Composite Nondestructive Evaluation Sciences Branch Research at NASA Langley

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NASA Langley Technical Interchange Meeting with University Of Texas at Arlington

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Outline

- Introduction of the Nondestructive Evaluation Sciences Branch
- Joint Work with Center for National Research Council (CNRC) Canada for Composite Bond Strength NDE
- Bond Strength Assessment using Phased Based Ultrasonic Measurements

Nondestructive Evaluation Sciences Branch at NASA

- 24 Full-Time Personnel
  - 18 Civil Servants
  - 6 Support Contractors
    - Technician, IT and Admin Support
- Extensive Skill Mix
  - 10 PhD's
  - 41% Physicist
  - 26% Engineers
  - 22% Technicians
  - 11% Other

- NDE Research Laboratory
  - Thermal Imaging
  - Ultrasonic Scanning
  - Phased-Array Ultrasound
  - Electromagnetics
  - Computed X-Ray Tomography
  - Photo & Thermal Elasticity
  - Scanning Electron Microscopy
  - Terahertz Imaging
  - Fiber Optic Sensors Fab.
  - Nano & Mems Sensor Fab
  - Raman Spectroscopy

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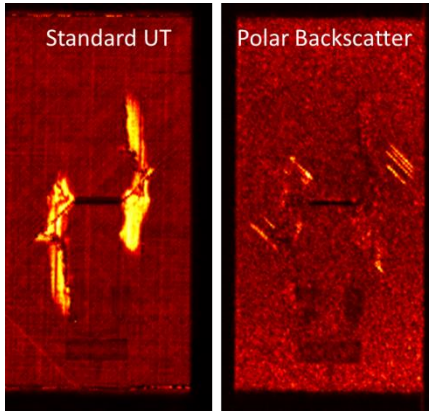
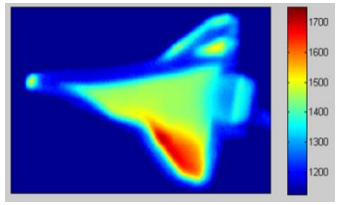
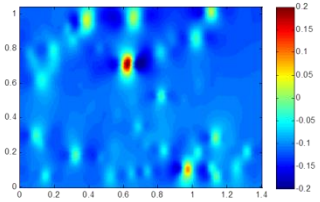
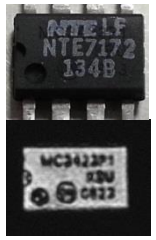
The Nondestructive Evaluation Sciences Branch continues to be the only branch level organization for nondestructive evaluation research within NASA. It is 1 of 2 within the Federal Government.

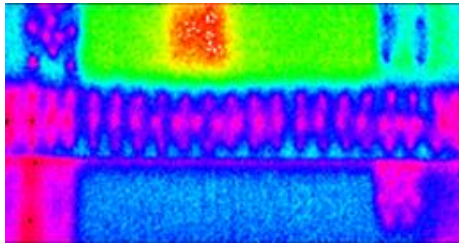
NDE Inspection Capabilities

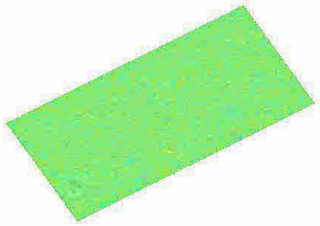








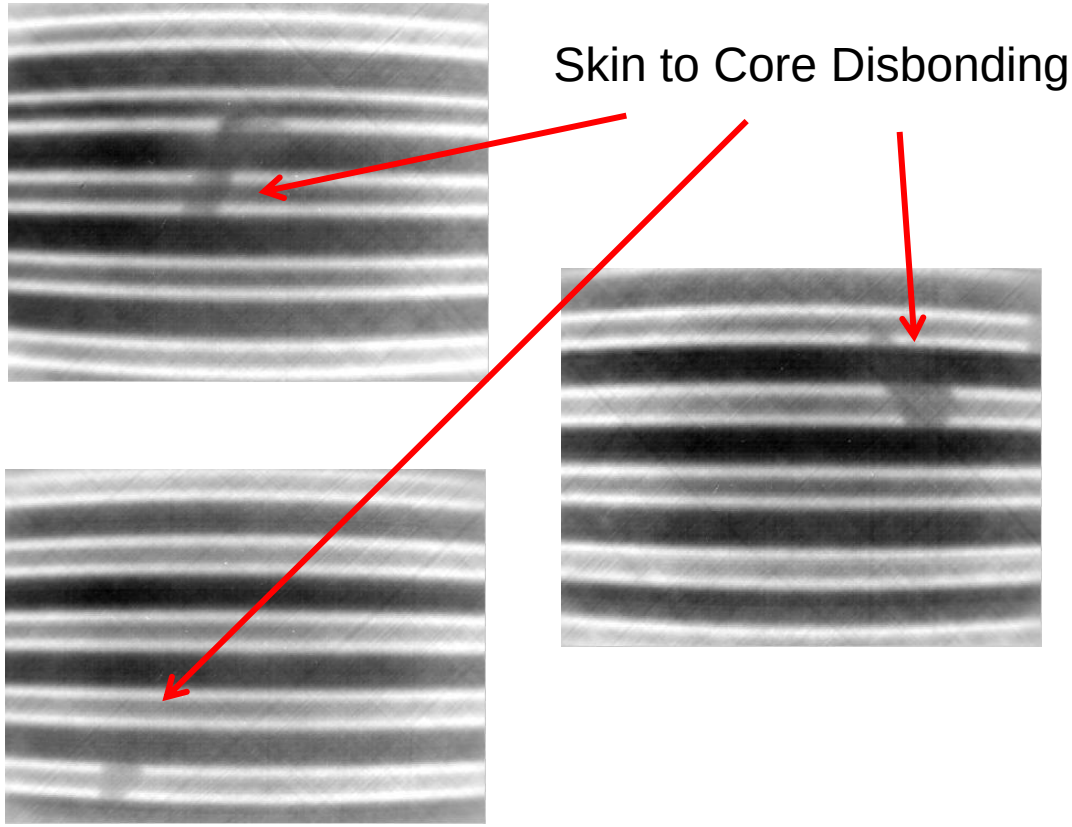




- Thermal Imaging
  - Flash, step, scanning, passive, vibro, etc.
- Ultrasonic
  - Immersion, nonimmersion, air coupled, etc.
  - Phased-Array Ultrasound
  - Nonlinear Ultrasound
- Electromagnetics (Eddy Current)
- Digital Radiography
- Computed X-Ray Tomography
  - Microfocus to <5µm resolution
  - 7 Foot working envelope
- Backscatter x-ray
- Photo & Thermal Elasticity
- Scanning Electron Microscopy
- Terahertz Imaging
- Raman Spectroscopy

Large Area NDE





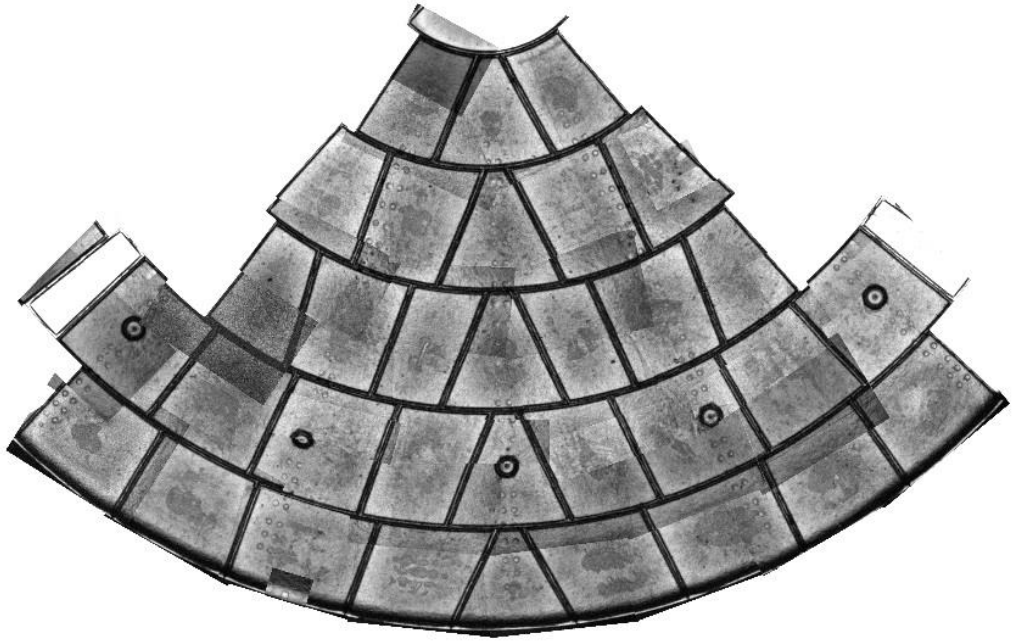
Composite Cylinder ~33 ft. Dia

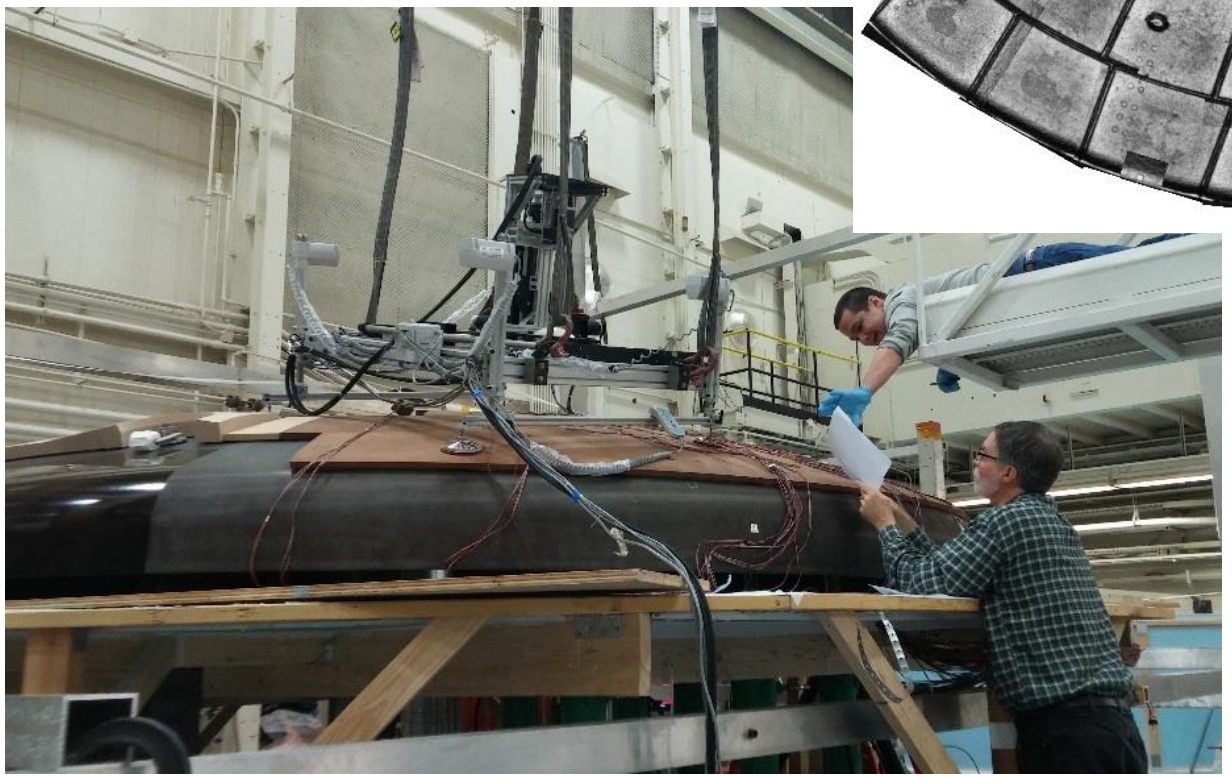


- Multiple technologies
  - Ultrasound, Thermography, Terahertz,and Eddy Current
- High speed inspection
  - 10-12 in. / sec.
- Rapid data reduction
  - GPU optimized analysis
  - Automated defect recognition
  - Material characterization

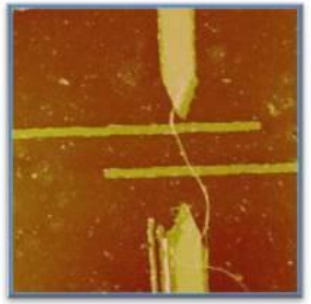
NDE of Unique Material Systems

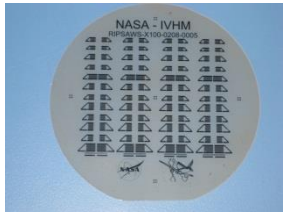
ORION Heat Shield
Manufacturing
Demonstration Unit

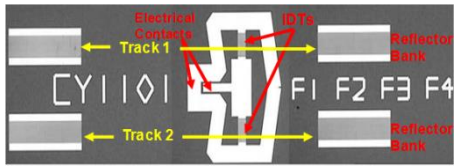


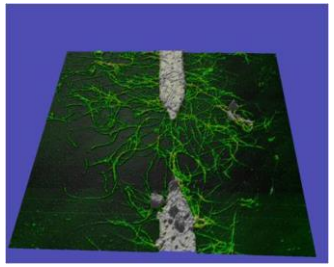


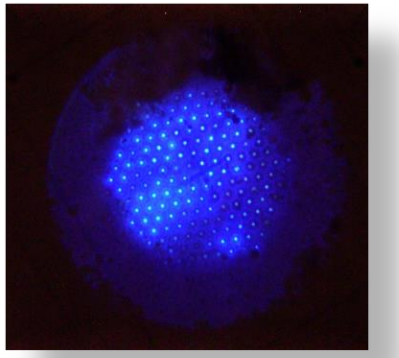
Structural Health Monitoring (SHM) Capabilities (*insitu* NDE)





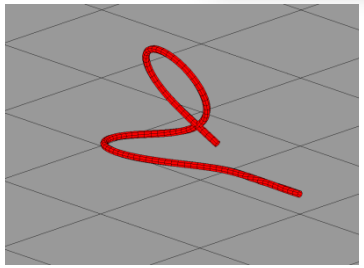


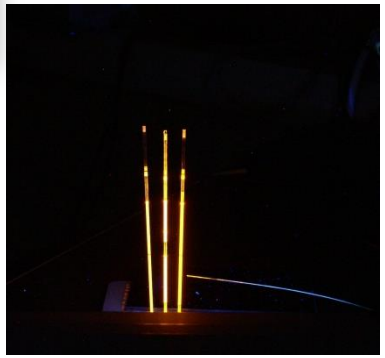


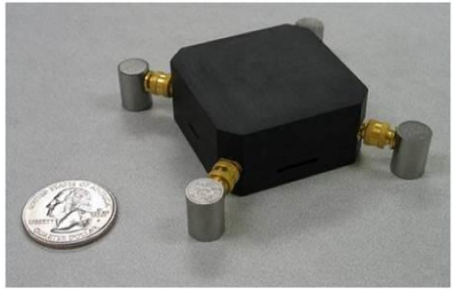


- Acoustic Emission
- Fiber Optic
  - Strain, Temperature, Shape, and acoustic sensing
  - XRay detection
- MEMs Surface Acoustic Sensors
  - Strain, Temperature, Impact, Lightening strike, etc.
  - Wireless, Passive or Active
- Carbon Nanotube Sensors
  - Strain, Temperature









Composites NDE Handbook

Title: Development of an NDE Methods and Capabilities Handbook
Objective: Assemble appendices of NDE Methods and Capabilities Handbook.
Approach: Appendices contain detailed information regarding the purpose of the Handbook, its scope and limitations, fabrication of standards and round-robin testing completion. Results from Appendix E will be rolled up into main body of report.

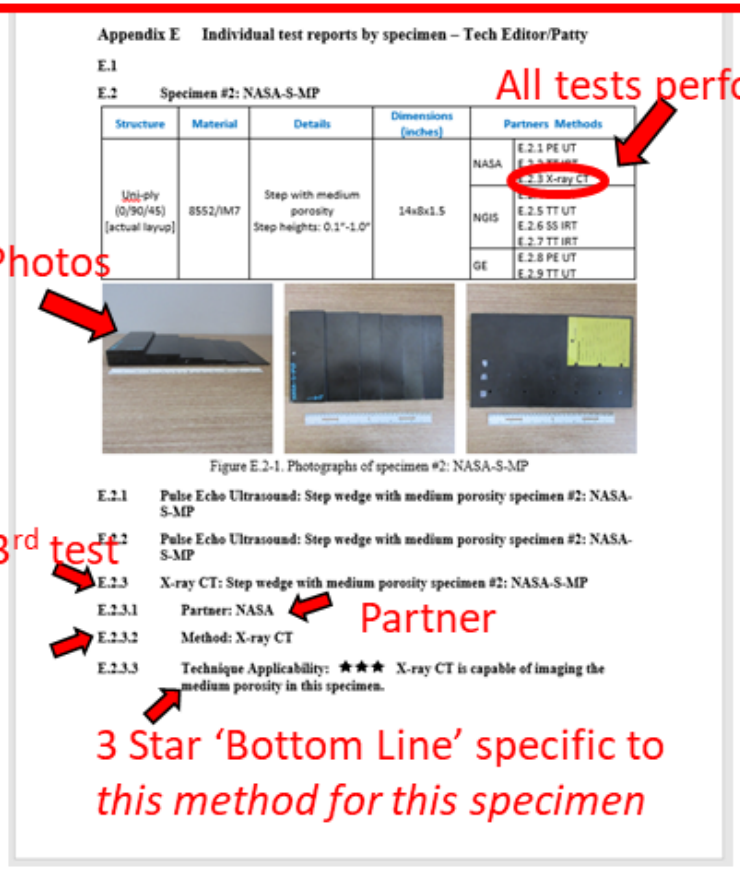
- A. State of Practice Survey Report
- B. Overview of Standards: List of standards, Test Matrix, Photos and Descriptions – Listed by Defect Type
- C. Manufacturing documents
- D. Validation reports from IDIQ
- E. Individual test reports by specimen

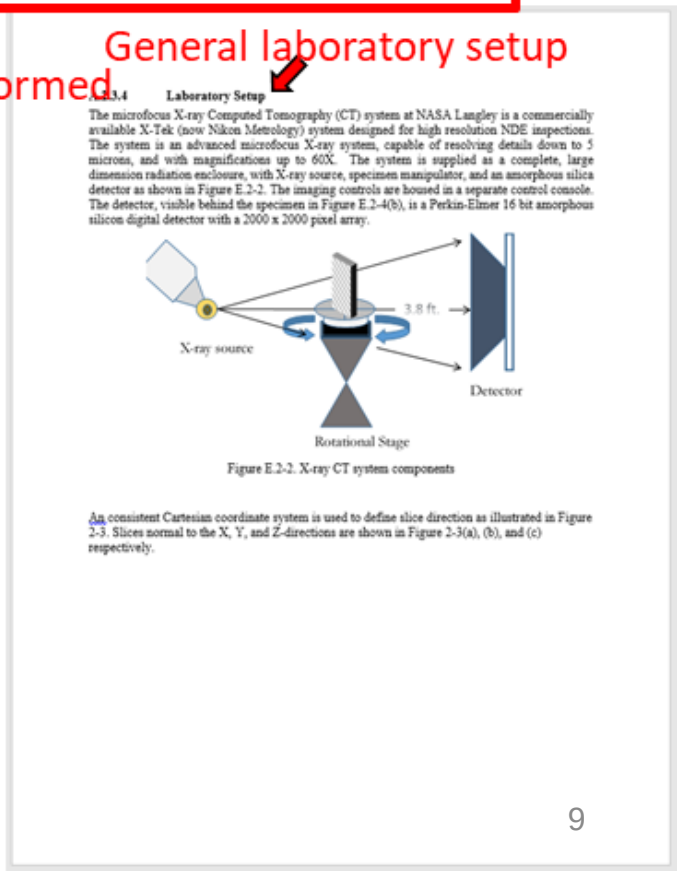
Deliverables

- Handbook Publication: NASA TM-2020-220568
- NDE Standards Samples Available
- Digital Data Record of Preprocessed Inspection Data
- Acceptance by Industry and within the "Composites Materials Handbook-17.

Significance: The Handbook will reduce the time required to develop qualified inspection processes for composite aircraft structures during the development, certification, and manufacturing phases by providing a reference that helps minimize trial and error and provides guidance on best practices, techniques, and settings, for specific flaw types and geometries.

Stand-alone reports for each specimen by each technique by each partner





Planned Joint Work with Center for National Research Council (CNRC) Canada

- Five year effort
  - Scheduled for approval around end of 2021
- Joint work with CNRC for bond strength NDE
- Bond Strength Assessment using Phased Based Ultrasonic Measurements
  - Demonstrated on glass adherents
- Metal adherents will be used initially
  - Statistical methods will be used to determine bond strength given measurement noise and other parameters (surface roughness, material property variation, etc.)
- Goal is to demonstrate technology on composite adherents

Ultrasonic, Phased-Based NDE of Bond Strength

- Ultrasound inspection technique measures phase-shift due to variation in bond line properties
- Phase-based technique sensitive to sub-wavelength variations in stiffness
- Proof of concept completed on ideal system (optically flat adherends, controlled laboratory environment)
  - Demonstrated detection of weak bonds due to minute contamination
  - Demonstrated measurement of adhesive stiffness with degree of cure
- Efforts under TTT to implement technique on composite substrates

Ultrasonic Phased-Based NDE of Bond Strength-Introduction

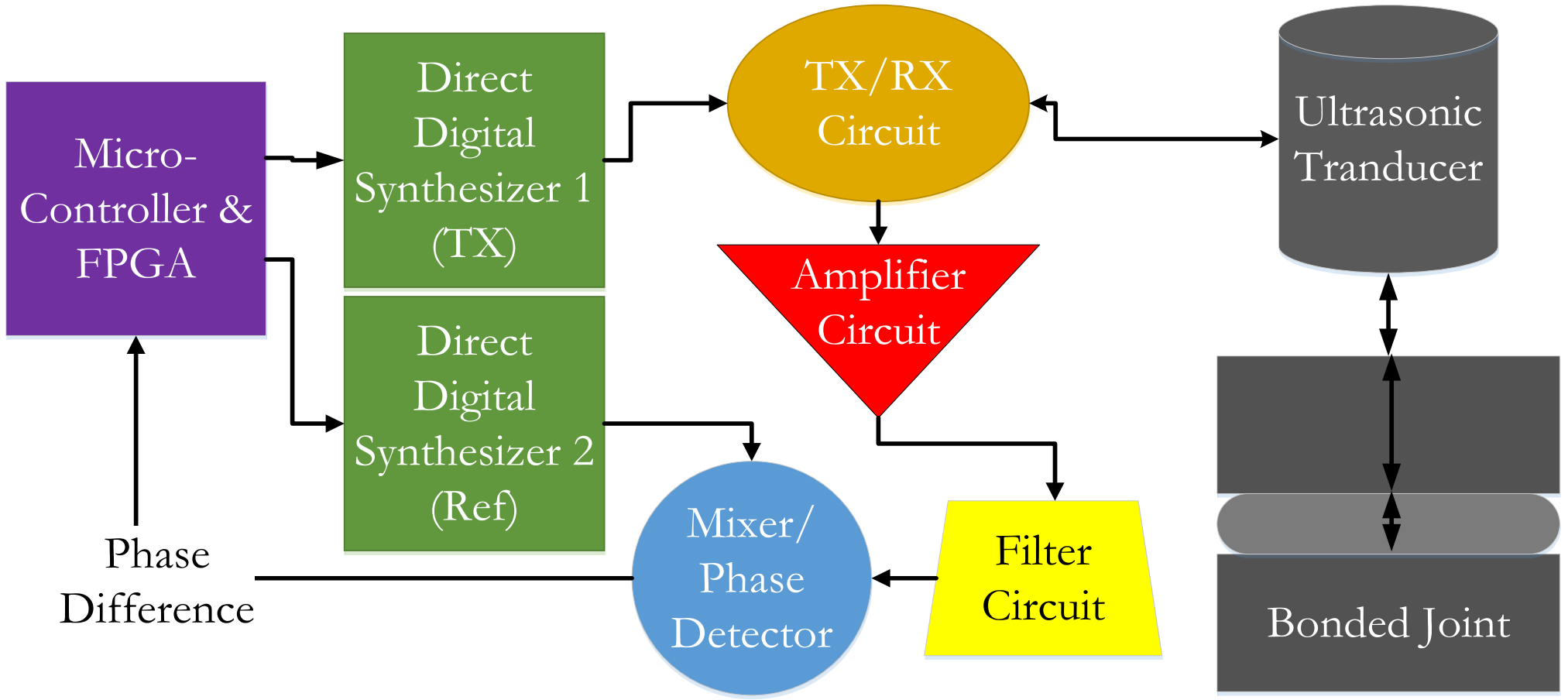
Problem

- Next-gen. composites rely on adhesive bonding
- Conventional NDE only IDs major bonding problems
- No widely-adopted NDE for interfacial bond strength and detecting "kissing bonds"
- Bond strength ensured by process control and destructive testing

Objective

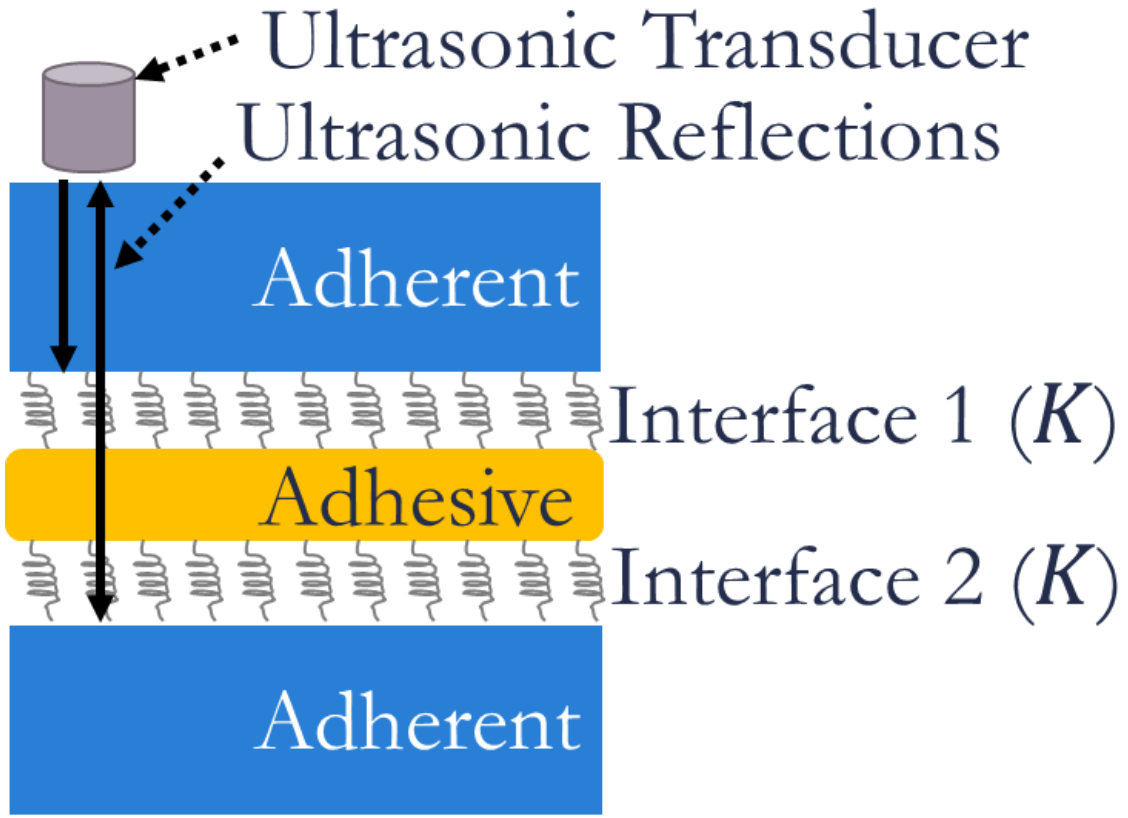
- Investigate swept-frequency ultrasonic phase measurements of bondline reflections for the ability to measure interfacial bond strength
- Observe how changes in interfacial stiffness affect phase response near ultrasonic resonance of bondline

Constant Frequency Pulsed Phase-Locked Loop Ultrasonic Phase Measurement Method



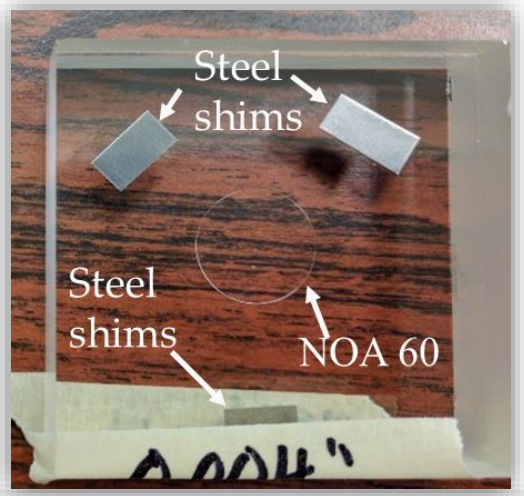
Theory of Ultrasonic Interaction with Imperfectly Bonded Interfaces

- Imperfect interfaces modeled by distributed spring system
- Previous work has shown linear relationship between K and bond strength
- Model developed J. Cantrel 2015 and 2018.
- Curve fit of model to data to obtain interfacial stiffnesses.
- Haldren et al. "Swept-frequency Ultrasonic Phase Evaluation of Adhesive Bonding in Tri-layer Structures" second place in the 2020 H.J.E. Reid award competition.
- Recently retired NASA expert retained under DRA 2021.



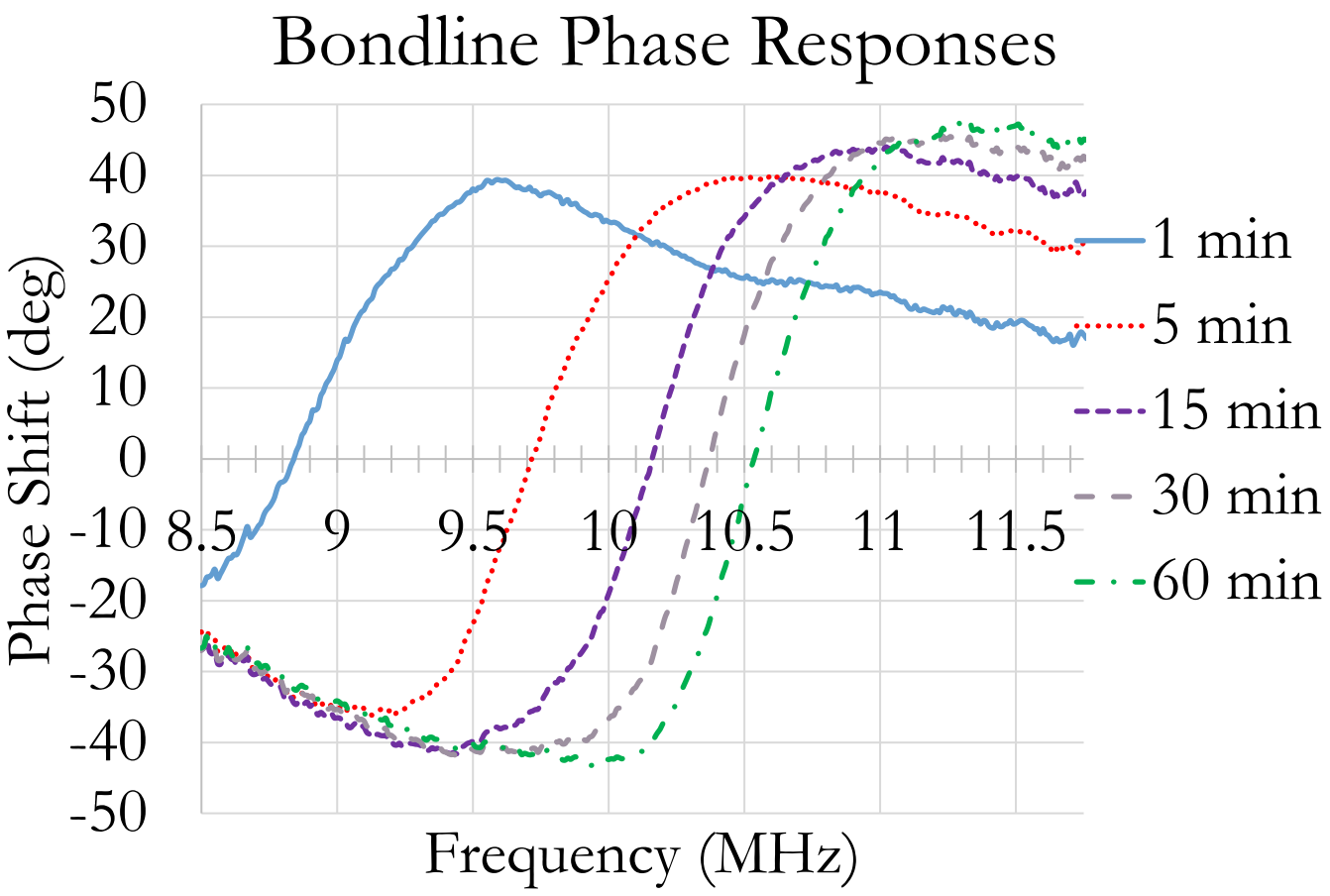
Experimental Setup

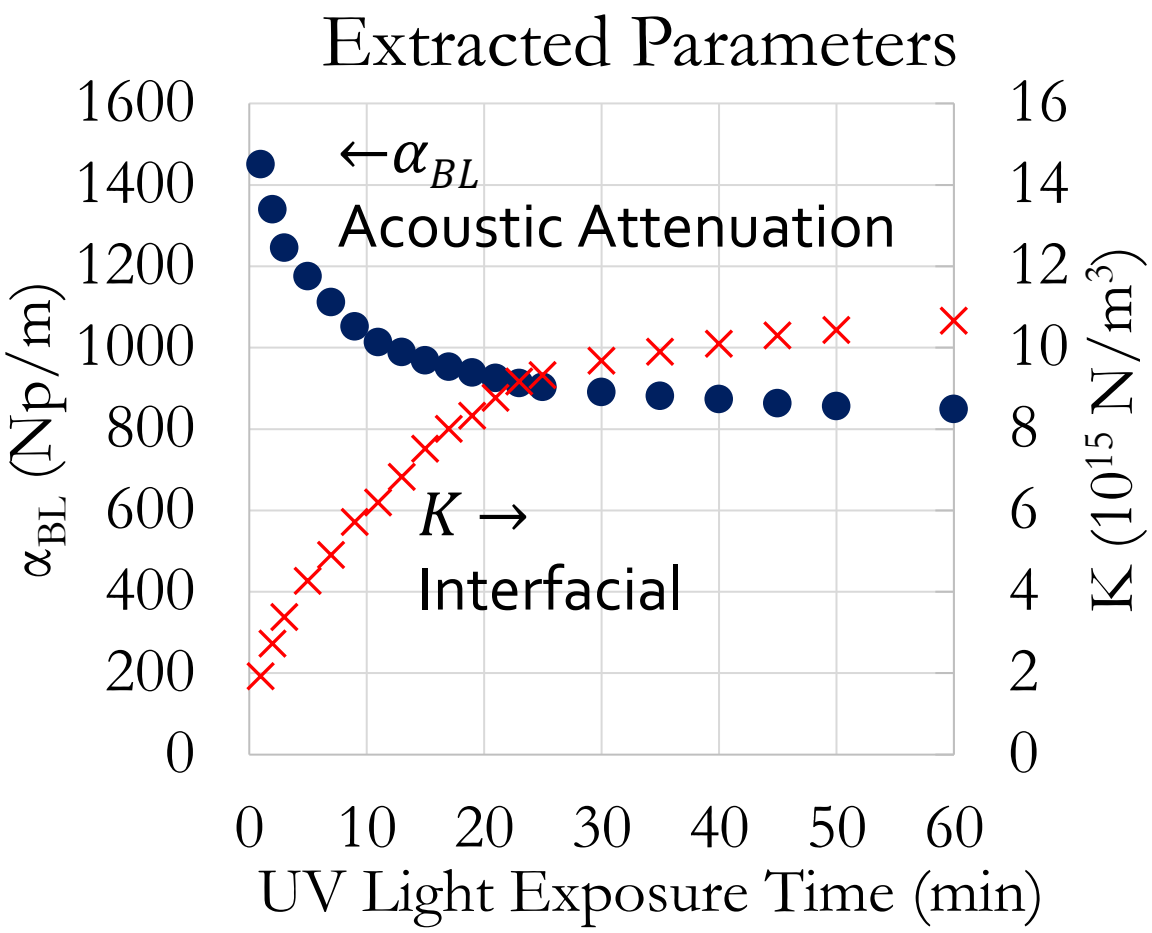
- ~11mm thick Borofloat glass bonded with UV-curable Norland Optical Adhesive (NOA) 60 with varying UV exposure times
- Steel shims used to maintain bondline thickness
- Measured $\phi(f)$ near ultrasonic resonance ($L_{BL} = \lambda_{adh}/2$)
- Extracted interfacial stiffness and adhesive attenuation via curve-fitting with model
- Two studies:
  1. In-situ ultrasonic phase measurements during cure
  2. Post-cure ultrasonic phase and mechanical strength measurements



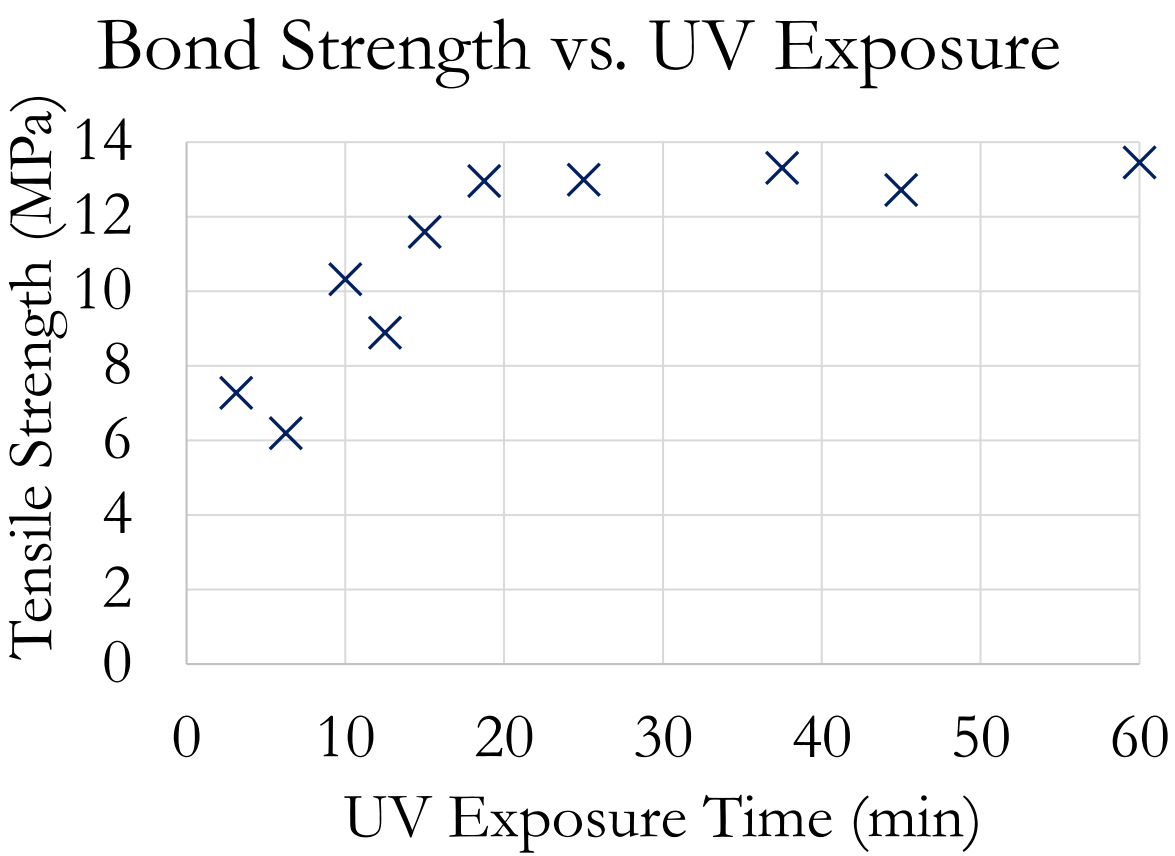


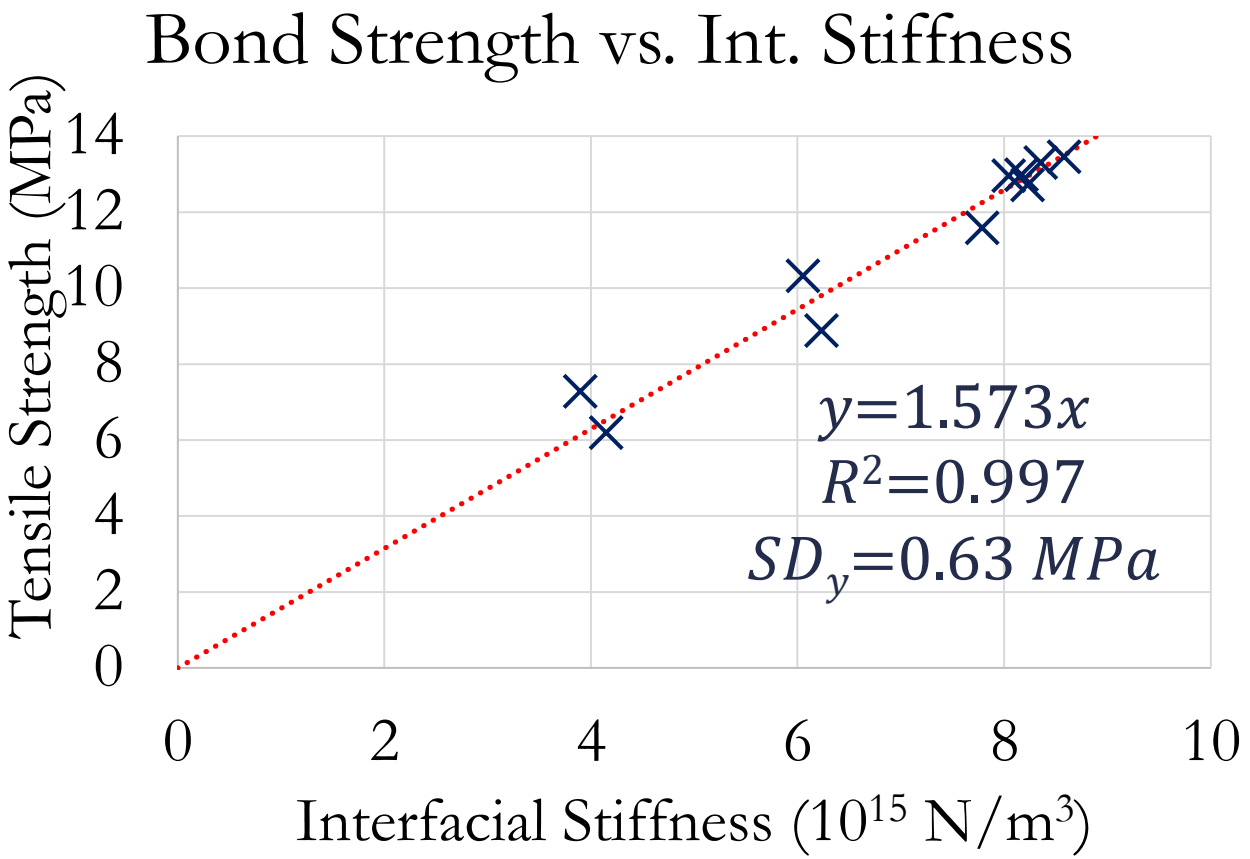
In-Situ Phase Monitoring Results





Post-Cure Phase Measurement Results





Summary

- Swept-frequency ultrasonic phase measurements used to analyze resonance response of glass/UV-curable adhesive SLJs
  - Quantitative measurement of interfacial stiffness
  - Sensitive to reduced interfacial bond strength
  - Interfacial stiffness linearly related to bond strength with $SD_y = 0.63\ MPa$
- Future investigations on real-world joints and "kissing bond" detection
- Compatible with commercial ultrasonic transducers and conventional inspection setups
- Promotes the use of advanced composite structures in aerospace and automotive designs