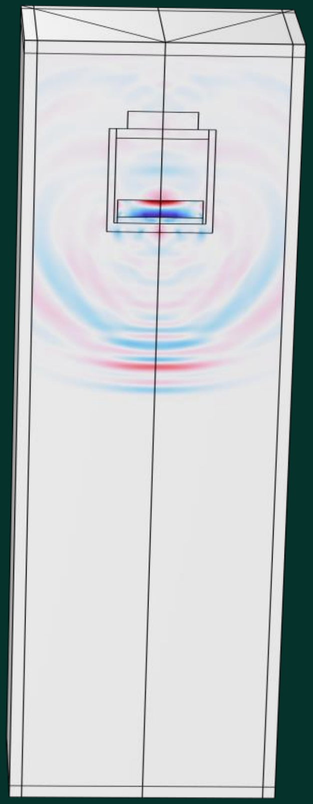
3D Ultrasonic Simulations for Pulse Echo and Pitch Catch Testing



Haiqi Wen

Lead Scientist @ Baker Hughes

Oil and Gas Production Process

Upstream

- Exploration: Locating potential sites for oil and gas drilling and extraction
- Drilling: Boring a hole using a drill bit to create a well for oil and natural gas production
- Extraction: Oil and natural gas flows up from the well bore and fracturing fluid is then recovered .

Midstream

- Processing: Oil and natural gas are separated, then transferred to the gas processing plants.
- Storing: Natural gases are usually stored in underground spaces such as depleted reservoirs, while finished oil products, crude oil and refined oil commonly use above ground tanks as storage.
- Transportation: Unrefined oil is transported via tankers and pipelines, while final petroleum products travel to the market through trucks, railroad cars, etc…

Downstream

- Refining: Converting oil and natural gas into petroleum products that can be used for various purpose.
- Distribution: The finished petroleum products are distributed to business and consumers.

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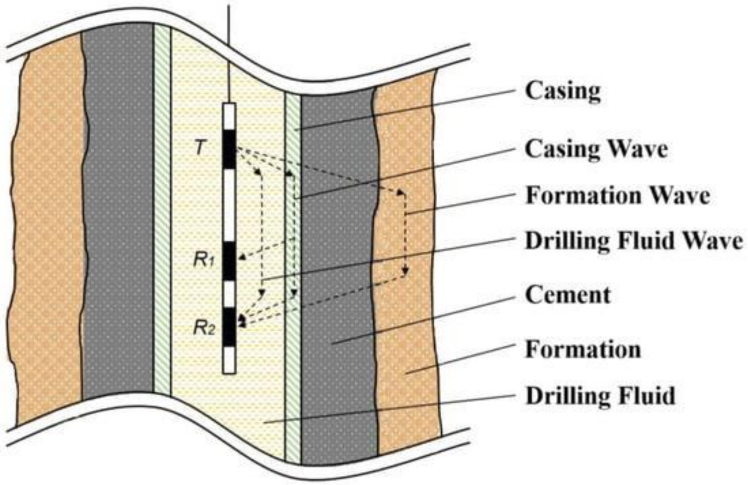
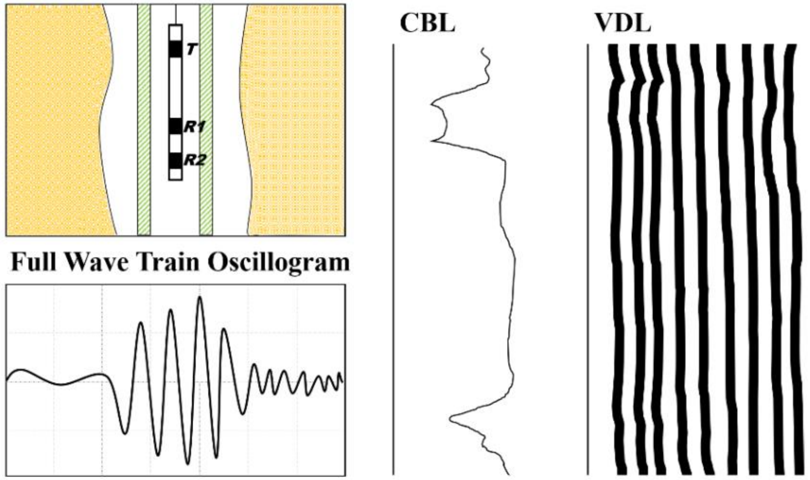
Cement Bonding Evaluation

Well cementing is a key procedure during well construction, The cement sheath provides a hydraulic seal that prevents fluid communication between producing zones in the borehole and blocking the escape of fluids to the surface.

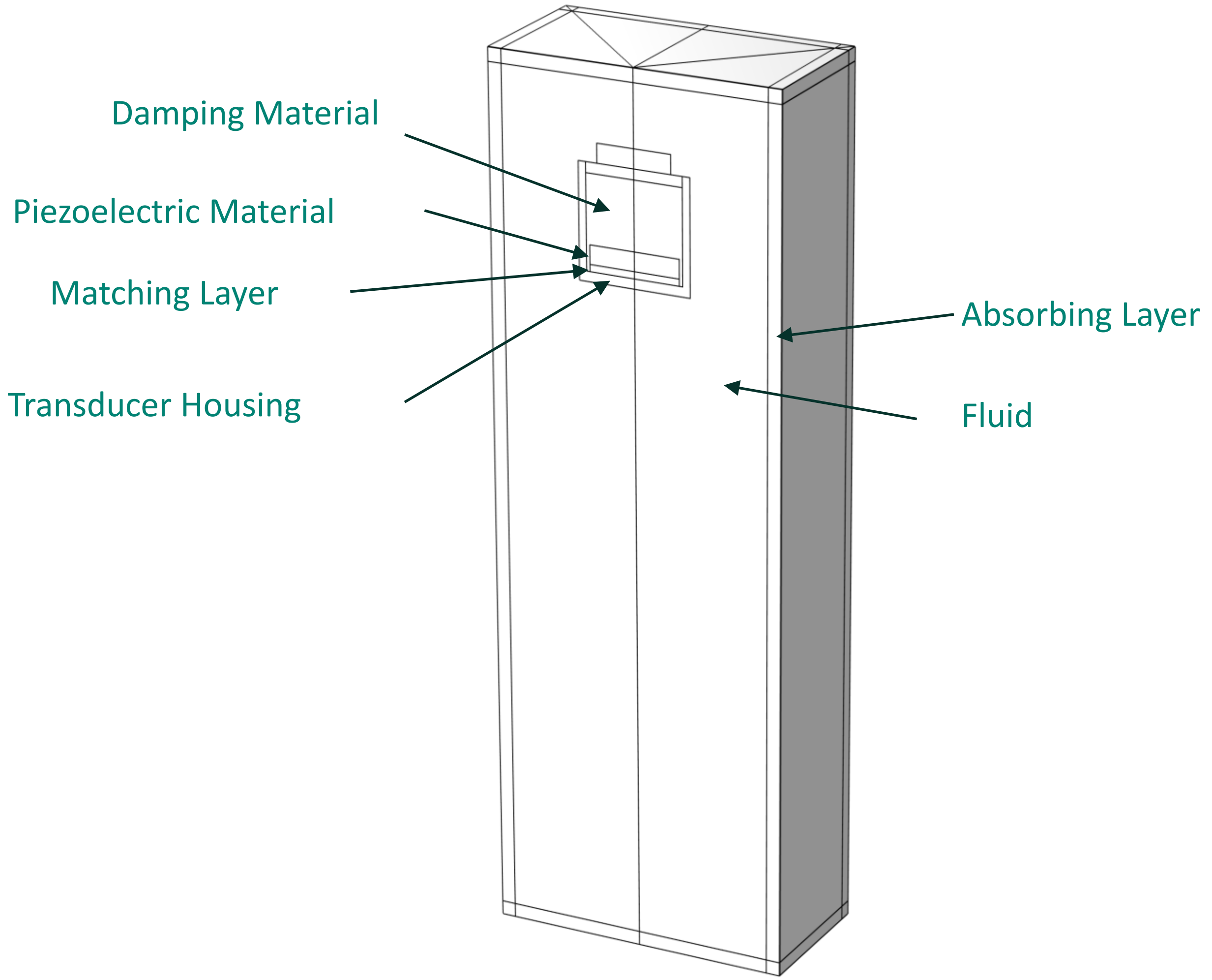
Cement-bonding logs (CBL) and variable-density log (VDL) leverage ultrasonic tools run on wireline to provide highly reliable estimates of well integrity and zone isolation.

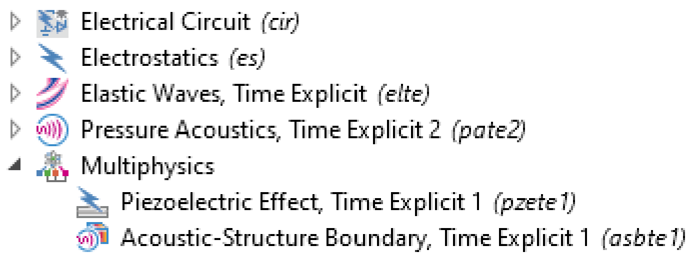




Fang et al. 2022

Piezoelectric Transducer Modeling





In this study, four physics modules are introduced to the Multiphysics model:

- Electrostatics module (es) is coupled to the Elastic Waves, Time Explicit (elte) module to transform voltage signal to elastic wave.
- Elastic Waves, Time Explicit (elte) module is coupled to Pressure Acoustics, Time Explicit (pate) module to model fluid-structural interaction at the transducer's boundary.
- An external electrical circuit is coupled to the terminal of the piezoelectric element.

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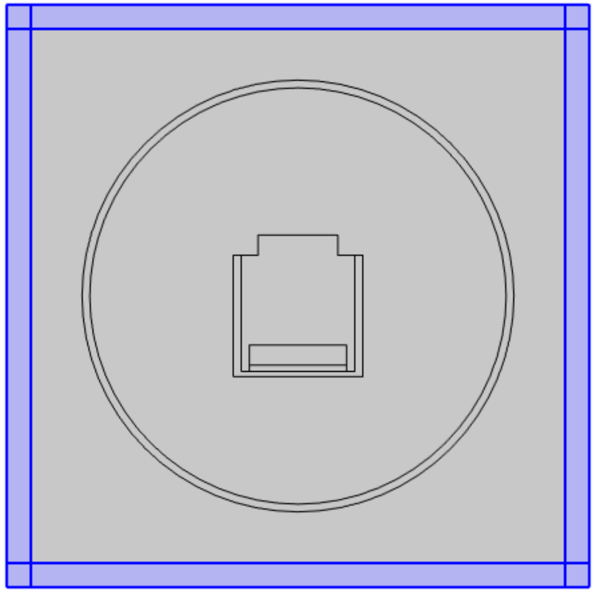
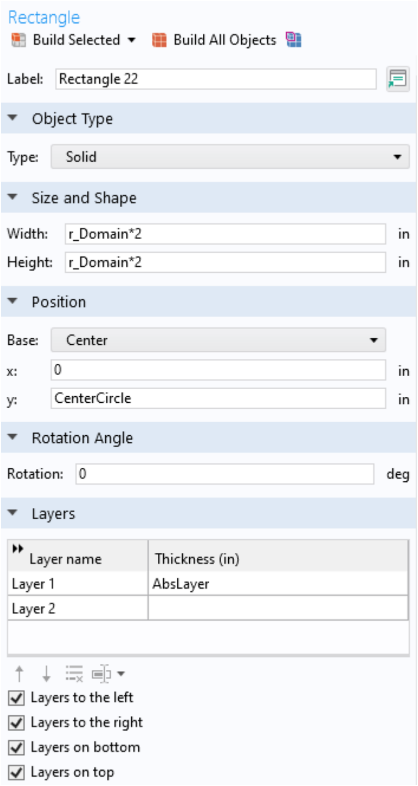
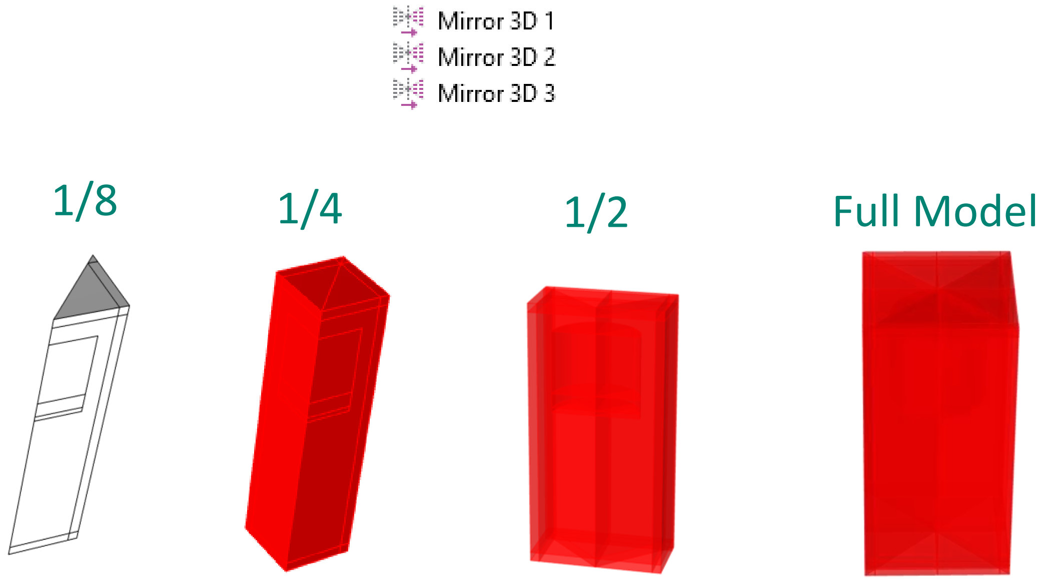
Boundary Conditions







Only 1/8 of the model is simulated to improve computation efficiency. Full model response can be obtained by creating mirror data sets.

Absorbing layer is introduced to absorb acoustic waves and prevent reflection

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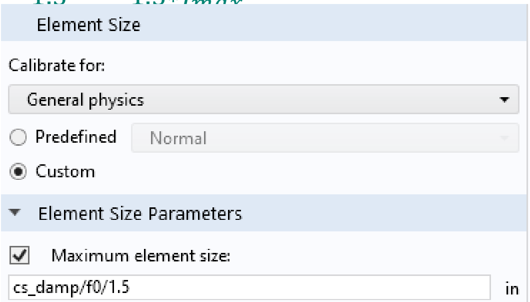
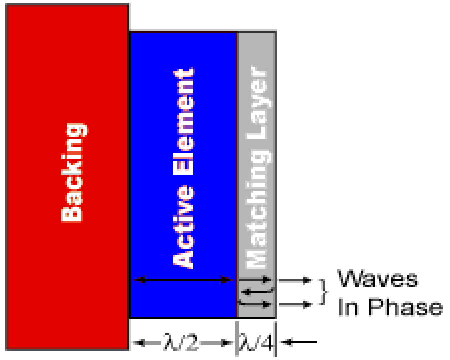
Transducer Dimension and Mesh Setting

Thickness of the piezoelectric transducer is set to $\frac{1}{2}$ of the wavelength, the thickness of the matching layer is set to $\frac{1}{4}$ of the wavelength.

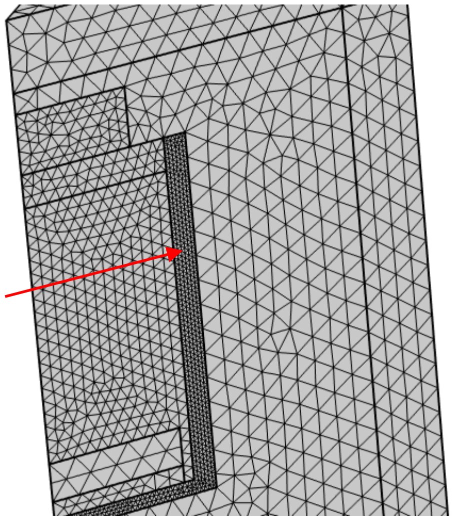
In this study, a dG time-explicit method is used to solve the system. The default for Elastic Waves interface is to use quartic shape functions. The maximum element size is defined as $h_{max} = \frac{\lambda_{min}}{1.5} = \frac{c_{min}}{1.5 * f_{max}}$



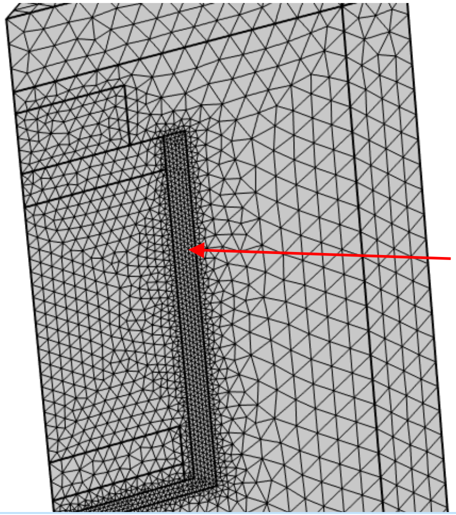
t_piezo	cp_pzt/f0/2	0.00825 m
t_matching	cp_match/f0/4	0.0026339 m



Mesh size does not to be continuous at interface



Pair Acoustic-Structure Boundary, Time Explicit 1 *(aspte1)*



Acoustic-Structure Boundary, Time Explicit 1 *(asbte1)*

Mesh size is continuous at interface

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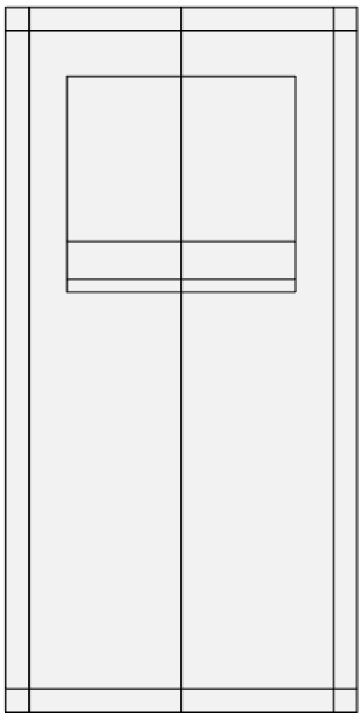
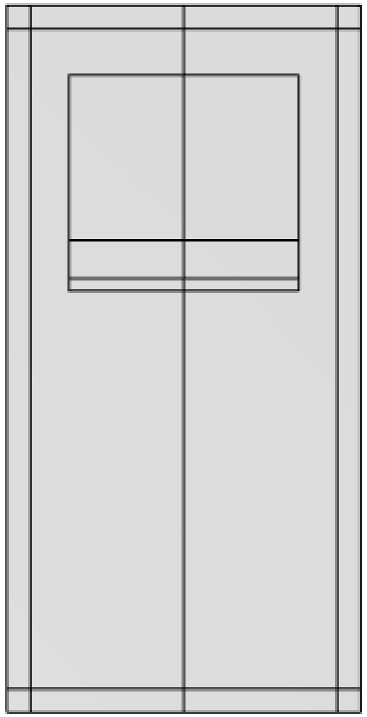
2D Axisymmetric Model vs 3D Model

F0 = 280 kHz

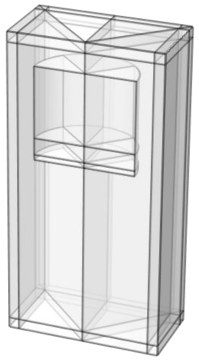
2D Axisymmetric Model

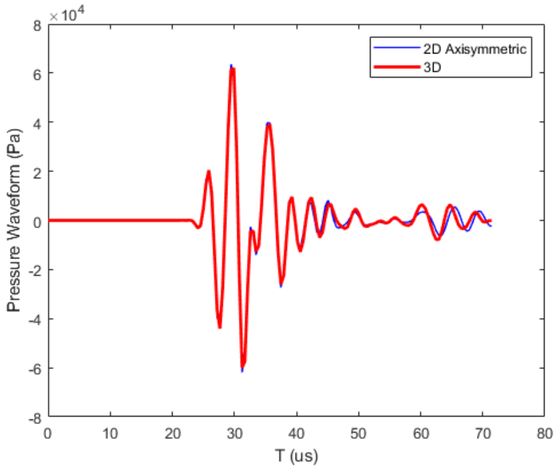


3D Model



3D model results were obtained by evaluating the pressure response at the yz-cut plane (x = 0)





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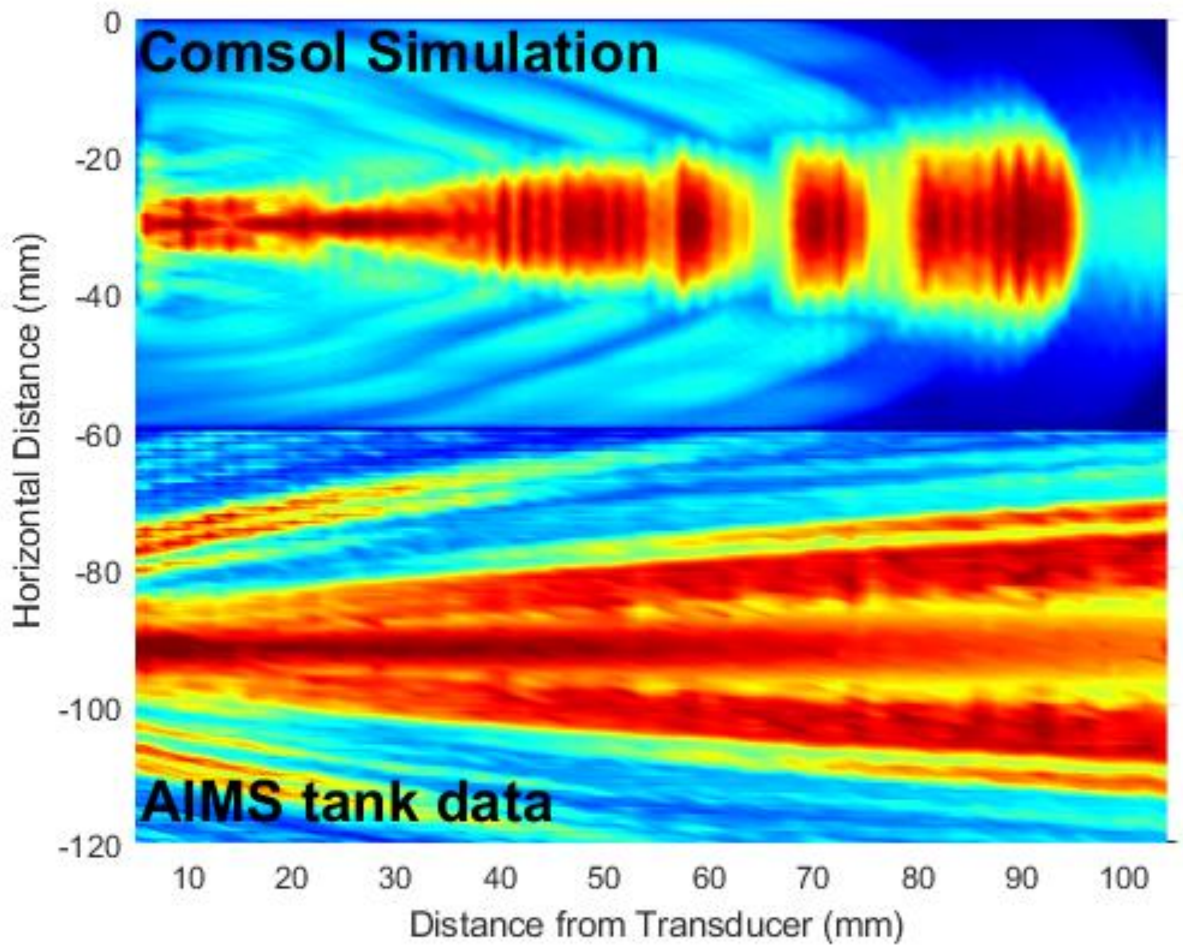
Model Validation

Transducer's center frequency is at 280 kHz
Amplitude is normalized.

Peak Pressure



- Simulation and measurement data agrees well at near field. The maximum pressure is found on axis.
- Side lobes were observed in measurement data, whereas the model results does not exhibit side lobe.
- Local cancellation are found in simulation, while the experiment data shows a continuous decay.

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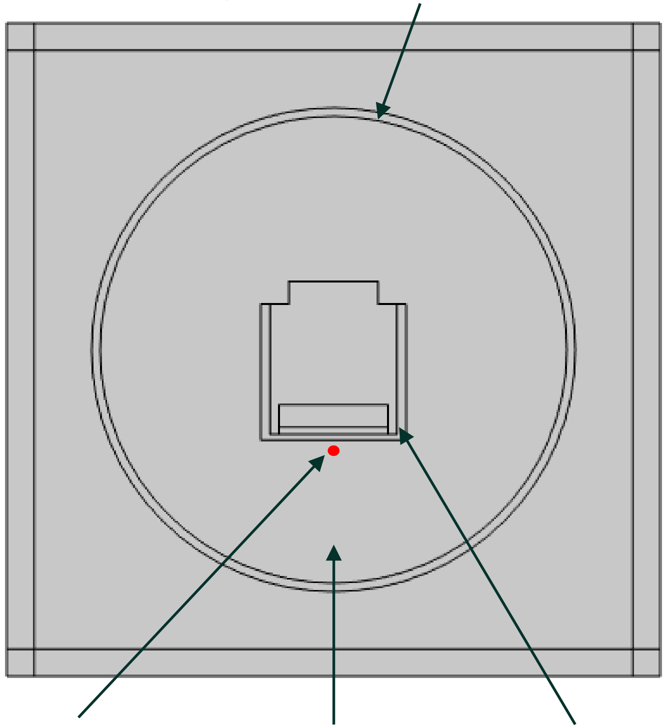
Pulse Echo Simulation

Pulse-echo is an ultrasonic non-destructive testing (NDT) technique using ultrasonic pulsed waves to find defects in materials.

7 in casing (0.5 in thickness)

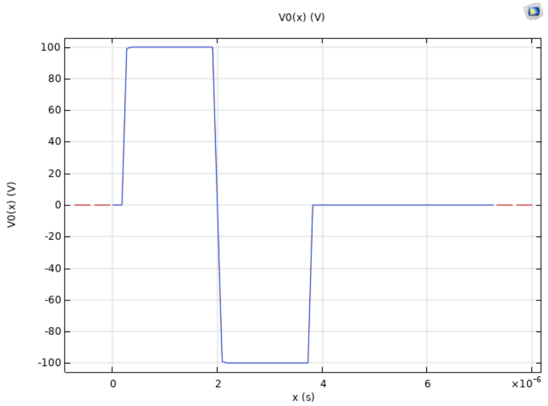


Pressure Probe

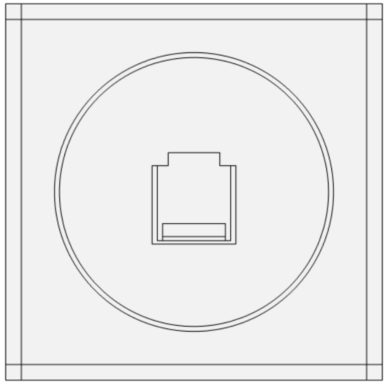
Fluid

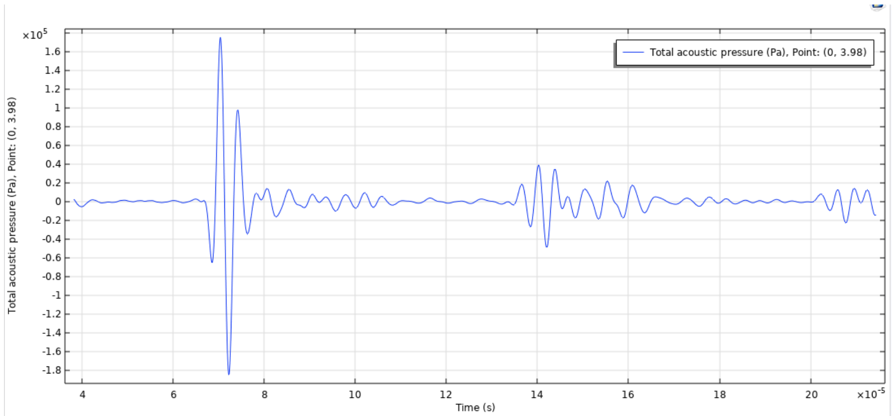
Transducer

Modified Square Pulse Signal



Wave Propagation





Pressure Waveform

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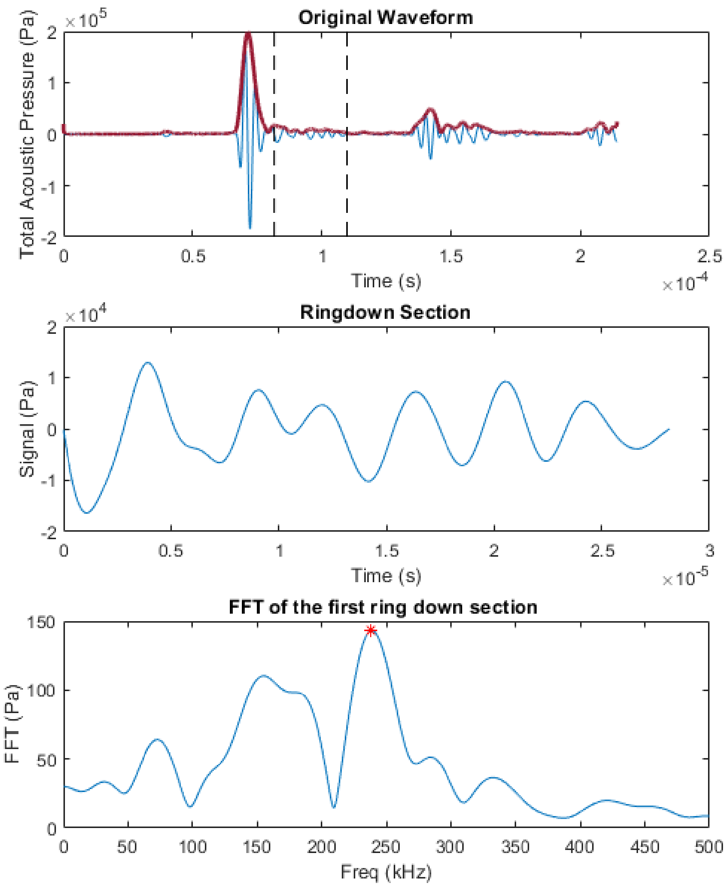
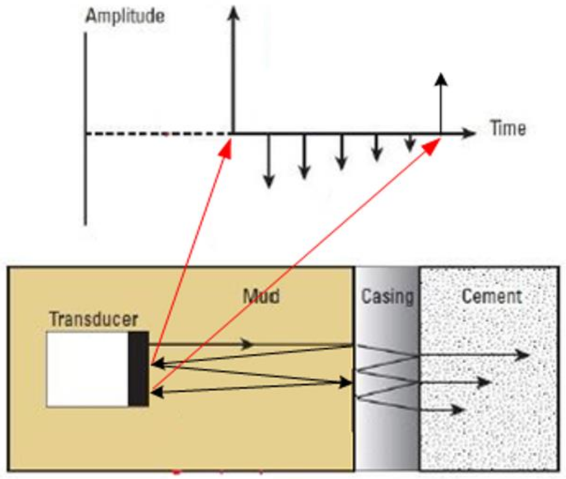
Estimate Casing Thickness

Extract Waveform Envelope using Hilbert Transform



$$h_{casing,estimate} = \frac{c_{p,casing}}{2 * f_{ringdown}} = 0.476\ inch$$

$$h_{casing,actual} = \frac{c_{p,casing}}{2 * f_{ringdown}} = 0.5\ inch$$



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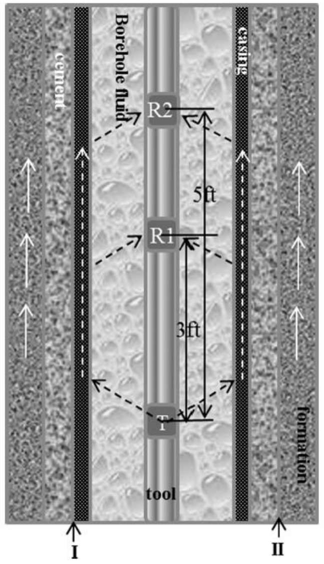
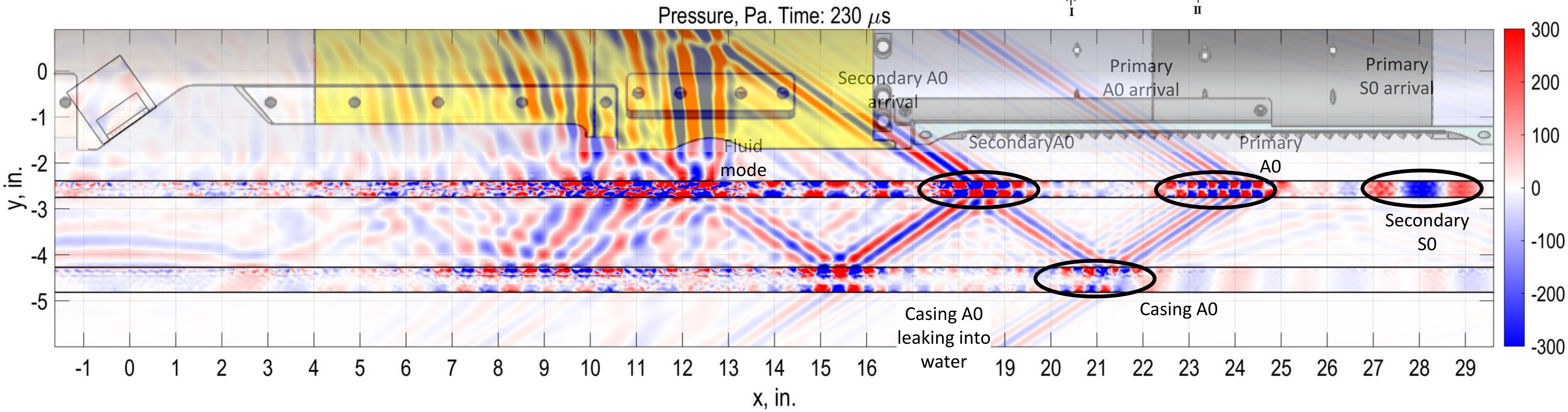
Pitch Catch Simulation

Unlike the pulse-echo testing, where the same transducer is used to send and receive the signal. In pitch-catch testing, a transmitter and one or multiple receiver are used to send and receive the signal





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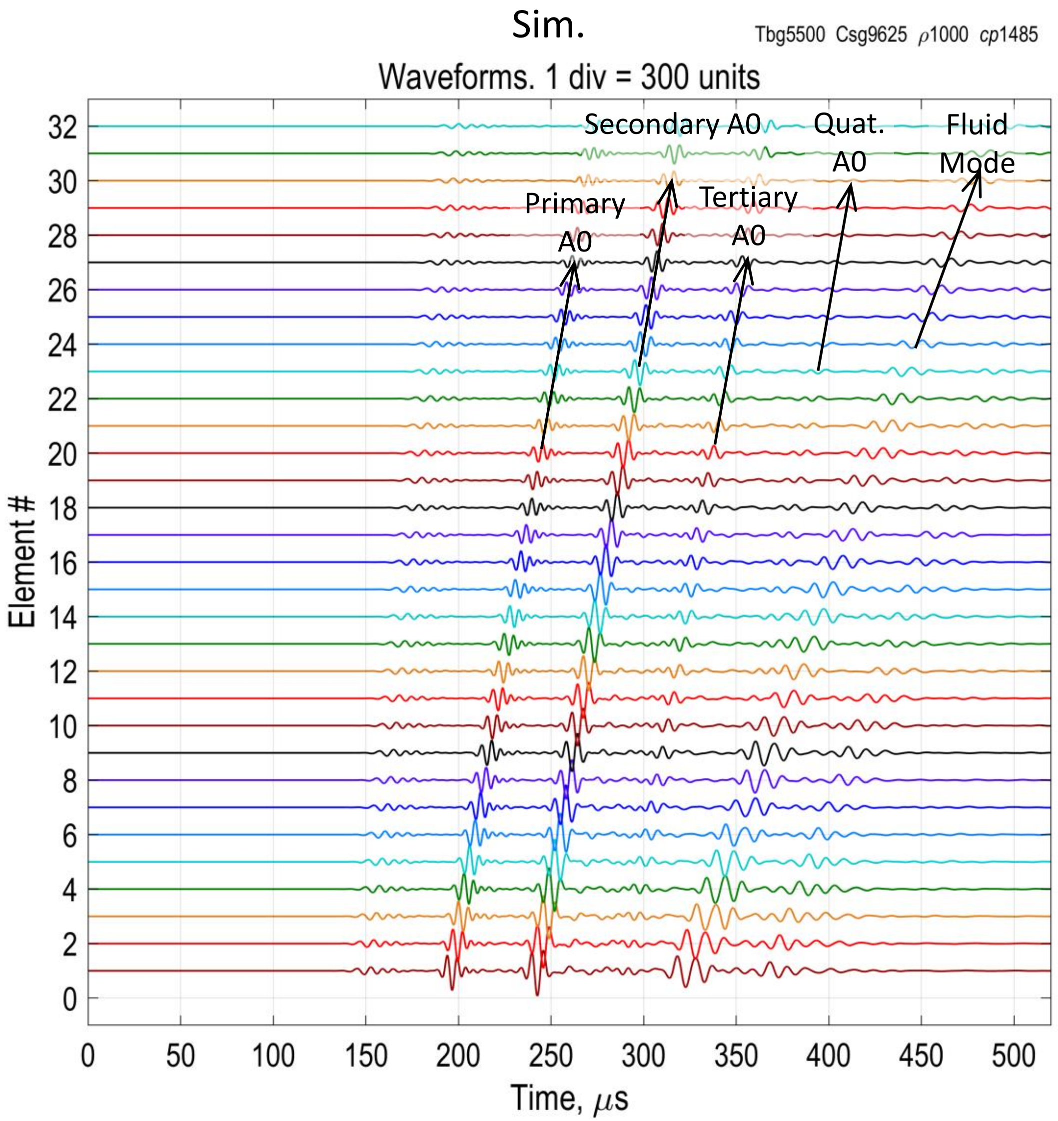
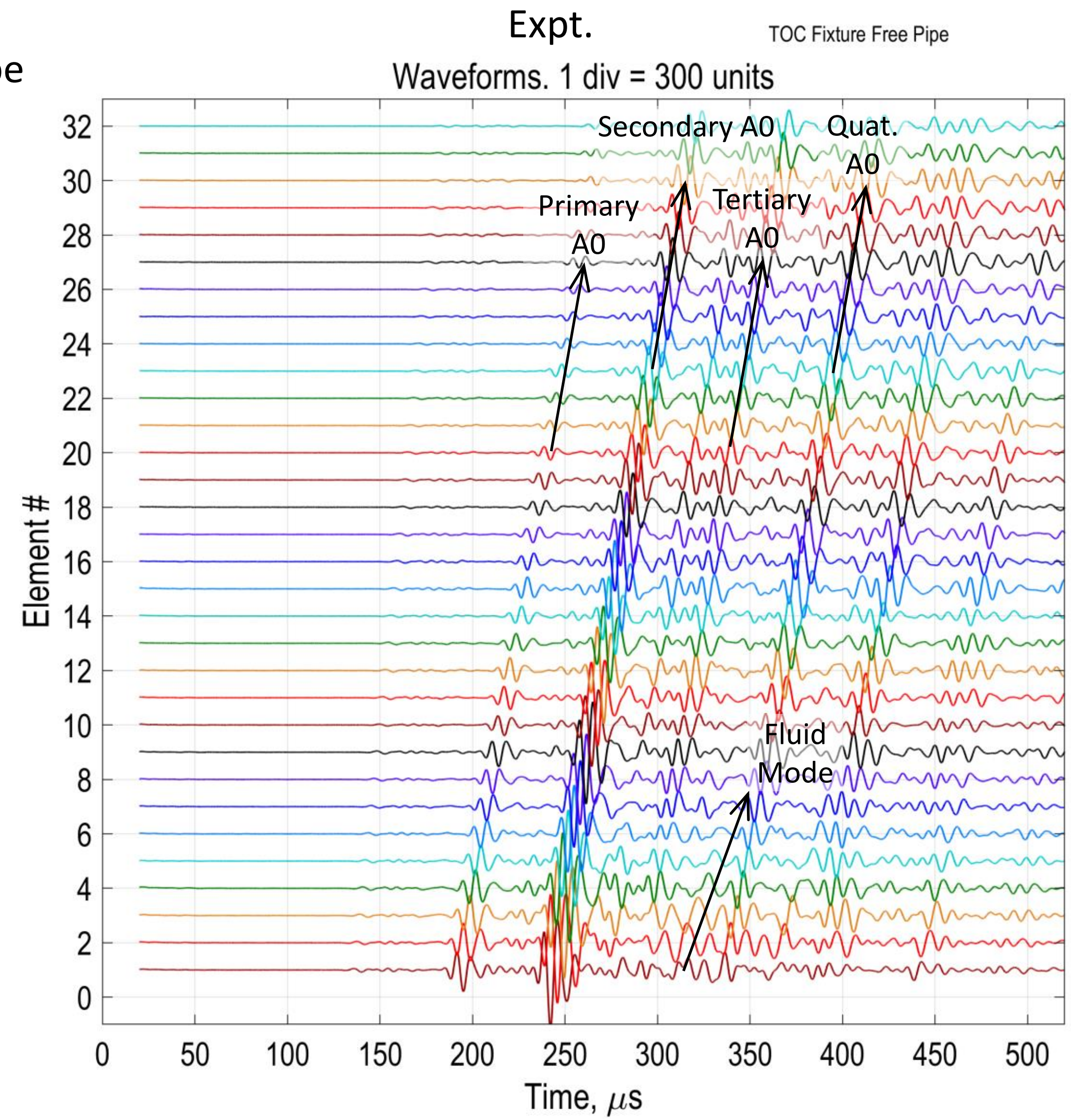
Simulations vs. TOC Fixture Measurements. Waveforms

Free Pipe





Summary

- In this study, ultrasonic piezoelectric transducers are coupled to the fluid to study acoustic wave propagation in pulse-echo and pitch catch simulation.
- The model can be used to characterize transducer's free field response, estimate casing thickness and provide cement bonding evaluation.
- Overall, COMSOL model simulations are capable to capture the experimental response. With good tuning, the model can be used to develop transducers and test setups to reduce prototyping cost.

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