SPACE LAUNCH SYSTEM SCALE MODEL ACOUSTIC TEST IGNITION OVERPRESSURE TESTING

Don Nance and Peter Liever

Jacobs ESSSA Group/MSFC ER42

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Summary

- Multiple transient events occur during the startup of the solid rocket motors for each test in the SMAT IOP test series; this simulates what is expected for SLS
  - Only interested in the SMAT solid rocket motors for overpressure analysis
  - SMAT liquid engines are not appropriate SLS Core engine overpressure analysis
- Each event produces a complex transient signal and requires systematically assessing each instrument’s waveform individually
- The events characterized and discussed are
  - Source overpressure (SOP)
  - Ignition overpressure (IOP)
  - Duct overpressure (DOP)
- The overpressure suppression system architecture is evaluated and suppression system knockdown factors are determined and compared to the SLS baseline
- The SMAT IOP test series are used to validate the CFD models used to generate the SLS IOP environments and also verify the environments

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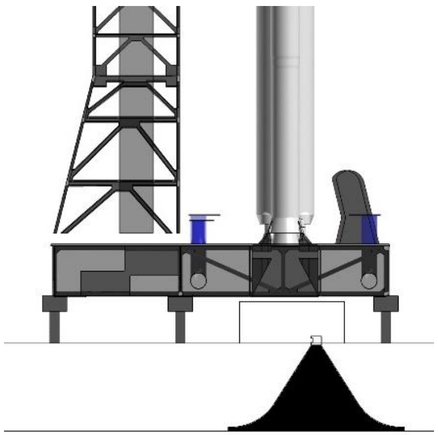
SMAT IOP Series

- Objectives:
  - Support the verification of the predicted SLS IOP environments *Work in progress*
    - Obtaining data for use in IOP analytical models
    - Improve of IOP analytical models
  - Quantify the effectiveness of the IOP suppression system *Work completed*

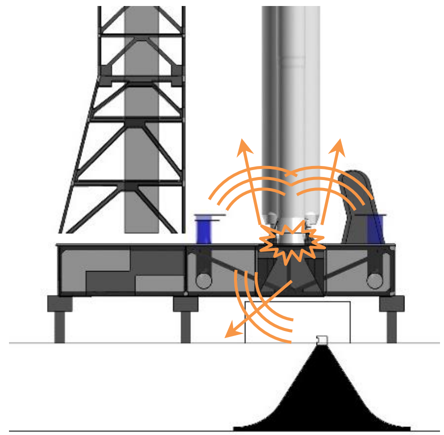
- Consisted of three primary hot fires with the vehicle in the hold-down position

Test ID	Date	Configuration Description	Water Sound Suppression Systems Target Flow Rates		
			Rainbird (gpm)	Exhaust Hole (gpm)	LPT (gpm)
PC123-FA-HF-01	16-Apr-2014	Full Assembly Hold-Down Dry	0	0	0
PC123-FA-HF-02	24-Apr-2014	Full Assembly Hold-Down Wet	0	226	866
PC123-FA-HF-03	02-May-2014	Full Assembly Hold-Down Wet	0	226	866

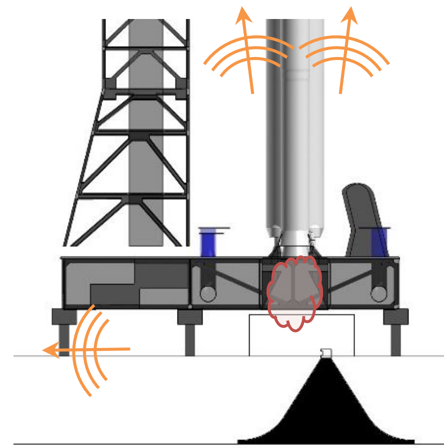
Overpressure Event Identification and Characterization



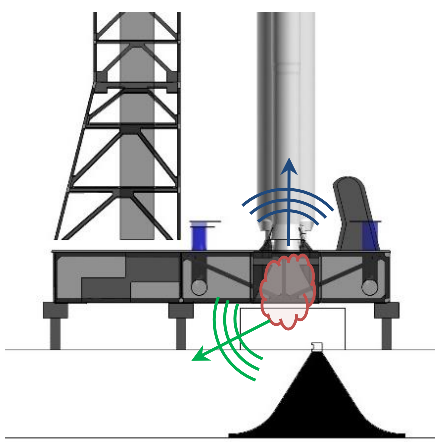
(a) Ignition command sent



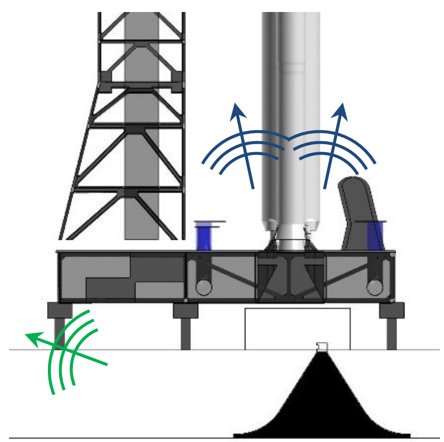
(b) Igniter pulse develops near nozzle



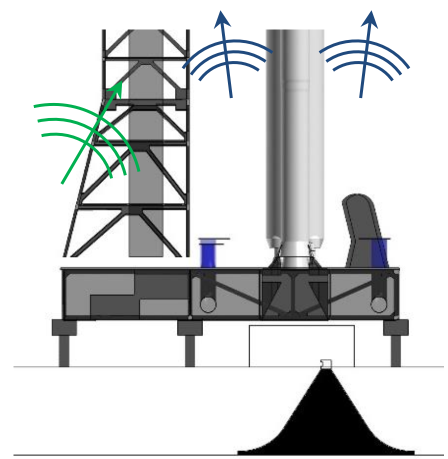
(c) Igniter pulse propagates up the vehicle



(d) SOP develops

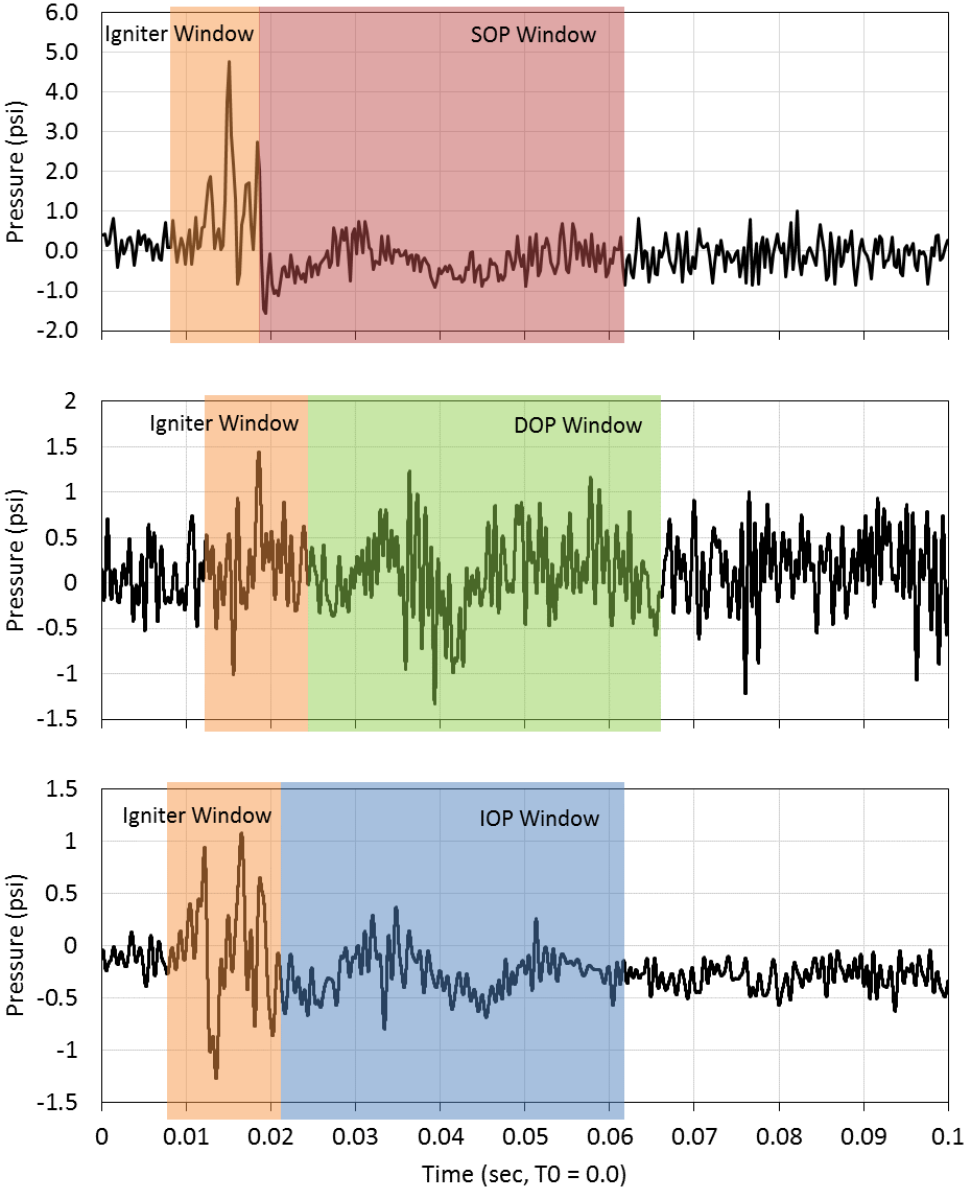


(e) IOP and DOP propagate out exhaust duct and trench

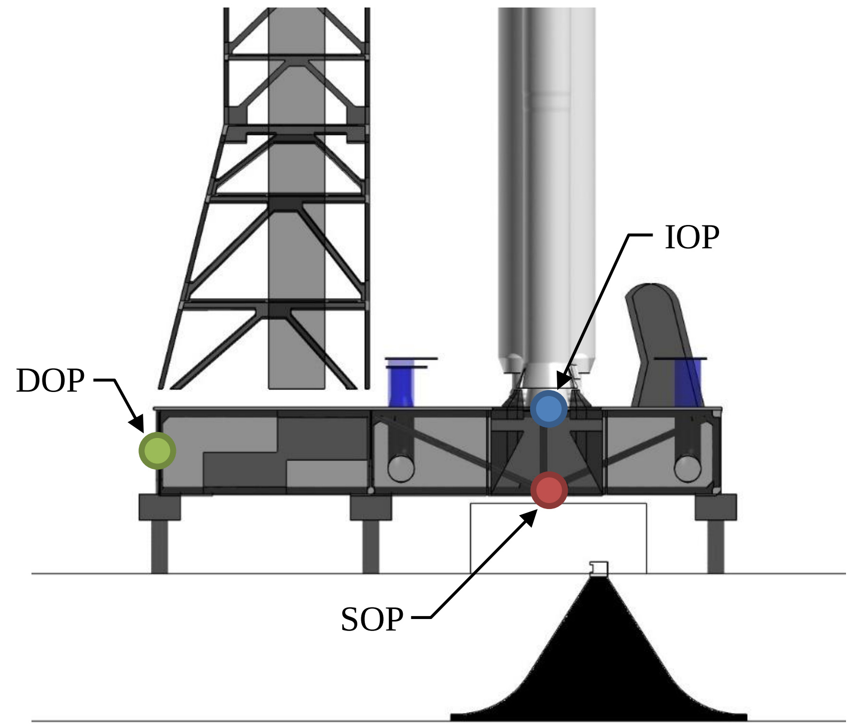


(f) IOP and DOP impinge along the vehicle

Overpressure Event Identification and Characterization



Measurement Locations



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Frequency Scaling

- Frequency scaling is used to determine the low-pass filter model-scale cutoff frequency that corresponds to the desired full-scale overpressure cutoff frequency

$$f_S = \frac{\dot{P}_S}{\dot{P}_F} \frac{\overline{P}_F}{\overline{P}_S} f_F$$

Chamber Pressure Rise Rate Ratio | Steady State Chamber Pressure Ratio

- The full-scale motor performance parameters were obtained from the five-segment reusable SRM demonstration motor number 1 (RSRMV-DM1) data
- Subscale cutoff frequency corresponding to a full-scale frequency of 100Hz

SMAT Test ID	East RATO Cutoff Frequency (Hz, based on RSRMV-DM1)	West RATO Cutoff Frequency (Hz, based on RSRMV-DM1)
PC123-FA-HF-01	1,433	1,438
PC123-FA-HF-02	1,256	1,320
PC123-FA-HF-03	1,304	1,482

- Prior to further post-test data reduction, the subscale data were filtered using a Chebyshev type II IIR low-filter with a cutoff frequency of 1500 Hz
  - To simplify the analysis a common subscale cutoff frequency of 1500 Hz was used for all data sets
  - The implications of the use of this common subscale cutoff frequency are minor in terms of the subsequent data reduction because the amplitude contribution at higher frequencies is very small and does not make an appreciable difference in the resulting amplitude

Amplitude Scaling

- Amplitude scaling is necessary to determine the equivalent full-scale amplitude of the subscale data
- Amplitude scaling theory is required to account for differences in motor-to-motor ballistics to aid in the determination of knockdown factors between tests; however, the full-scale equivalent amplitude of the subscale data gathered during the SMAT IOP test series is not of interest for analysis described herein
- The basic amplitude scaling equation shown below simply for edification

Overpressure Peak Ratio

Effective Duct Diameter Ratio

$$\frac{P_F^+}{P_S^+} = \frac{D_F}{D_S}\frac{\dot{P}_F}{\dot{P}_S}\frac{\bar{P}_S}{\bar{P}_F}$$

Chamber Pressure Rise Rate Ratio

Steady State Chamber Pressure Ratio

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Ballistics Scaling

- Ballistics scaling is required to accurately compare the subscale tests and evaluate the effectiveness of the IOP suppression system scaling

$$BF_B = \frac{\bar{P}_B}{\bar{P}_A}\frac{\dot{P}_A}{\dot{P}_B}$$

Steady State Chamber Pressure Ratio | Chamber Pressure Rise Rate Ratio

- Average test-to-test ballistics factors for the primary SMAT IOP hot fires

Ballistics Factor	Average
BF_1 for HF-02 to HF-01	0.897
BF_1 for HF-03 to HF-01	1.028
BF_2 for HF-01 to HF-02	1.115
BF_2 for HF-03 to HF-02	1.146
BF_3 for HF-01 to HF-03	0.973
BF_3 for HF-02 to HF-03	0.873

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Knockdown Factors

- Knockdown factors are values that represent ratios of the overpressure amplitude in one configuration to the overpressure amplitude in another configuration, e.g., from the dry configurations to the water-suppressed configurations
- Zero-to-peak amplitude is commonly used to calculate the knockdown factor, but in more complex waveforms, peak-to-peak amplitudes may also be used
- Motor-to-motor differences must be taken in account when determining knockdown factors

$$KF = \frac{P_A^+}{P_B^+ BF_B}$$

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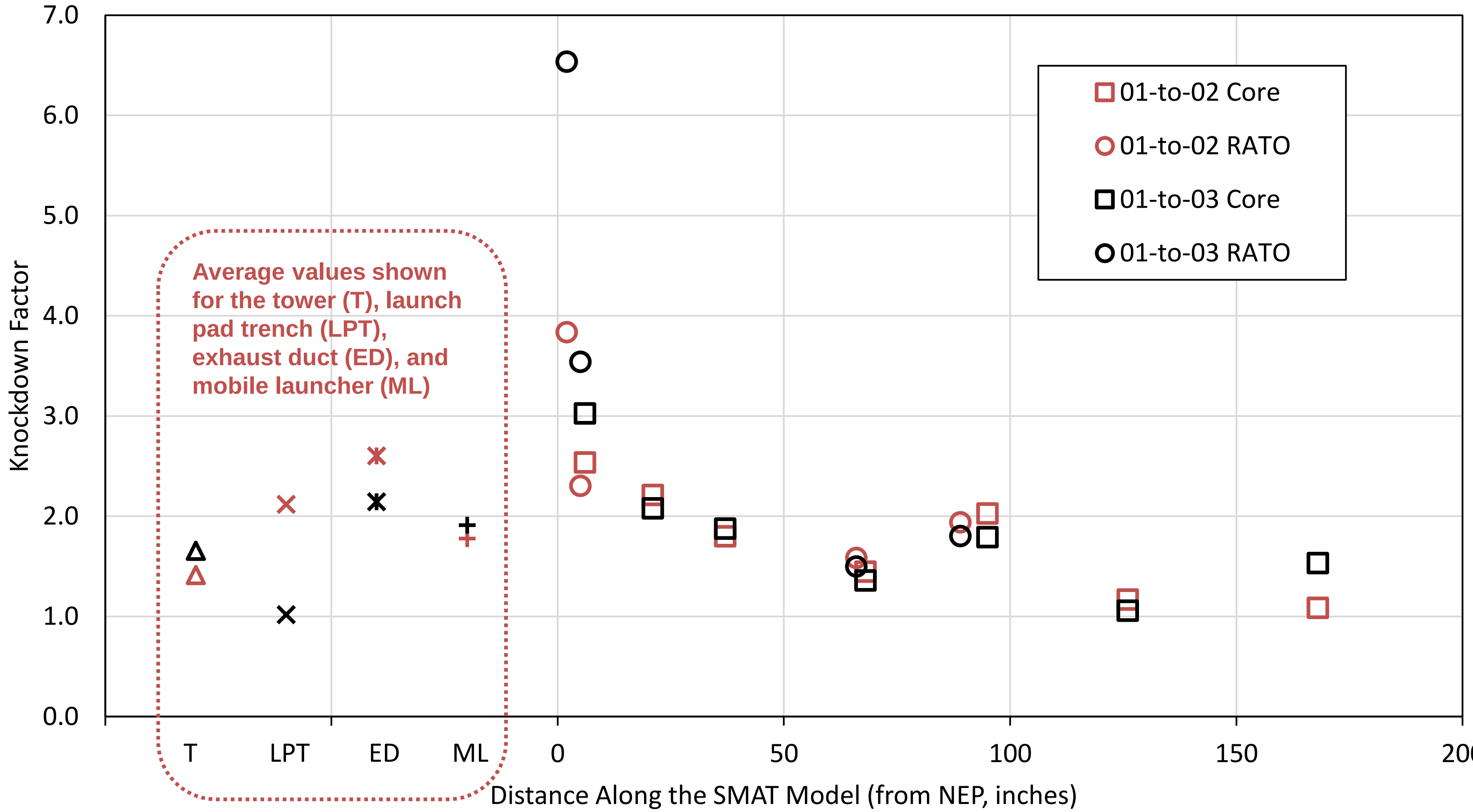
Knockdown Factors



The average zero-to-peak knockdown factor along the vehicle model for 01-to-02 is 2.0, and the average for 01-to-03 is 2.4.

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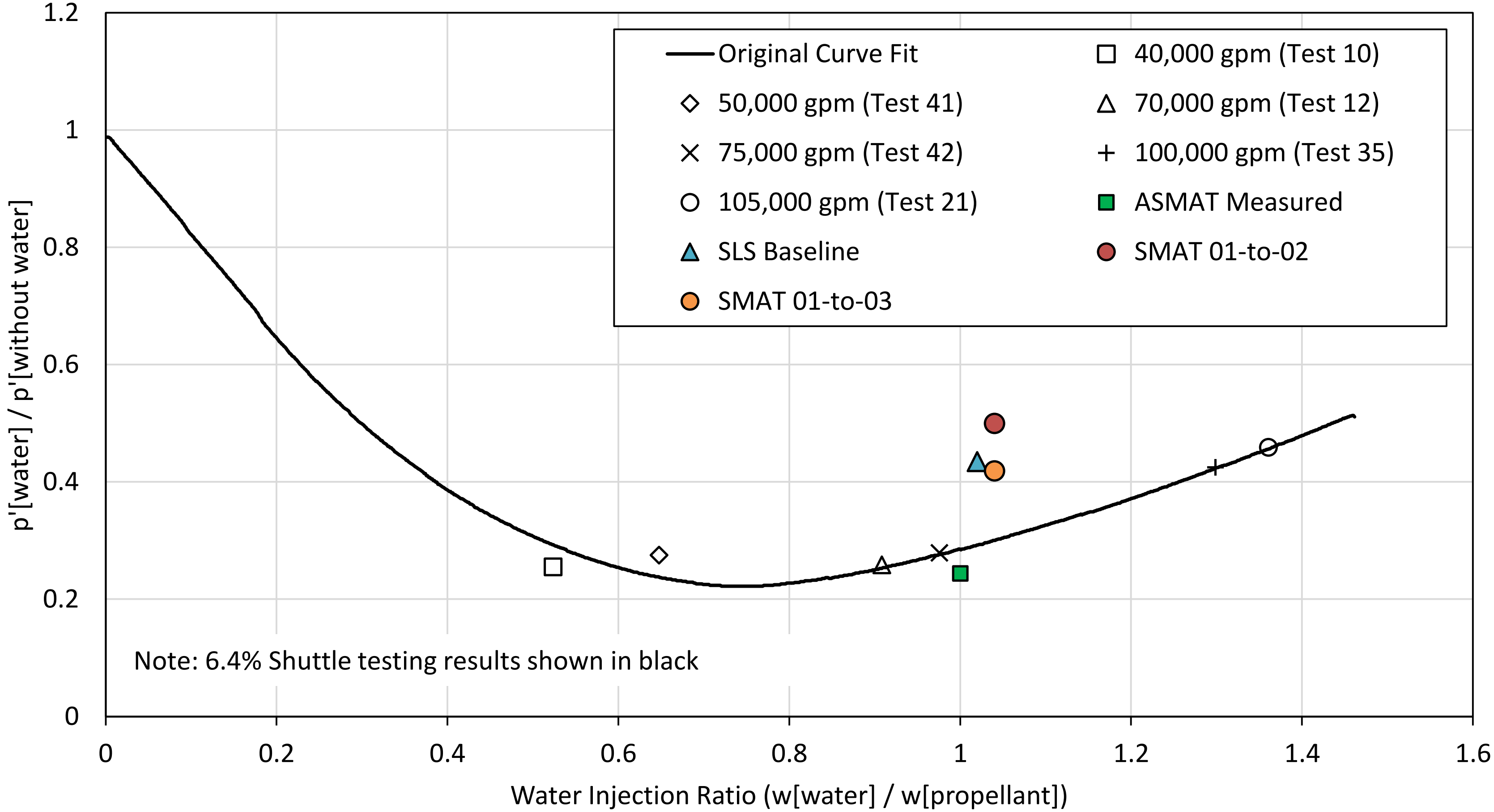
Knockdown Factor Comparison



It should be noted that Williams et. al.* has shown droplet size and droplet survival distance to be inconsequential in regards to the scaling of knockdown factors from subscale to full scale architectures; thus the scaling of the knockdown factors provided herein from SMAT to SLS is one-to-one

*Williams, B., Davis, P., Putnam, G., and Yang, H., "Input for Space Launch System Scale Model Acoustics Test Review," ESSSA-FY14-01944, September 2014

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CFD Model

- SMAT HF-01
  - Vehicle model in the hold-down position
  - Dry, no sound suppression system water

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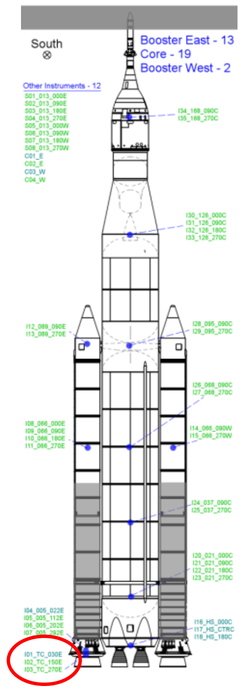
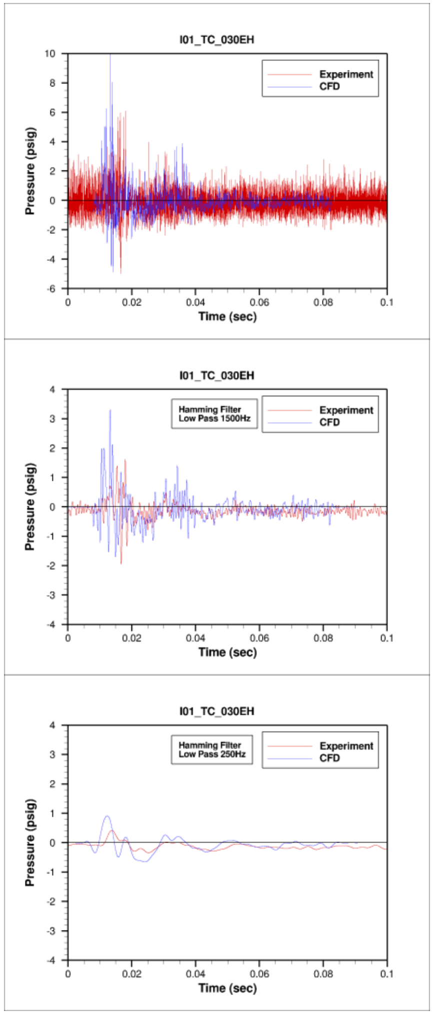
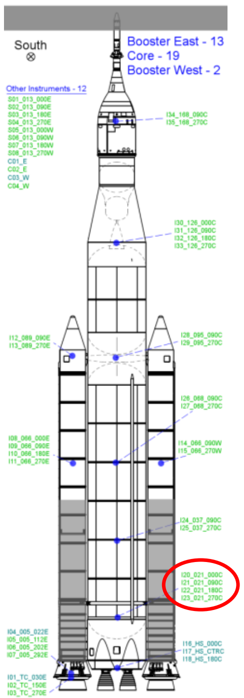
CFD Results – Vehicle Model Aft End



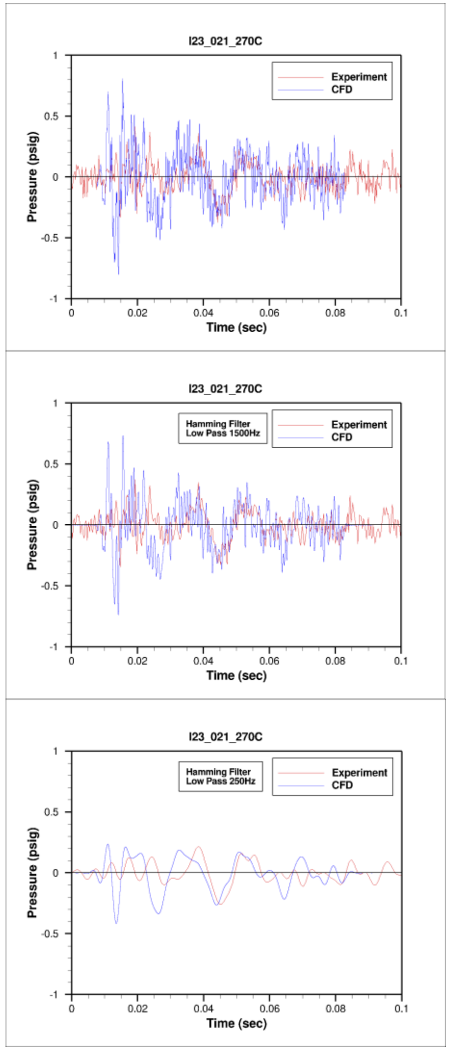
Location: East Booster, Aft Skirt Thermal Curtain, Pointed Down, 30°
Sample rate: 256000 Hz

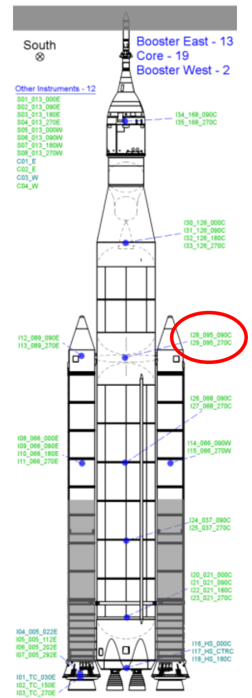


CFD Results – Along the Vehicle Model

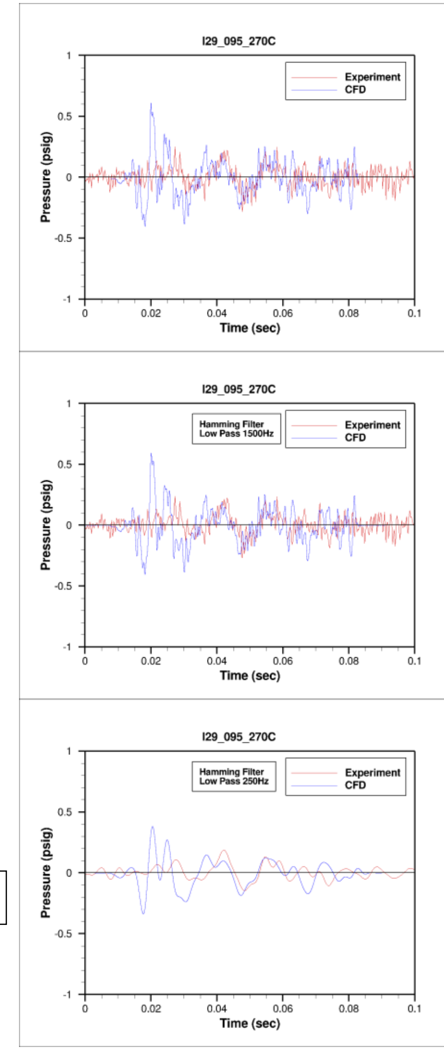


Location: Core/C3-1/270°
Sample rate: 4000 Hz





Location: Core/C4/270°
Sample rate: 4000 Hz



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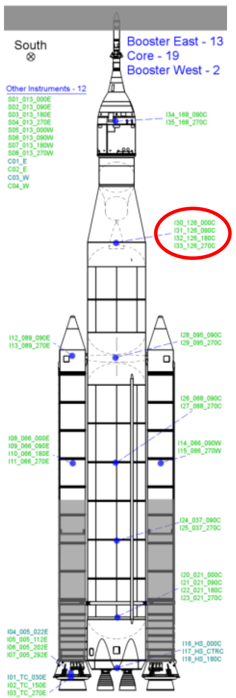
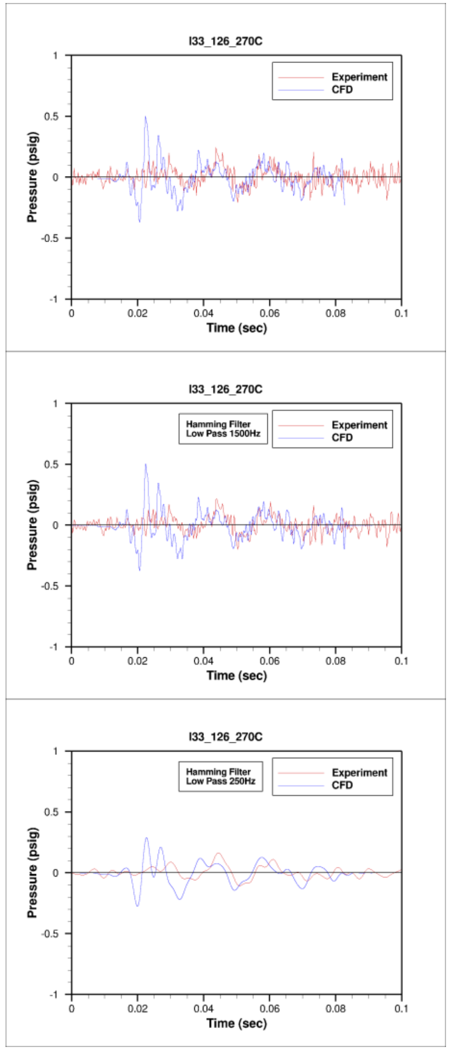
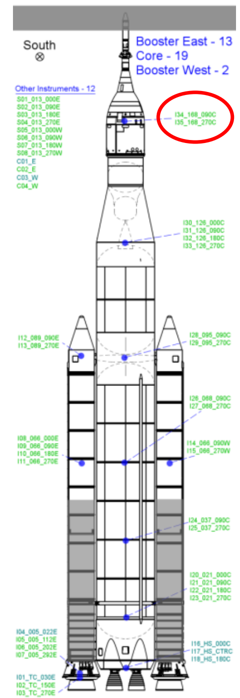
CFD Results – Along the Vehicle Model

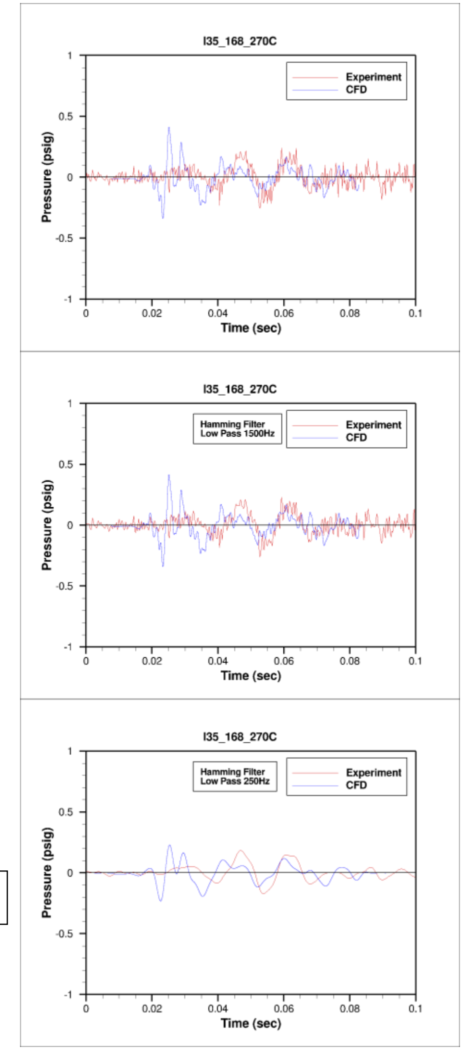


Location: Core/P1/270°
Sample rate: 4000 Hz





Location: Core/P4/270°
Sample rate: 4000 Hz



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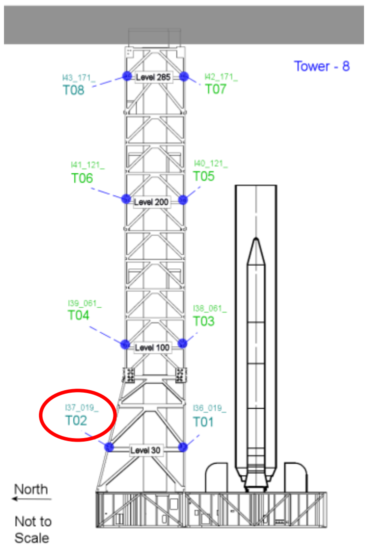
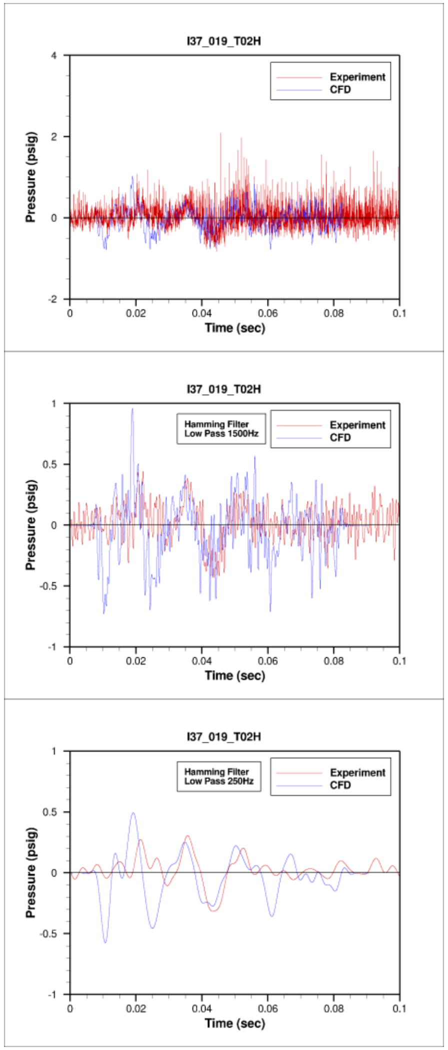
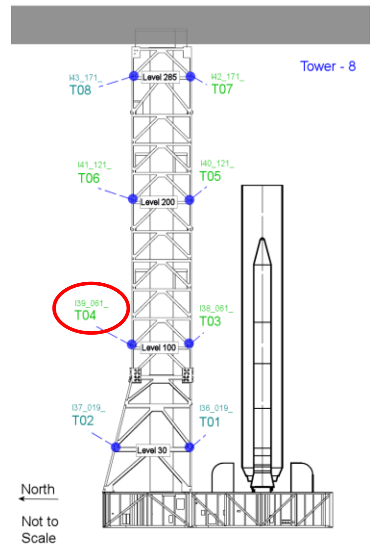
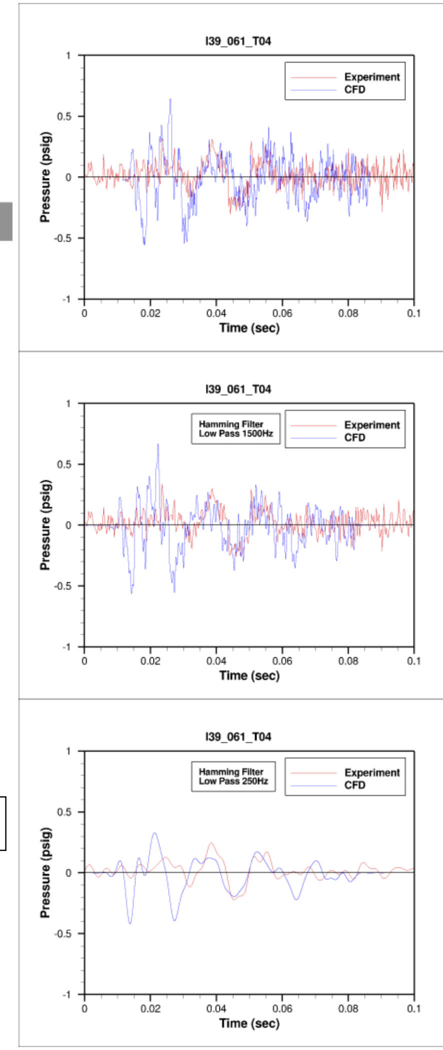
CFD Results – Along the Tower





Location: Tower/Trench Side/Level 30
Sample rate: 256000 Hz





Location: Tower/Trench Side/Level 100
Sample rate: 4000 Hz

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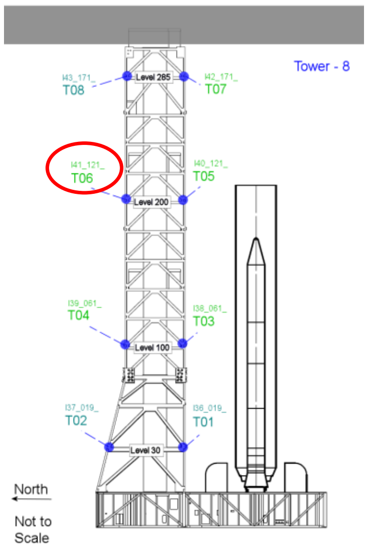
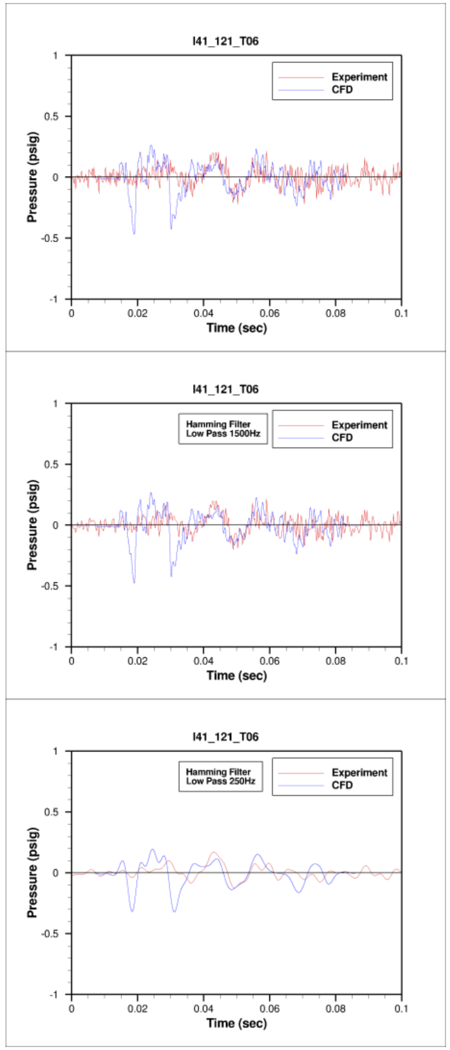
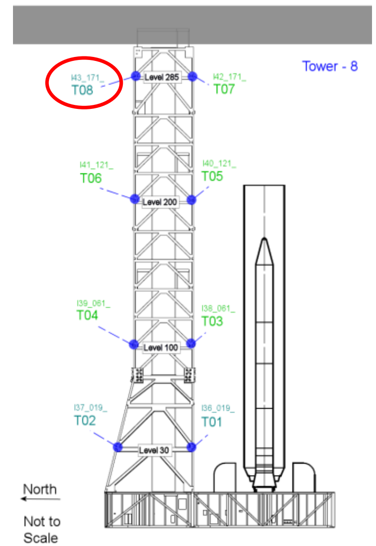
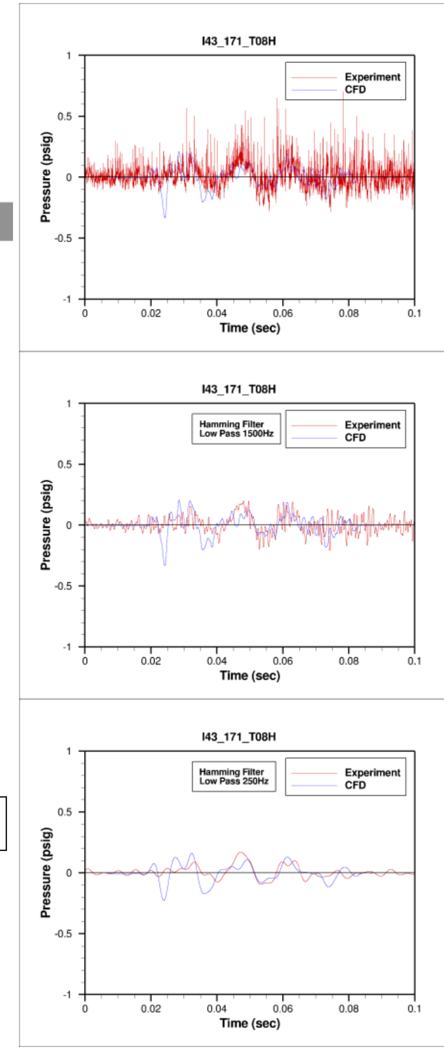
CFD Results – Along the Tower





Location: Tower/Trench Side/Level 200
Sample rate: 4000 Hz





Location: Tower/Trench Side/Level 285
Sample rate: 256000 Hz

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