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Validation and Determination of Significant Simulation Parameters Using the Smoothed Particle Hydrodynamic Code Neutrino

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Introduction

- Flooding
  - Occurs throughout the world
  - Can cause extensive damage
  - Cannot be prevented
- Improvements or new tools to optimize the cost of mitigation efforts are valuable
- Simulating flooding events
  - Determine what might get damaged
  - Guide mitigation efforts to prevent damage
  - Need to be validated
  - Need significant parameters identified

Experimental Setup

- Large-scale oscillating tank
- Dimensions: 6 m (19.7 ft) long x 1.2 m (3.9 ft) high x 2.5 m (8.2 ft) wide
- Steel frame with acrylic walls and bottom
- Oscillated using a hydraulic actuator with a sine forcing function
- Pressure transducer on end wall 0.1016 m (4 in) from the bottom

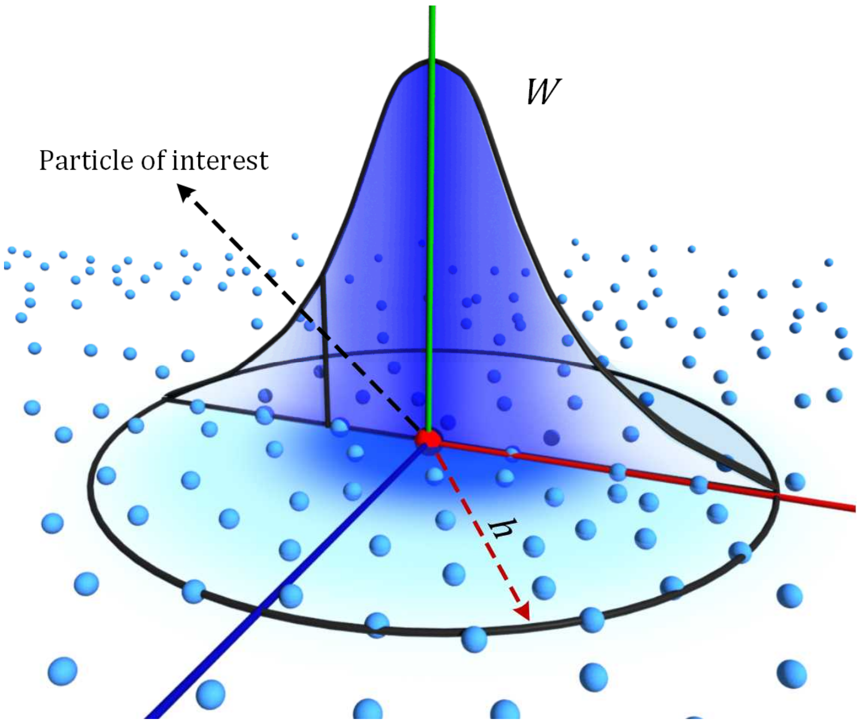
Experimental Setup (cont.)

- Experiment:
  - 0.1524 m (6 in) water depth
  - 0.1016 m (4 in) forcing amplitude
  - 0.11 Hz frequency
  - 60 cycles
  - Repeated 4 times with minor variations to account for some uncertainties

Run	Water Depth (m)	Frequency (Hz)	Amplitude (m)	Variation
1	0.1524	0.11	0.1016	Reference run
2	0.1524	0.11	0.1016	Identical to Run 1
3	0.1524	0.11	0.102108	Change of forcing amplitude by 1%
4	0.1534	0.11	0.1016	Change of water depth by 1 mm

Smoothed Particle Hydrodynamics

- SPH
  - Water discretized into fluid particles
  - No explicit inter-particle connectivity
  - Contribution of surround particles based on a smoothing kernel
    - Cubic B-Spline
- SPH code Neutrino was used
  - Incompressible SPH solver
  - Water-air mixing and surface-tension effects were not modeled
  - Only water phase is considered

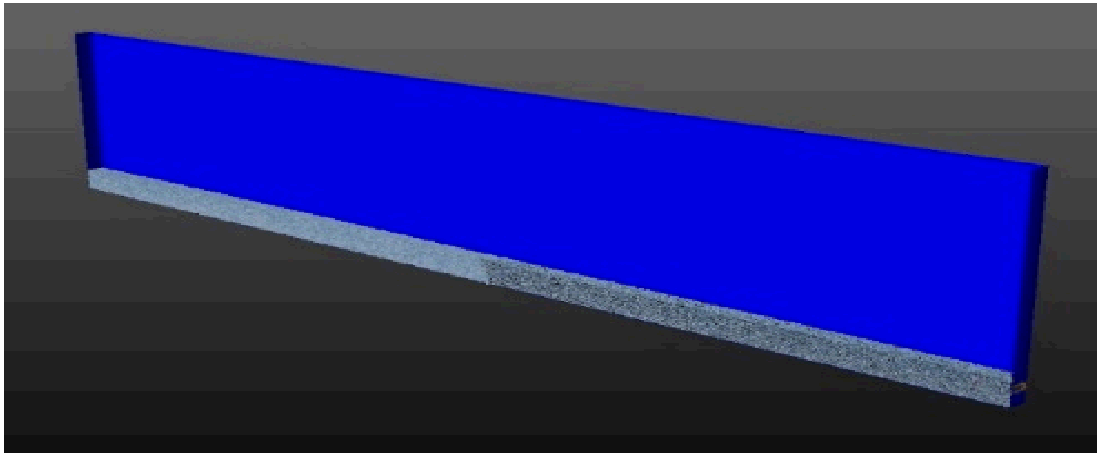


http://neutrinodynamics.com/

Simulation Setup

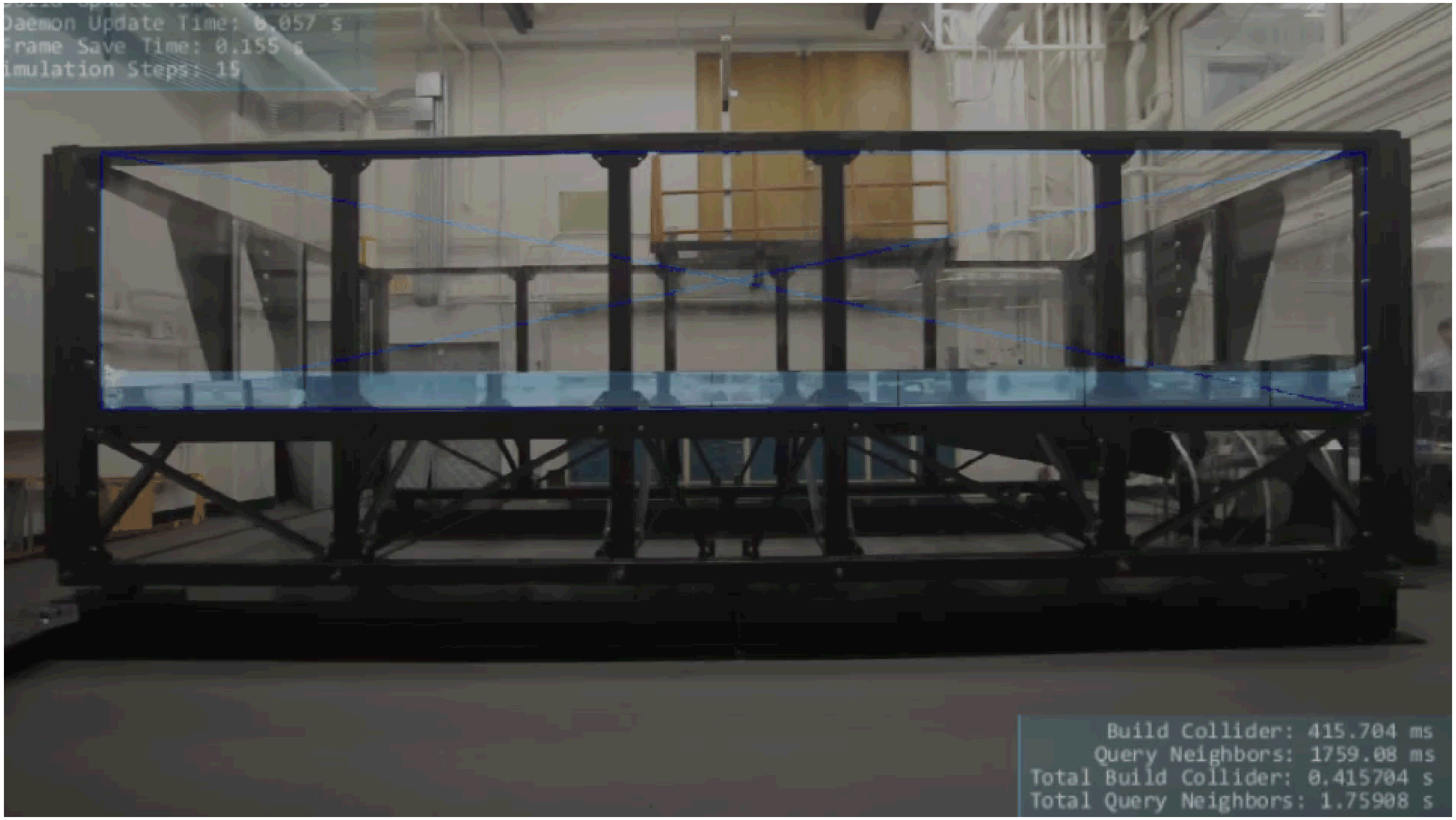
- Constructed to match experimental setup
- Reduced width of simulation tank to 0.2 m
  - Characterized as 2D experiment
  - Computational runtime reduced
    - ~16.7 hours for particle size of 0.01 m for 30 cycles
- Number of fluid particles controlled
- Measurement field for end-wall pressure

- Simulation tank and end-wall measurement field needed to oscillated
  - Dynamic expression python script added to the position of each
  - Used the following equation:
    - $z(t) = A\sin(2\pi f t)$
    - Allows for continuous movement
    - Prevents erratic or explosive-like behavior of the particles



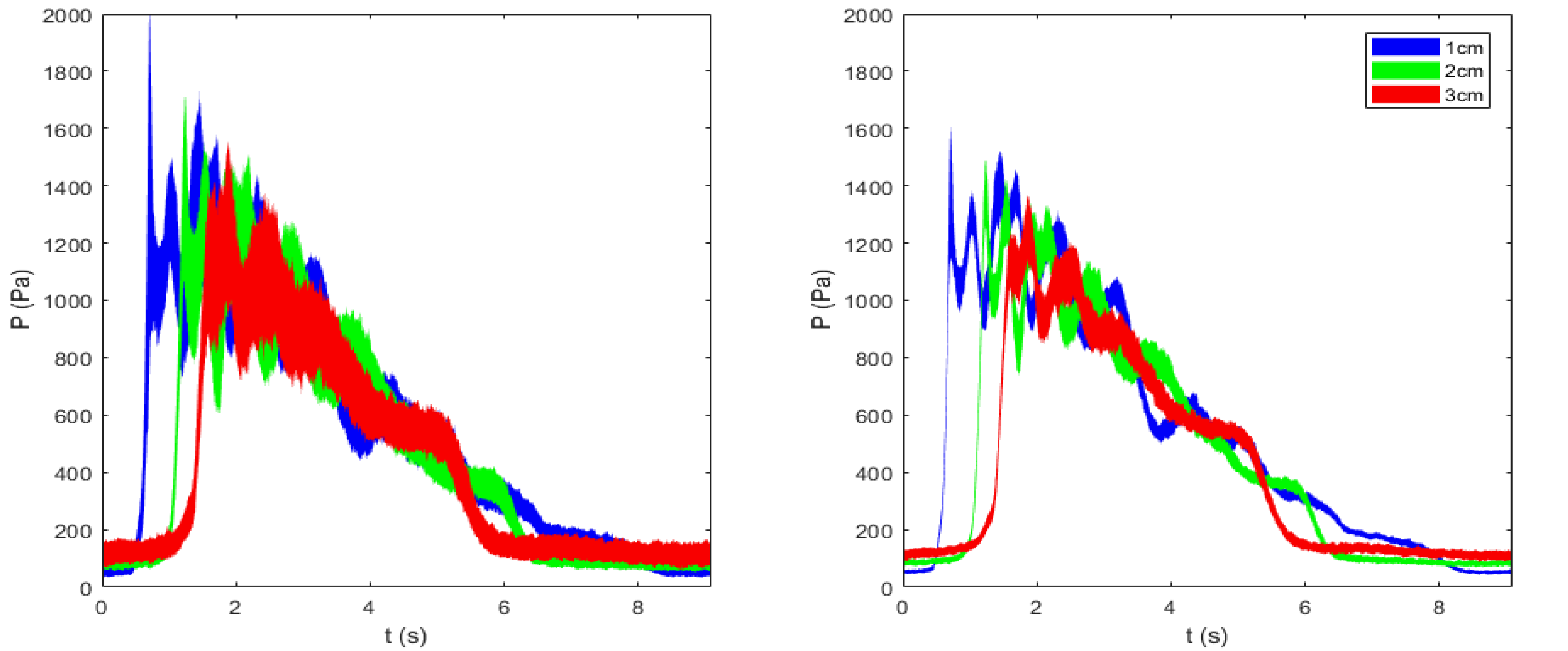
Initial Results Comparison

- Wave surface profile for 0.1016 m (4 in), 0.49 Hz, 30 cycle experiment
  - Qualitative comparison
  - 0.0125 m particle size



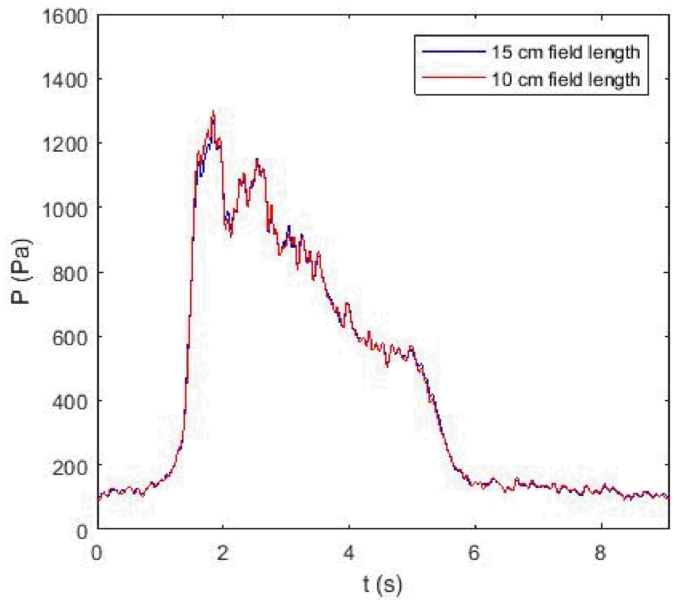
Validation Simulation Conditions

- Varied several parameters to match the experimental results
- Particle size
  - End-wall pressure compared
  - 0.03 m, 0.02 m, and 0.01 m particle sizes
  - Determined the 90% (left) and 50% (right) bounds

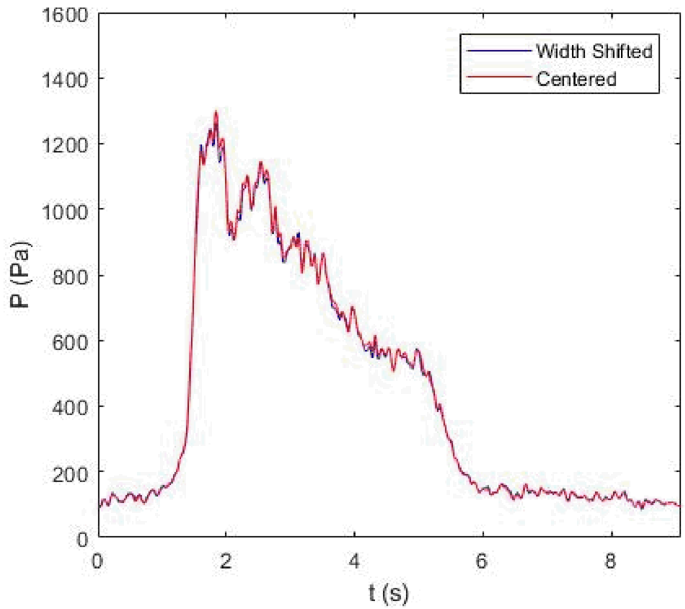


Validation Simulation Conditions (cont.)

- Measurement field size
  - X-axis width constant
    - 2D experiment
  - Y-axis height constant
    - Replicate pressure transducer
  - Adjusted z-axis length
    - 0.15 m and 0.1 m
  - Last 10 of 60 cycles averaged

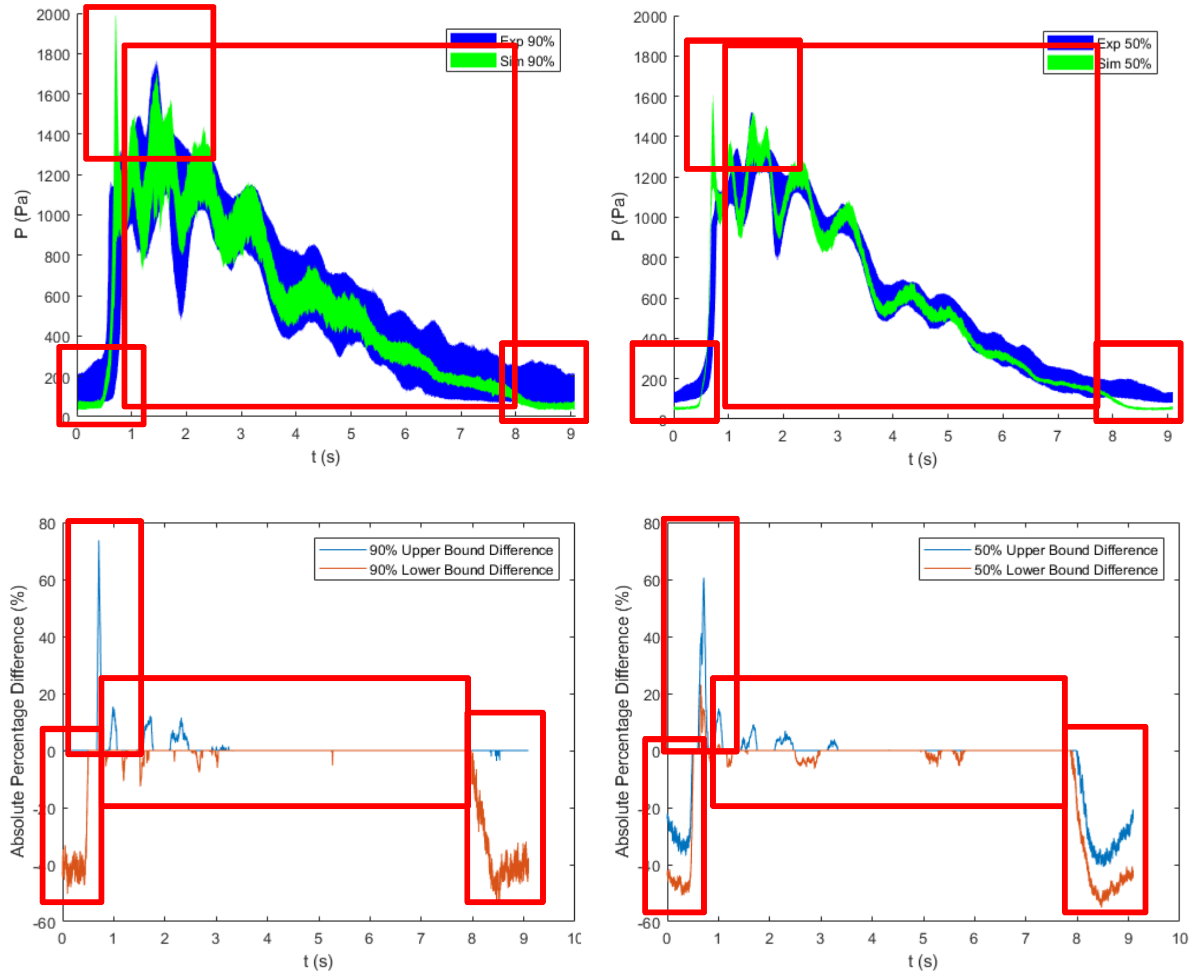


- Measurement field location
  - Y-axis location constant
    - Replicate pressure transducer
  - Z-axis location constant
    - Must be on end-wall
  - Adjusted x-axis location
    - Centered and 0.015 m shift to the right
  - Last 10 of 60 cycles averaged



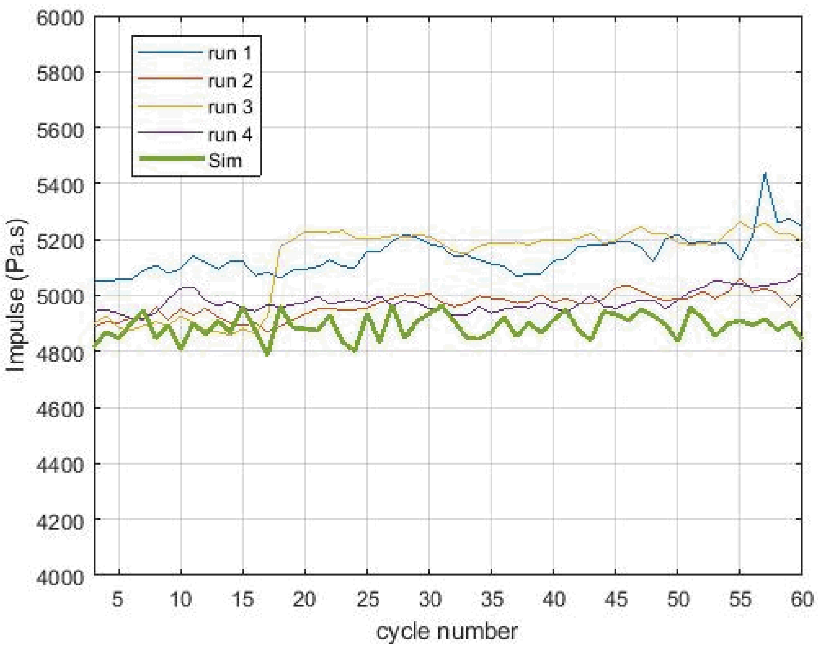
Validation Results

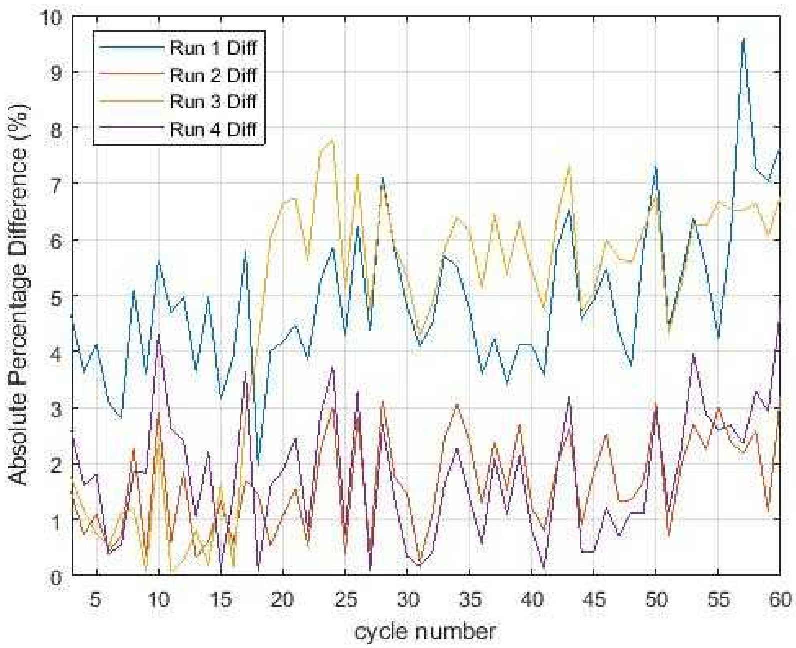
- 90% and 50% pressure bounds compared
- <15% difference majority of the time
- ~40% difference at beginning and end of the cycle
- ~75% difference at peak pressure: time dependent
- ~11% difference at peak pressure: time independent
- Refinement of parameters could improve accuracy



Validation Results (cont.)

- Impulse pressure was compared
- Within 10% for all four experimental runs
- Within 5% for two experimental runs





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Significant Parameter Determination

- More than 30 parameters
  - Neutrino simulation parameters
  - Experimental measurement uncertainty
- Parameters selected based on applicability to the experiment
- 7 parameters selected for investigation

Parameter	Importance Discussion
Stop threshold	Affects the level of incompressibility enforcement.
Particle size	Changes the resolution of the simulation.
Interaction-Radius to Particle-Size Ratio	Changes the number of particles influencing the particle of interest.
Fluid settling uncertainty	Affects the fluid depth.
Forcing function amplitude uncertainty	Affects the forcing function of the simulation.
Forcing function frequency uncertainty	Affects the forcing function of the simulation.
Pressure transducer location uncertainty	Affects the measurement field location in the simulation.

Significant Parameter Determination (cont.)

- Used RAVEN to determine significant parameters
- Neutrino and RAVEN coupled
  - RAVEN can modify input files, run, and analyze Neutrino results

- Methodology
  - Select a single parameter
  - Determine parameter's value range
    - Uniform distribution
  - Sample 5 values
    - Monte Carlo sampler
  - Plot results for comparison

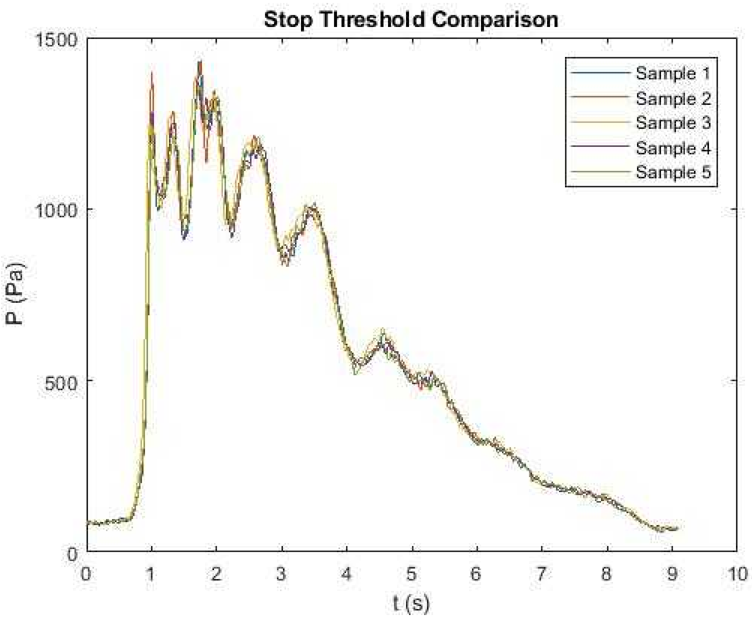
Parameter	Value Range	Default Value
Stop threshold	0.0001 to 0.01	0.001
Particle size	0.007 m to 0.02 m	0.01 m
Interaction-radius to particle-size ratio	2.0 to 2.4	2.0
Fluid settling uncertainty	$-0.4\delta_r$ to $0.4\delta_r$*	0
Forcing function amplitude uncertainty	0.1012 m to 0.102 m	0.1016 m
Forcing function frequency uncertainty	0.1099868 Hz to 0.110011 Hz	0.11 Hz
Pressure transducer location uncertainty	0.1006 m to 0.1026 m	0.1016 m
* where δ_r is the particle size		

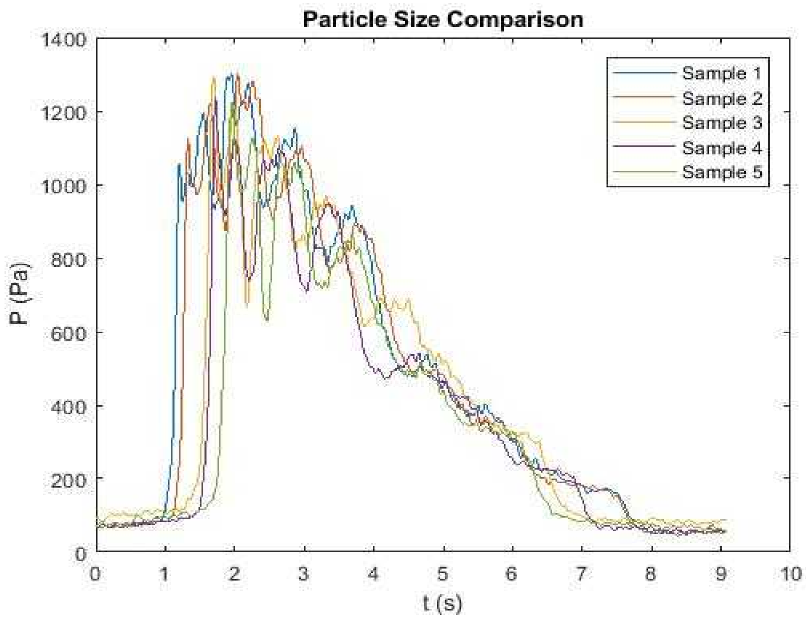
Significant Parameter Results

- Sampled 5 values per parameter using RAVEN
- Ran 30 cycles of the tank
- Average pressure for each sample was plotted for comparison
- 35 total simulations

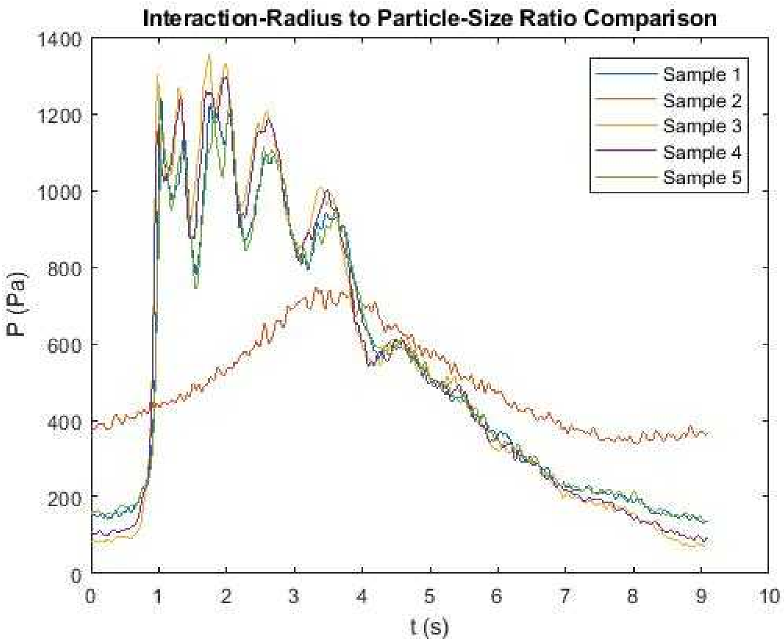
Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Stop threshold	0.005188	0.009604	0.000482	0.008365	0.004260
Particle size (m)	0.009004	0.009710	0.018166	0.011869	0.017700
Interaction-radius to particle-size ratio	2.083384	2.149816	2.013502	2.042695	2.089326
Fluid settling uncertainty	0.027887	0.920035	-0.922877	0.669684	-0.691674
Forcing function amplitude uncertainty (m)	0.101436	0.101541	0.101956	0.101291	0.101270
Forcing function frequency uncertainty (Hz)	0.110007	0.110008	0.110011	0.109989	0.109992
Pressure transducer location uncertainty (m)	0.102298	0.102340	0.101516	0.102578	0.101047

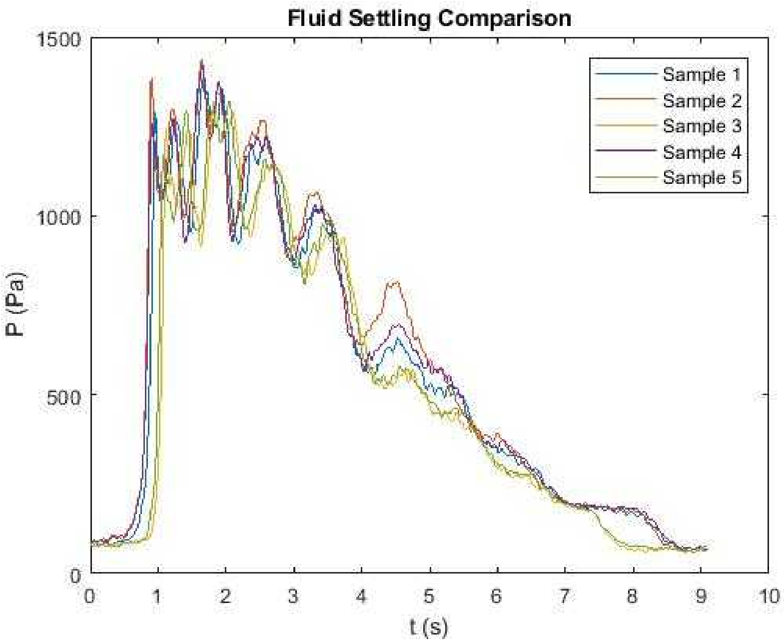
Significant Parameter Results (cont.)



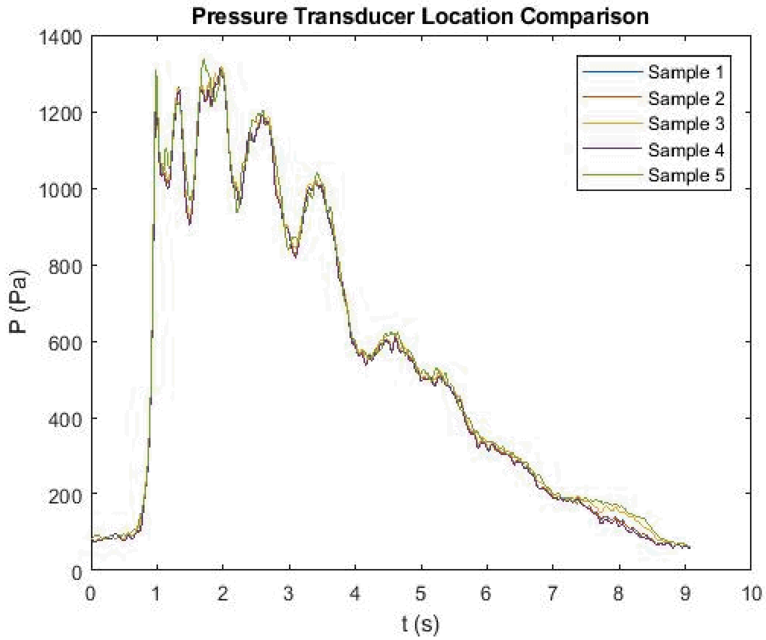


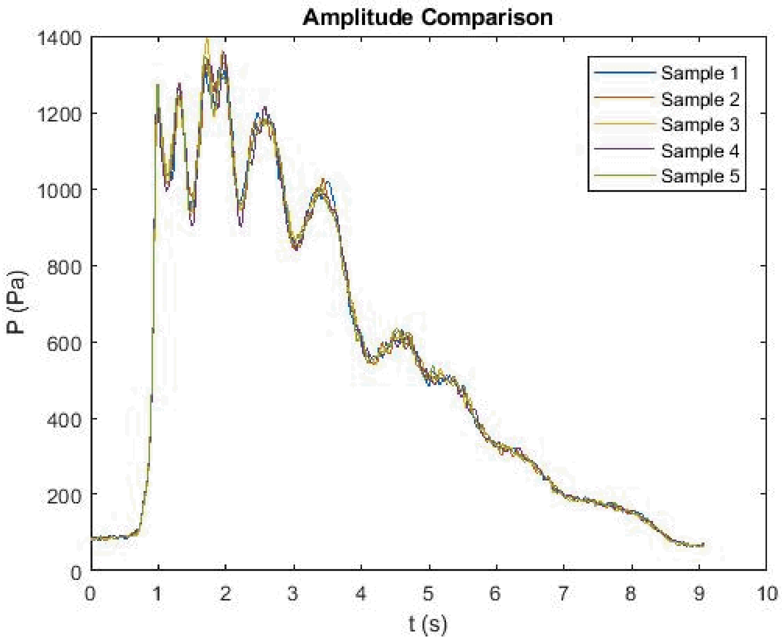
Significant Parameter Results (cont.)





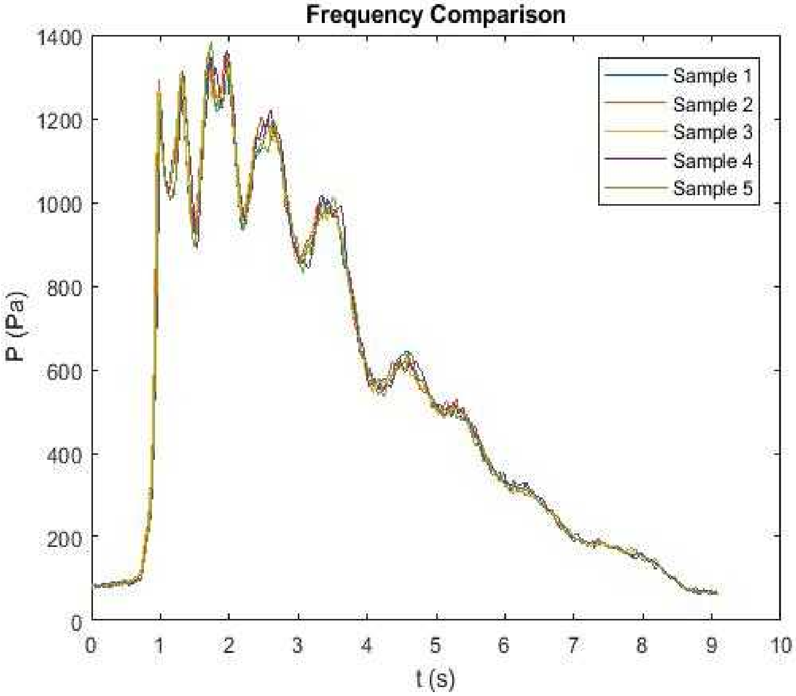
Significant Parameter Results (cont.)





Significant Parameter Results (cont.)

- All parameters provide some influence to the output
- High fluctuation parameters
  - Particle size
  - Interaction-radius to particle-size ratio
  - Fluid settling
- More research needed to quantify the significance of each parameter



Conclusion

- Large-scale oscillating tank experiment conducted and simulated using Neutrino
- 90% and 50% pressure bounds compared
  - <15% difference the majority of the time
  - ~40% difference at beginning and end of the cycle
  - ~75% difference at peak pressure: time dependent
  - ~11% difference at peak pressure: time independent
- Pressure impulse compared
  - Within 10% of all four experimental runs
- Identified 7 parameters from over 30 parameters
- Used RAVEN to randomly sample 5 values for each parameter
- Particle size, interaction-radius to particle-size ratio, and fluid settling provided greatest fluctuation of output
- Current work and next steps:
  - Quantify significance of each parameter
  - Wave surface profile and velocity comparisons
  - Optimize the values of the significant parameters

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