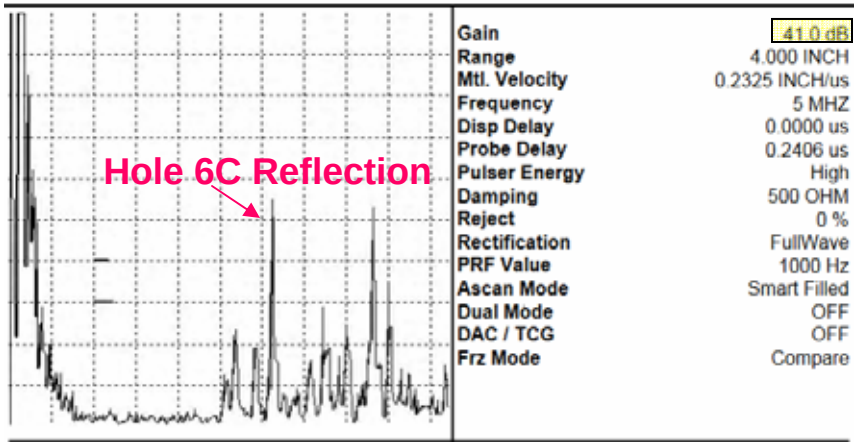
- 0.25” long Crack at Pos5 in Box Beam Fitting
- Probe in Hole 5C



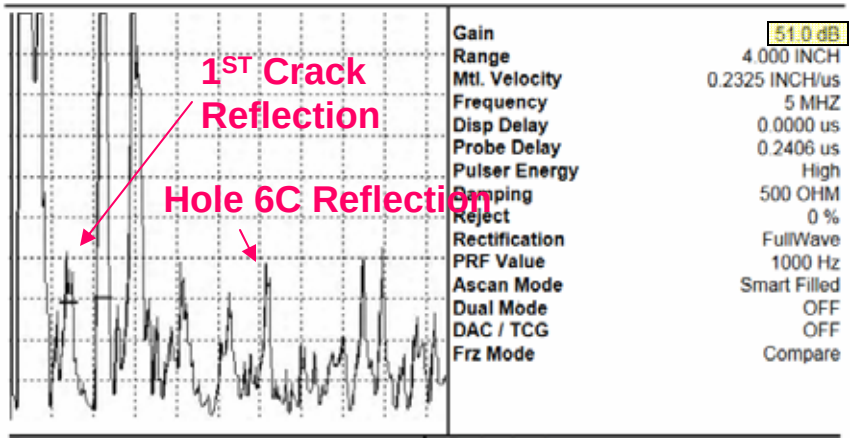
C-5 CBBF Application
Verification Testing – Example A-Scans

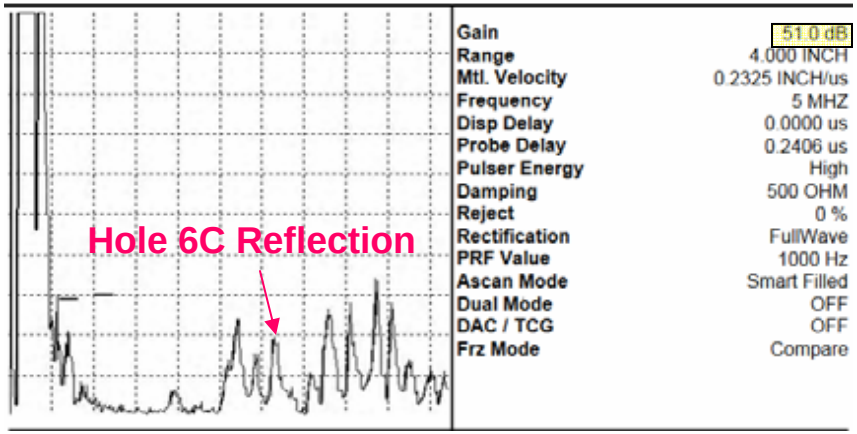
Inspection of 0.25” Crack at Pos5 from Hole 5C – Specimen not in Assembly





Inspection of 0.25” Crack at Pos5 from Hole 5C – Assembled with Sealant

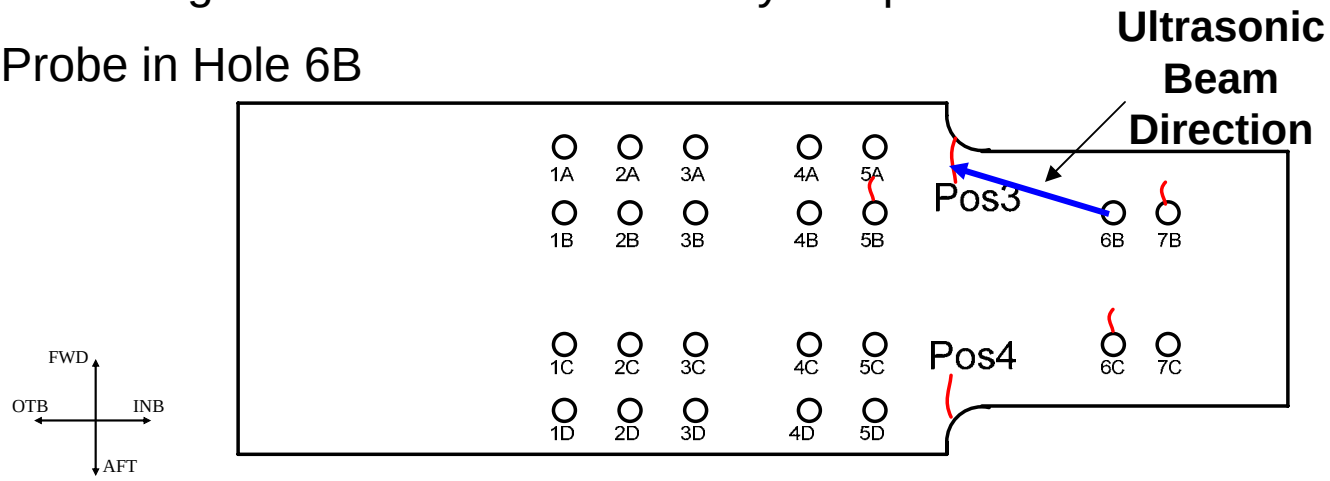




C-5 CBBF Application Verification Testing

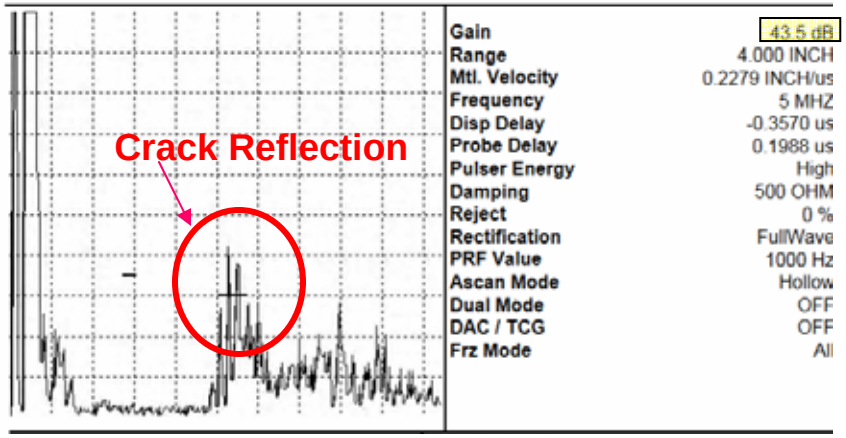
Verification Testing – Example 2:

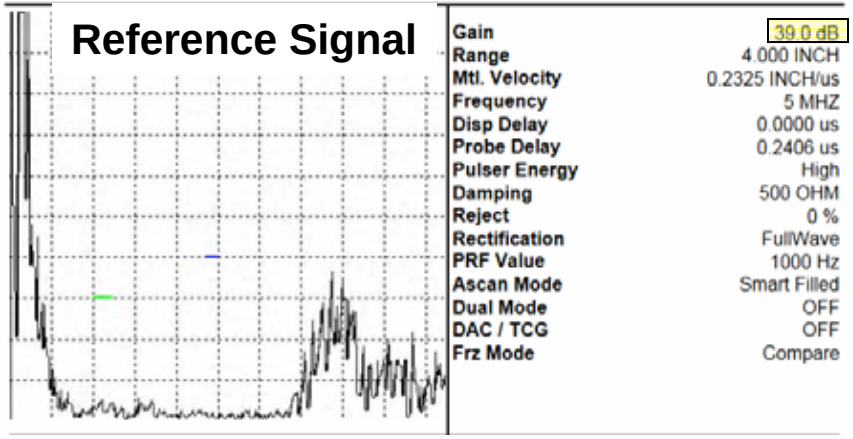
- 0.09” long Crack at Pos3 in Ti Safety Strap
- Probe in Hole 6B



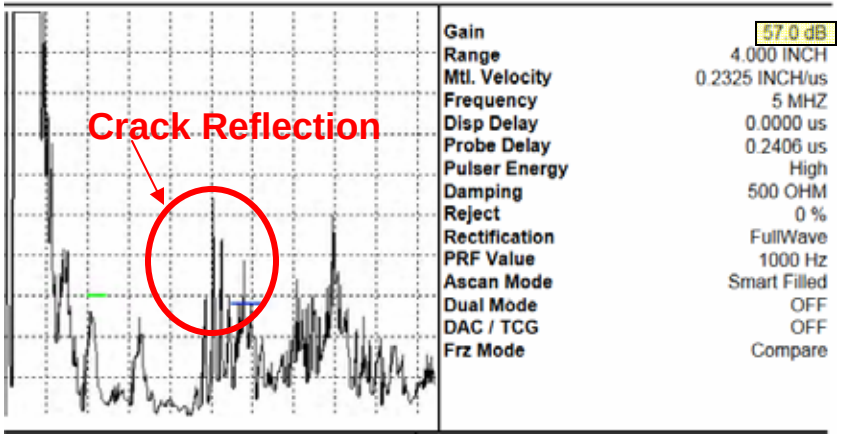
C-5 CBBF Application
Verification Testing – Example A-Scans

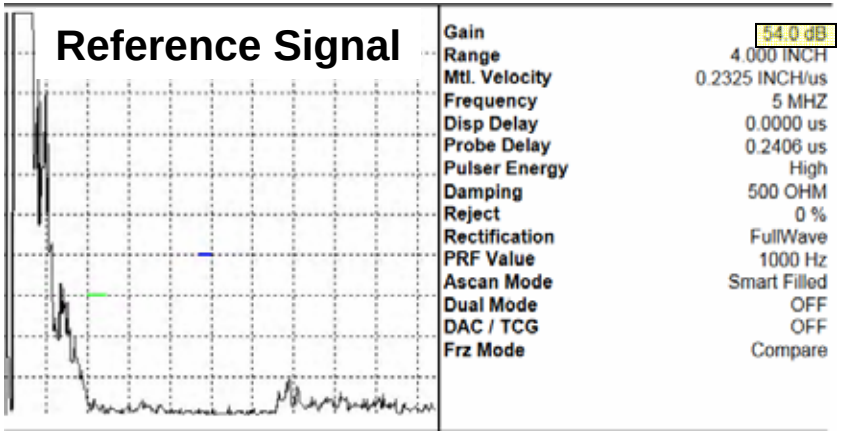
0.09” Crack at Pos3 from 6B – Specimen not in Assembly





0.09” Crack from 6B – Assembled with Sealant





C-5 CBBF Application
Verification Testing Results

- Verification test series using the inspection equipment (USN-58L and Bolt Hole Probes) in combination with the C-5 CBBF verification test articles

- Tests were designed to demonstrate the functionality of the ultrasonic inspection system

- Tests reveal influence of assembly/sealant on UT data by performing each inspection with layer disassembled, assembled, or assembled with sealant
  - Reflection signals are reduced or damped for the assembled, fastener-tightened structure compared to those obtained within disassembled layer
  - Sealant causes additional signal reduction; Signal-to-noise-ratio, however, is still acceptable

C-5 CBBF Application Verification Testing Results

- Most critical inspection are the corner cracks in the Ti Safety Strap; can be detected reliably from either Hole 6B (Pos3) or 5D (Pos4)

- Cracks in Pos5 (Box Beam Fitting) can be detected reliably from all inspection holes; Failure of the Box Beam Fitting usually occurs at this location

- All crack sizes, down to or 0.06” in the Y-Fitting, could be detected

- However, at some locations crack related reflections could be identified, but it would be difficult to identify these signals as flaw indications on the aircraft

C-5 CBBF Application
Procedure Implementation

- SKT and iTi performed training for the Bolt Hole UT Inspection Procedure on the C-5 Box Beam Fitting Structure at WR-ALC
- Following the Training, an official Validation/Verification process was conducted successfully
- The Level II UT inspectors handled the equipment with ease and understood the requirements for both probe handling and A-scan data analysis

- ➢ Inspection procedure and equipment are delivered to WR-ALC
- ➢ WR-ALC NDI Personnel are enabled to continue using the procedure without contractor support

Summary

- **Delivered Enhanced Bolt Hole Ultrasonic Testing Equipment and Procedure for C-5 Contour Box Beam Fitting (CBBF) to WR-ALC**

- **Generated C-5 CBBF cracked Test Articles for further NDI or POD studies**

- **Obtained positive Results for BHUT Proof-of-Concept Study for Crack Detection in C-130 CWB Structure adjacent to Wing Attach Angle at WS61**