Department of Structural Engineering

Detecting Major Damage in Internal Composite Structural Components

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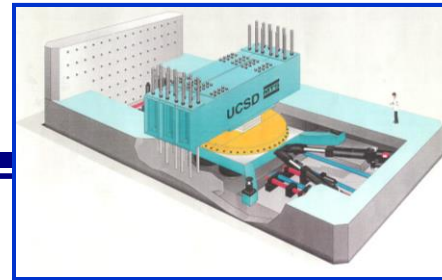
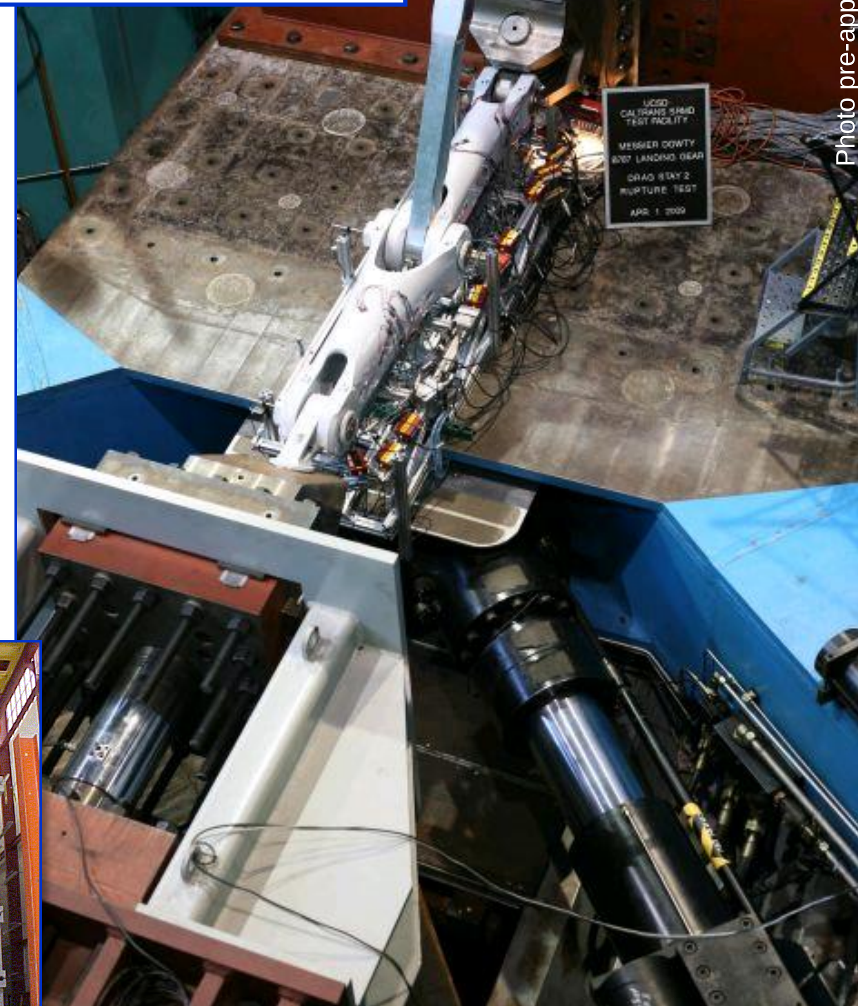
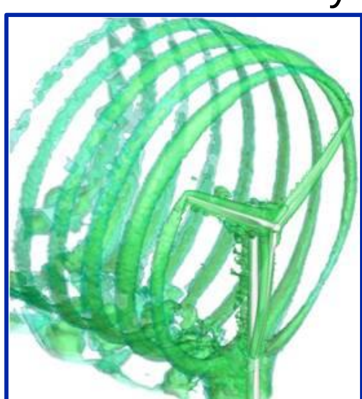
Structural Engineering @ UCSD

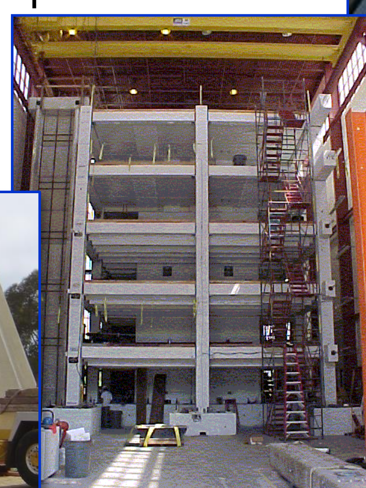
- Structural Engineering @ UCSD has *__unique vision__* focusing on *__all types of structures__*:
  - aerospace, marine, wind, bio, civil, geo
  - wide length scales: blood cell → full aircraft
  - experimental evaluation & simulation
  - SHM and NDE – grad & u-grad programs
- Key component of SE@UCSD is the Powell Structural Research Labs
  - world-class large-scale facilities
  - offers **unique capabilities**:
    - » 52 MN (12 Mlbs) dynamic test machine
    - » facility simulating blast impulse





Landing Gear Brace Certification Test





Center for Aviation Safety and Composite Structures

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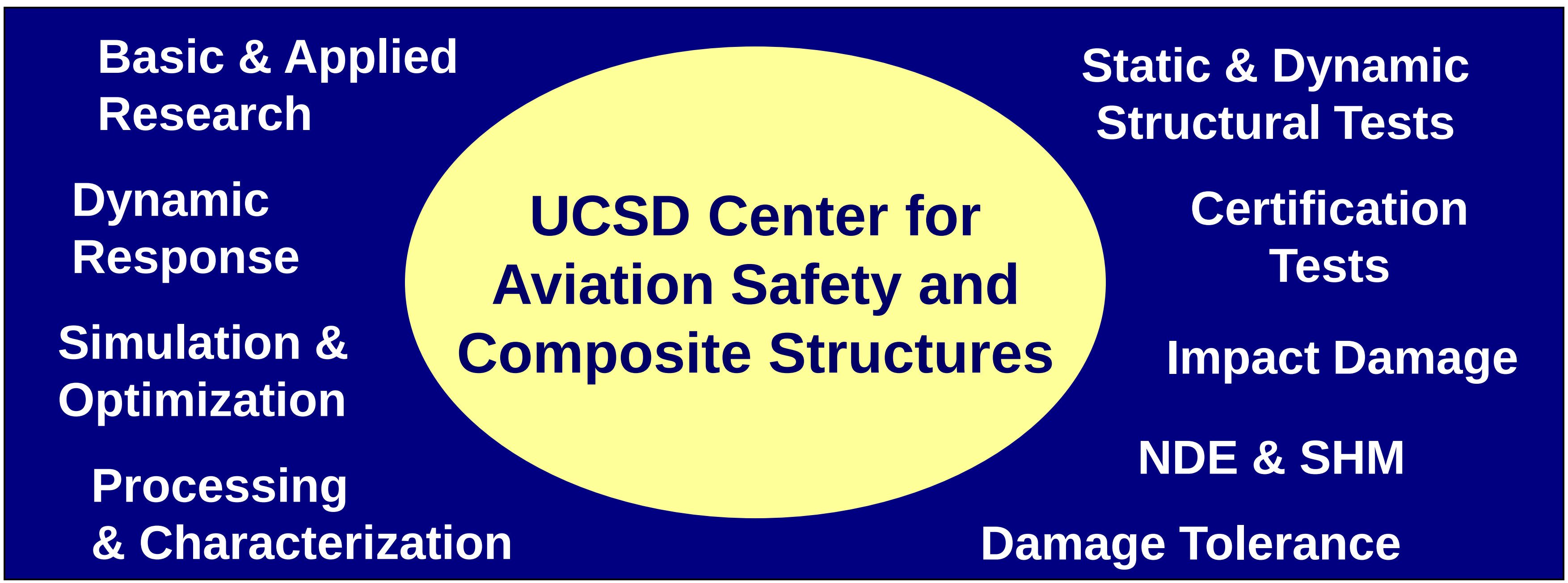
- Aerospace airframes and structures are now in the composites age
  - similar trend in other areas: automotive, marine, infrastructure, etc.
- ***UCSD Composites Aviation Safety Center*** addresses major issues
  - structure/system-level structural evaluation, non-destructive evaluation and health monitoring/management
  - modeling and simulation, optimization
  - material-scale research, processing

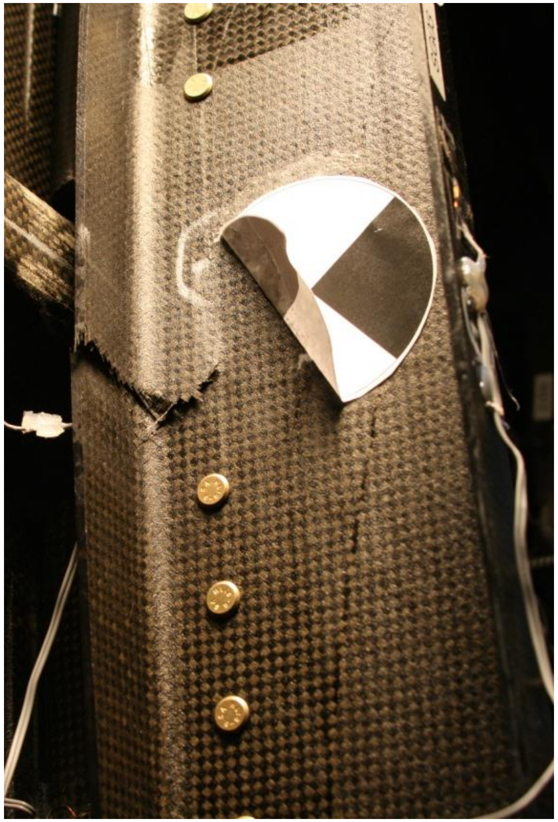


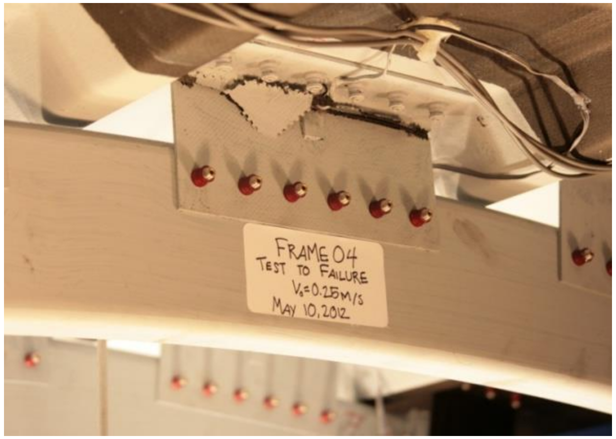
Motivation

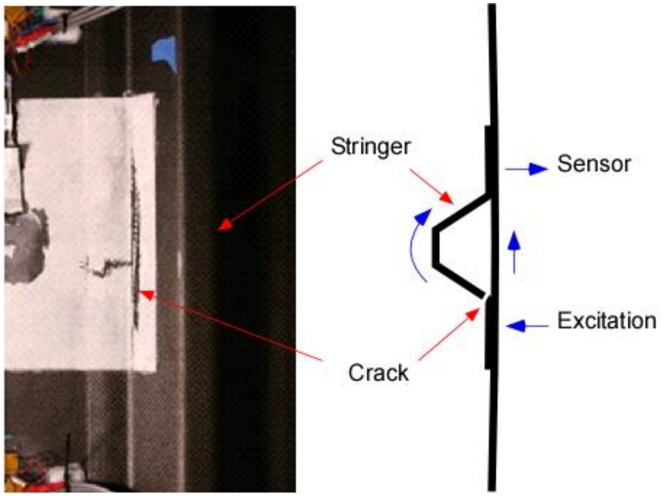
- damage from ground service equipment (GSE) can be difficult to visually detect
  - blunt impact damage problem
- key interest: presence of **major damage to internal structure** (frame, shear tie, stringer)
  - cracks usually not detectable by typical one-sided NDE from external skin
- need quick NDE tool to decide if further inspection/action needed

Objectives

- establish detection method for finding major damage to internal structure:
  - severely cracked frames
  - damaged shear ties
  - stringer heel crack
- detection performed only from exterior skin-side
- system must be “ramp friendly”
- longer-term: relate NDE-measurements with damage location, mode, and size/severity

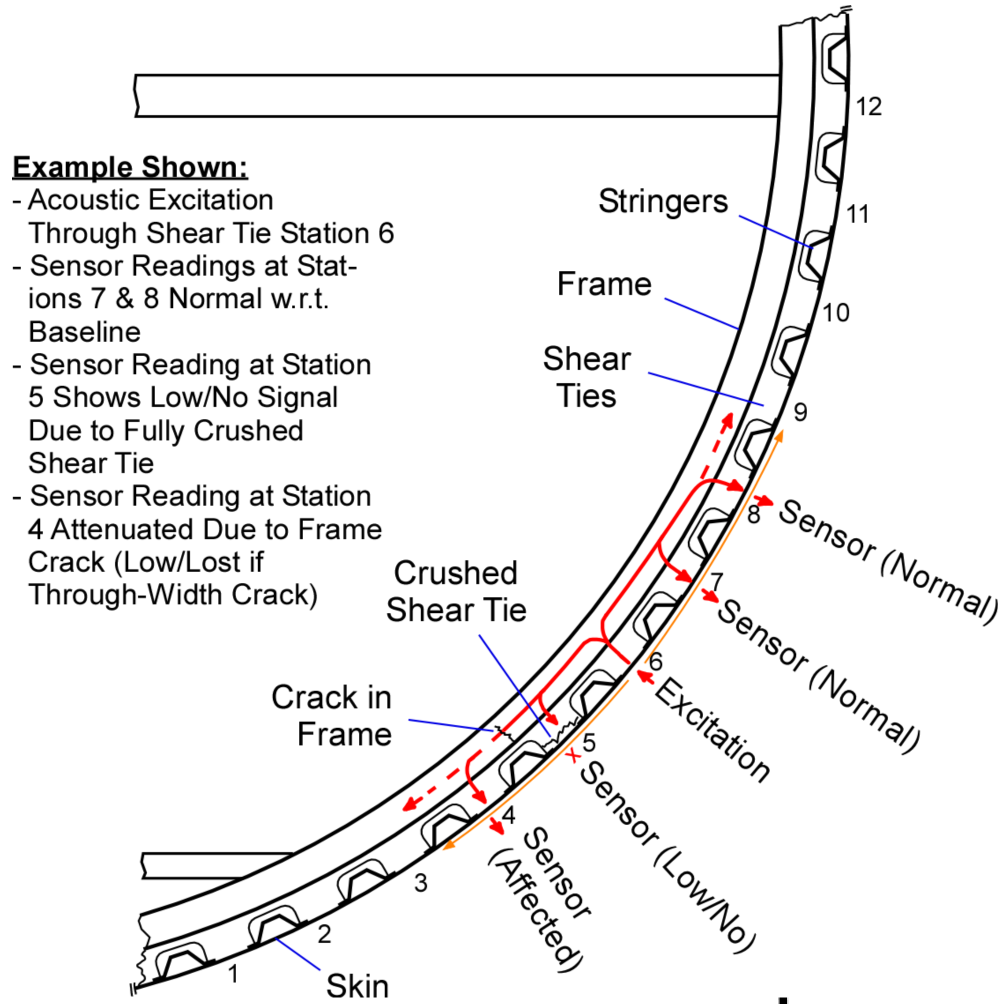


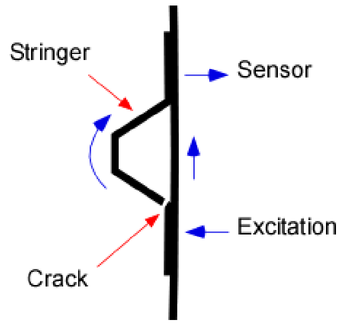




Approach

- pitch-catch guided wave approach
- structures of interest form waveguide paths
- C-frame is like 1D waveguide – wave transmission along length affected by damage
  - excitation → through skin → in through shear tie → travel along frame → out through various shear ties → through skin → sensor
  - broken shear tie and frame will attenuate/modify signal
- key issues:
  - dominant frequencies associated with waves/modes sensitive to damage
  - complex geometry, many interfaces
- stringer heel crack – wave propagation through skin and stringer paths





Test Specimens

Use Existing Damaged Specimens

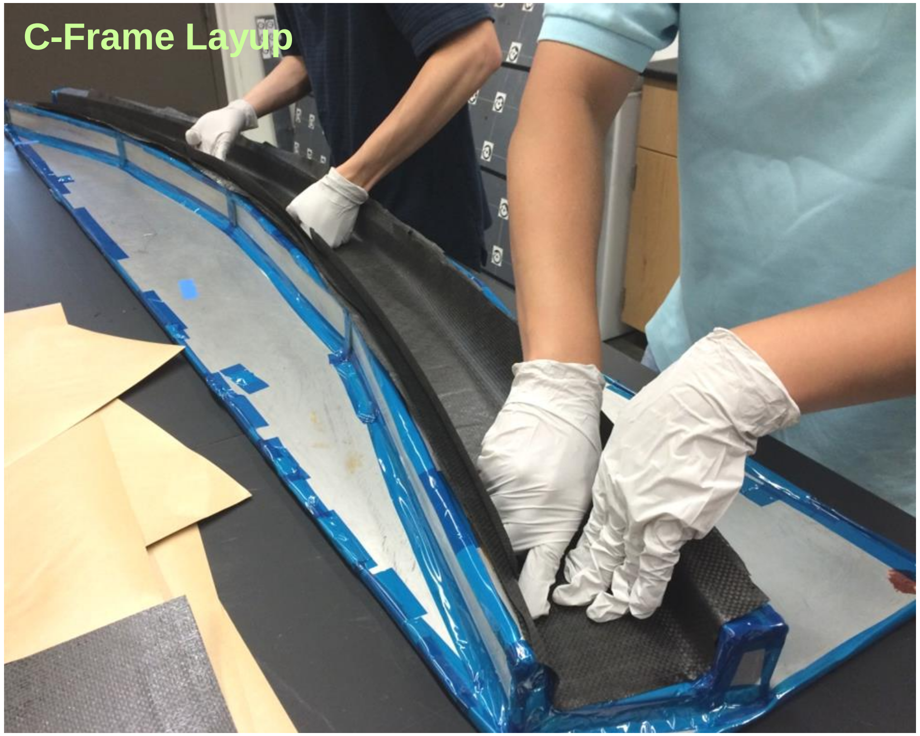
- previously-tested specimens from FAA project “Impact Damage Formation on Composite Aircraft Structures”
- FrameXX panel series
  - C-frame crack
  - shear ties crushed
- StringerXX panel series (stringer-only panels)
  - stringer-skin disbonding
  - stringer heel crack
  - shear ties crushed

New Specimens

- C-frames – pristine stand-alone frames
  - 3 new frames fabricated
  - 1 previously-fabricated “spare”
- shear ties – qnty ~16 available “new” untested

Test Video 1

Test Video 2

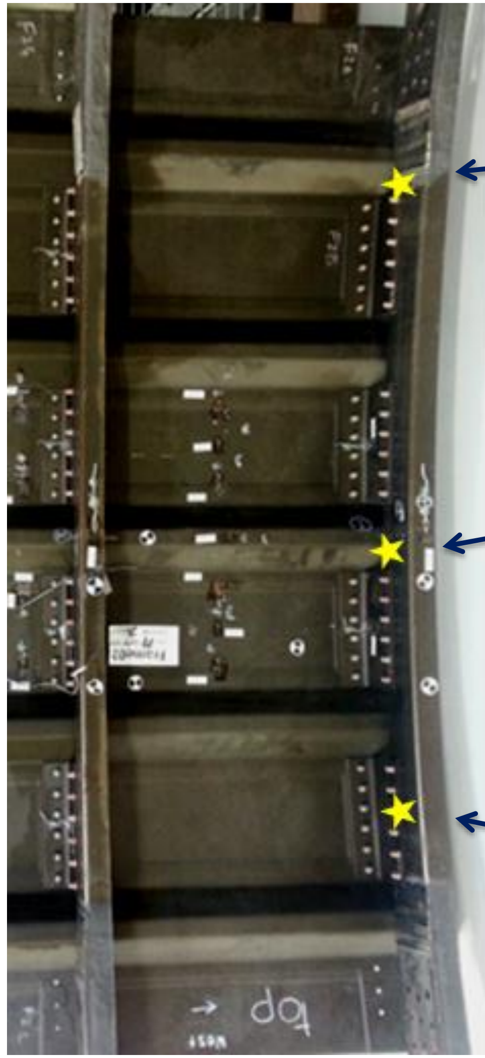


Prior Specimens – Damage Survey

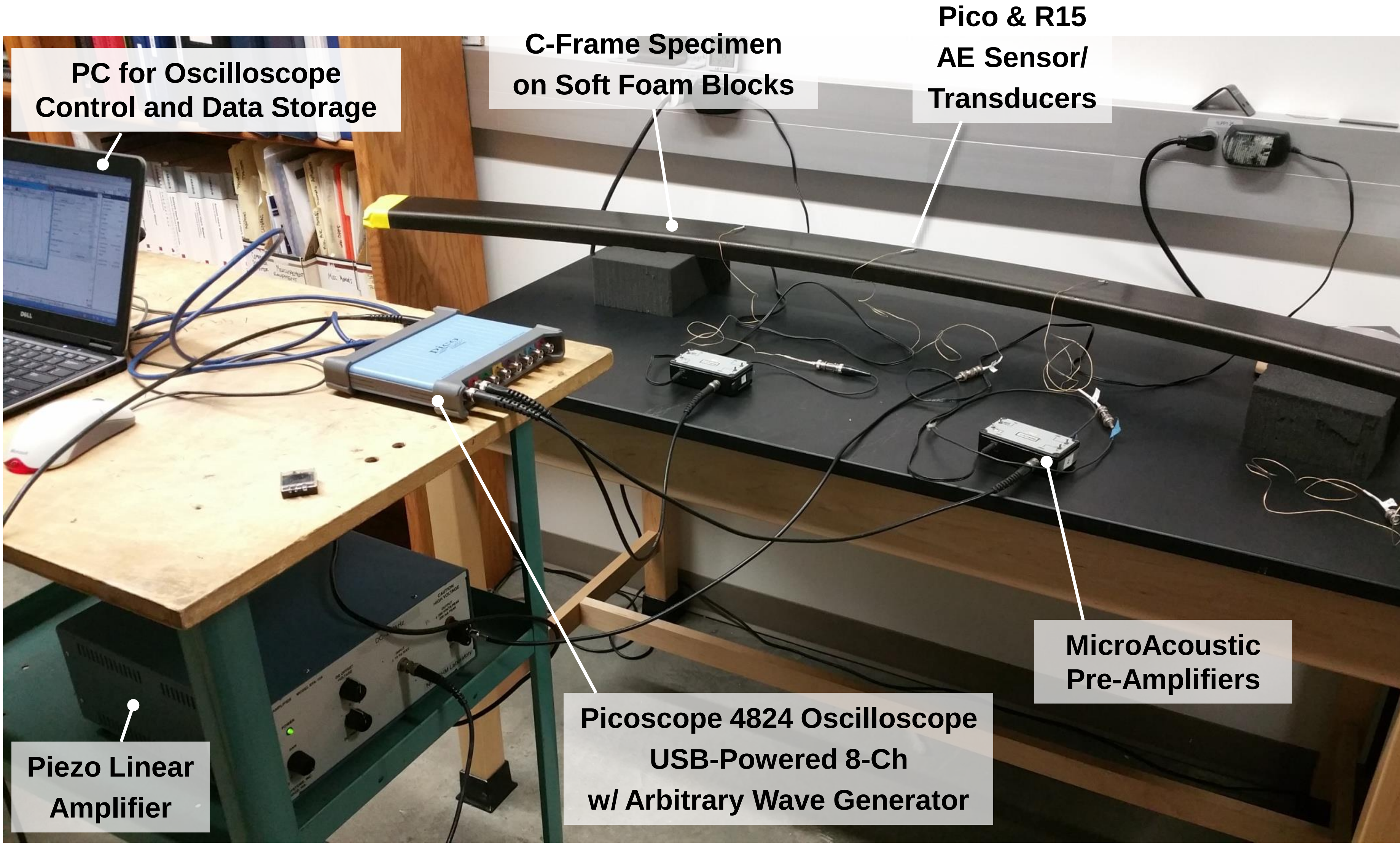
Blunt Impact Damage in Existing Specimens – use for NDE Tests

- **partially-cracked frame** available in panel Frame02
- **cracked/crushed shear ties** in all specimens (Frame01 to Frame04)
- **stringer disbonds** in panel Stringer02
- **stringer heel crack** in panel Stringer05

Partially-cracked frames – from specimen Frame02



Equipment: Test Setup



Seeking equipment allowing assembly of “ramp-friendly” portable system.

Sensor Hold Downs

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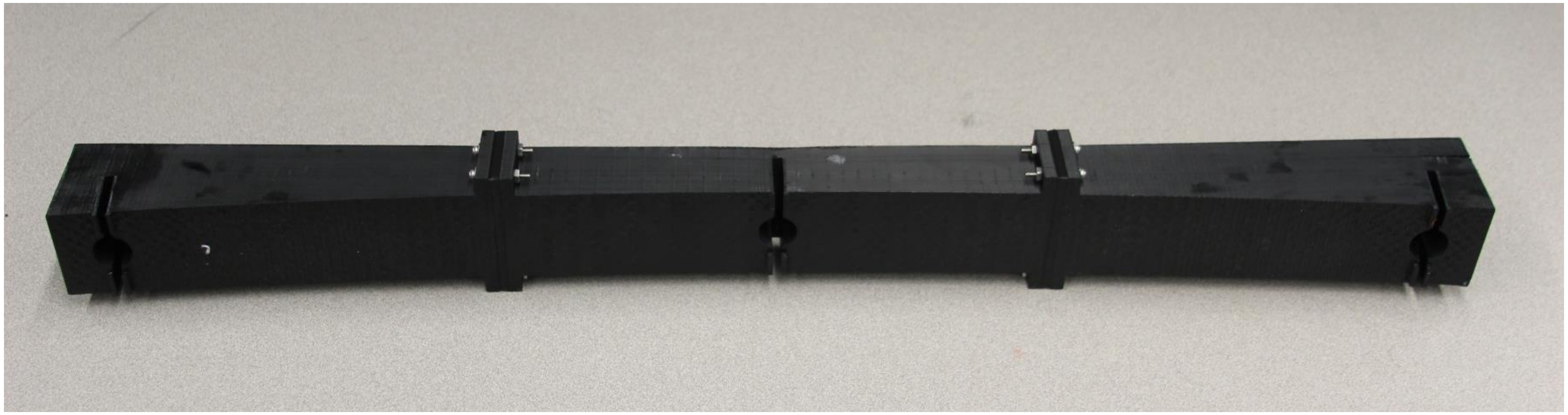
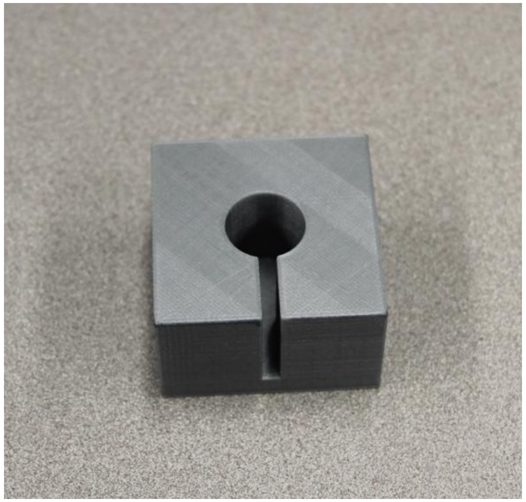
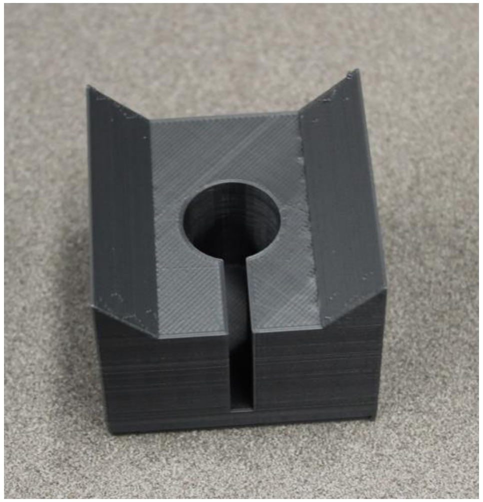
- **Sensor Hold Downs made from 3D printing to hold sensors on the composite components**







Sensor Hold Downs

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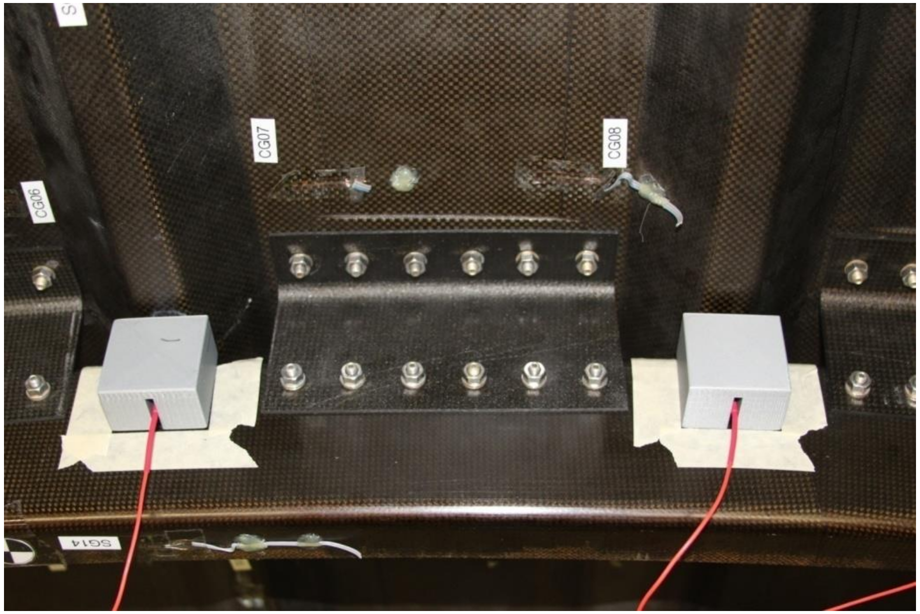
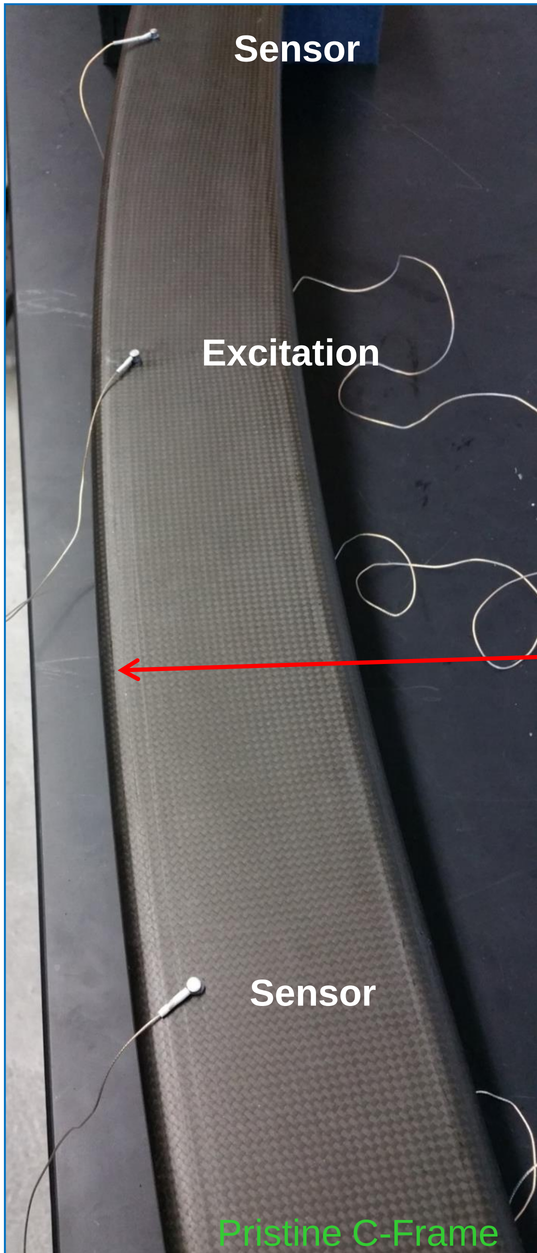
- **Sensor Hold Down Mounted onto Composite Panel Skin using Air Suction Cup (Left) and Composite C-frame using Double Sided Tape (Right).**



Frame Only

GUW Tests on Damaged C-Frame



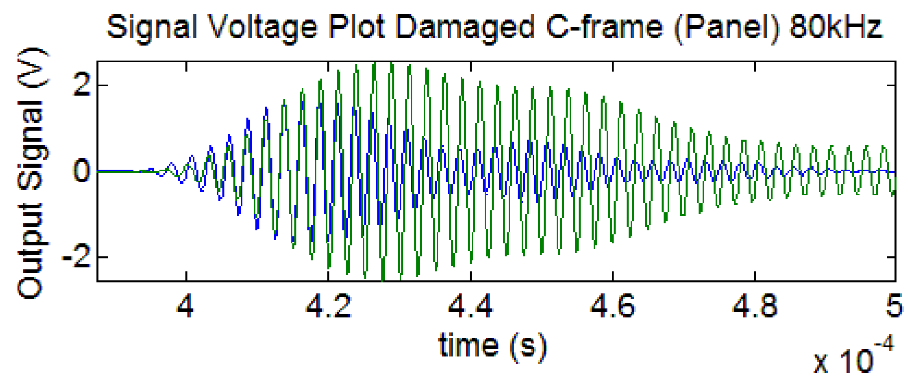
Frequency sweep conducted to find dominant frequencies (80 kHz shown below).

Expect: presence of damage → attenuation of signal.

Damaged C-frame installed in panel:

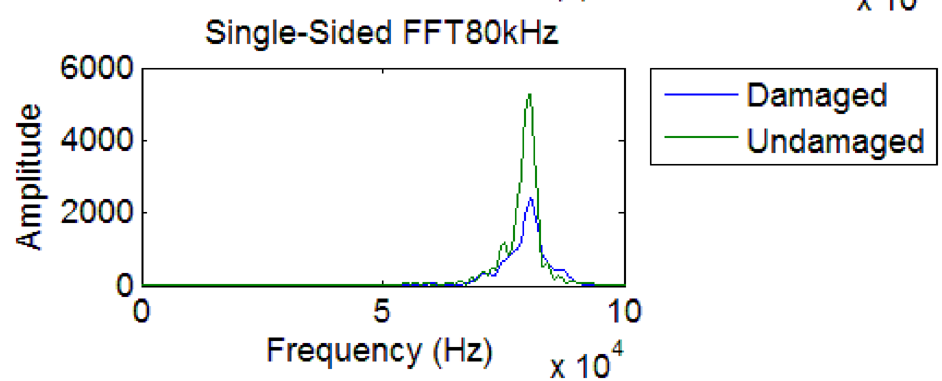
- significant attenuation (55%) through damaged path
- ***crack in C-frame flange detectable*** for sensors directly mounted to frame – next: test sensing through skin

Partial Crack



Sensors located 305 mm (12 in.) from Excitation.

Excitation: 5-cycle sinusoidal burst sent at various frequencies.



Shear Ties Only

- Measure From Skin to Frame (External & Internal Access)

Frame02 Panel Experiment

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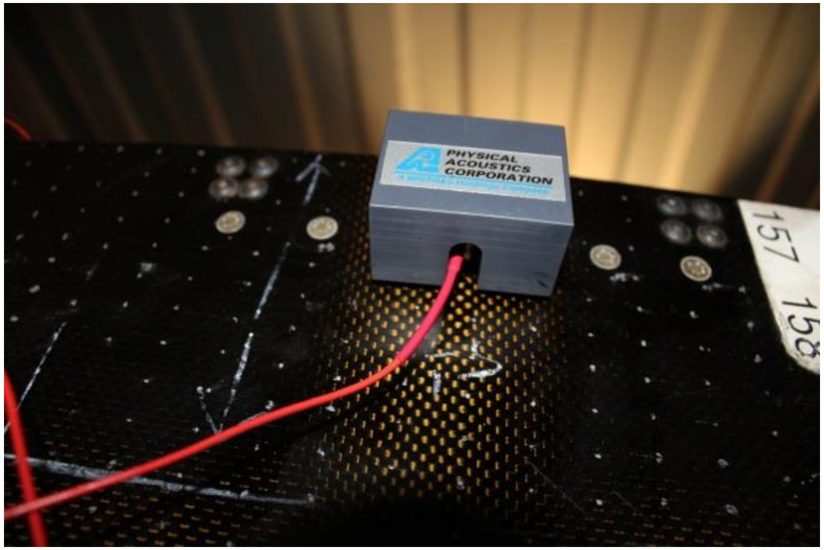
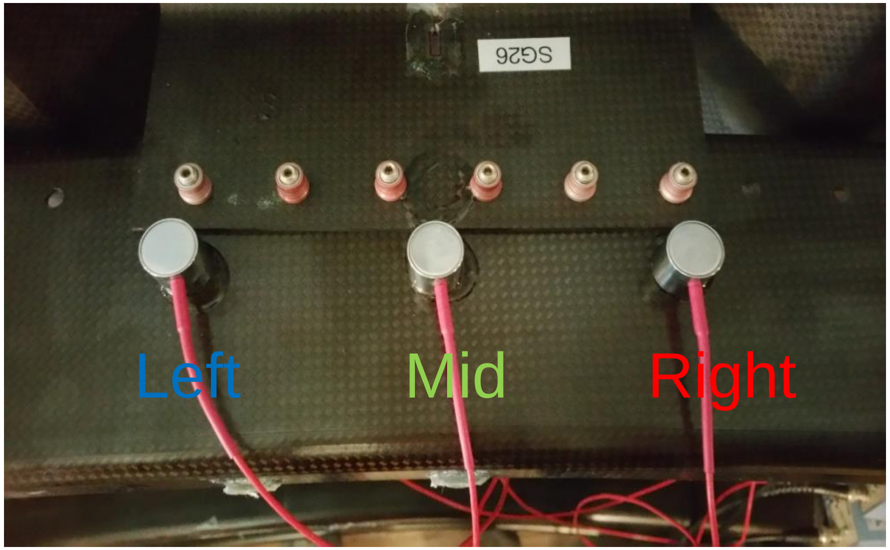
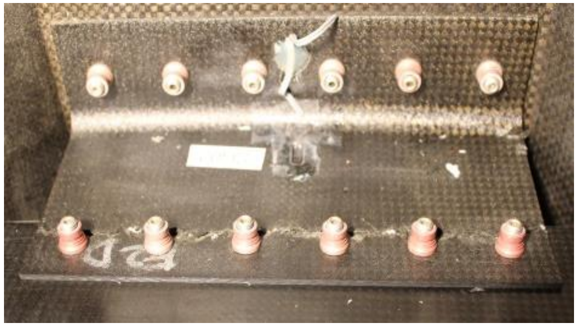
- **Guided Ultrasonic Wave Test Performed on Frame02 Panel to Observe Wave Propagation through Different Shear Tie Damage Cases**





Shear Tie 11

Shear Tie 06



Shear Tie 02

Frame02 Panel Experiment

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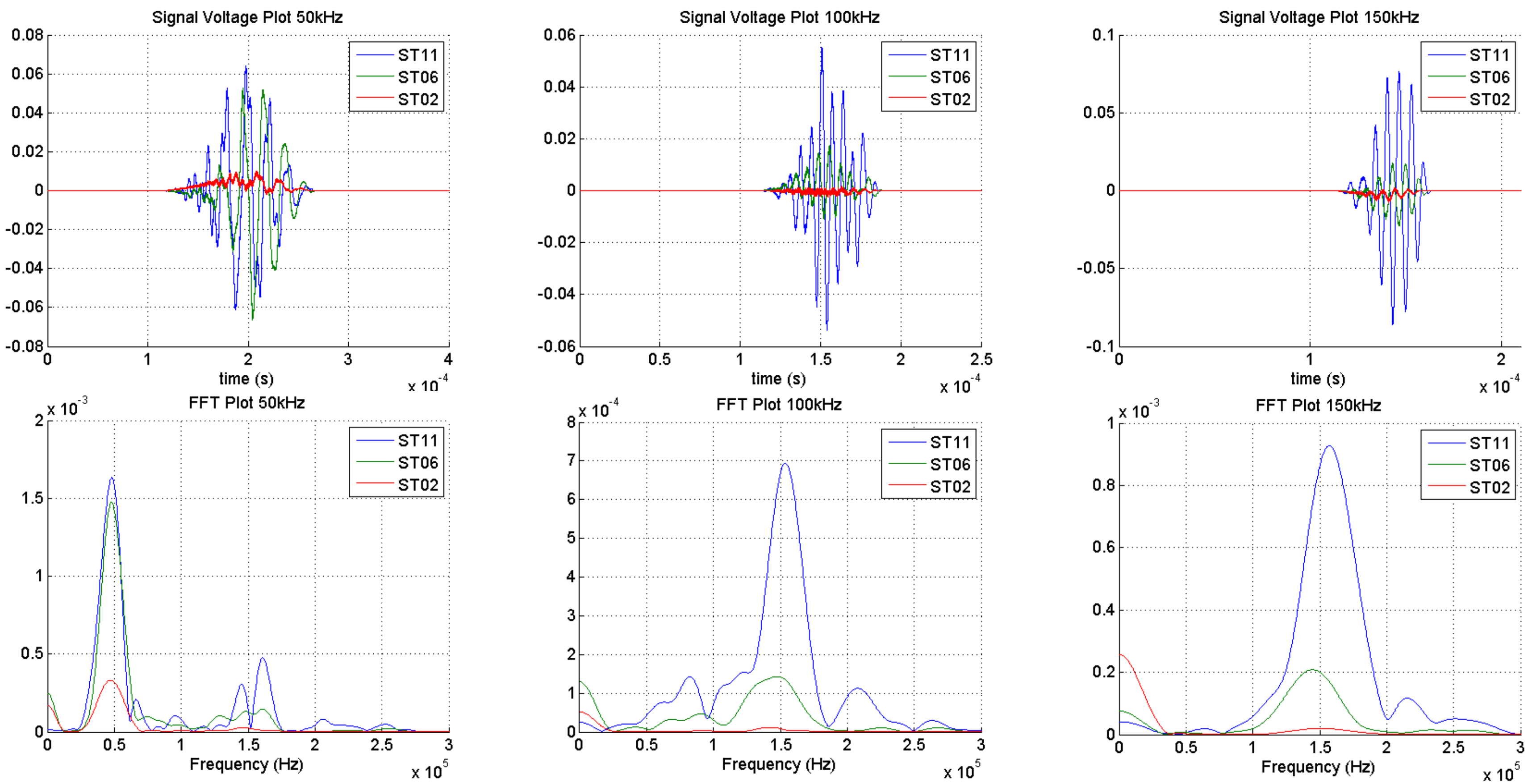
- **Skin to C-Frame Mid**
  - Shear Tie 11 is Undamaged
  - Shear Ties 06 has partially cracked at the corner
  - Shear Ties 02 has completely cracked along the bolt lines

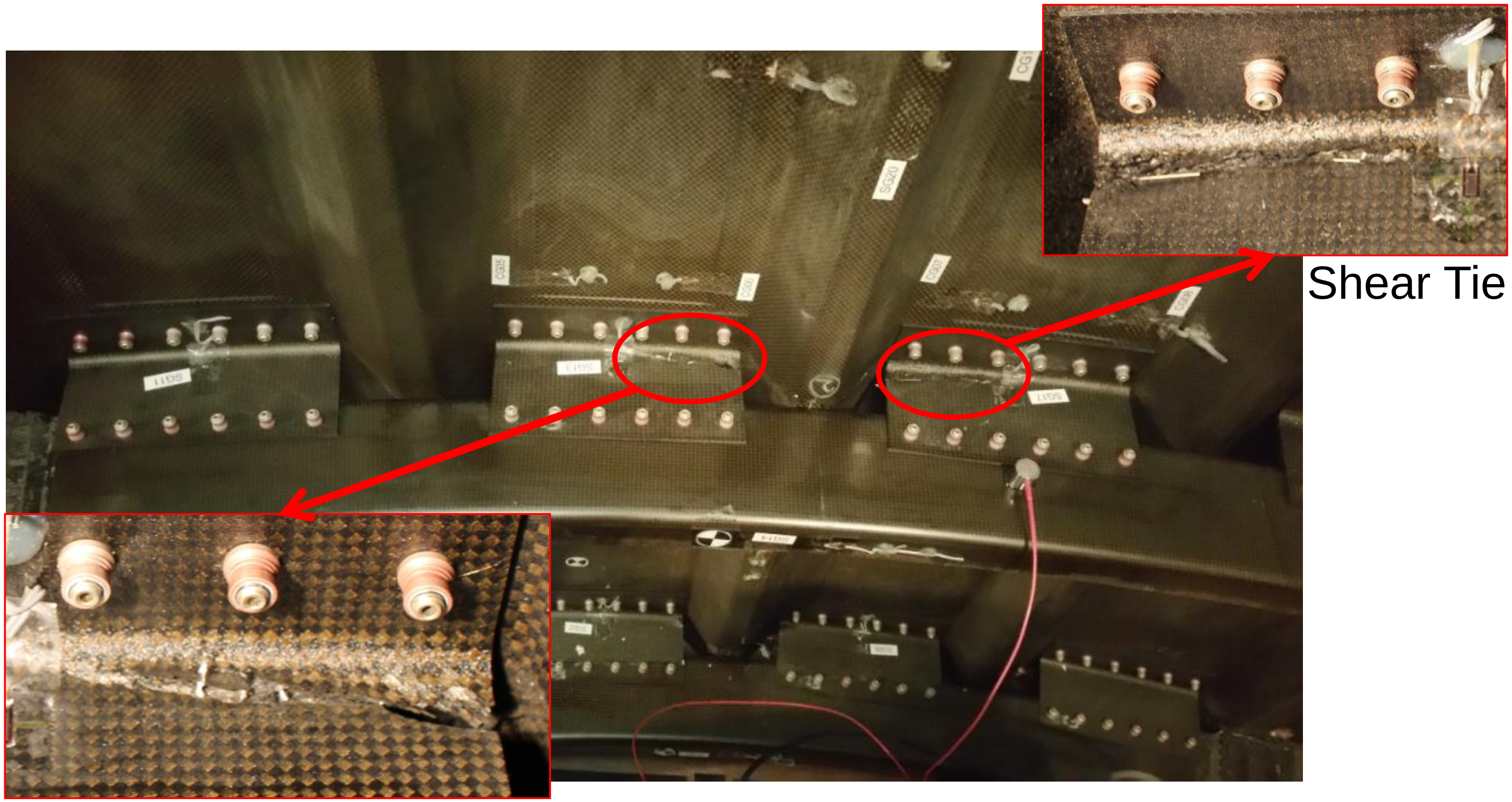


Shear Ties With Skin

- Measure From Skin Side (Only External Access)

Frame02 Panel Experiment

- **GUW Test on C-frame02 Section:**
  - **Skin to Skin Test with Existing Damage on C-frame02 Section**



Shear Tie 06

Shear Tie 07

Frame02 Panel Experiment

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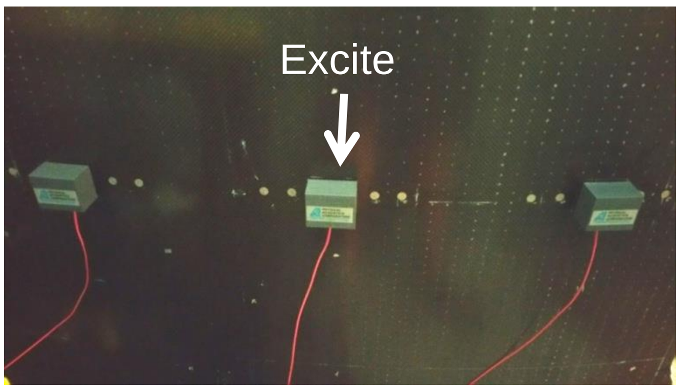
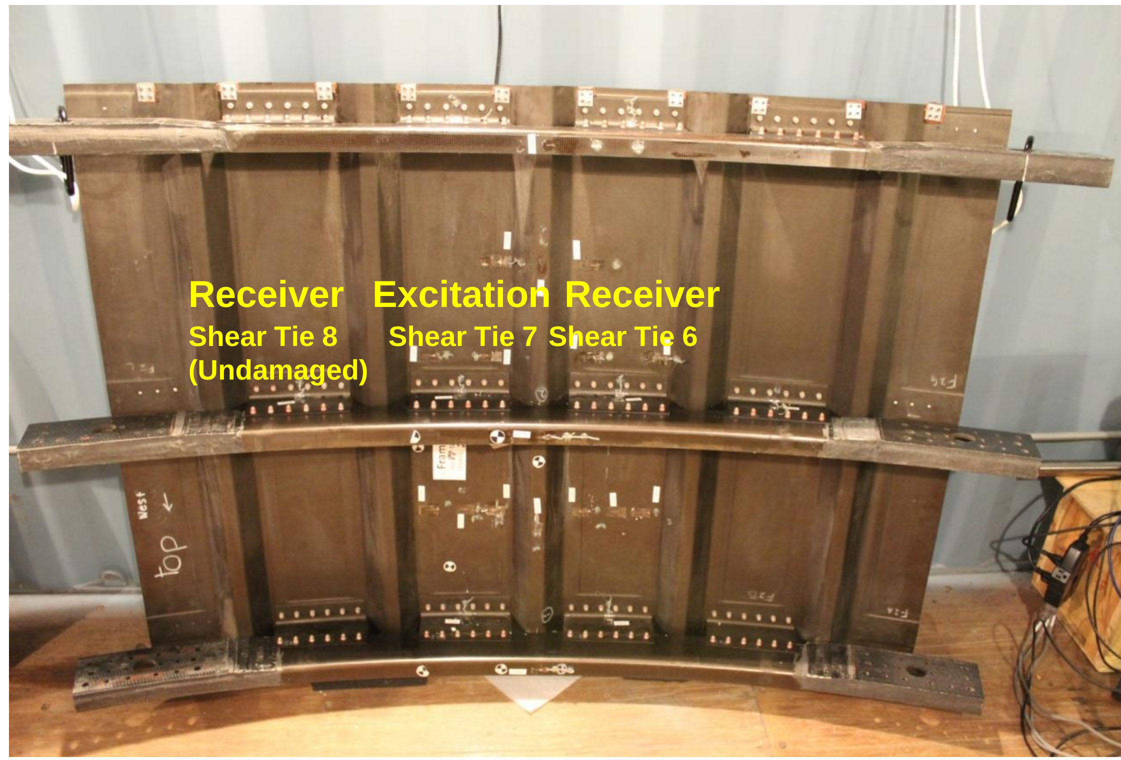
- **GUW Test on C-frame02 Section:**
  - **Skin to Skin (Damaged Path through ST06 vs. Undamaged Path through ST08)**

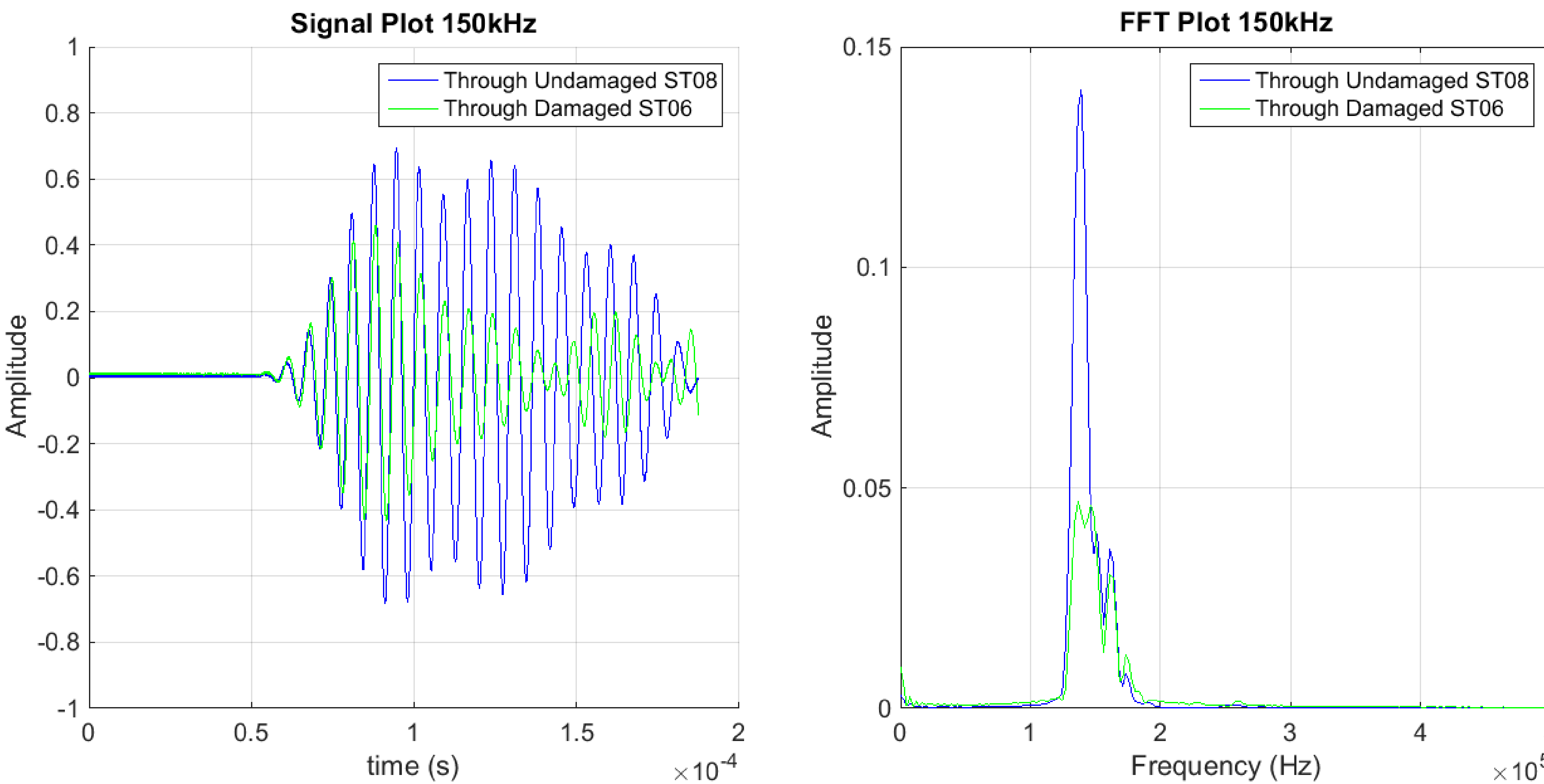
Skin-Side View





Frame02 Panel Experiment

- **GUW test result: 150kHz Excitation**
  - **Excited from ST07 Skin to ST08 Skin and ST06 Skin**



Other Transmission Studies

Path: Through Skin vs. Into C-Frame

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- **Frame02 Panel: Skin vs C-frame**

Frame02 Panel Experiment

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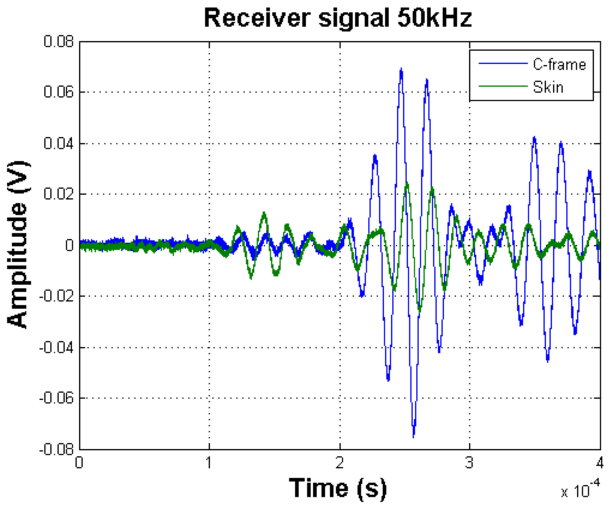
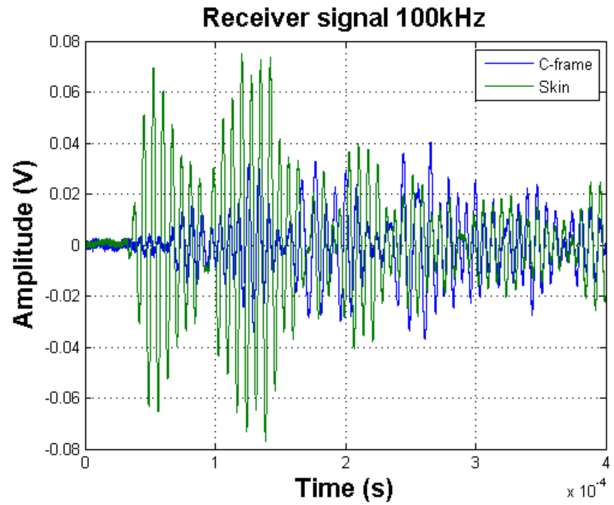
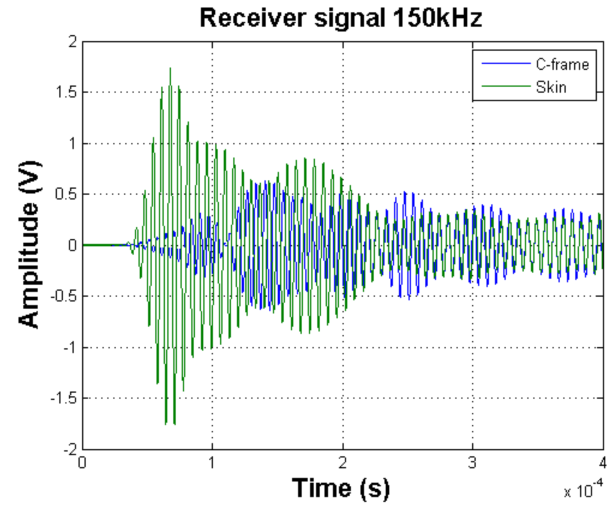
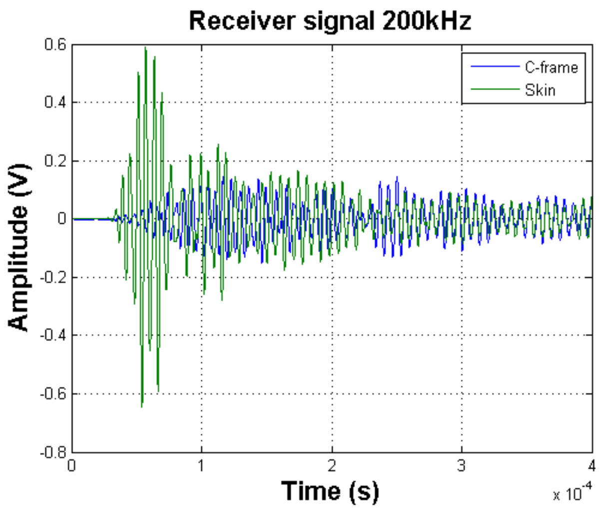
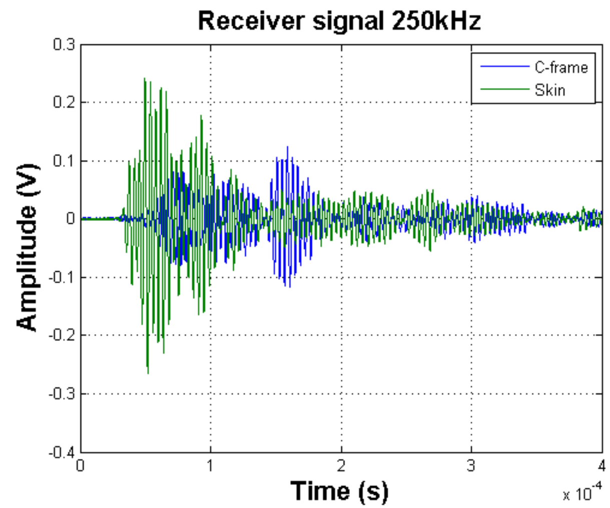
- **Frame02 Panel: Skin vs C-frame**











Transmission Through Bolted Joints

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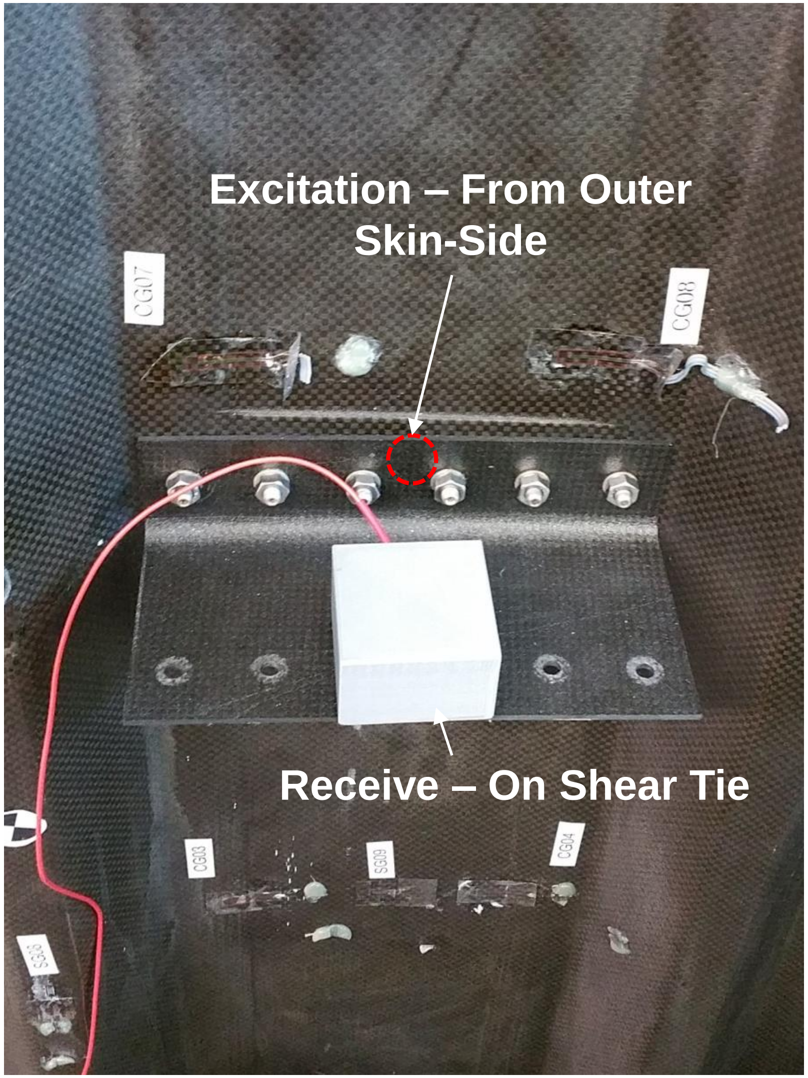
Bolt Torque Effect

- Wave is actuated from the exterior skin → received from shear tie at frame location
- Frequency sweep test performed from 50 – 250kHz with different torque levels:
  - » hand tight to 70 in-lbf
- From previous sensor tests, sensor transmits and receives predominantly:
  - » in-plane waves at 150kHz
  - » out-of-plane waves at 50kHz



Bolt Torque Differences

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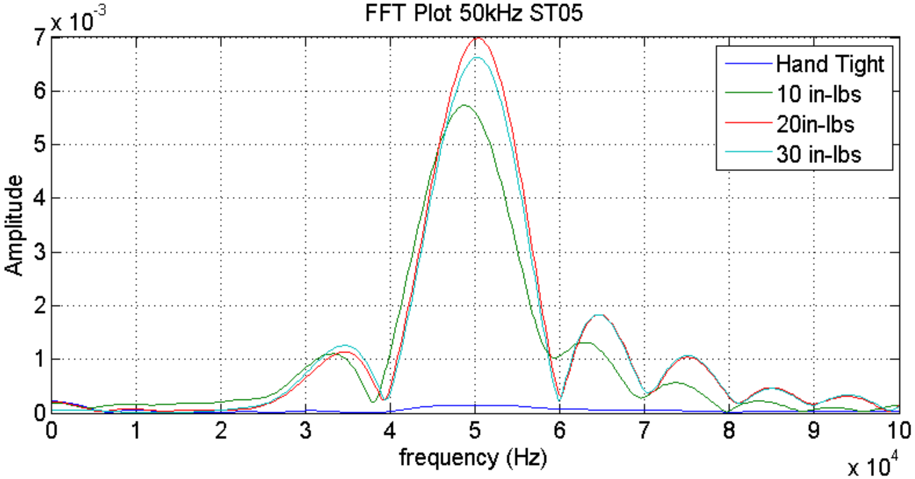
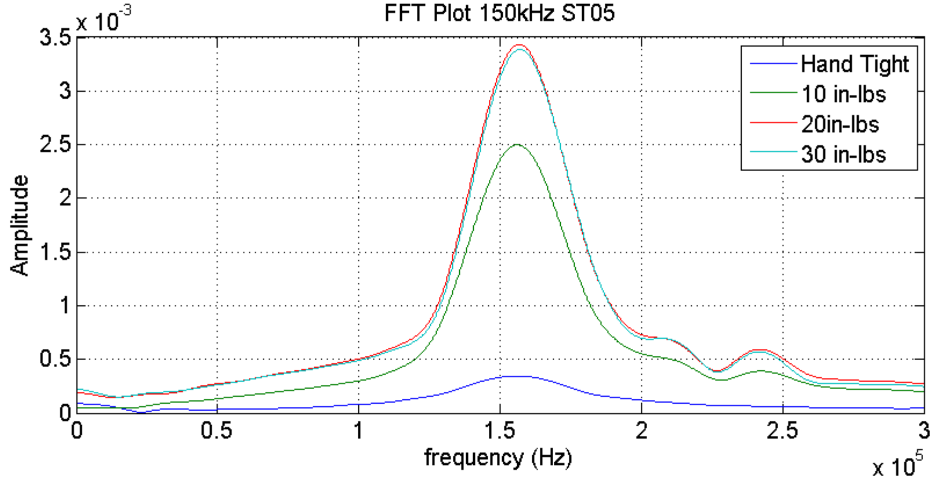
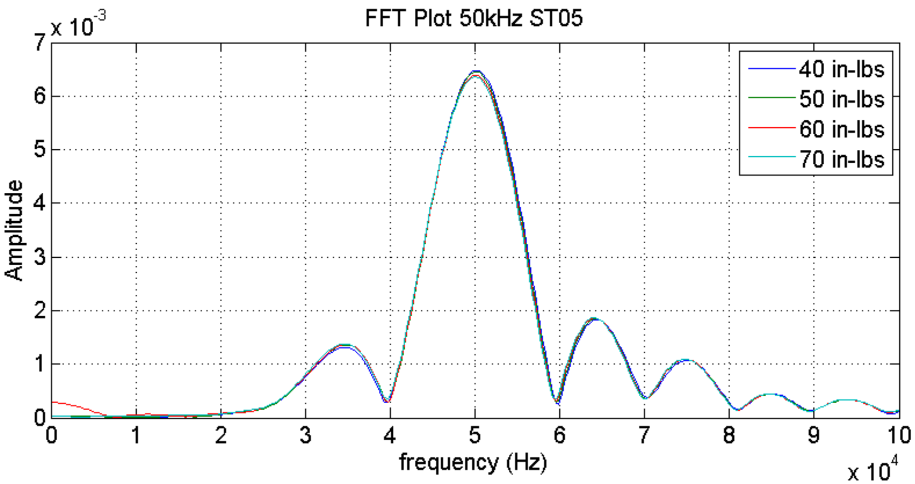
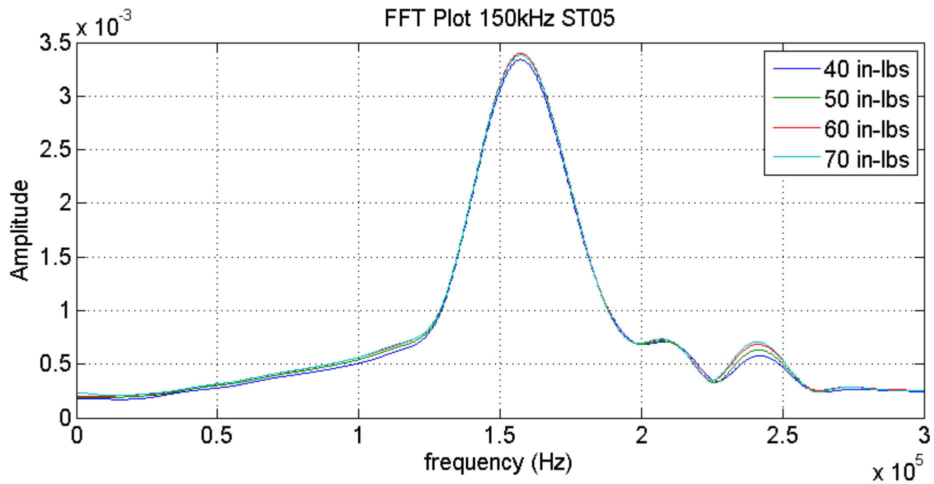
50 kHz | **150 kHz**









Peak transmission at 20 in-lbs
No change from 40 to 70 in-lbs

No change from 20 to 70 in-lbs

Bolt Torque Differences

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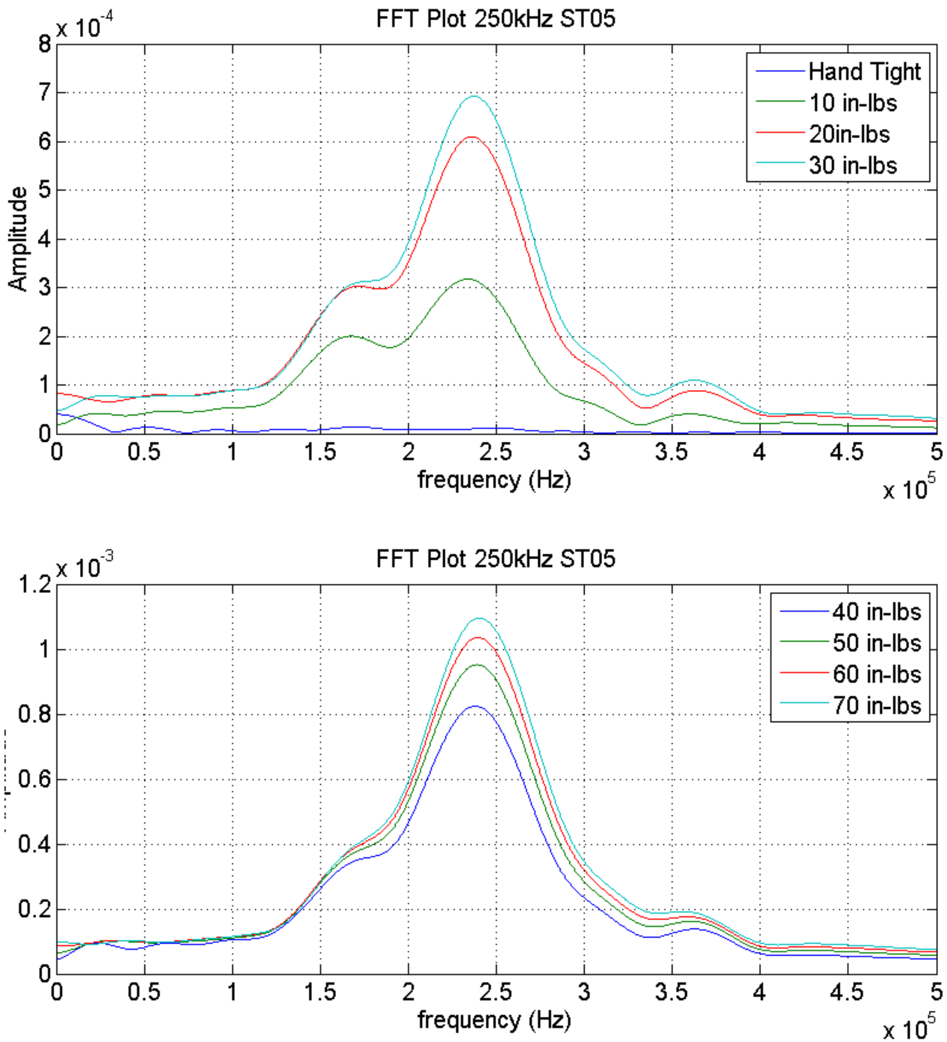
250 kHz



Continually increasing with higher torque (up to 70 in-lbs)

Bolt Torque Summary:

- At 50 kHz, non-monotonic behavior, with peak transmission at 20in-lbs
- At 150 kHz, no strong dependency on bolt torque above 20 in-lbs
  - assumed to be from sensor's in-plane dominant sensitivity at 150 kHz
- At 250 kHz, increasing bolt torque from 20 to 70in-lbs shows almost linearly-increasing wave energy transmission
- **Transmission sensitive to toque, frequency and sensor**

Summary

- Proposed methodology found capable of detecting major damage in frame
  - guided wave tests showed significant acoustic wave attenuation for cracked frame & shear ties
- External-side measurements able to find damage
  - many issues: frequency selection, effects of joints, repeatable coupling quality

- Current/future activity
  - advanced signal processing algorithms
    - multiple features used to form statistics-based damage detection criteria
    - demonstrated to work well for skin-adjacent damage
  - need to build stronger foundational understanding of response – especially in order to relate measurements with damage information (damage mode, size estimate)

Acknowledgement: research conducted via funding from FAA JAMS CoE (Joint Advanced Materials Center of Excellence), Program Manager David Westlund. Also thanks to Rusty Jones and Larry Ilcewicz of FAA.