Sensor Systems and NDE Technology Section

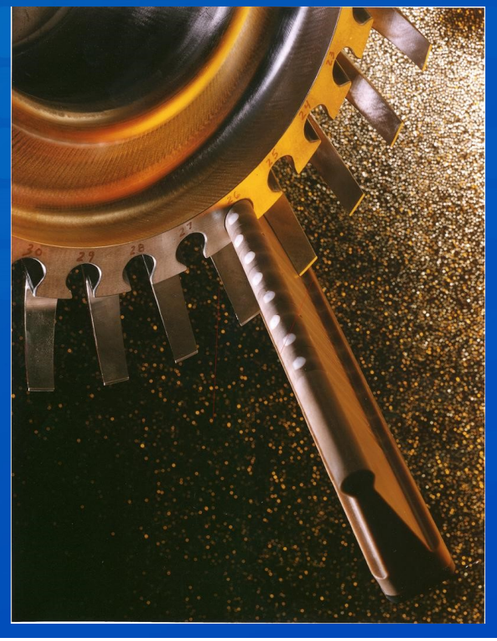
January 2017

Sensor System and NDE Technology Section Staff and Project Breakdown

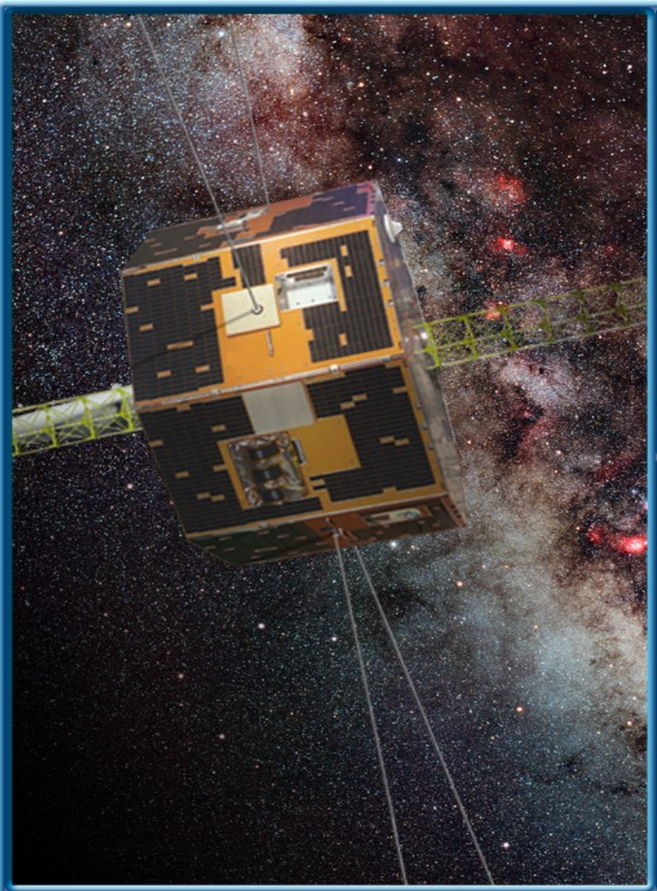
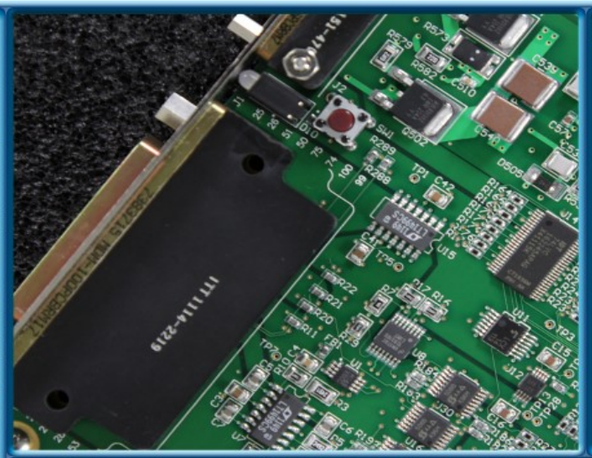
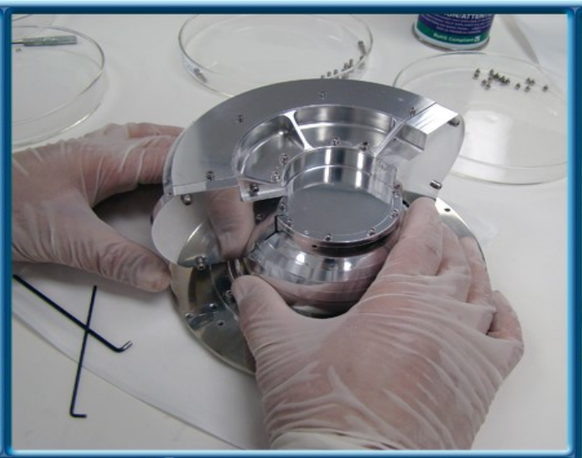
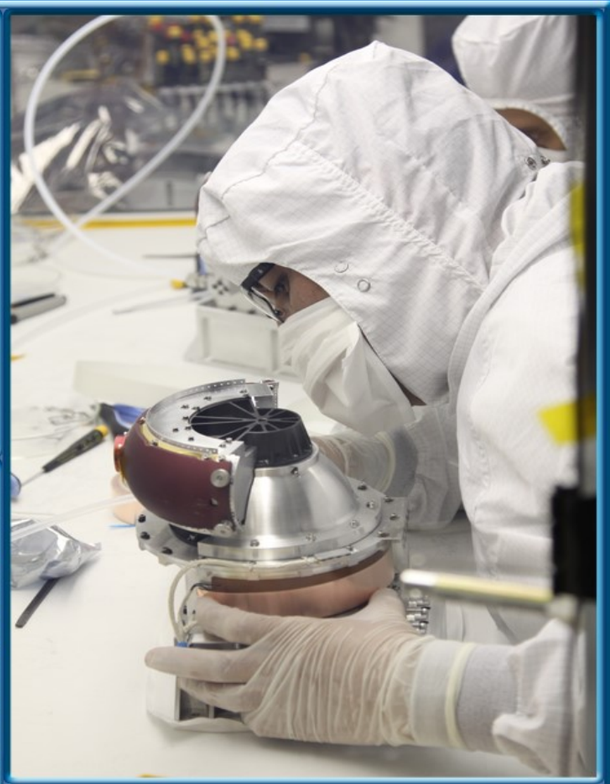
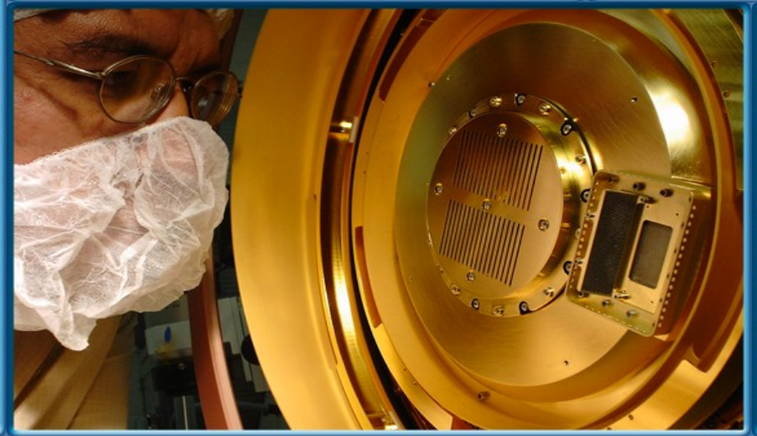
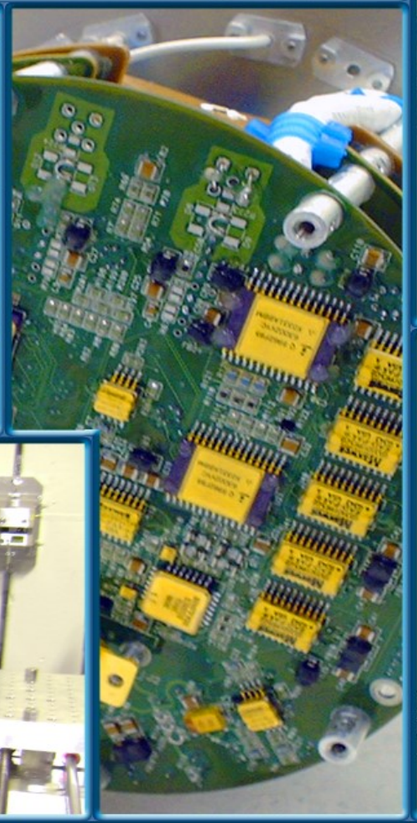
- Total staff – 17
  - 16 hold technical degrees (EE, ME, and physics)
  - 5 with Ph.D.
- Projects typically in one of three areas
  - NDE technology / inspection services – short duration
  - Development services – specialized procedures or system development
  - On-going research programs
- Project make-up
  - Predominately commercial (domestic and international) – 70%
  - Primary industries are Oil and Gas, Nuclear Power, and Aerospace

Sensor Systems and NDE Technology Department

Developing sensors, techniques, systems software, and instrumentation for nondestructively evaluating materials, components, and processes to measure or monitor their quality and/or readiness for service.

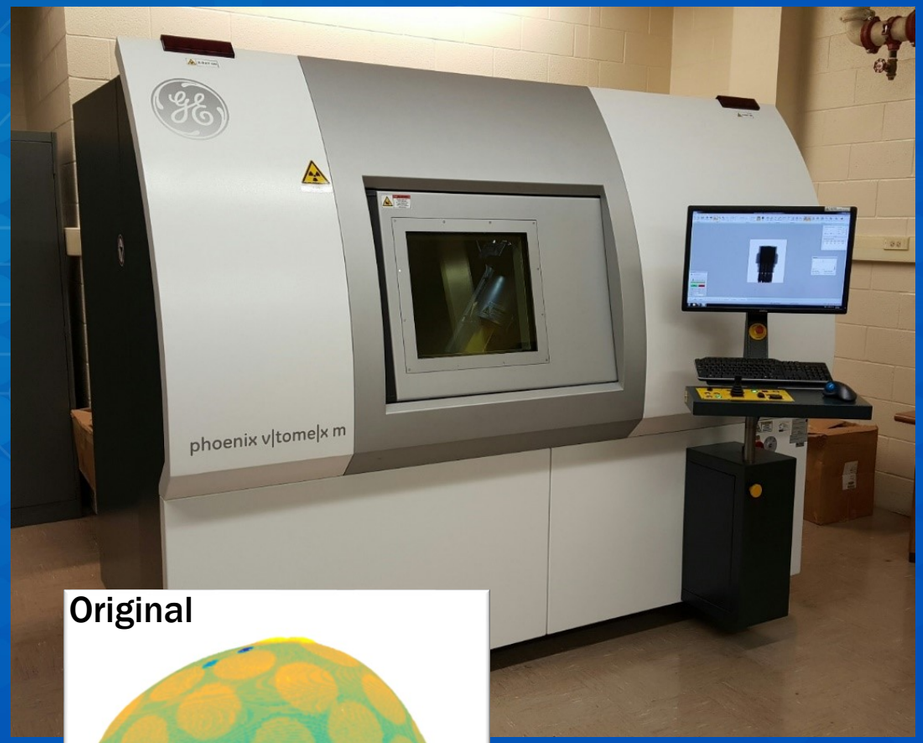


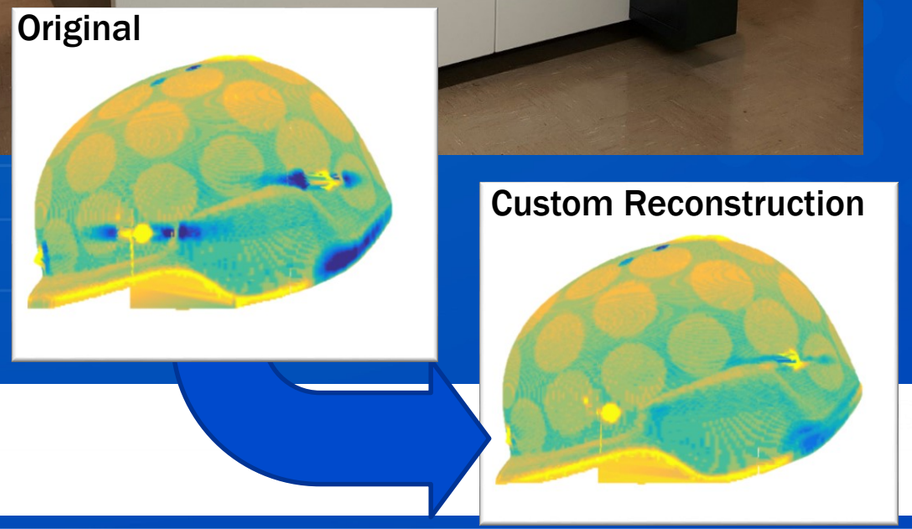
Space-Qualified Inst Hardware Fab and Test


Industrial X-ray Computed Tomography (CT)

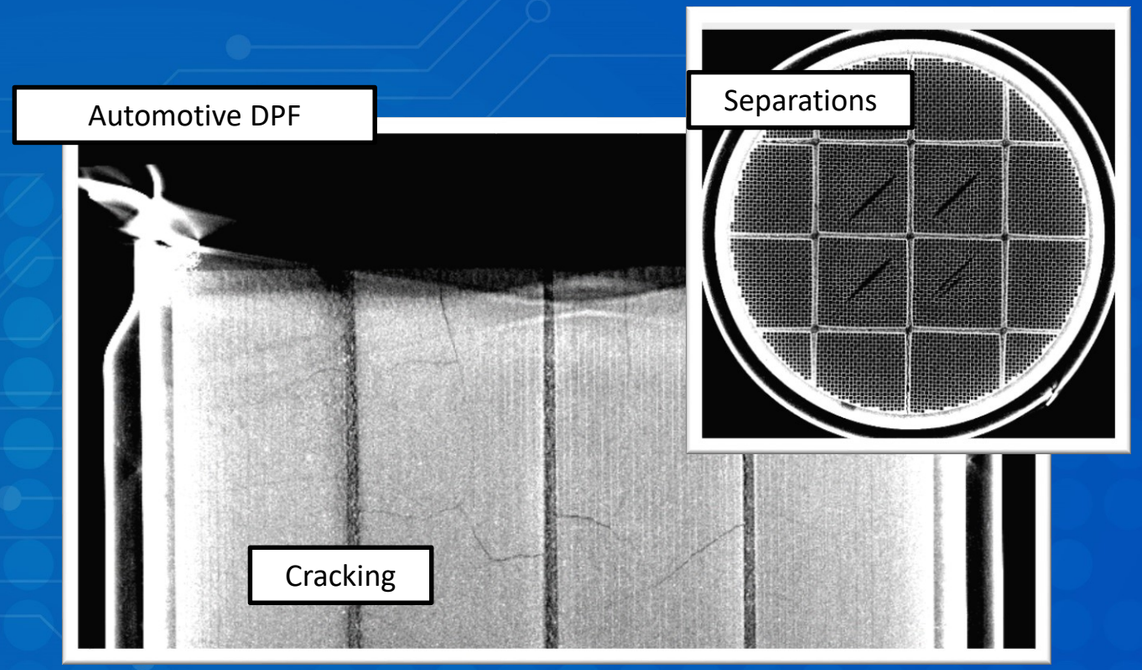
- Facility
  - GE Phoenix V|Tome|x m® – microfocus cone-beam system
  - Max tube voltage – 240kV
  - 16” x 16” detector with resolution of 2000 x 2000 pixels
  - Typical resolutions 10-100 micron/voxel
  - Samples up to 20” effect diameter, 31” height and weight of 110 lbs.
- Software
  - Volume Graphics® 3D visualization and Analysis software
  - Advanced reconstruction software developed by SwRI for improved

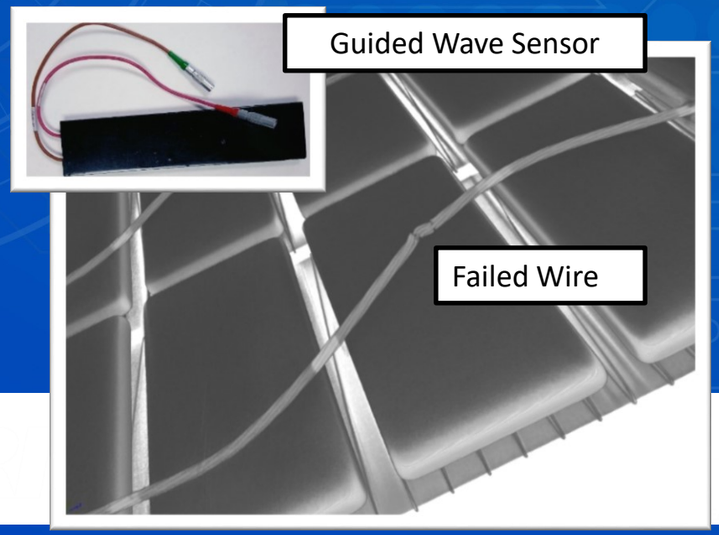


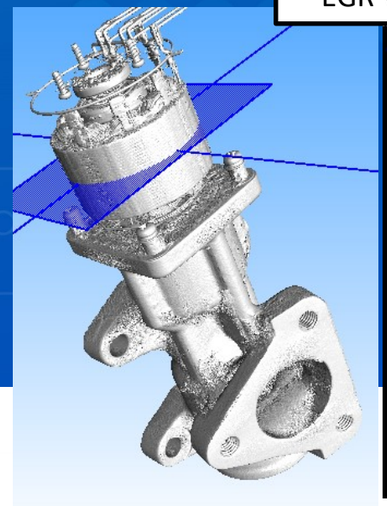


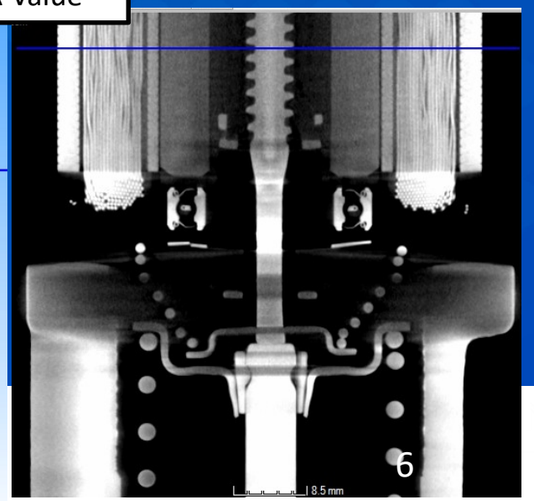
Example CT Applications

- Failure Analysis
- Metrology
- Reverse Engineering
- Computer Model Input
- Verification / Validation
  - Additive Manufacturing
  - Part-to-CAD comparison
  - Assembly Analysis









SOUTHWEST RESEARCH INSTITUTE

NASGRO®

Fracture Mechanics and Fatigue Crack Growth Analysis Software

What's New in:

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KEY TERMS:
NASGRO®
FLAGRO
life assessment
crack growth
fracture
mechanics
damage tolerance
structural integrity
analysis
materials
database
consortium
software
stress intensity
factor
boundary element
method
fracture control
critical crack size

NASGRO® is a suite of programs used to:

- Analyze fatigue crack growth and fracture
- Perform assessments of structural life
- Process and store fatigue crack growth properties
- Analyze fatigue crack formation (initiation)

NASGRO Version 8.1 was released on May 18, 2016.

NASGRO is licensable for a fee. Over 610 single-seat licenses to NASGRO have been obtained by a wide range of users from different industries.

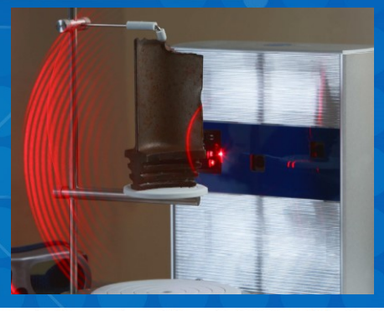
The materials database includes a large set of crack growth rate and fracture toughness data. The stress intensity factor library provides models for over 78 different crack geometries.

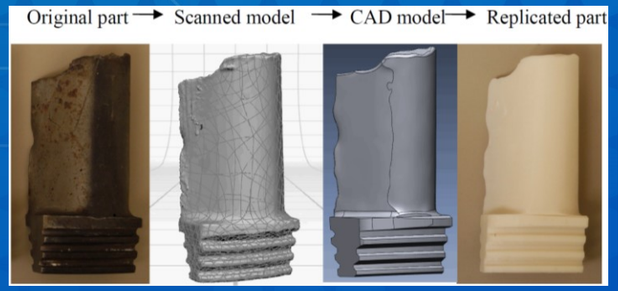
In 2003, NASGRO® Version 4.0 received the NASA Software of the Year Award and an R&D 100 Award from R&D Magazine as one of the 100 most technologically significant new products of the year.

NASGRO was originally developed at the NASA Johnson Space Center to perform fracture control analysis on NASA space systems. A growing interest in NASGRO among a variety of industrial users motivated NASA to develop a new partnership with industry. NASA and Southwest Research Institute® (SwRI®) have signed a Space Act Agreement under which SwRI formed and manages a consortium to provide guidance and support for future NASGRO development and user services. The NASGRO Consortium is now being organized for its sixth three-year cycle (2016–2019).

In-House AM Capabilities

- Additive Manufacturing: Stratasys 400mc FDM 3D Printer
  - Build material: ABS-M30
  - Build Size Footprint: 10”x14”x10”
  - Print Resolutions:
    - 0.005”
    - 0.007”
    - 0.010”
    - 0.013”
- Reverse Engineering
  - 3D Laser Scanning
  - Coordinate Measurement Machine (CMM)

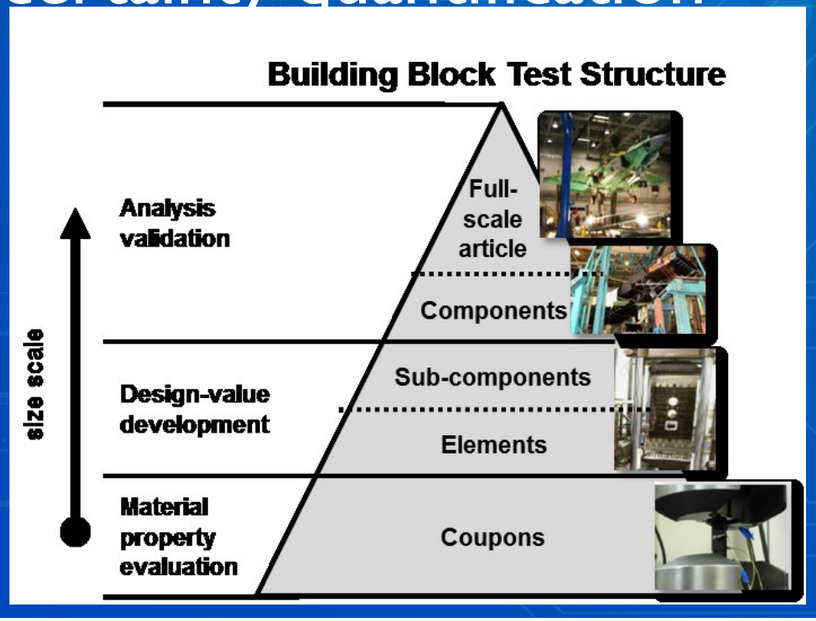


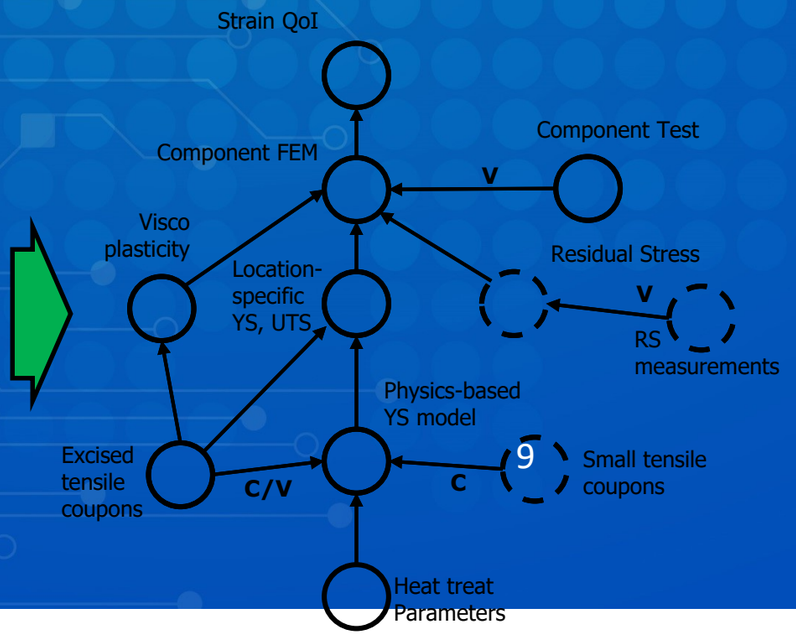


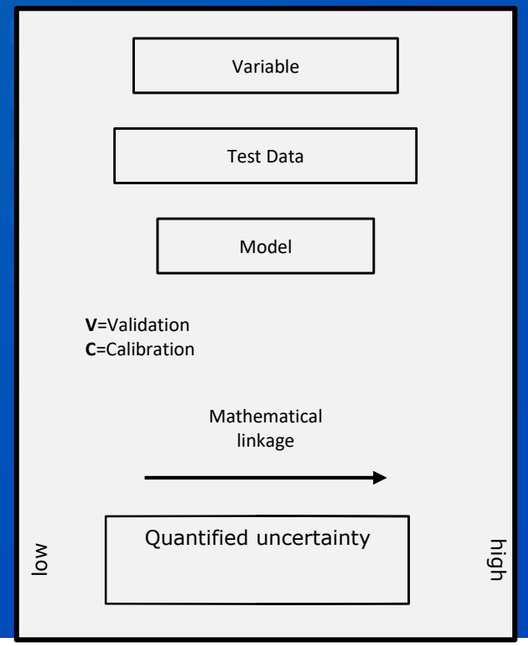
For more information contact David Jones at x3306 or djones@swri.org

A New Framework for Rapid Qualification

- The traditional building block approach to qualification was not designed for technologies like Additive Manufacturing where the part and material are made simultaneously
- As part of the DARPA Open Manufacturing program, SwRI is developing a new framework for qualification that relies on computational tools and rigorous uncertainty quantification



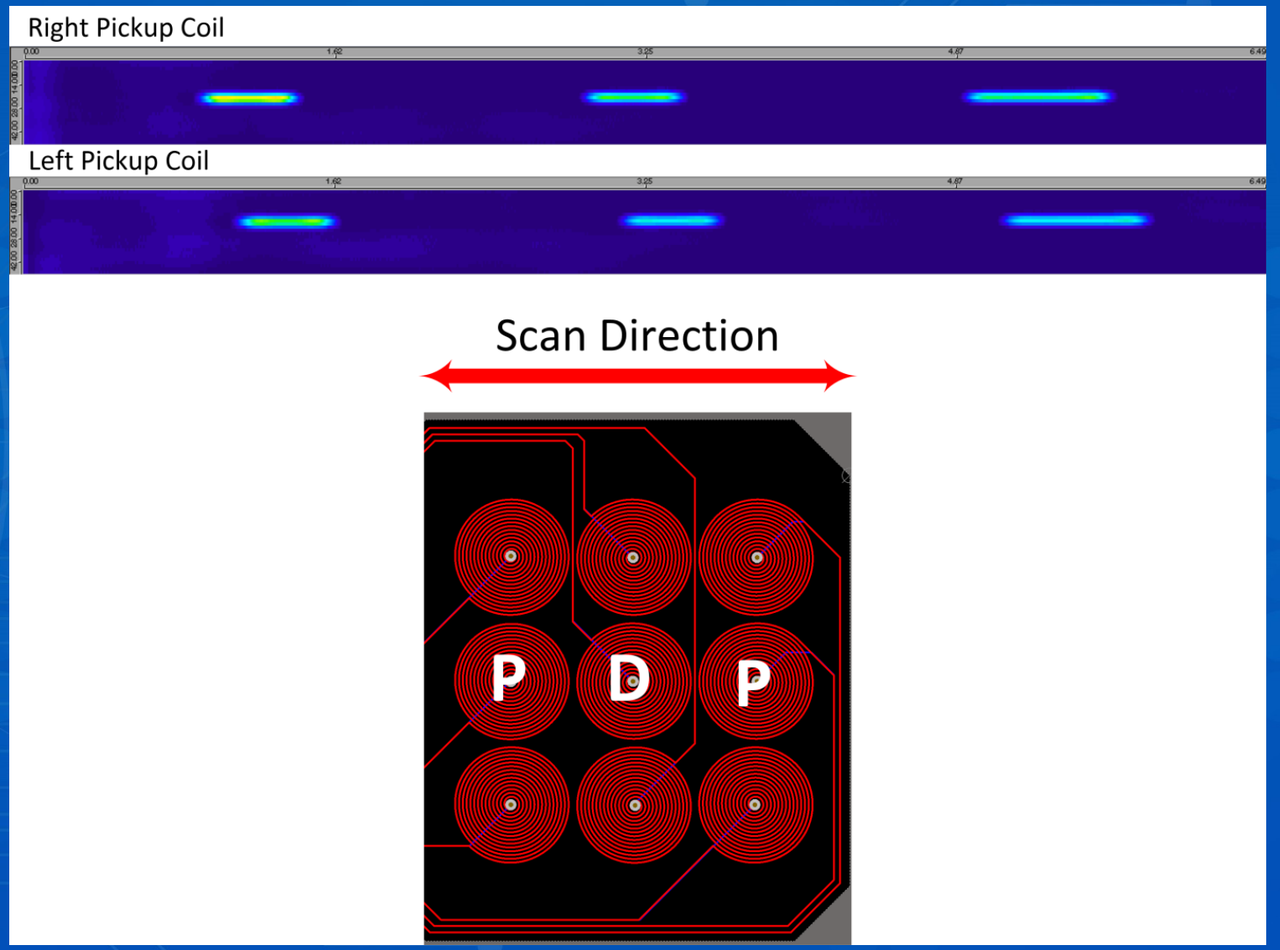




Flexible ECT Probe Array

- Flexible PCB technology
  - Consistent mechanical & electromagnetic properties
  - Flexible Kapton® polyimide substrate easily matches concave and convex surfaces minimizing liftoff effects
  - Low recurring manufacturing cost
- Low profile design allows insertion and inspection in regions of limited space

Original 3x3 Driver/Pick Array C-Scan

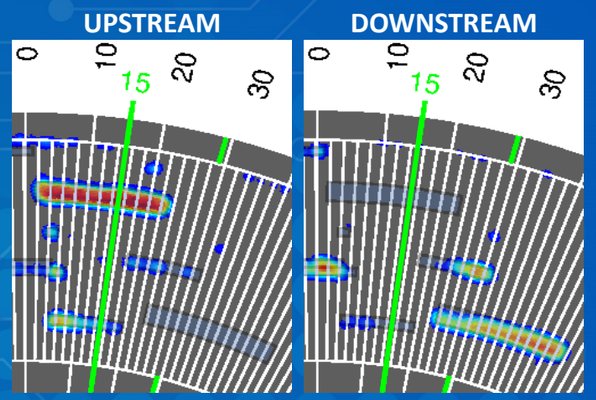


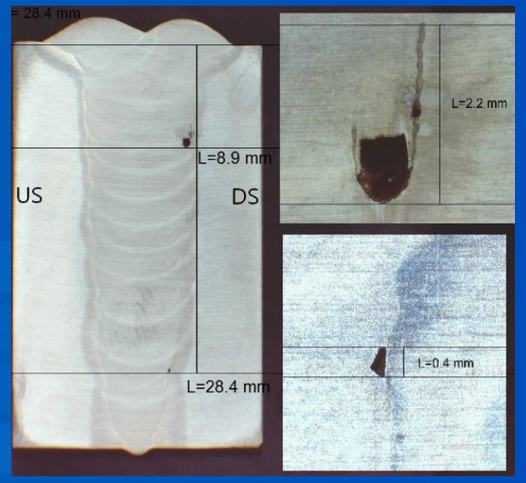
AUT Weld Inspection Validation

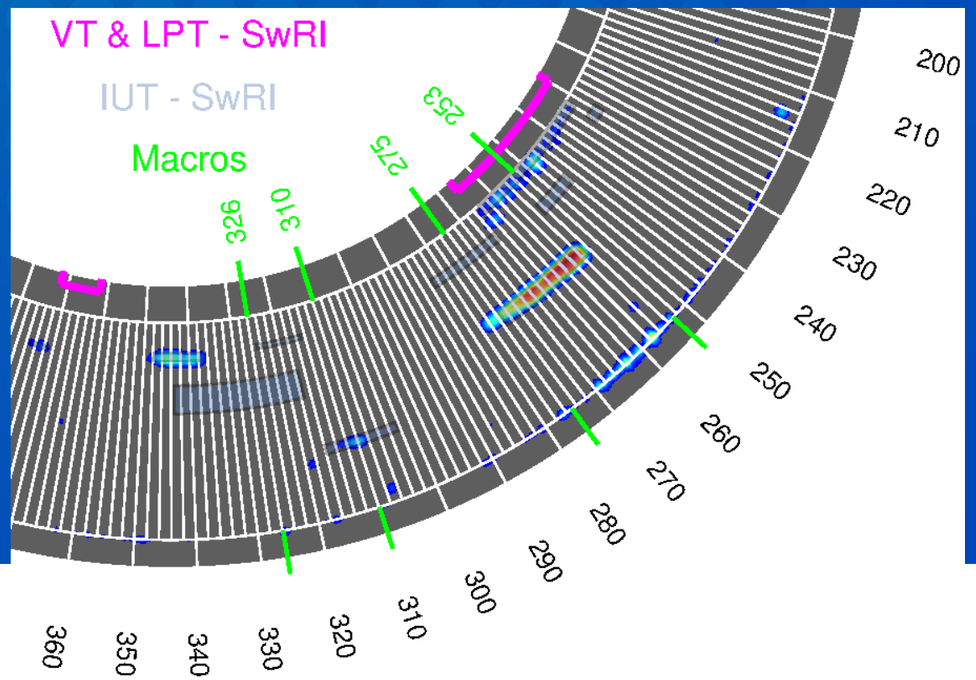
- Automated Ultrasonic Testing (AUT) is an accepted pipe inspection practice for offshore flowlines and risers
- SwRI supports the offshore industry by providing independent, quantitative assessment of AUT inspection performance
- Typical Program Sequence
  1. Test welds designed with intentional flaws based on ECA
  2. AUT vendors conduct blind tests
  3. SwRI independently evaluates welds
     - Radiographic, Visual, and Immersion Ultrasonic Testing
     - NDE reports summarized and matched against AUT data.
  4. SwRI confirms NDE results through destructive testing (DT).
  5. Combined NDE/DT results used to statistically quantify AUT performance.
     - Probability of Detection
     - Sizing and location capabilities

AUT Weld Inspection Validation

- Key SwRI Capabilities
  - Services performed in-house
    - NDE (UT, PT, MT, etc.)
    - DT (sectioning, imaging)
    - Maintain control of quality
  - Custom-built IUT System
  - Custom software for post-processing and analysis
    - Review data from IUT, AUT, RT, etc. together
  - Client-driven statistical analyses, including PoD





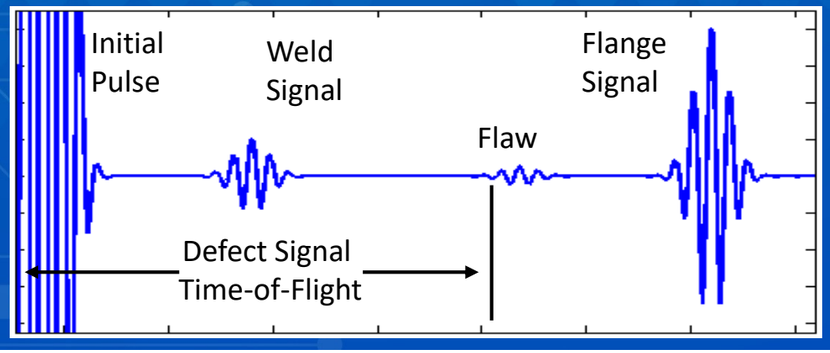


Guided Wave Technology

- Guided waves are acoustic waves whose wavelength is close to or greater than the part thickness
  - Propagation is guided by structure (goes around bends, along surfaces, etc.)
  - Typically lower frequencies (20-500 kHz) than for conventional ultrasonic testing
- Advantage – allows inspection over large distances from a single location for corrosion and cracking in many industrial structures
  - Pipelines, cables, plates, etc.
- Sensitivity as small as 2-5% of the cross-sectional area
- Purpose of the technology is to locate significant damage quickly, cost efficiently for subsequent repair and/or characterization using conventional NDE techniques

Guided Wave Technology

- SwRI developed a unique GWT technology - magnetostrictive sensing (MsS)
  - Uses magnetostriction to generate and receive waves
  - Unique wave modes more efficiently generated using this technique
  - Works at higher temperatures and in harsher environments than other technologies
  - Sensor cost can be very low
- SwRI produced systems have been used by inspection companies
  - Over 100 systems sold worldwide

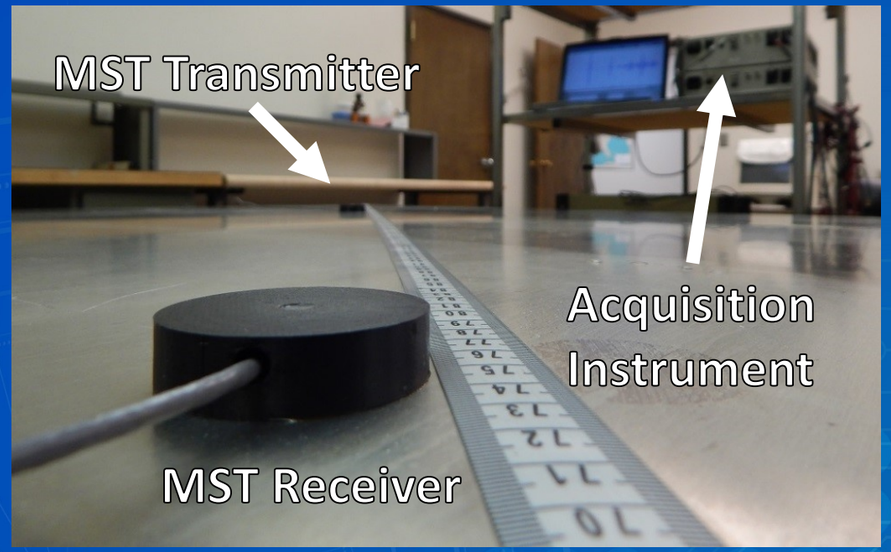


Monitoring with MsS Guided Waves

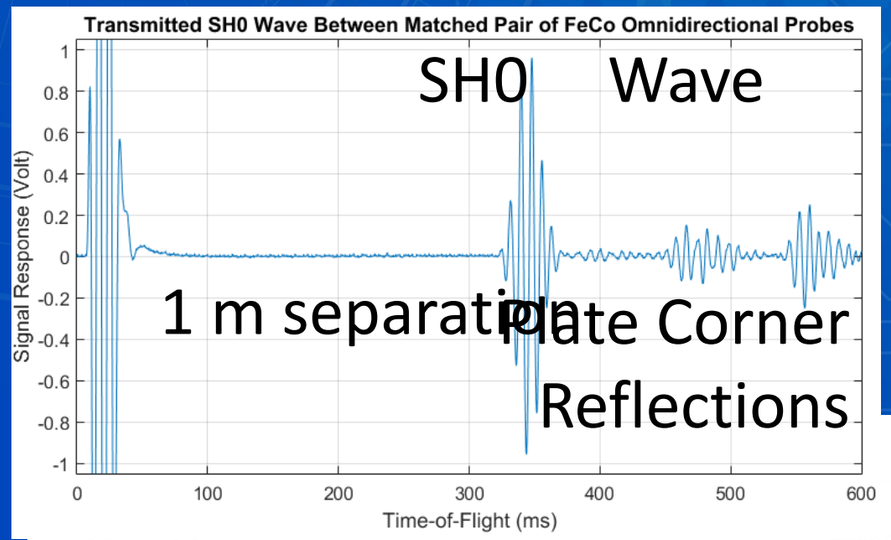
- Guided wave testing was originally developed for inspection
  - Data collected once / inspection report generated based on that data only
  - Comparison between historical inspections possible using reports
- A monitoring approach has been developed in recent years to expand the capability of guided wave testing
  - Sensors permanently installed
  - Multiple datasets acquired over time
    - Trending arrival amplitude changes over time
    - Baseline compensation
- Major advantages of monitoring versus inspection
  - Periodically acquire data more frequently than with individual inspections
  - Large reduction in labor costs (only single sensor installation process)
  - Advanced signal processing possible to improve detection sensitivity

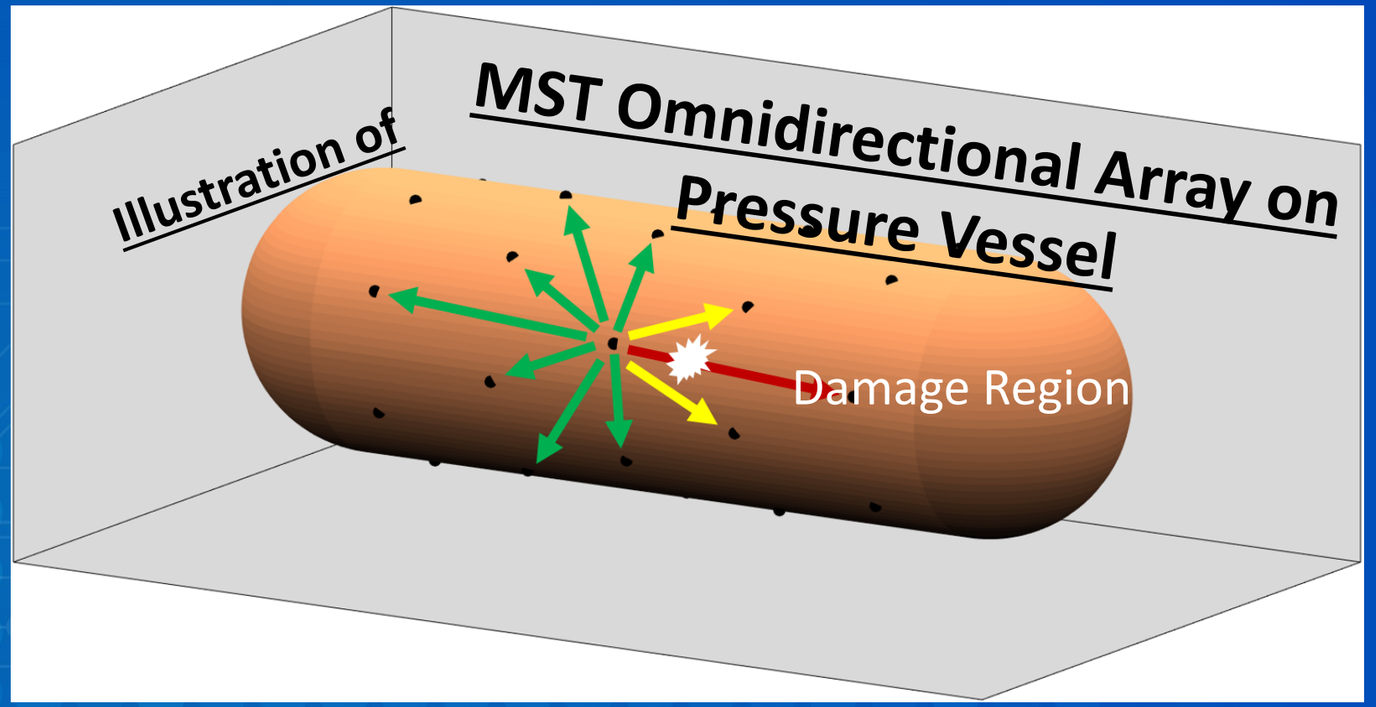
Structural Health Monitoring with a Sparse Array of Omnidirectional Magnetostrictive Transducers

- In 2009-2011 Southwest Research (SwRI) collaborated with the Electric Power Research Institute (EPRI) to develop and field test a structural health monitoring (SHM) system for vessel structures composed of an array of magnetostrictive transducer (MST) plate probes. The system effectively detected the presence of pre-existing damage on operating plant vessels and tracked regions of damage propagation.
- In 2013, SwRI began investigating the use of an MST omnidirectional probe design. A sparse array of omnidirectional probes can be implemented to provide tomographic imaging capabilities for SHM.
- Currently, SwRI is working to develop an omnidirectional MST design that can operate at elevated temperatures and then conduct laboratory tests of sparse array configurations on plates to demonstrate SHM capabilities.



Above: Matched pair of MST omnidirectional probes mounted on the diagonal axis of a 1.8 m square plate.
Below: Captured transmitted wave.

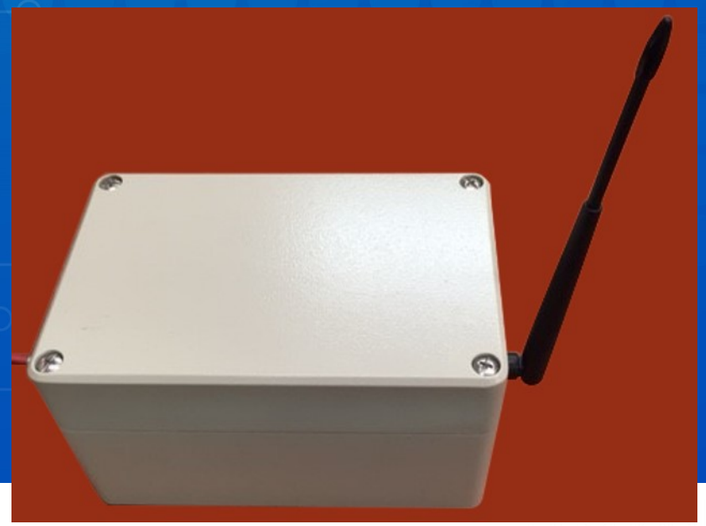




- An array of MST Omnidirectional probes distributed over array layout may be evenly or irregularly distributed.
- All probes are multiplexed to a single monitoring instrument.
- Array provides overlapping coverage over component critical areas.
- The array arrangement offers the capability of tomographic reconstruction of the monitored surface.

Enclosed MsS Monitoring System

- Prototype battery-operated, stand-alone system for guided wave monitoring
  - Designed to operate continuously for several years
  - Periodically acquires data & wirelessly transmits it to base station
    - Range between neighboring sensor & base station up to 4 miles
  - Small footprint (approximately 6” x 4” x 5”) and less than 5 lbs.
- Single base station can be used for multiple devices

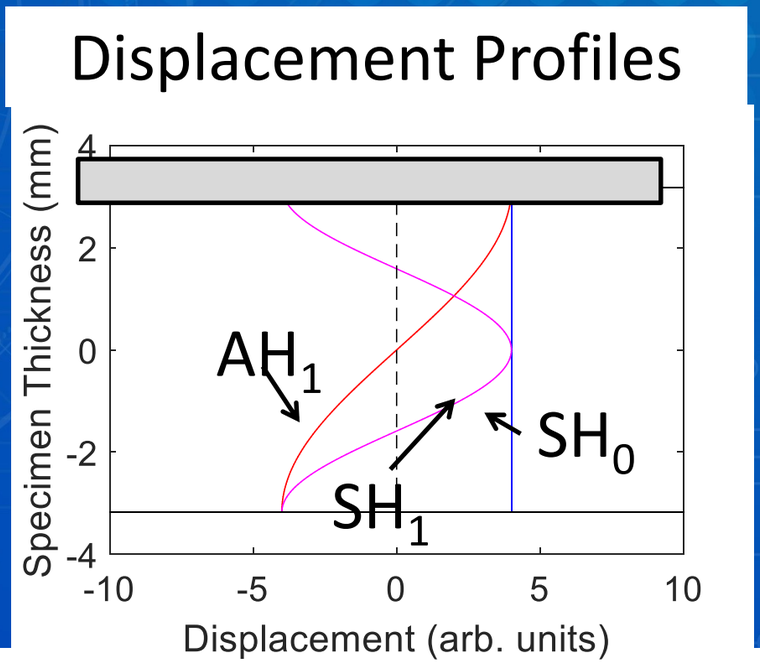


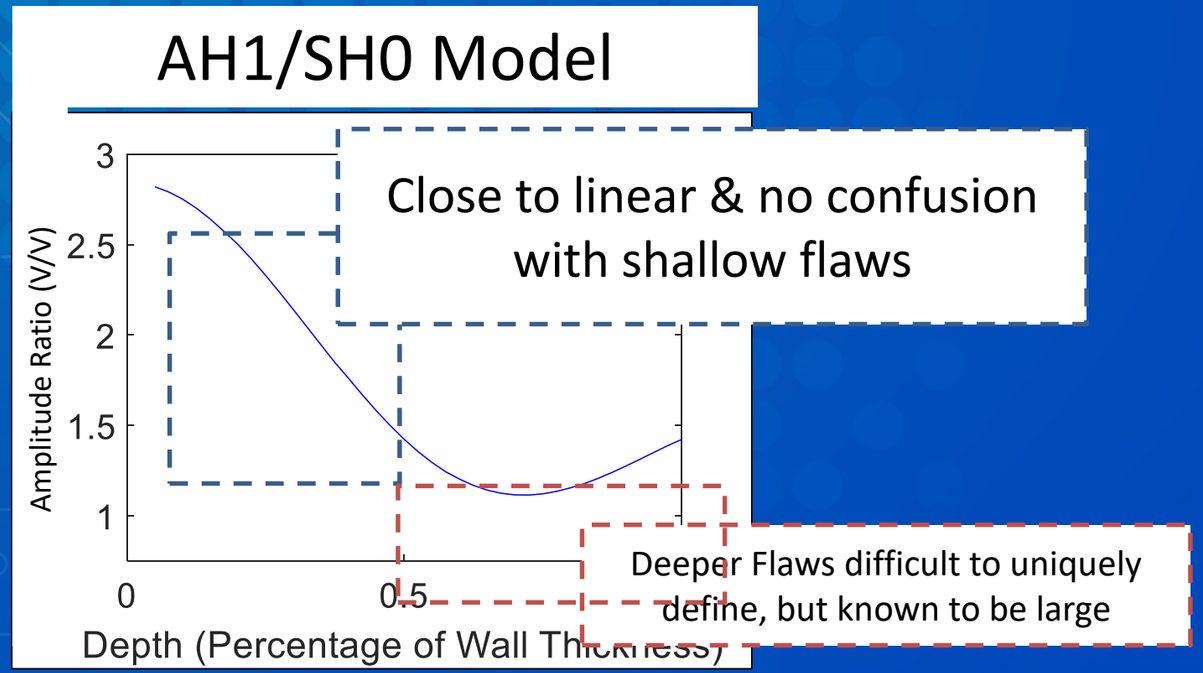
Defect Sizing using Guided Waves

- Guided wave inspection is normally used for rapid screening only
  - Signal sensor inspects large areas
  - Defect located quickly but accurate sizing not always possible
  - Other, local, NDE approach used to assess severity
- Sometimes other NDE approaches cannot be used (e.g., access limited) -> Need to size flaw using guided wave information
- Conventional sizing approach exploits the fact that a large defects will produce a large reflected signals
  - Calibrate echo amplitude based on "known" arrivals (welds)
  - Approximate defect area (i.e., not depth) using amplitude
  - Use other information (width from multiple sensors) to measure extent
  - Combine everything together get an estimate of remaining wall
- Challenge is that many things can affect amplitude of the signal (attenuation from coatings, welds, etc.)

Defect Sizing using Guided Waves

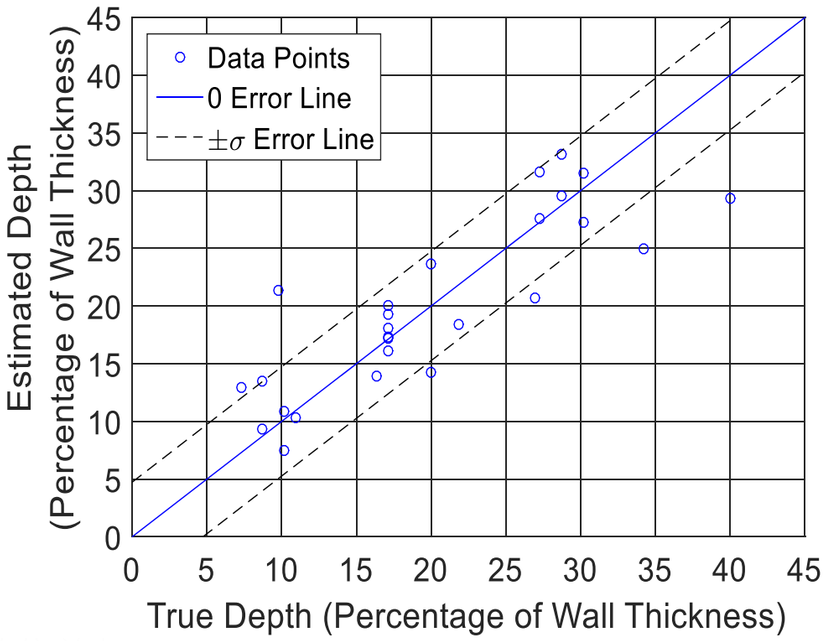
- Developed new approach to depth size using guided waves that does not need geometry calibration because a) features do not always exist and b) response from feature is an approximation
- New approach employs multiple guided wave modes propagated from a single sensor to size the flaw





Experimental Sizing Results

- **Evaluated technique with data acquired from a guided wave sensor on a steel plate**
  - 6.4 mm plate thickness but results scalable to any thickness
  - Flaws were notches cut with EDM process / 84 total flaws
  - Defects as small as 10 mm and as wide 60 mm
  - Guided wave sensor had a large range of different propagation path lengths



- **Large Flaw Set (58 flaws)**
  - Flaws only categorized as large (>40%)
  - 52 flaws correctly classified as >40%
  - 6 flaws with mid depths (30-40%) classified as >40%
- **Small Flaw Set (26 flaws):**
  - No defects classified as >40% and all sized
  - Little measurement bias
  - StdDev is ~4.7%
  - Max error ~12%