SCALE MODEL THRUSTER ACOUSTIC MEASUREMENT RESULTS

Acoustical Society of America

166th Meeting Session 2pNS

Noise, Physical Acoustics, and Structural Acoustics and Vibration: Launch Vehicle Acoustics

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ESSSA Group

Agenda

- Overview
- Single Thruster
- Quad Thruster
- Single vs. Quad Comparison
- Solid vs. Liquid Comparison
- Conclusions
- Backup

Overview

- Subscale rocket acoustic data is used to predict acoustic environments for full scale rockets
- Over the last several years acoustic data has been collected during horizontal tests of solid rocket motors
- Space Launch System (SLS) Scale Model Acoustic Test (SMAT) was designed to evaluate the acoustics of the SLS vehicle including the liquid engines and solid rocket boosters
- SMAT is comprised of liquid thrusters scalable to the Space Shuttle Main engines (SSME) and Rocket Assisted Take Off (RATO) motors scalable to the 5-segment Reusable Solid Rocket Motor (RSTMV)
- Horizontal testing of the liquid thrusters provided an opportunity to collect acoustic data from liquid thrusters to characterize the acoustic environments
- Acoustic data was collected during the horizontal firings of a single thruster and a 4-thruster (Quad) configuration
- Presentation scope
  - Discuss the results of the single and 4-thuster acoustic measurements
  - Compare the measured acoustic levels of the liquid thrusters to the Solid Rocket Test Motor V – Nozzle 2 (SRTMV-N2)

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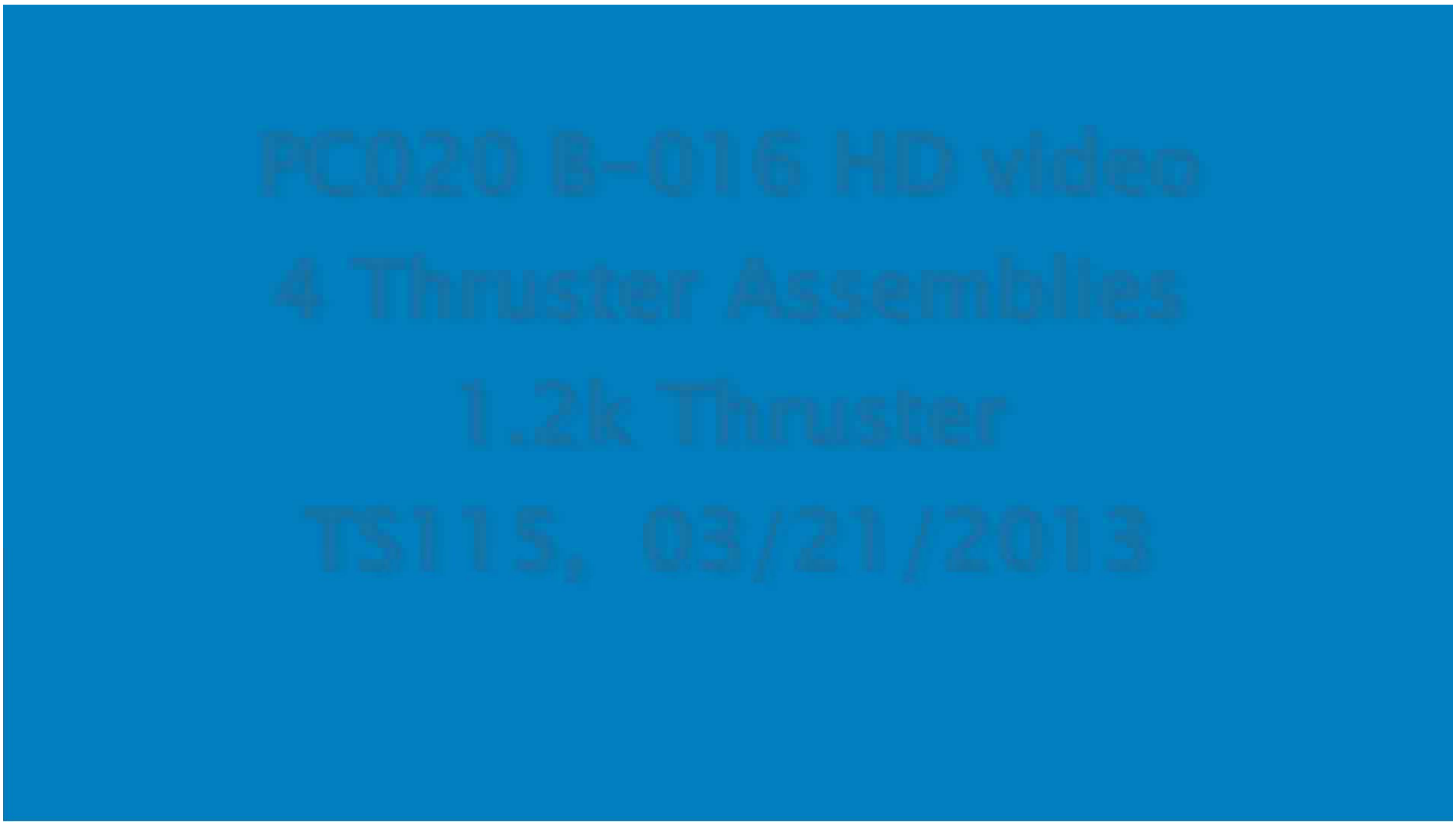
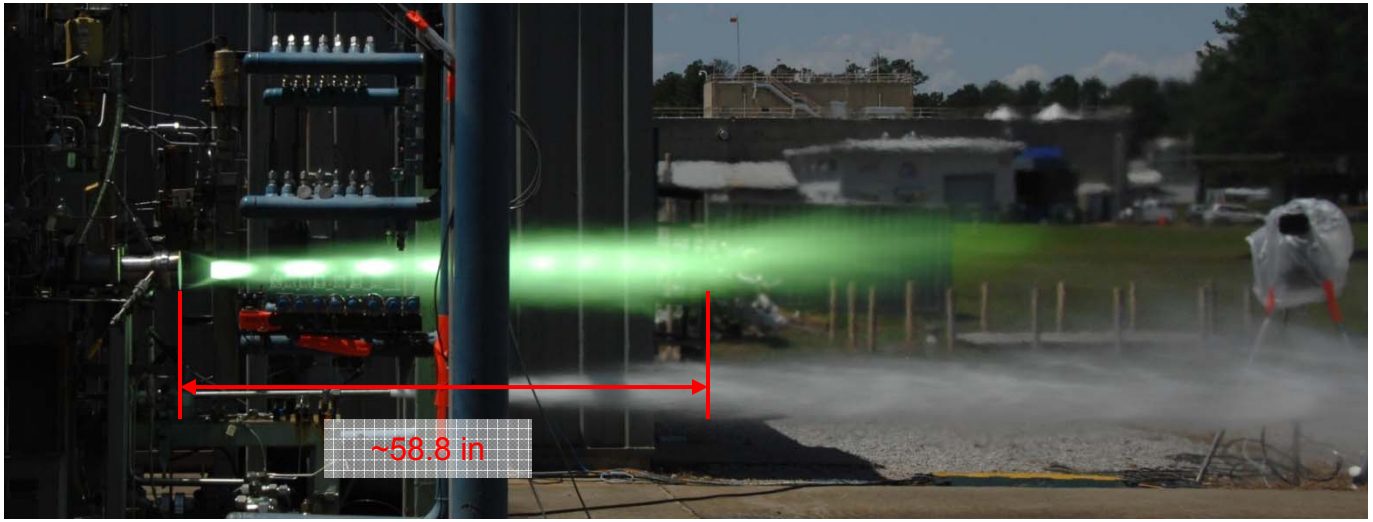
Quad Thruster Video



Thrusters

- Plume core length is approximately 13 nozzle exit diameters

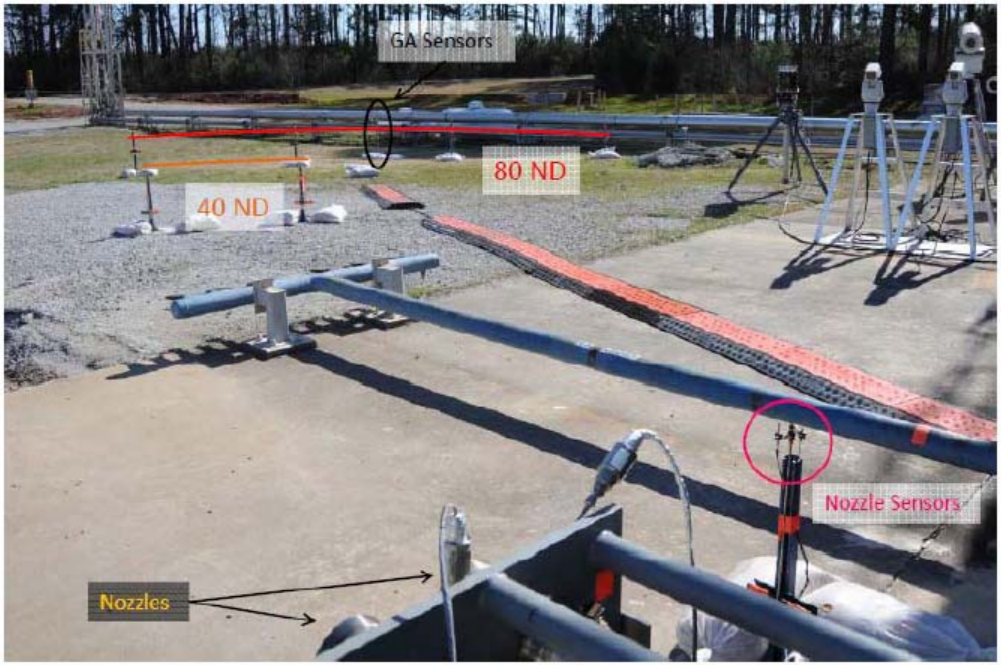


Single Thruster Test Firing

4-Thruster (Quad) Thruster Test Firing

Instrumentation Layout

- Acoustic measurements were taken in an circular array layout at 80 nozzle exit diameters from the nozzle exit plane (effective NED used for the quad thruster)
  - Single Thruster: 9.2 m circular array from 20 to 50 degrees in 10 degree increments
  - Quad Thruster: 18.4 m circular array from 20 to 50 degrees in 10 degree increments
  - STRMV-N2: 28.3 m circular array from 20 to 80 degrees in 10 degree increments
- Sensors were leveled with the nozzle exit elevation



Quad Thruster Acoustic Instrumentation

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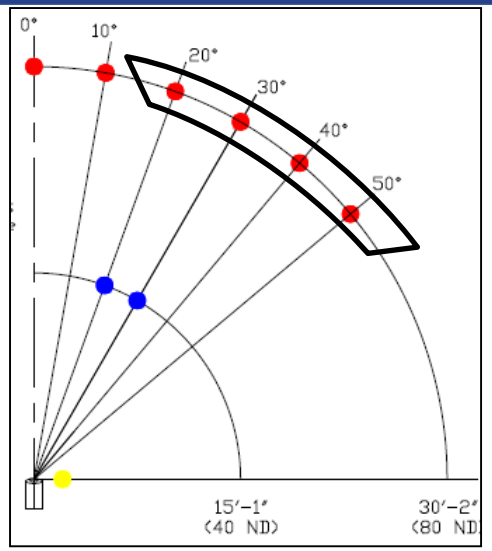
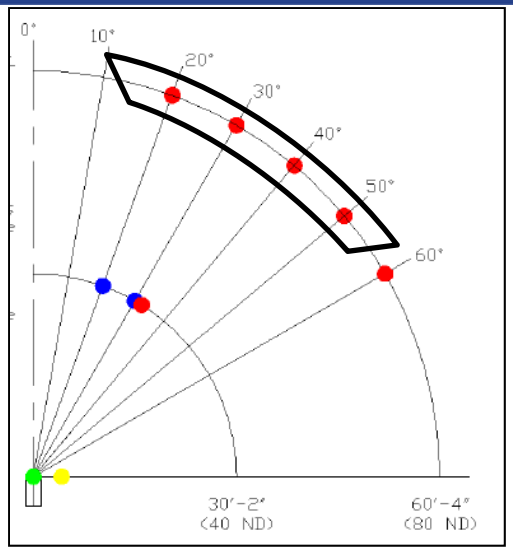
Instrumentation Layout

- Terrain and test stand structures limited the amount of measurements that could be setup for the array
- 4 measurements at 80 ND for thruster
- 7 measurements at 80 ND for the SRTMV-N2

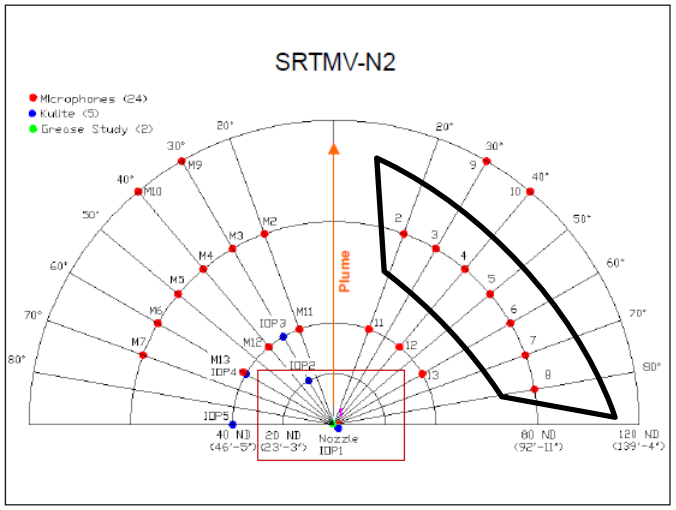


Single Thruster Instrument Layout



Quad Thruster Instrument Layout

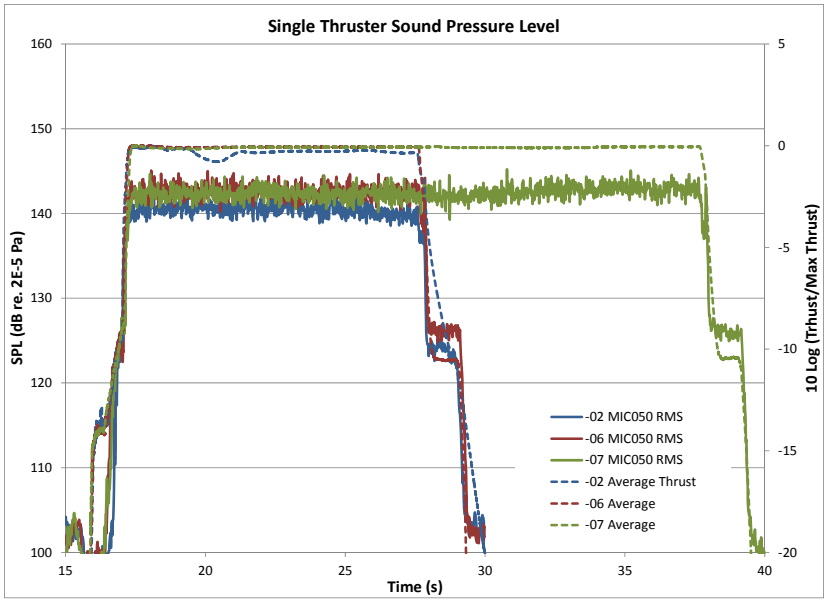
SRTMV-N2 Acoustic Instrumentation



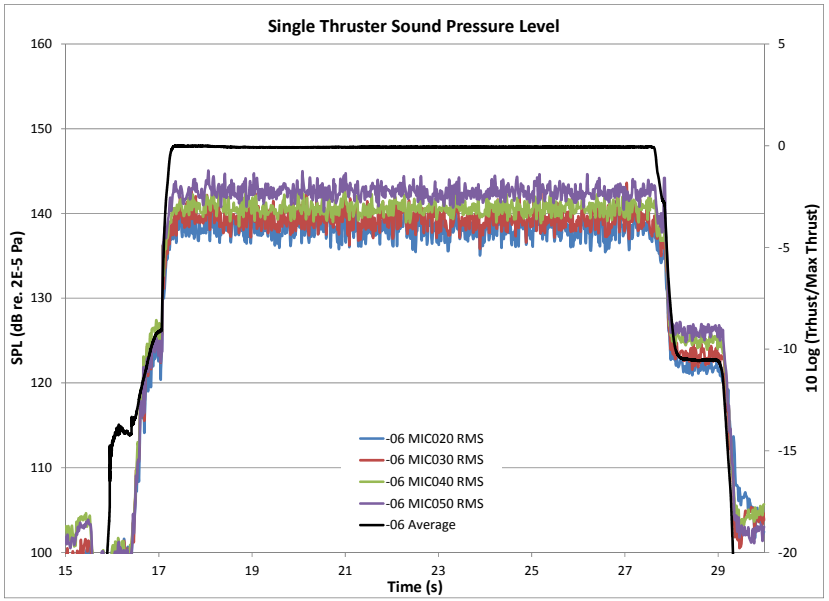
SRTMV-N2 Instrument Layout

Single Thruster SPL

- Single thruster main stage burn time between 10 and 20 seconds
- Steady thrust levels throughout the main stage burn
- Measured sound pressure levels follow the thrust levels
- Overall SPL evaluated during a 4.6 second time window

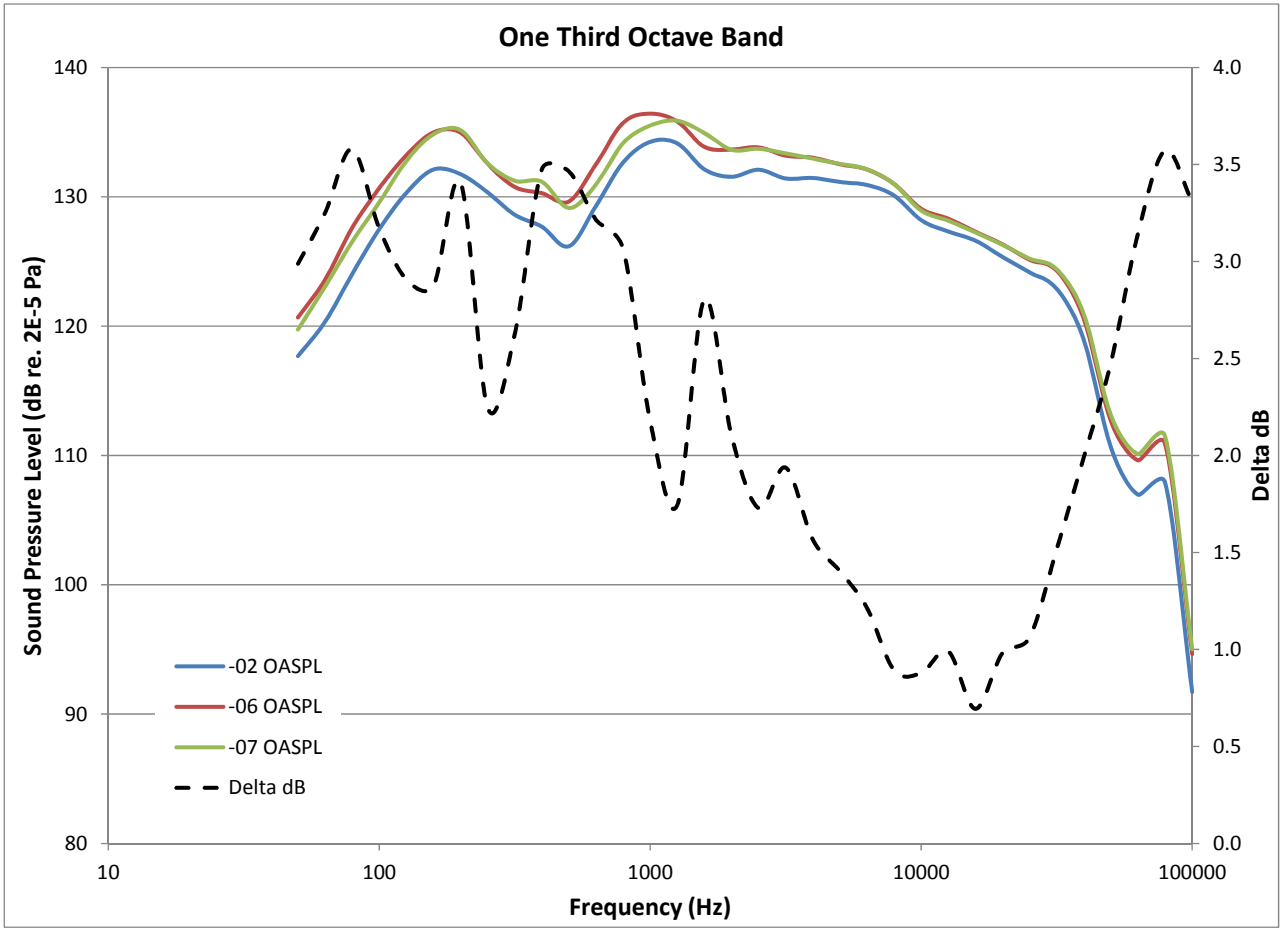


Single Thruster Test Sound Pressure Level and Thrust



Single Thruster Test 780 psi Sound Pressure Level and Thrust per Receiver Angle

Single Thruster – 1/3 Octaves



- Three single thruster measurements at different pressure levels show similar OASPL trends
- Maximum of 3.5 dB spread between the three measurements
- Expected delta dB due to the chamber pressure level ~1.5 dB

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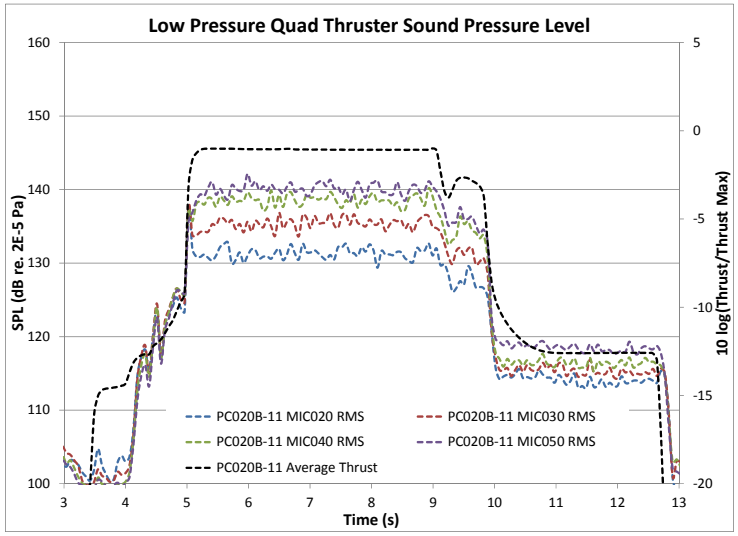
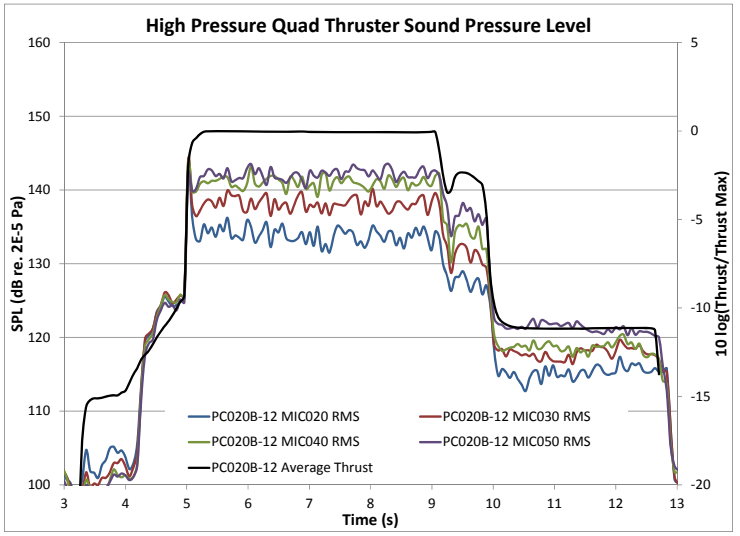
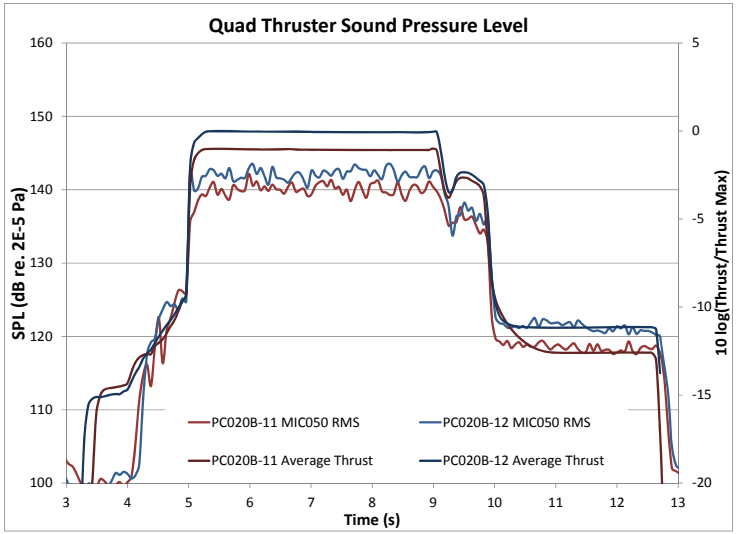
Quad Thruster

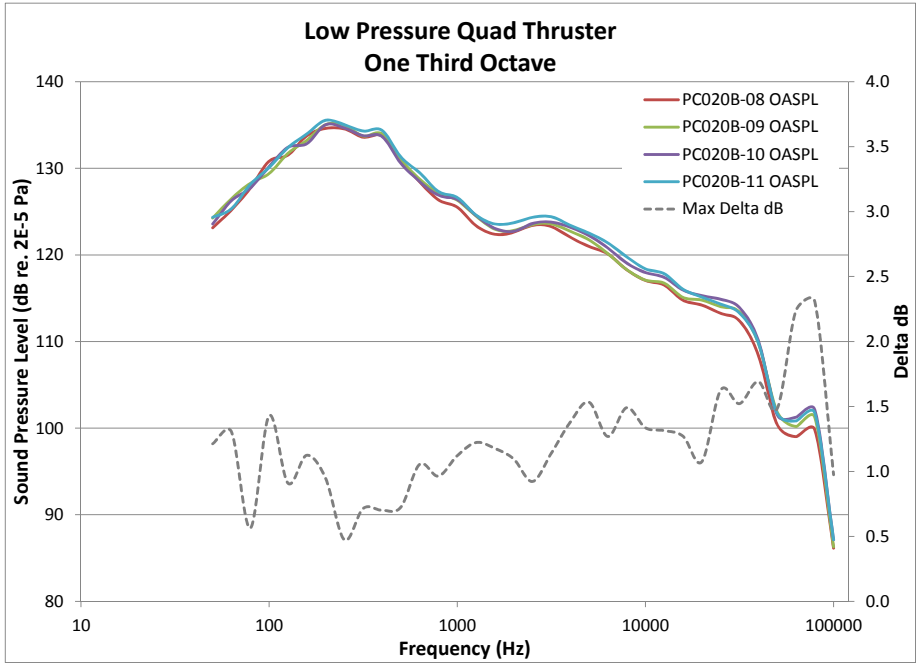


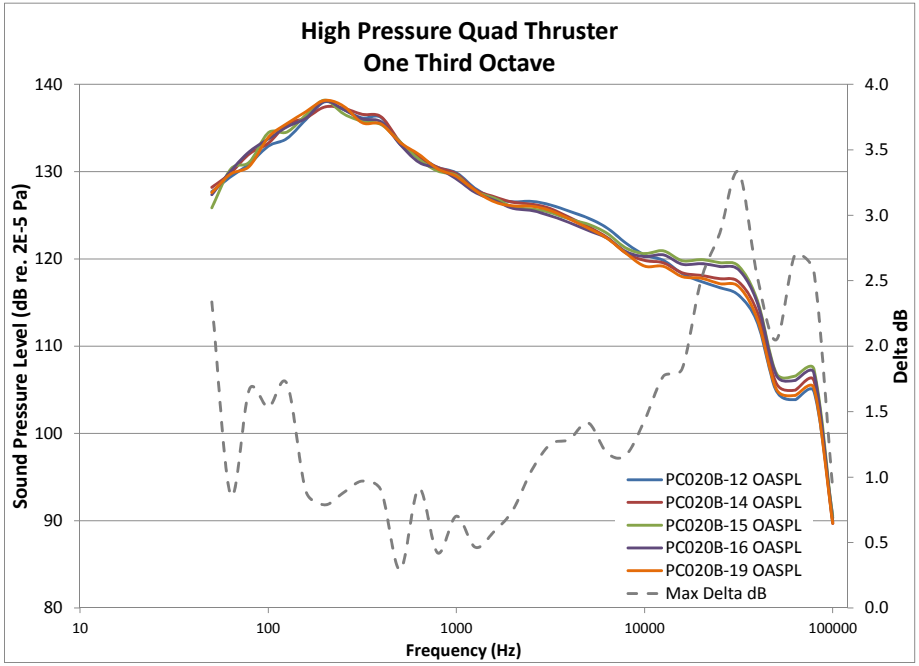


- Quad thruster main stage burns between 2 and 8 seconds
- Thrust levels are steady throughout the main stage burn
- Sound pressure levels follow the thrust levels
- Overall SPL evaluated during a 2.4 second time window



Quad Thruster





- Sound pressure level trace is repeatable for the quad thrusters at the two thrust levels
- Low thrust sound pressure levels shows a spread of less than 2.5 dB
- Maximum of 3.5 dB spread at 30 kHz in the high pressure thruster test series

Scaling

- Single and quad thruster sound pressure levels were adjusted to the SRTMV-N2 sound pressure level
- Frequency was non-dimensionalized using the Strouhal number

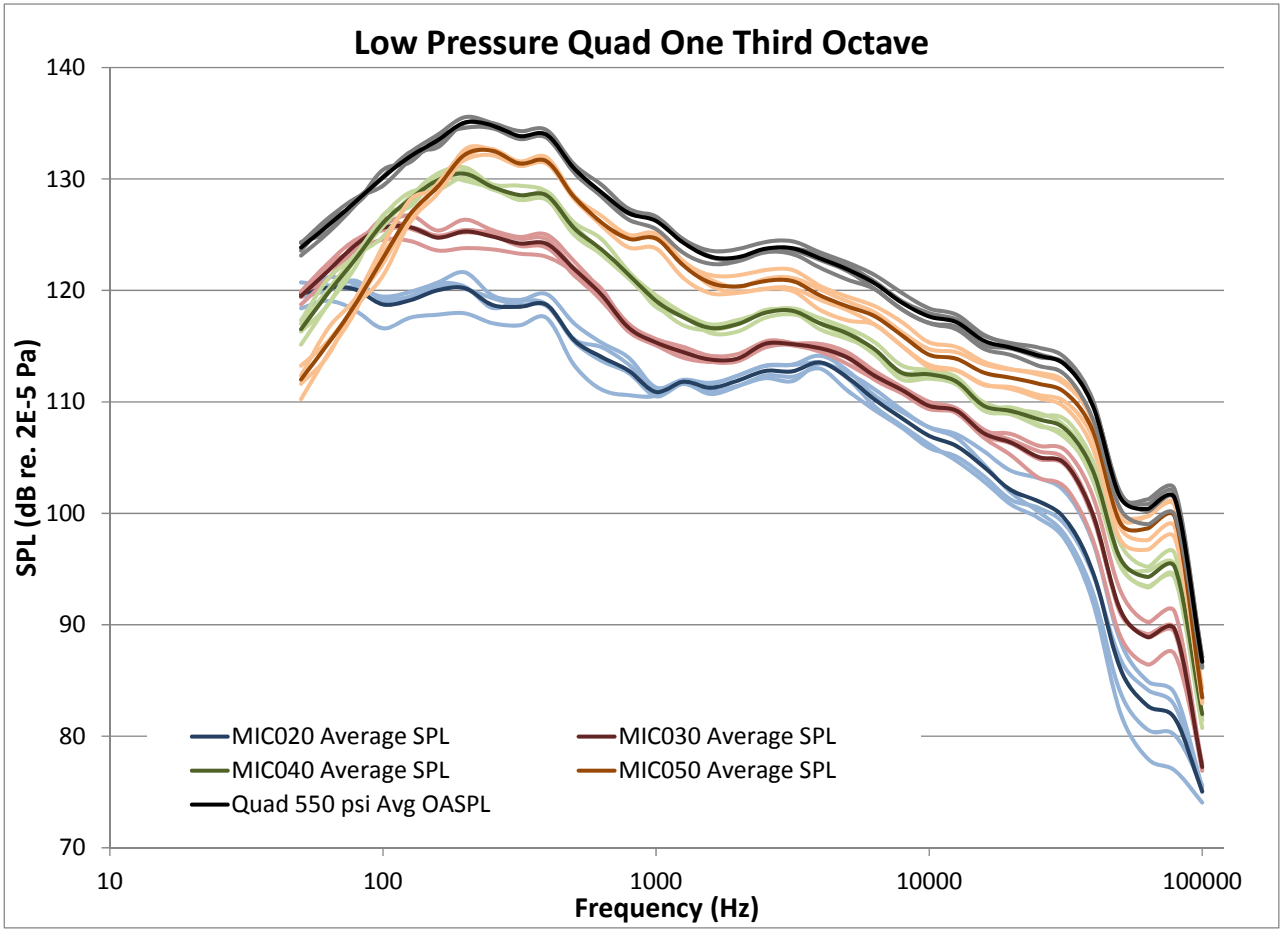
$$\text{Strouhal number} = \frac{fD_e}{V_e}$$

- Amplitude scaling based on sound intensity

$$\text{Adjusted SPL} = \text{SPL} + 10 \log\left(\frac{I_2}{I_1}\right) \qquad \frac{I_2}{I_1} = \frac{\eta_2}{\eta_1}\frac{\dot{m}_2}{\dot{m}_1}\left(\frac{V_2}{V_1}\right)^2\left(\frac{R_1}{R_2}\right)^2$$

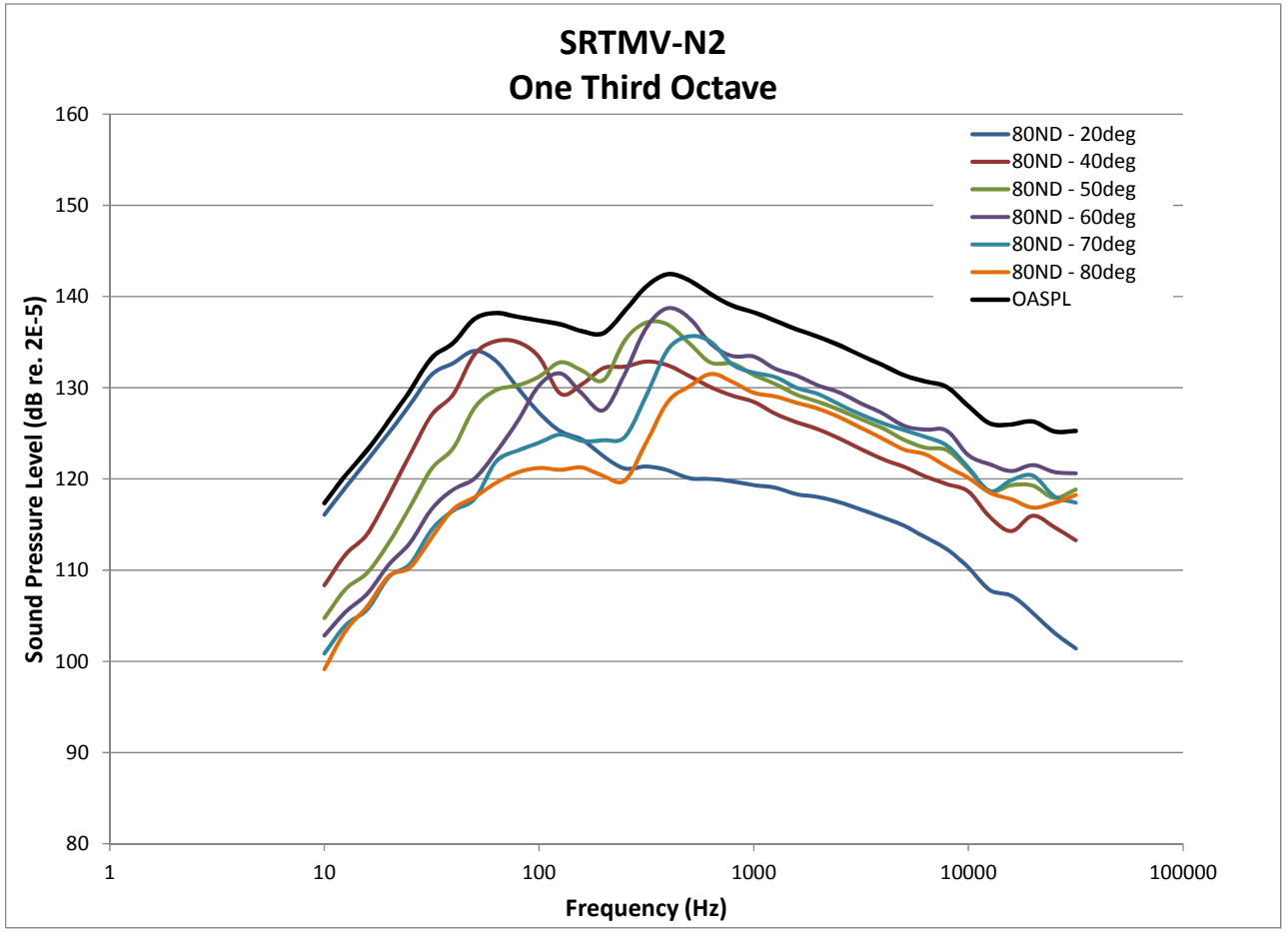
	Single 555	Single 780	Quad 550	Quad 710	SRTMV-N2
De (m)	0.11	0.11	0.23	0.23	0.35
Ve (m/s)	3,986	4,038	3,981	4,019	2,360
η	0.20%	0.20%	0.20%	0.20%	0.52%
ṁ (kg/s)	1.16	1.58	4.29	5.62	33
R (m)	9.2	9.2	18.4	18.4	28.0
Thrust (N)	4,626	6,361	17,094	22,584	77,444
ΔSPL	4.49	3.05	4.84	3.59	0.00
OAPWL	165.7	167.1	177.4	178.6	179.8

Quad Thruster Data



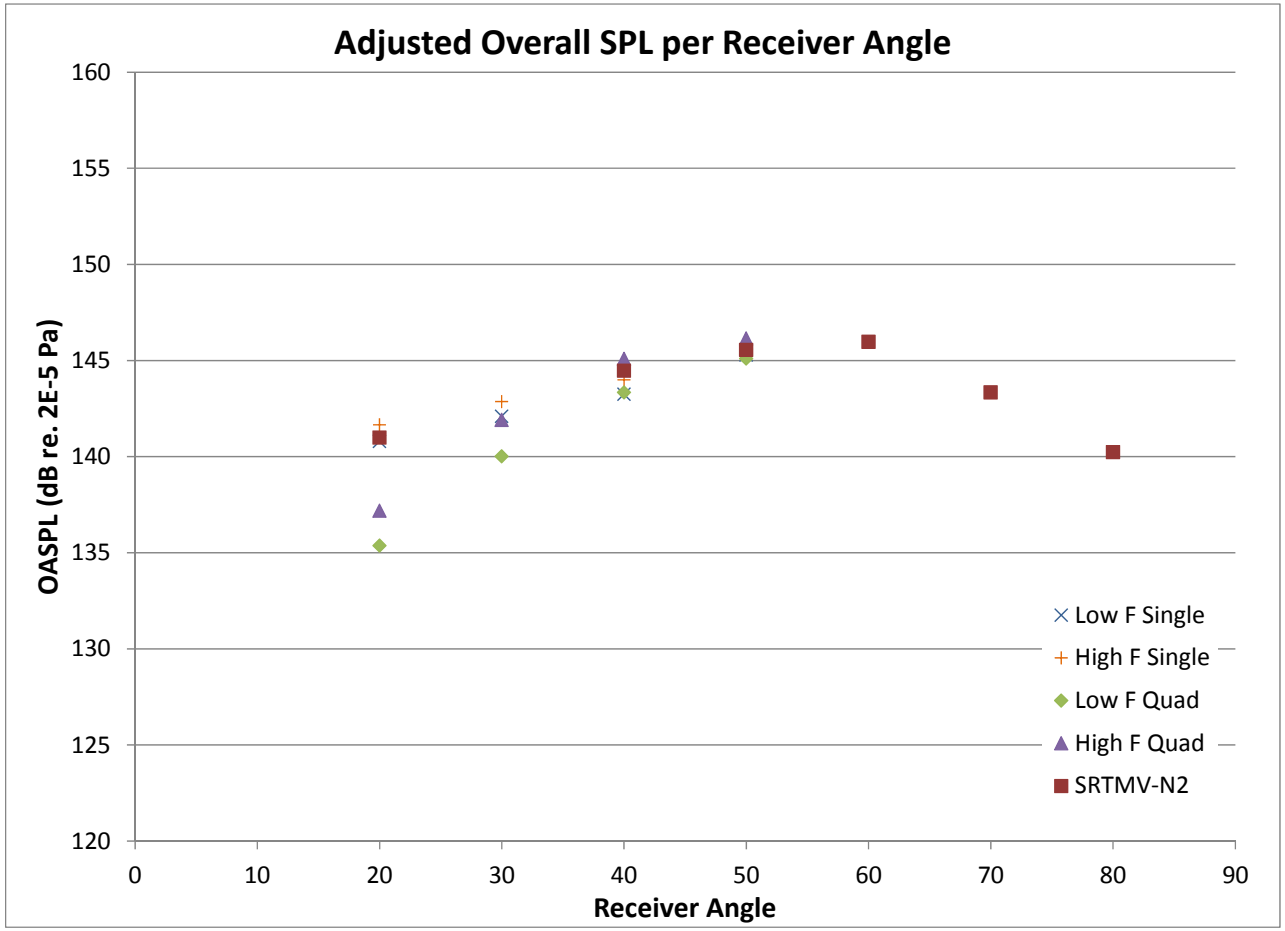
- Measurements are within 3 dB of each other up to 20 kHz for all receiver locations at both pressure levels
- Average OASPL for each thrust level was used to scale the quad thruster measurements based overage SPL at each receiver location

SRTMV-N2 Summary



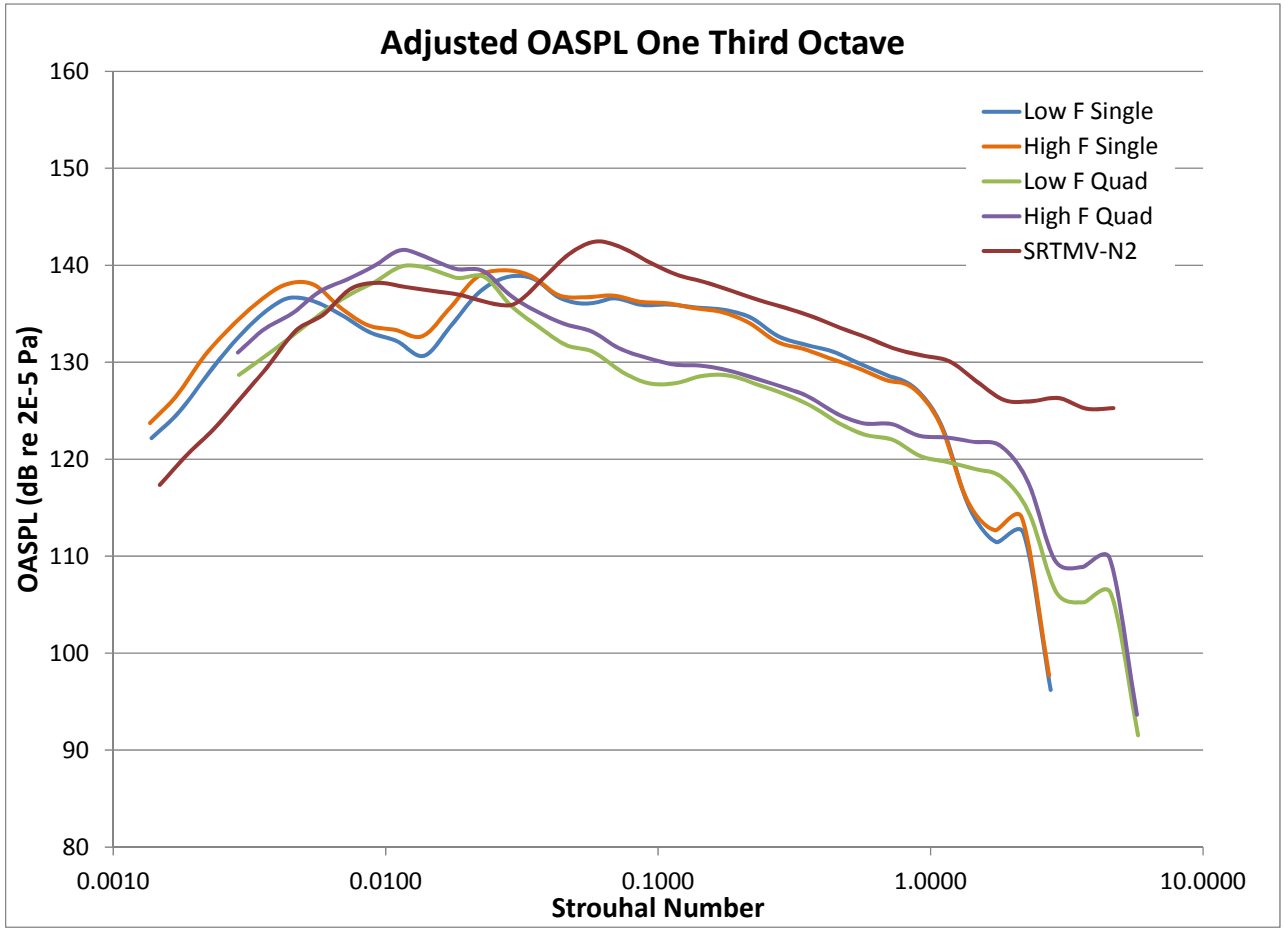
- Receivers located in a circular array between 20 and 80 degrees from the plume centerline
- More data points available to calculate the overall sound pressure level
- Both single and quad thruster sound pressure levels were scaled to SRTMV-N2 levels

Adjusted Data



- Maximum spread is 6 dB at the 20 degree receiver
- Below 3 dB spread for the receivers at 30, 40 and 50 degrees

Adjusted Data



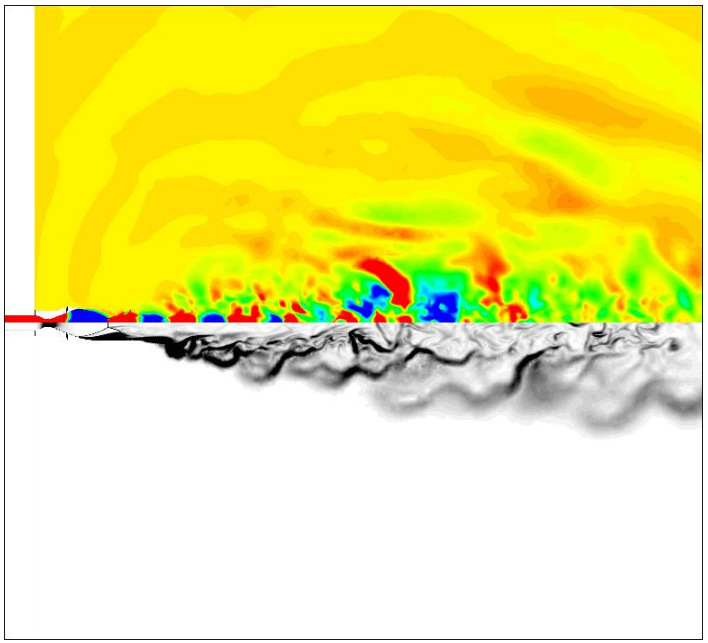
- Liquid thruster data peaks at a lower frequency than the solid motor
- Solid motor shows a higher SPL at the high frequencies possibly due to the high angle measurements
- Approximately 3.5 dB spread between the overall sound pressure levels

Conclusions and Forward Work

- Conclusions
  - Liquid engine measurements are repeatable within 3 dB up to 20 kHz
  - Overall sound pressure level spread between solid motor and liquid thruster is approximately 3.5 dB
  - Liquid thruster seems to peak at a lower frequency than the solid motor
  - Dataset provides a subscale liquid dataset for empirical prediction models

Forward Work - CFD

- Forward Work
  - SMAT acoustic environments assessments
  - CFD team currently generating plume models for plume studies and model verification
  - CFD based acoustic prediction model development
  - Acoustic environments scaling and predictions



Questions?