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Listening to Temperature: Ultrasonic Non-Destructive Identification of Material Phase and Temperature

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Under the guidance of David G. Moore, Department 01522, Sandia Delegated Representative

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SIC'EM Scientific Innovations in Composites and Engineering Materials

NNSA National Nuclear Security Administration

Sandia National Laboratories

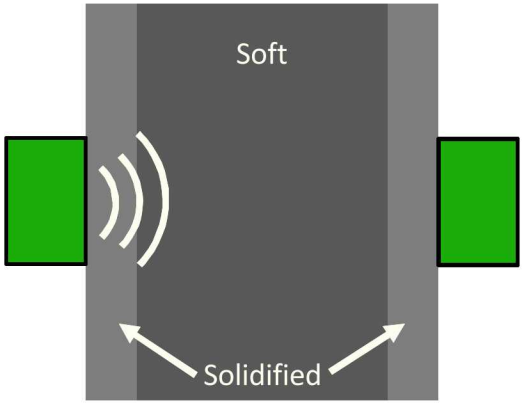
U.S. DEPARTMENT OF ENERGY

Overview

- Research motivation
- Ultrasonic theory basics
- Material Selection and Characterization
- Experimental Setup
- Data Collection and Processing
- Results

Research Motivation

- Needing to know the temperature of a material without being able to see or touch it
  - Inability to use invasive techniques
- Applications
  - Refineries and power plants
  - Food industry
  - Polymer composites



Research Motivation

What others have done:

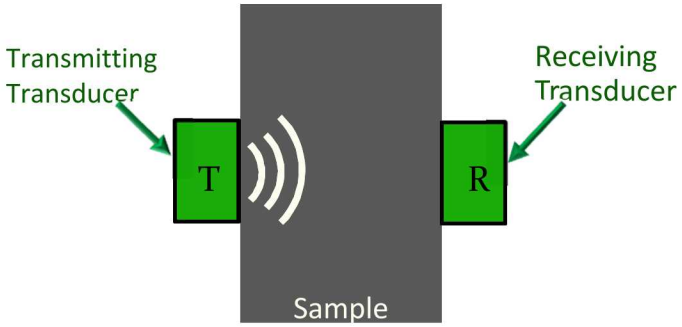
- Ultrasonics in gases
  - Temperature reconstruction in high-temperature applications, such as power plant boilers (Bramanti et al)
- Ultrasonics in food industry
  - Identifying the fat content of chocolate (Winkelmeyer)
- Ultrasonics in polymers
  - Measuring the degree of cure in epoxy resins found in fiber-reinforced composites (Lionetto and Maffezzoli)
  - Measure in-line melt temperature of a polymer melt in a single screw extruder (Brown et al)

Our goals:

- Two-phase application of ultrasonics
  - Solid/Liquid
- Phase identification
- Temperature identification
- 2D imaging of results

Ultrasonic Theory Basics

- Through transmission
- Ultrasonic parameters
  - Speed of sound of a material changes with temperature
  - Time of flight is recorded by data collection software
  - Attenuation varies with material temperature

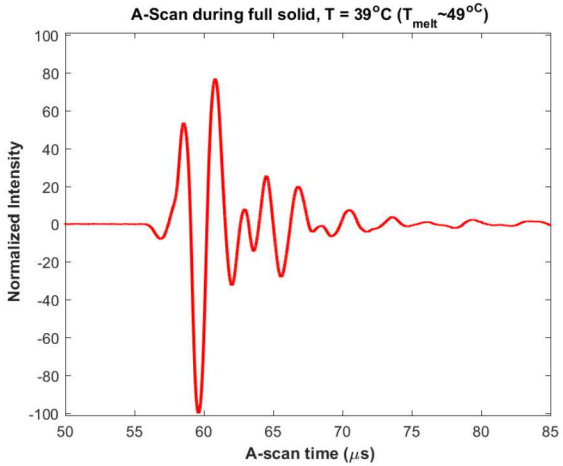


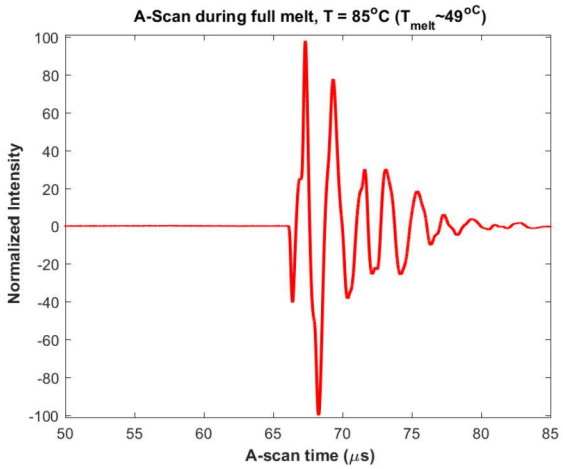
Experimental Equipment

- EUT3160 8-Channel Pulsar/Receiver
- Olympus 0.5 MHz/1.0” Transducer
- Graphtec GL820 Data Acquisition Device

Material Selection and Characterization

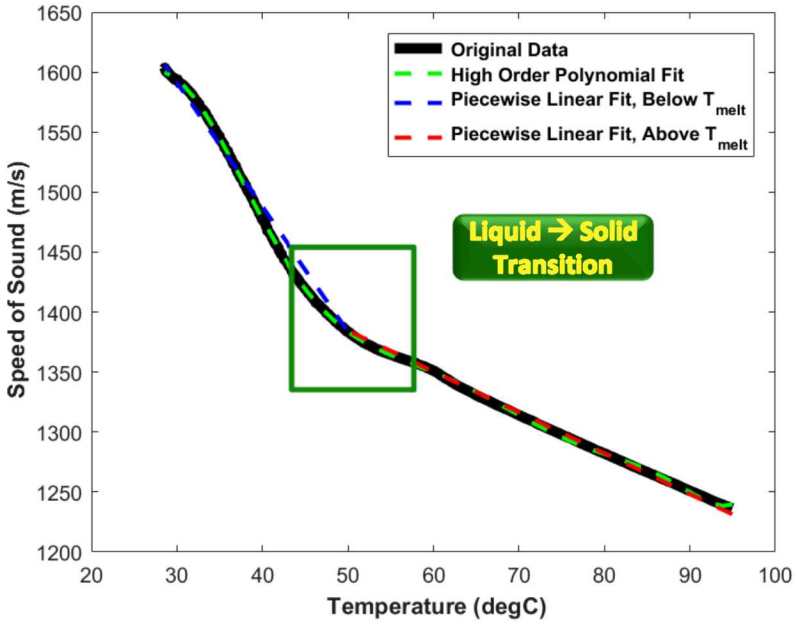
- Amorphous and semi-crystalline wax
- Highly attenuative
- Very low coefficient of thermal expansion
  - Prevents loss of contact between container and wax when solidification occurs
- Ascan taken when wax is completely solid compared to an ascan when wax is completely liquid
  - The time of flight is significantly different for the two temperatures





Material Selection and Characterization

- Using the time of flight at known temperatures, we can create a speed of sound master curve
- Speed of Sound curve
  - Significant slope change between 40 and 50 degrees Celsius suggests a phase change occurs in that temperature range
- DSC curve
  - Heat flow corresponds to the amount of energy needed to change temperature
  - Melt occurs at 46.5°C
  - Solidification occurs at 43.2°C



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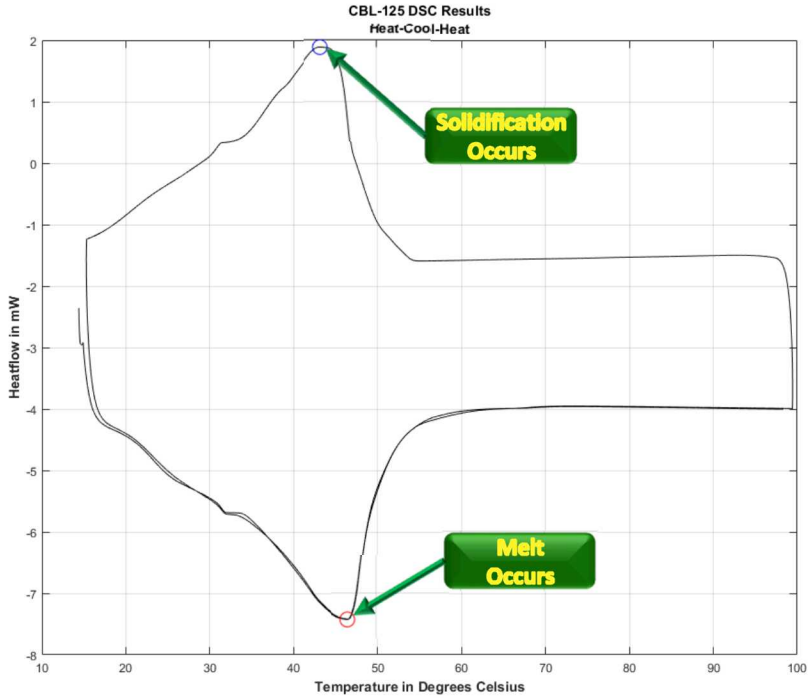
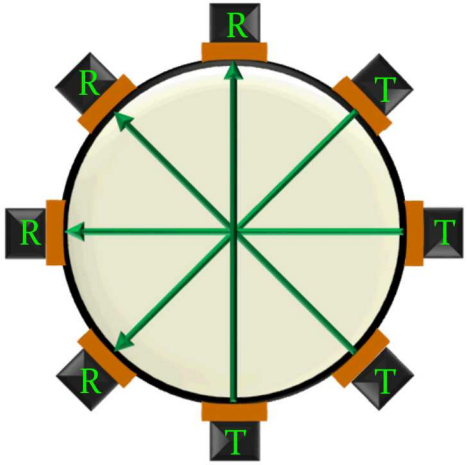


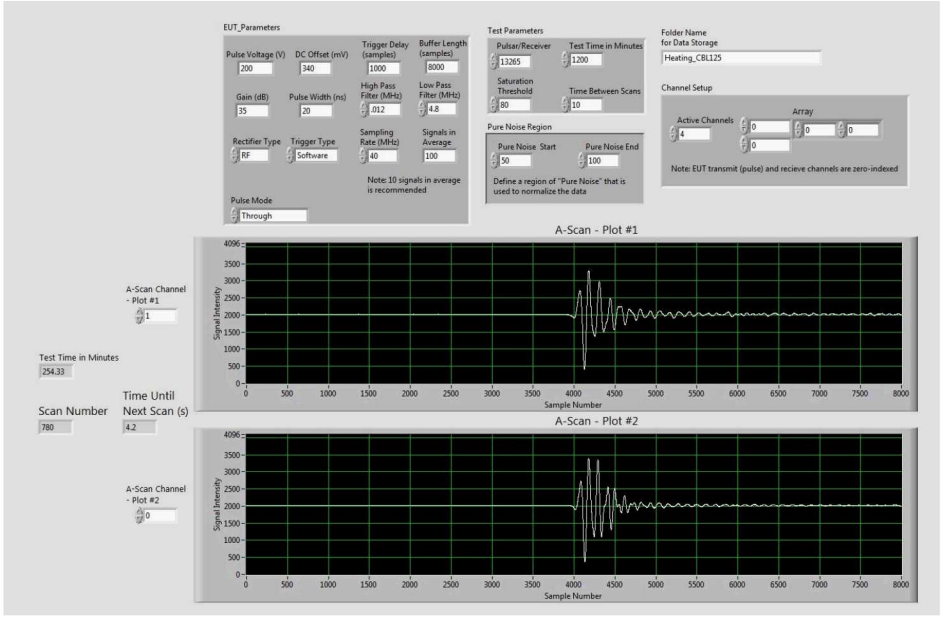
Experimental Setup

- 8 transducers aligned in 4 ultrasound paths
- Through-transmission
- Ultem between transducers and container
- Acoustic gel used to couple surfaces
- Thermocouple array of 9 thermocouples, including one which records the heater-block temperature



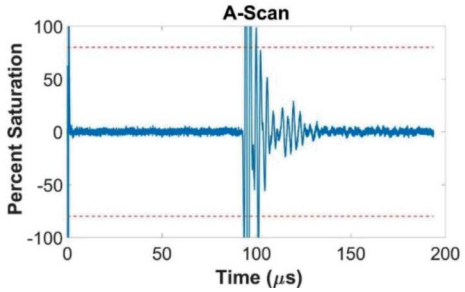
Data Collection

- LabVIEW Front Panel
  - View up to 2 ascans simultaneously
  - Able to change the ascan being plotted on-screen during the test
  - Countdown to next scan
  - Test run-time
  - Scan number
  - Array of transducer transmit/receiver pairs
  - Experiment parameters
  - Folder that data is stored in

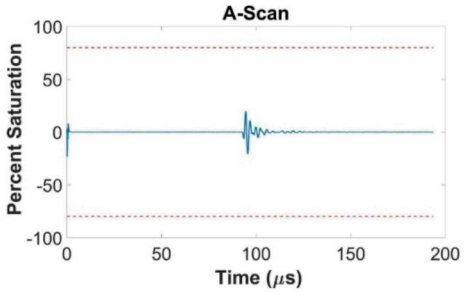


Data Collection

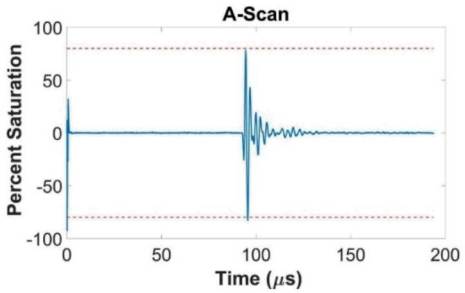
- LabVIEW Code
  - Aborts if pulsar/receiver cannot connect
  - Transmit and receive transducer do not need to be the same number
  - Adjusts the gain for each channel separately
  - Logs and saves the gain data as the test progresses
  - Logs and saves the ascan data as the test progresses



Signal Saturated



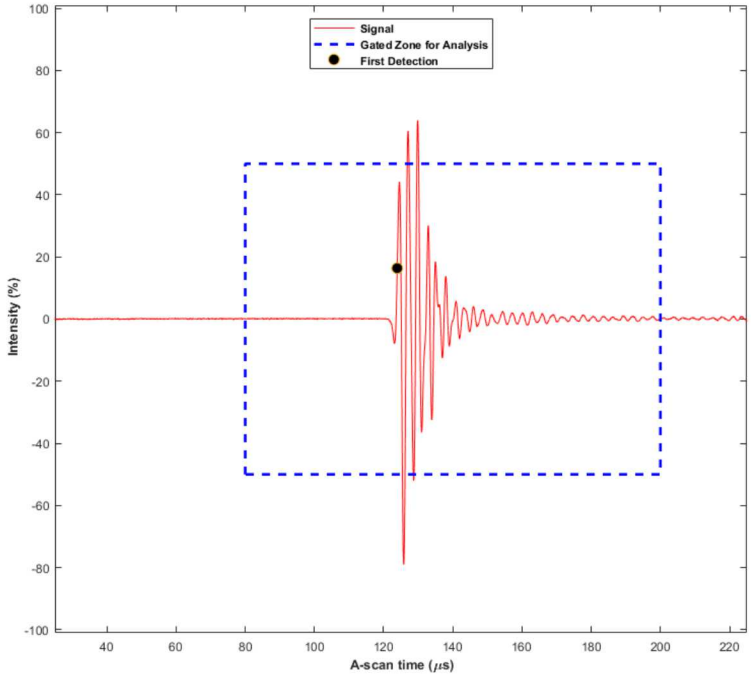
Low Data Resolution



Correct S-N-R

Data Processing

- **Process ultrasonic data**
- Examine gain data
- Analyze frequency spectrum
- Bscans



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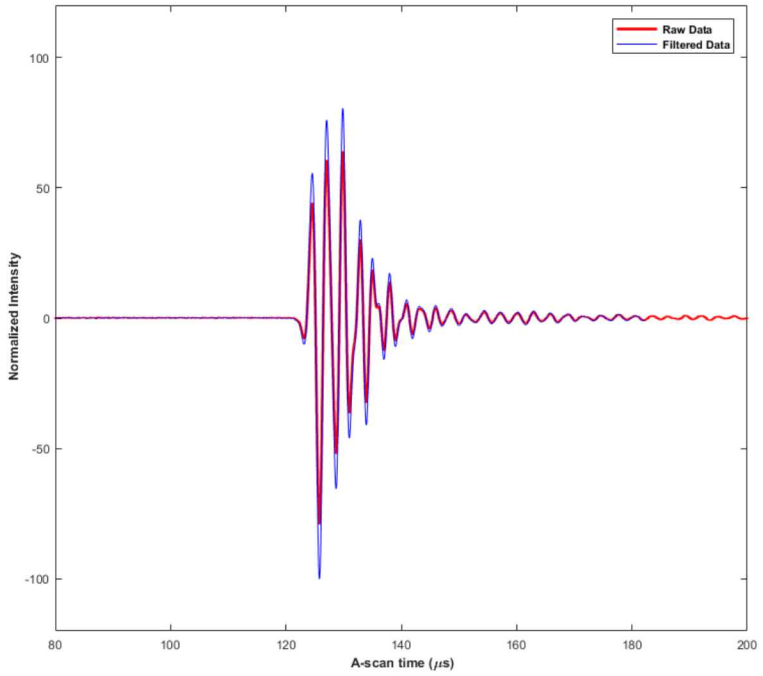

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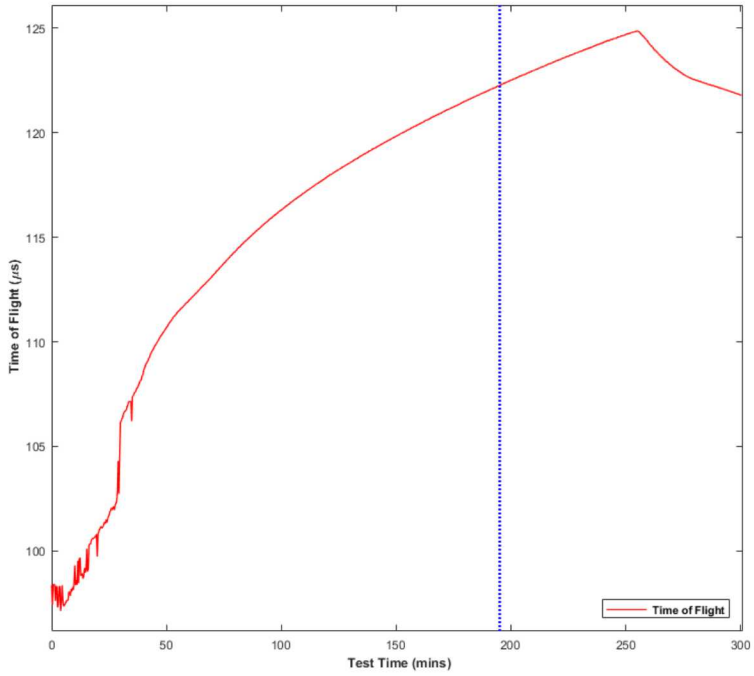

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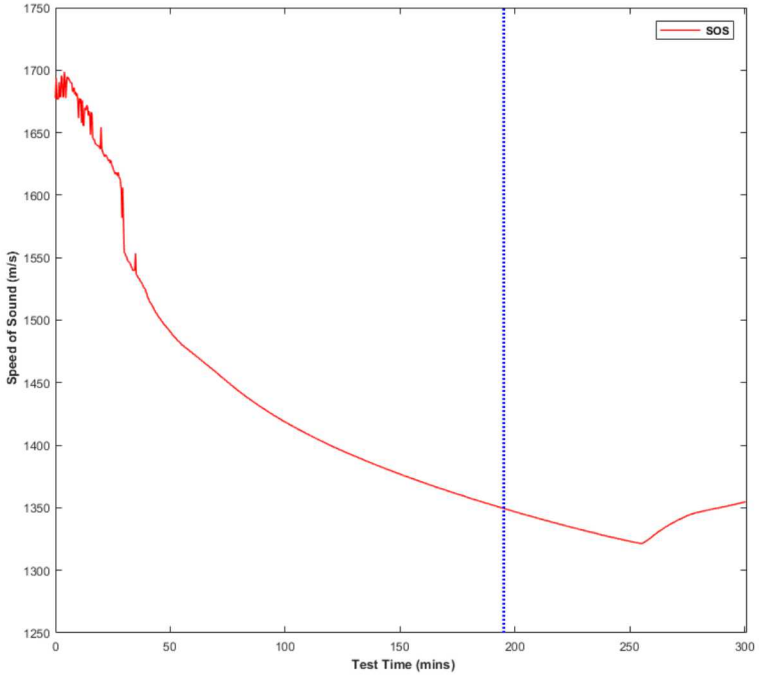
Effective Speed of Sound:

$$C_{wax} = \frac{X_{wax}}{TOF_{wax}}$$



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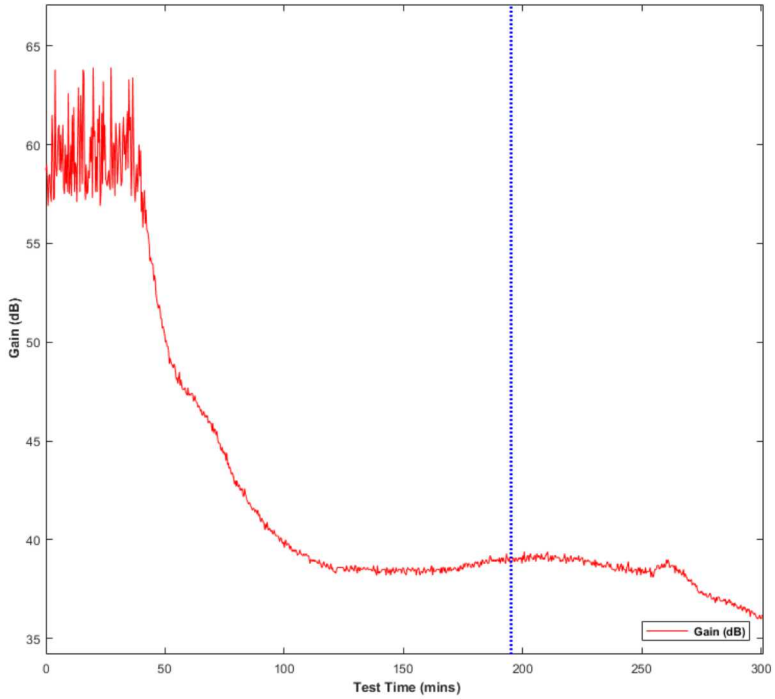

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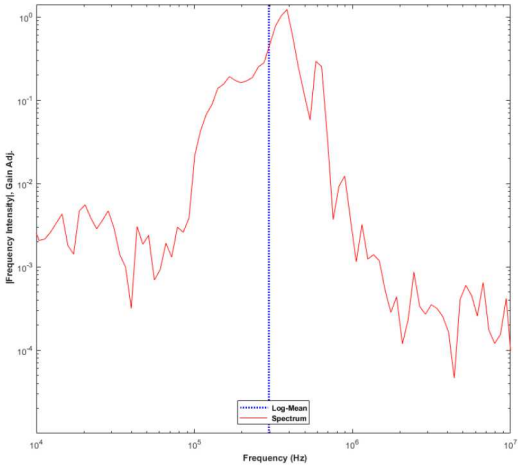

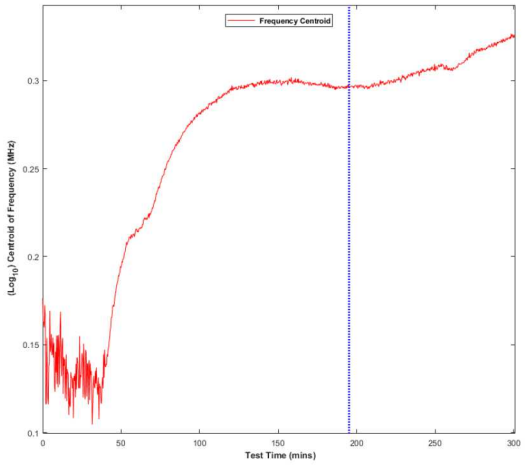

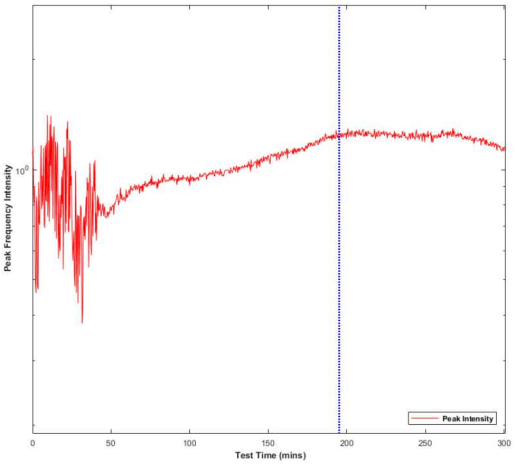

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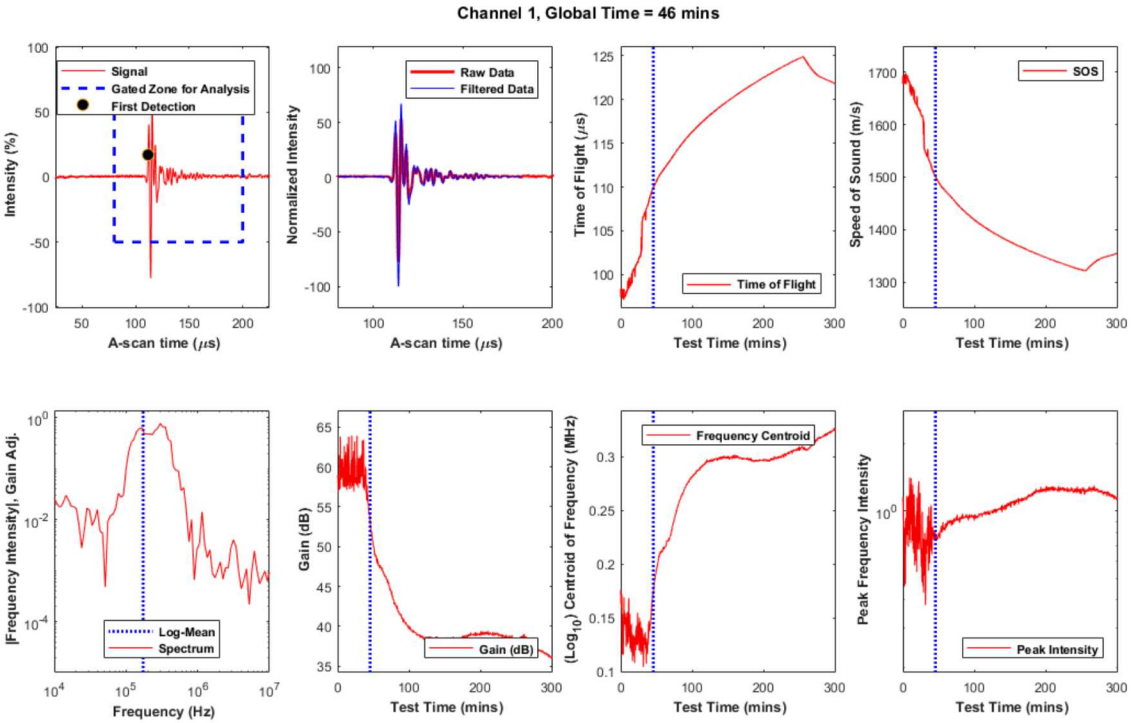

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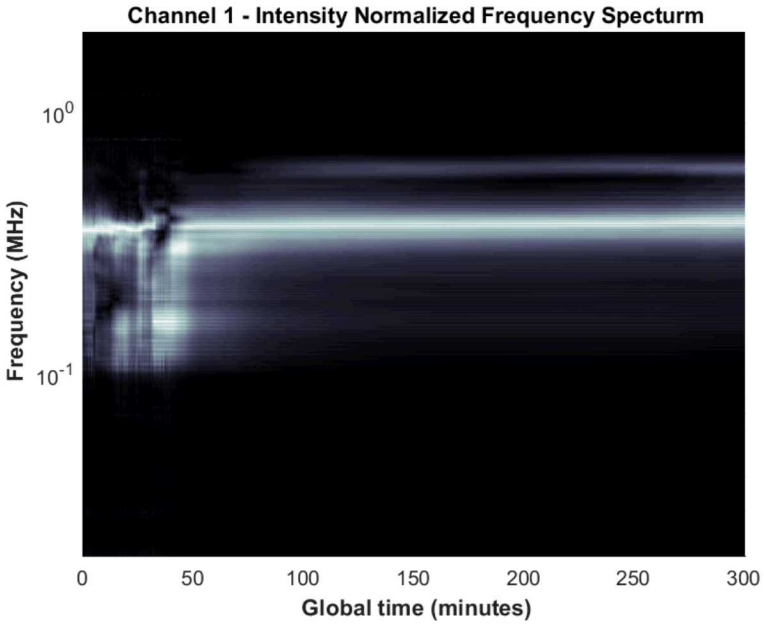

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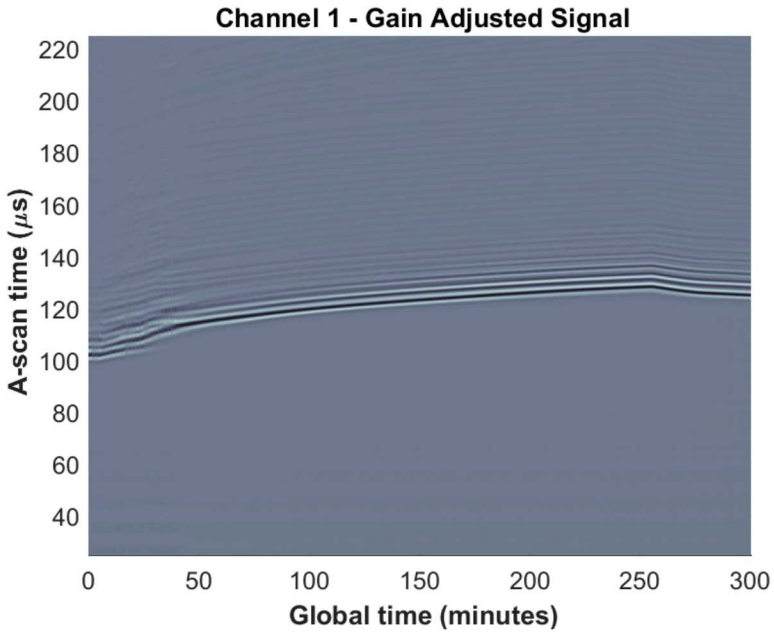

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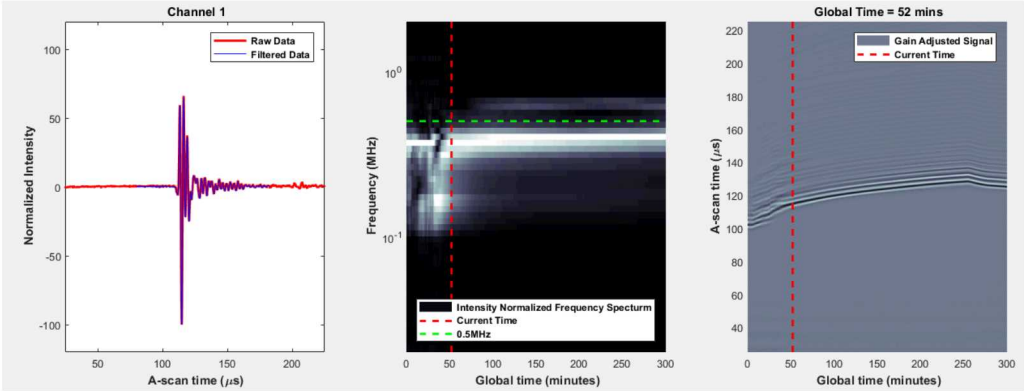
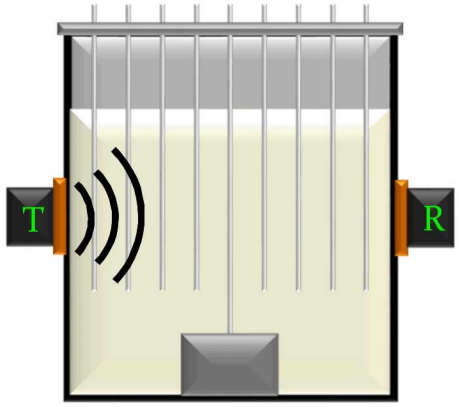
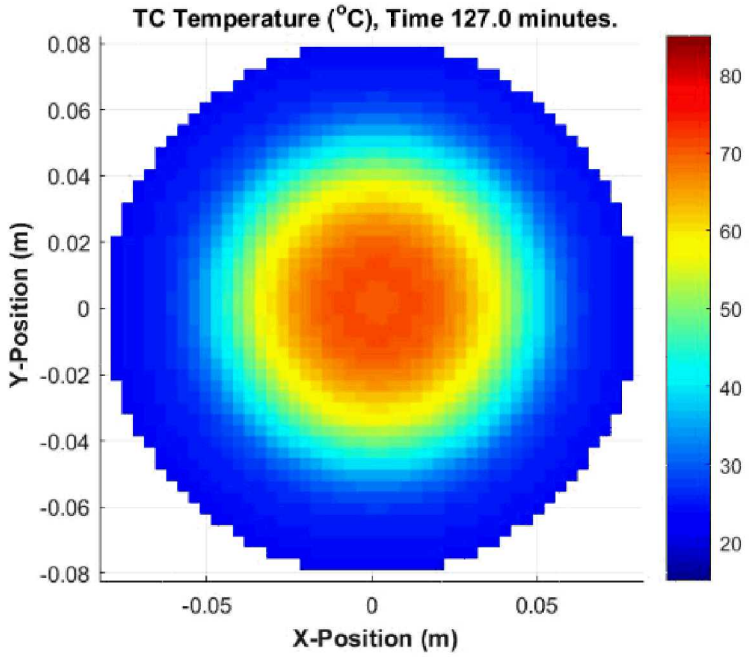


Data Processing - Thermocouples

- Linear array of thermocouples across the container
- 8 thermocouples recording planar temperature of wax
- 1 thermocouple recording heater block temperature, which is below the thermocouple plane and the transducer plane
- Surface plot of extrapolated radial temperatures

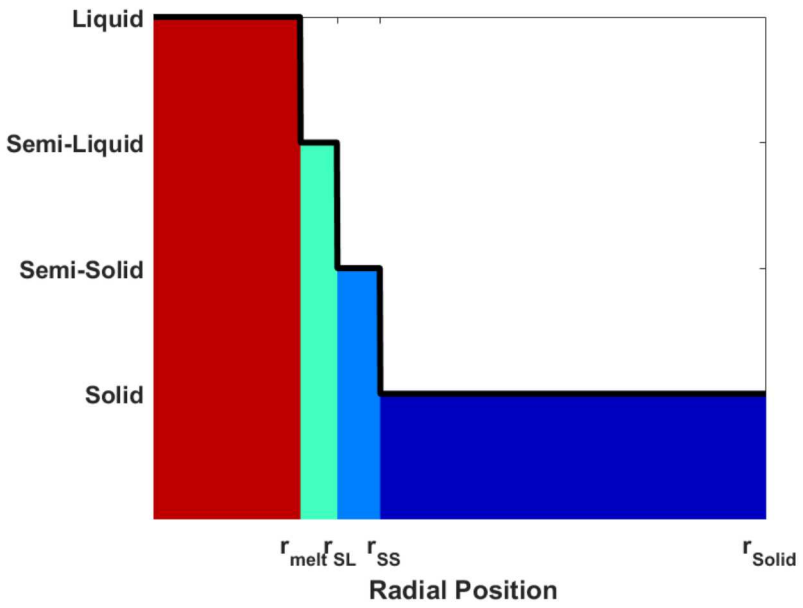




Data Processing - Phase and Temperature

- **Phase**
  - Three-step function for speed of sound
  - Phase estimated using speed of sound

- Temperature
  - Assumed temperature profiles
  - Boundary conditions
  - Temperature estimated



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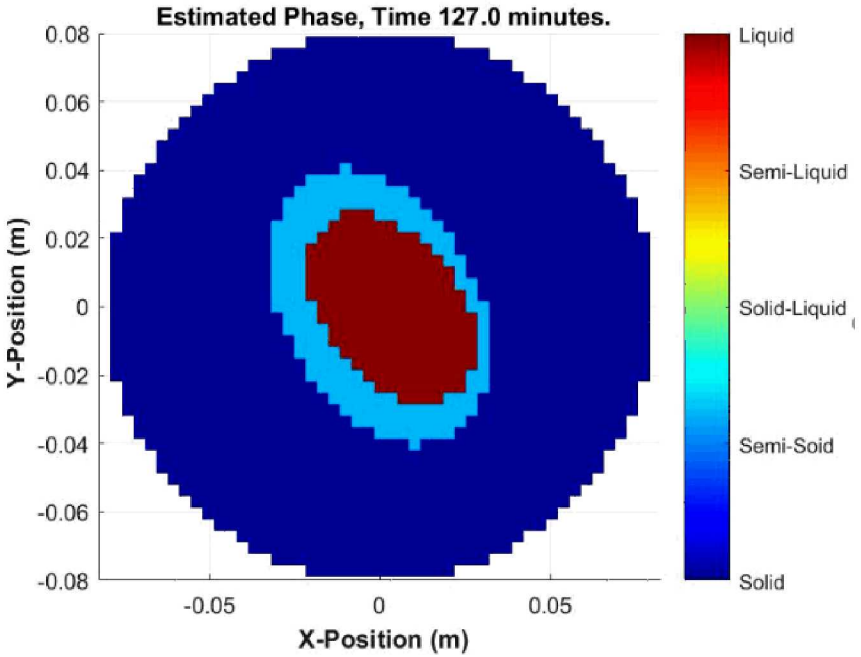

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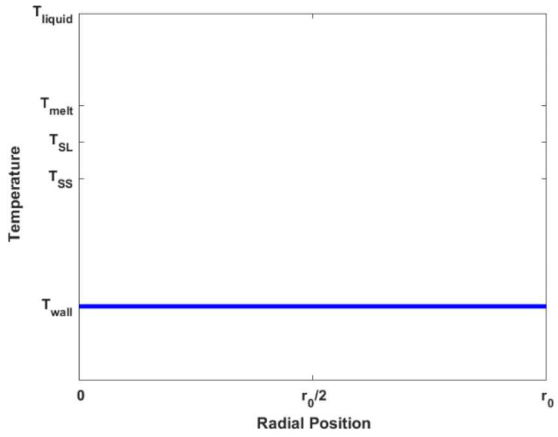

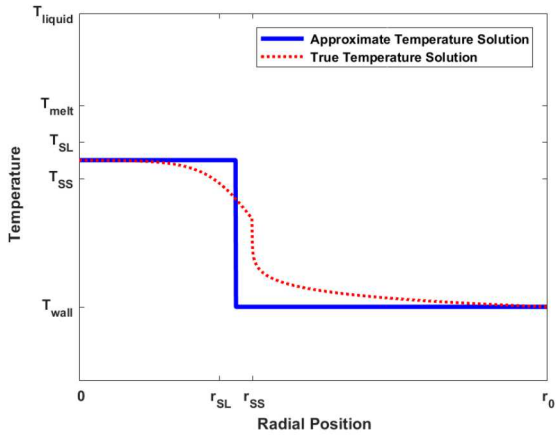

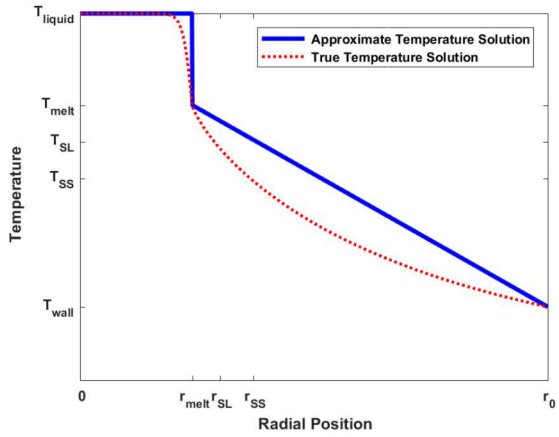

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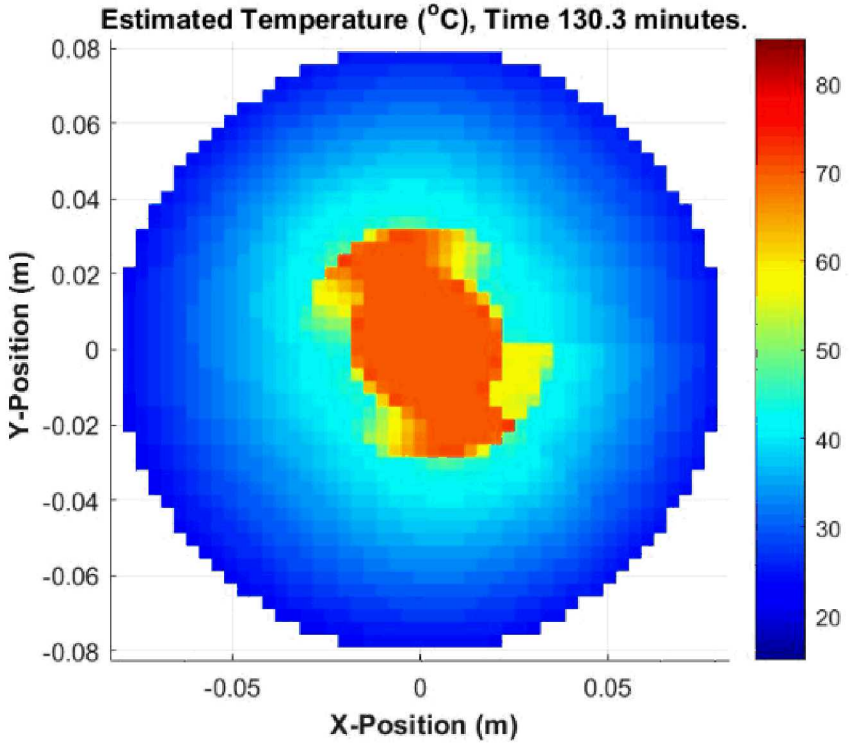
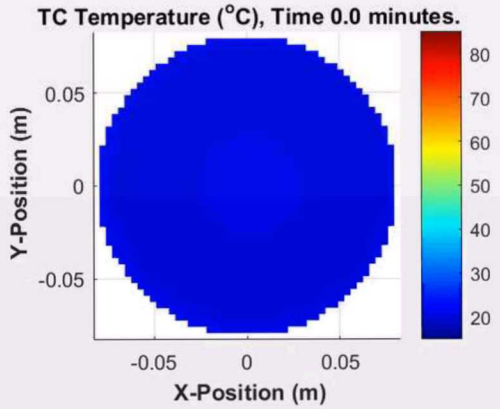
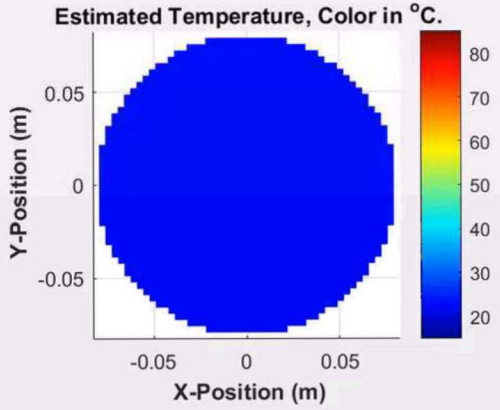
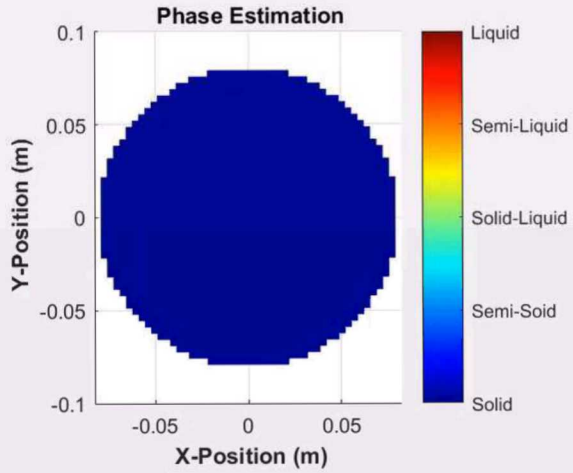


Results

- Comparison of ultrasonic data to thermocouple data for validation

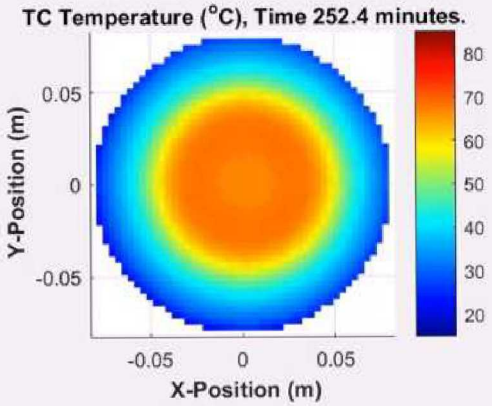


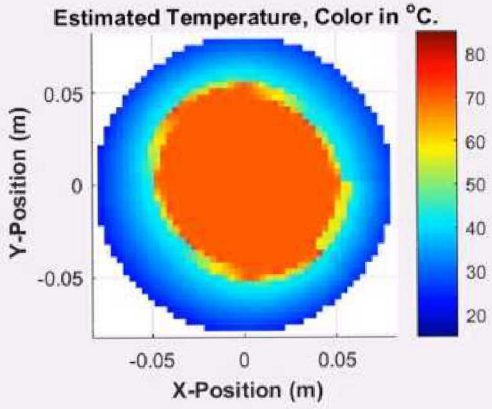


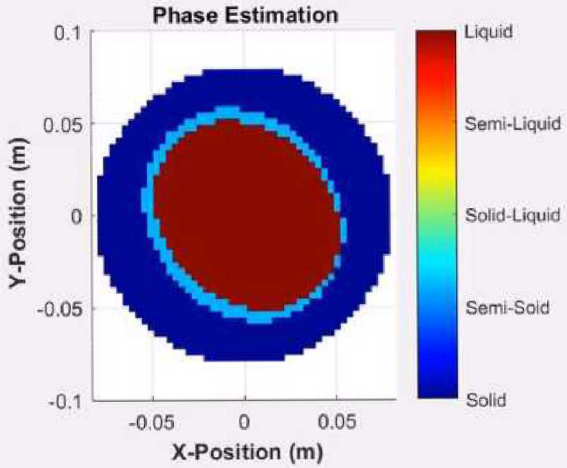


Results

- At 252 minutes into the test the heater is turned off
- Compare the photograph from that time to the three plots shown







Conclusions and Future Work

- Ultrasonics is a viable method for noninvasive phase and temperature identification

- Future work
  - Scaling experimental setup
  - 3D phase and temperature
  - Finite element modeling
  - Characterizing additional materials

Acknowledgements

- Industry Sponsor: Sandia National Laboratories
  - David Moore
- Graduate Advisor: Dr. David Jack

Questions?