Measurements of Ground Acoustic Environments for Small Solid Rocket Motor Firings

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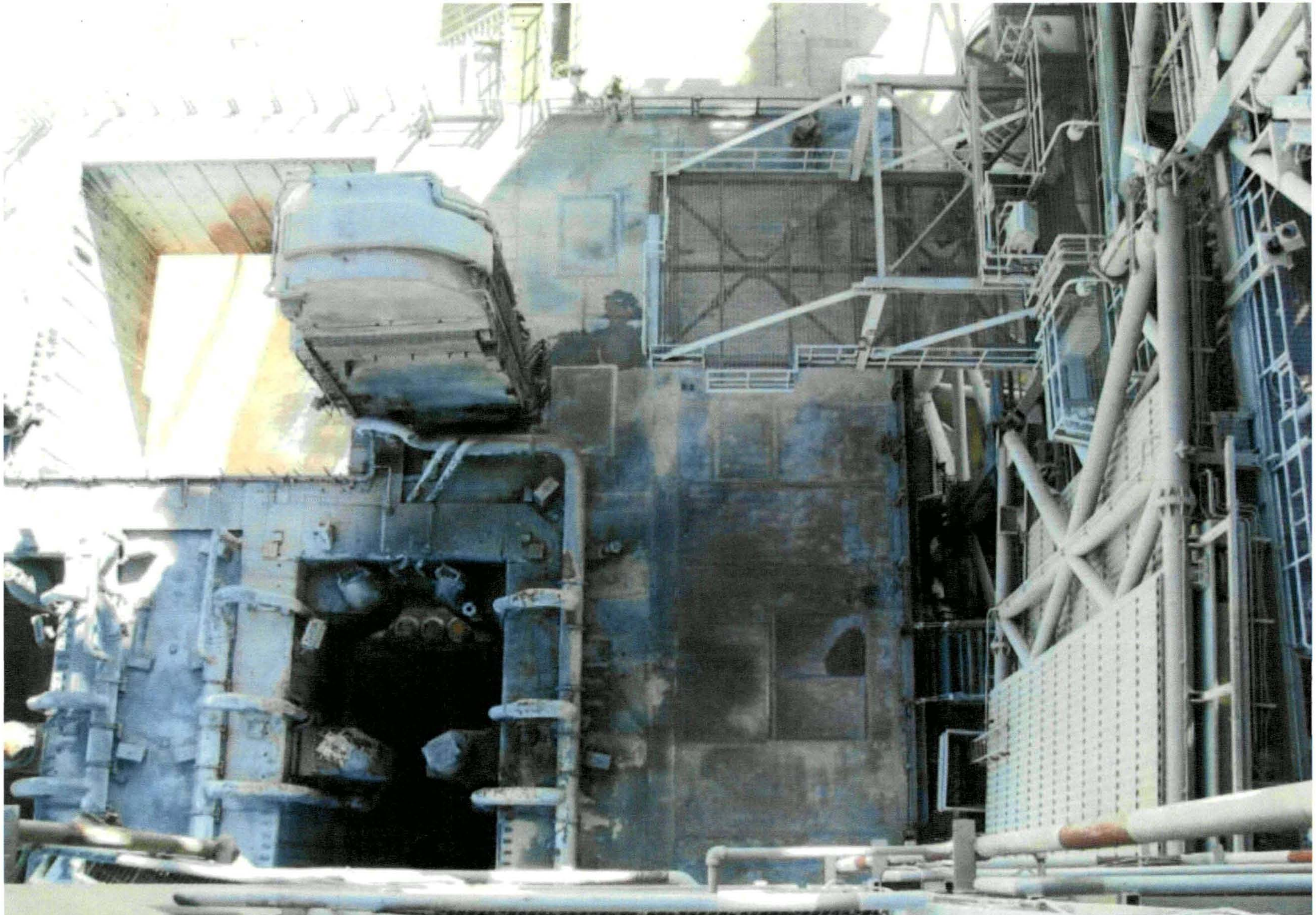
At Stake

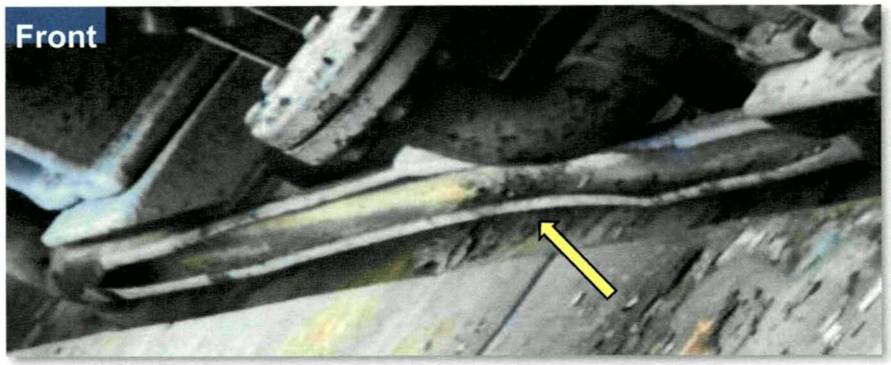
- Mobile launcher deck and tower are exposed to severe acoustic environments during launch.
- These environments, if not properly managed, can weaken ground support equipment and result in structure failure.

MLP “0” Deck: Birdseye View

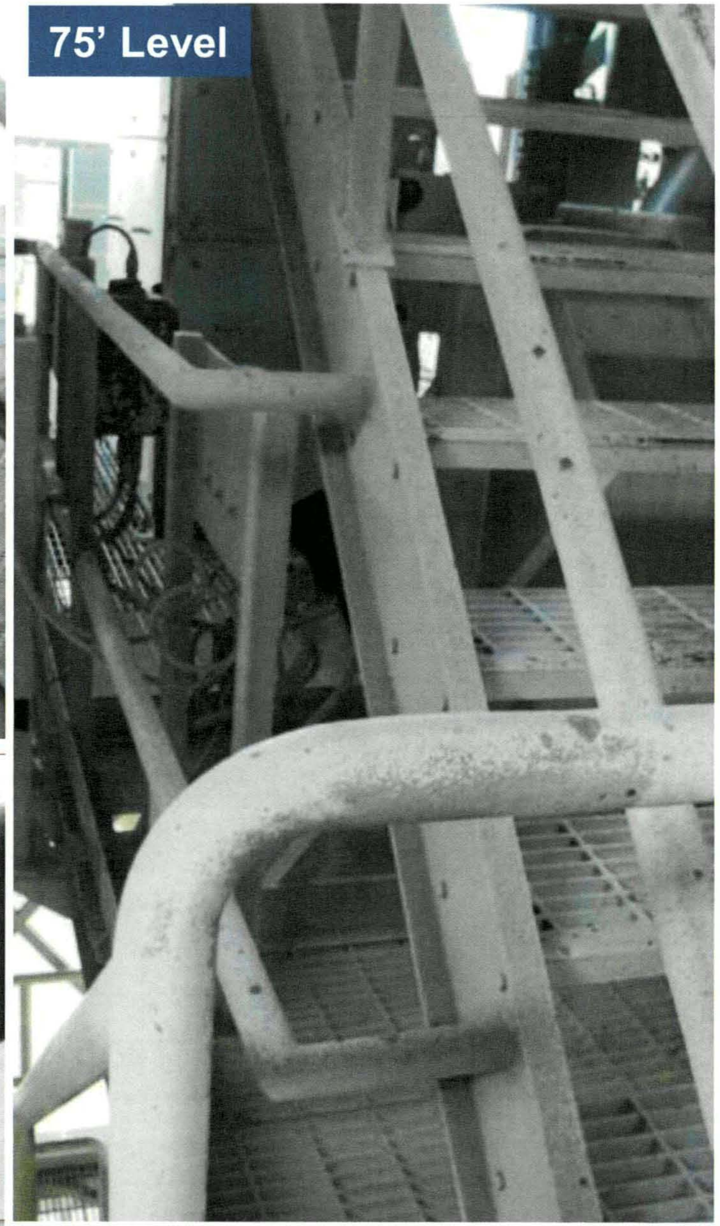


Ares I-X caused more damage than Shuttle

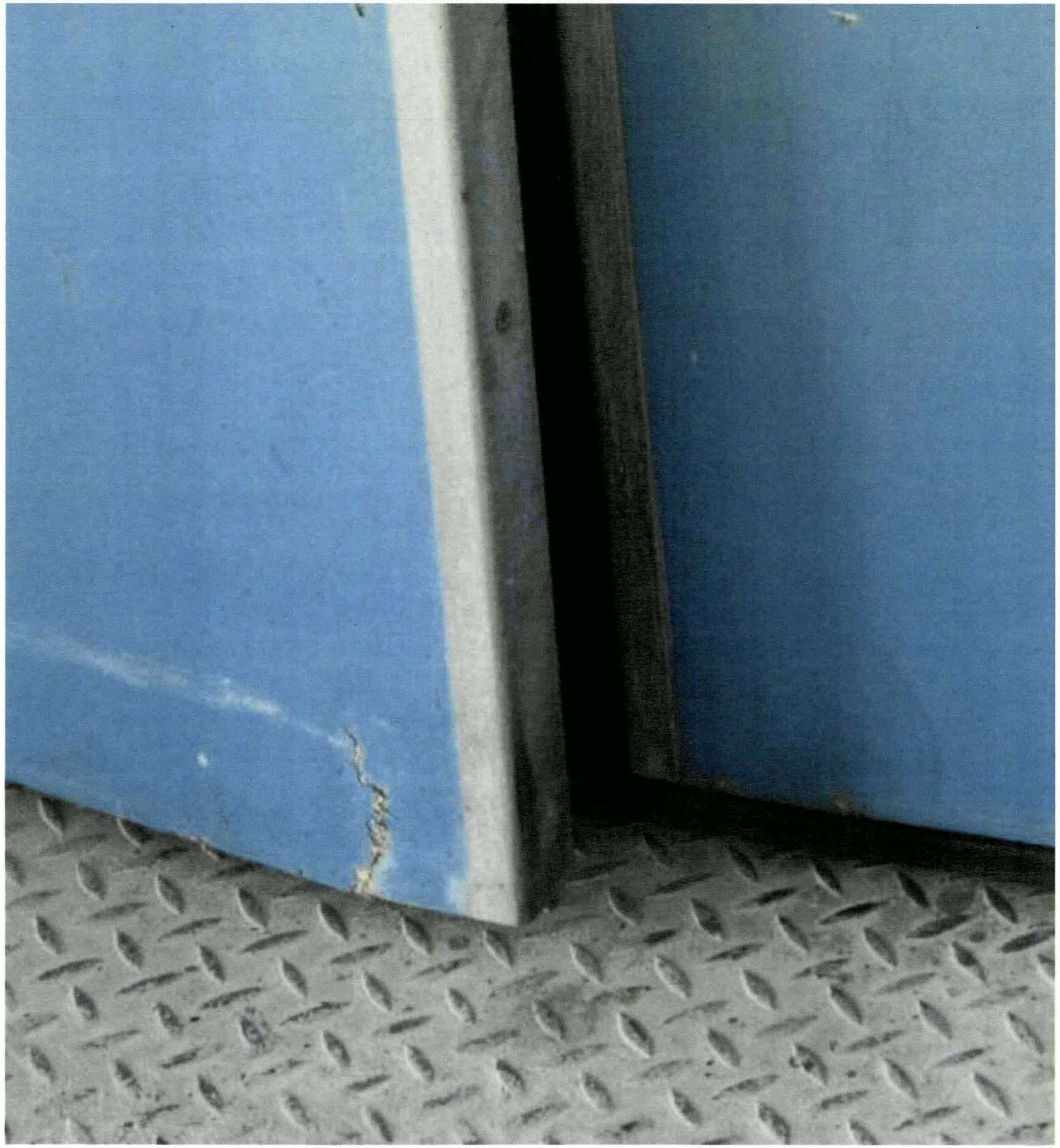
MLP "0" Deck: Water System Damage



FSS 95' Level: Handrail Damage



FSS 95' Level : Elevator Door Damage



Challenges

- The ground acoustic environments are different than the vehicle acoustic environments, typically more severe because of the close proximity of the rocket plume, which often involves direct impingement.
- Ground acoustics are more difficult to predict, and their measurement and data reduction remain challenging.

ASMAT Outline

- **Objectives**
- **Data Analysis**
  - Test Matrix
  - Instrumentation
  - Time-history Data
  - Data Processing
- **Discussion of Results**
- **Tube Resonance**
- **Conclusion**

ASMAT Objectives

- Characterize the acoustic ground environment with and without water suppression systems.
- Validate the ground acoustic prediction based on scaling of Saturn V data.
- Validate the semi-empirical acoustic analysis documented in Wyle report WR-08-39, “Ares I Near Field Launch Acoustic Environments, including Water Suppression, Drift and Impingement.”

Test Matrix

Test	Objective	Location		Water Systems						
		Elevation (Feet)	Drift (in)	Waterbags	Trench Water (gpm)	Exhaust Hole Water (gpm)	Rainbird (gpm)	Total water (gpm)	Rainbird Ww/Wp	Test Date
1	**IOP Series.** Hold down case with water bags.	0		Yes	873	291		1164	N/A	11/5/2010
2	**IOP Series.** Hold down case without water bags.	0		No	873	291		1164	N/A	11/10/2010
3	**IOP Series.** Dry case. Test primarily for IOP measurements.	0						0	N/A	11/18/2010
4	**Elevation Series.** Purpose is to find the elevation of max SPL. No rainbird water. IOP measurements not necessary	2.5 (50)	4.625		873	291		1164	N/A	1/20/2011
5	**Elevation Series.** Purpose is to find the elevation of max SPL. No rainbird water.	5 (100)	6.875		873	291		1164	N/A	1/28/2011
6	**Elevation Series.** Purpose is to find the elevation of max SPL. No rainbird water.	7.5 (150)	8.375		873	291		1164	N/A	2/3/2011
7	**Elevation Series.** Repeat at max SPL.	5	6.875		873	291		1164	N/A	2/15/2011
8	**Rainbird Series.** Purpose is to find effective flow rate of rainbirds at max SPL.	5	6.875		873	291	566	1730	2	2/23/2011
9	**Rainbird Series.** Purpose is to find effective flow rate of rainbirds at max SPL.	5	6.875		873	291	991	2155	3.5	3/2/2011
10	**Modified Rainbird Series (No LM)**	5	6.875		873	291	991	2155	3.5	5/12/2011
11	**Modified Elevation Series (No LM, No Rainbird)**	5	6.875		873	291		1164	N/A	5/19/2011
12	**Modified Rainbird Series (No LM)**	5	6.875		873	291	1275	2439	4.5	5/24/2011
13	**No Drift (No LM)**	5	0		873	291	991	2155	3.5	6/7/2011
14	**No Drift (No LM) No Rainbirds**	5	0		873	291		1164	N/A	6/14/2011
15	**Modified Elevation Series (No LM, No Rainbird)**	10	9.875		873	291		1164	N/A	6/27/2011
16	**Modified Rainbird Series (No LM)**	10	9.875		873	291	991	2155	3.5	6/30/2011
17	**Contingency (Dry at 5')**	5	0		0	0	0	0	N/A	7/12/2011

Completed

Instrumentation

- 39 ASMAT locations for ground acoustics measurements
  - 28 are on the Tower, 7 on ML deck, and 4 under ML
- Sensor naming convention:

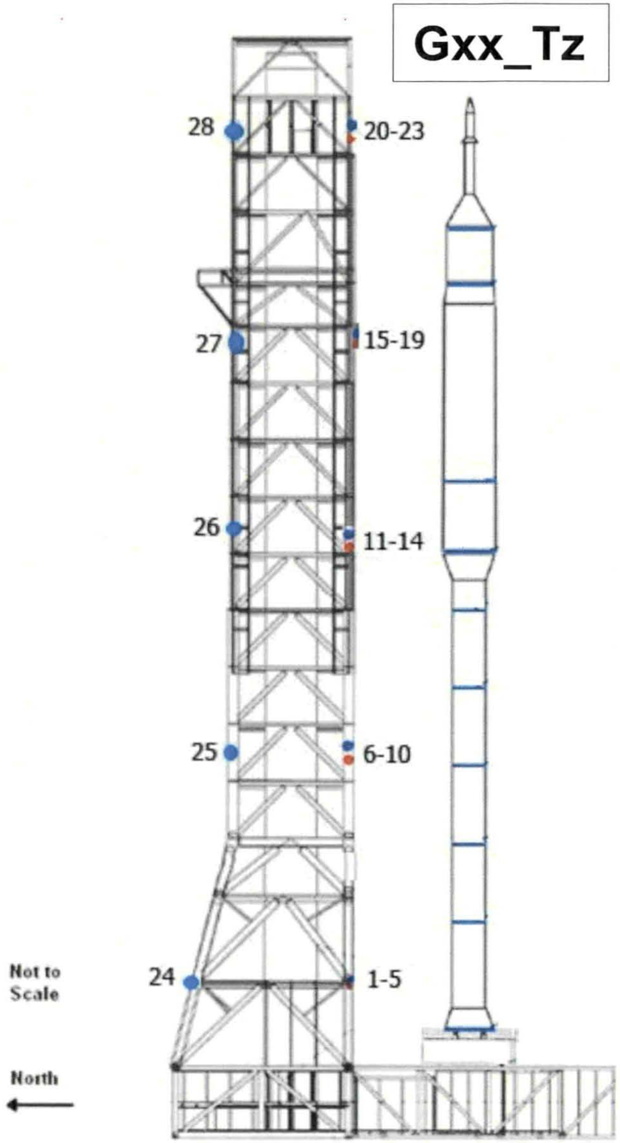
  $\boxed{\text{Gxx.Lz}}$

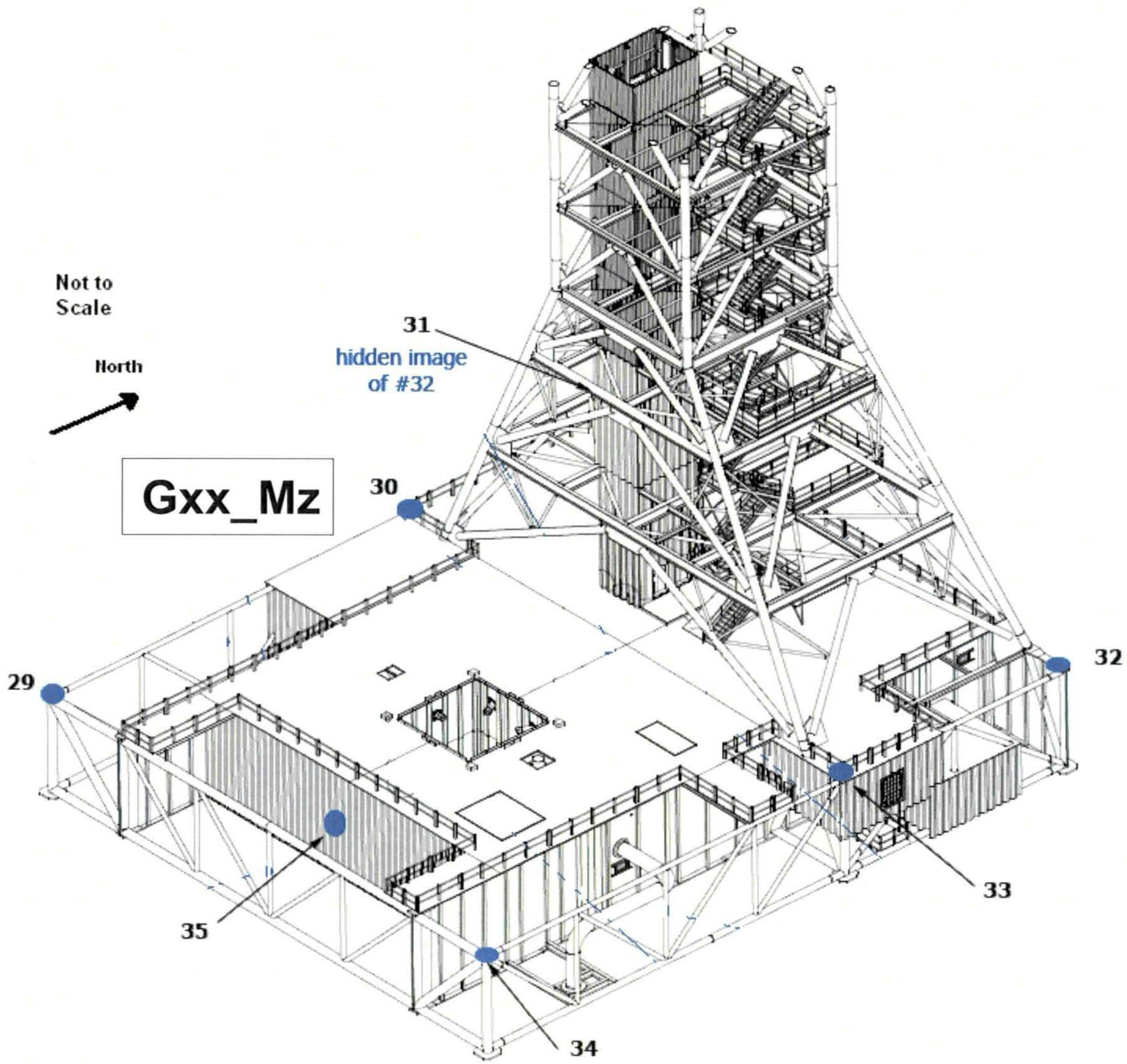
  where xx= sensor number,
  L= location (T:Tower, M:Deck, F:underside)
  z= ordered number within the location
- Sensor inventory
  - 49 microphones, model number B&K 4944-B.
  - 20 PCB S112A22 pressure probes
- Sensor mounting
  - Tower microphones flush mounted in cylindrical holders for protection
  - Microphones sometimes recessed or partially covered for protection.
    - Resonances must be calculated to adjust data

GA Instrumentation Calibration

- **All sensors sent to MSFC Calibration Lab for pre-test calibration**
  - These sensitivities were loaded in the Test Definition File
  - All data used in the analysis uses these traceable sensitivities
- **During test operations:**
  - All microphones and pressure probes underwent a pre-test check-out with a calibrated pistonphone
    - This verified that the sensor diaphragms were functional and responsive at an expected amplitude prior to test
  - Post-test check-out day of hotfire, using pistonphone
    - This was to determine if the sensors were still functional and if not, were replaced prior to the next test
- **Pre- and post-test ground acoustic pistonphone results were reported in hotfire debrief charts**

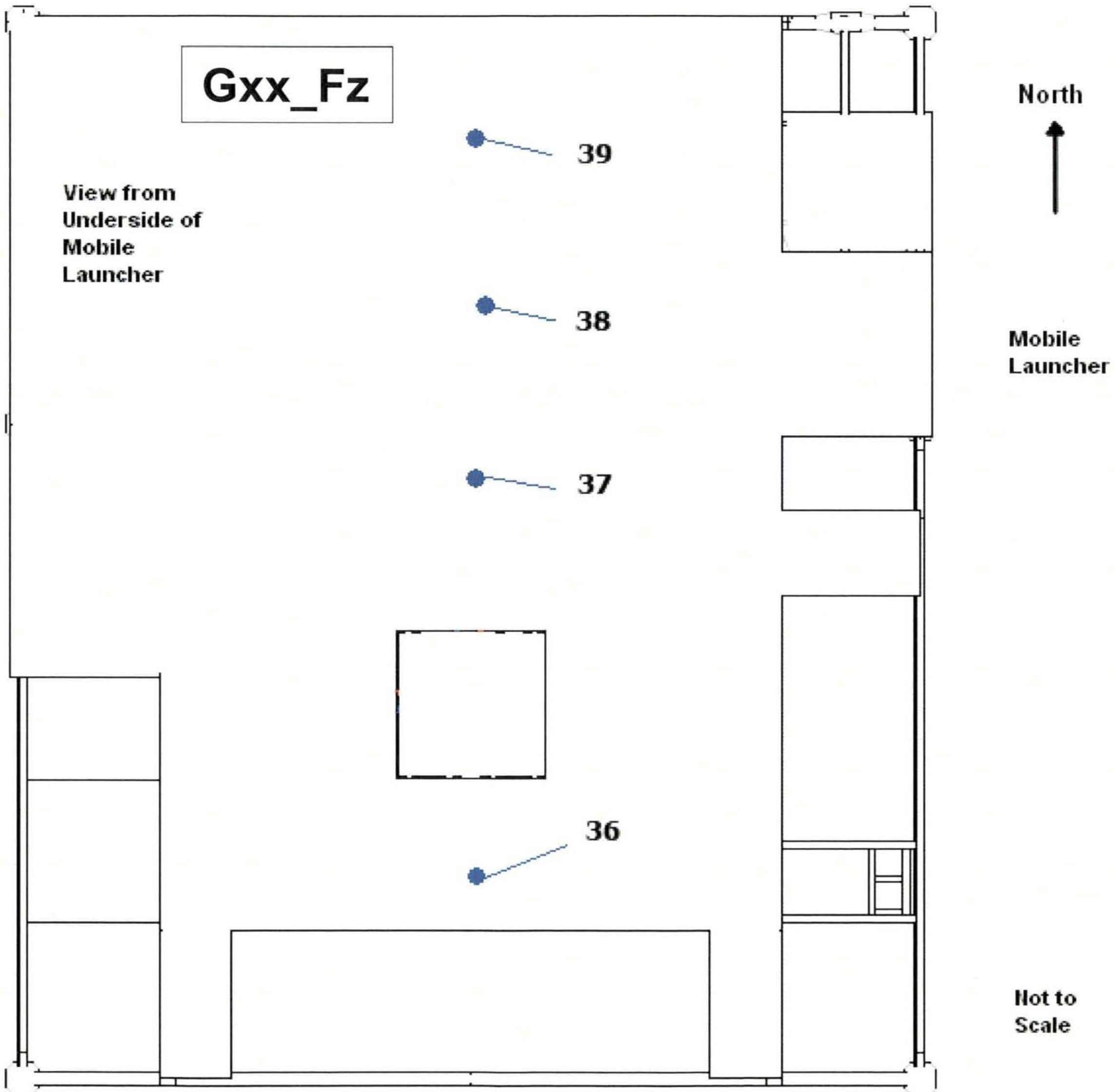
Instrumentation Layout





Instrumentation Layout

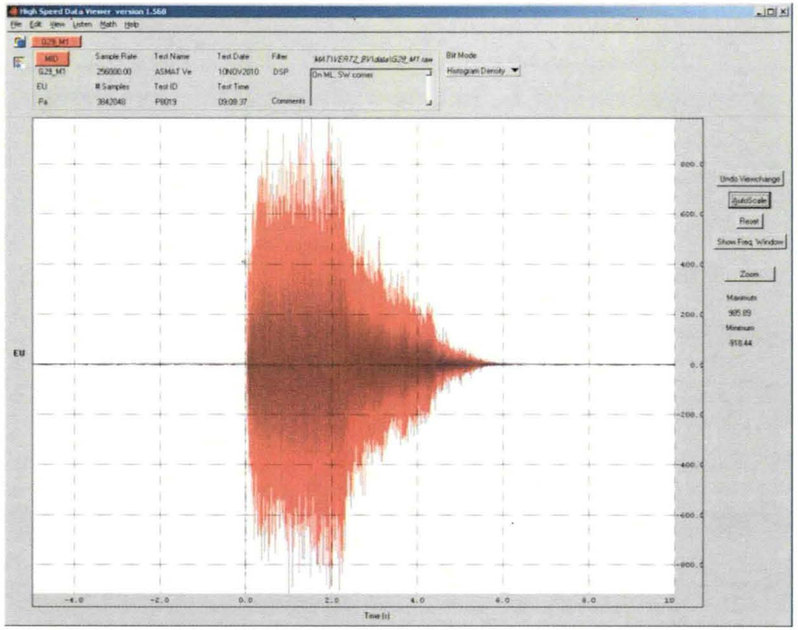
Mobile Launcher View from Underside

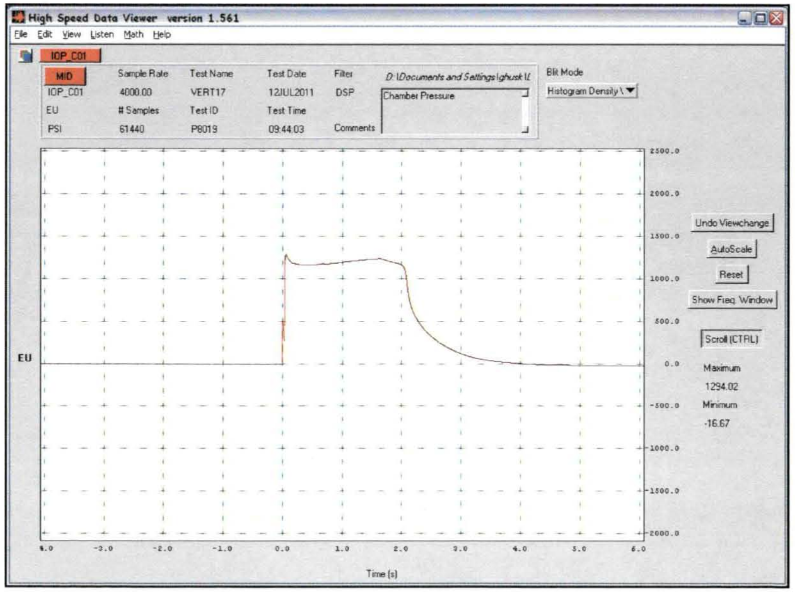


DATA ANALYSIS

Procedures

- **Use High Speed Data Viewer**
  - Confirm the validity of raw data
  - Check chamber pressure to determine the time offset
- **Decide an analysis time block**
- **Process data using FFT**
- **Review spectral plots for any anomolies**
- **Remove transient effect**
- **Remove cavity resonance**
- **Compare results for effects of**
  - Elevation
  - Rainbirds
  - Drifts
  - Launch Mount

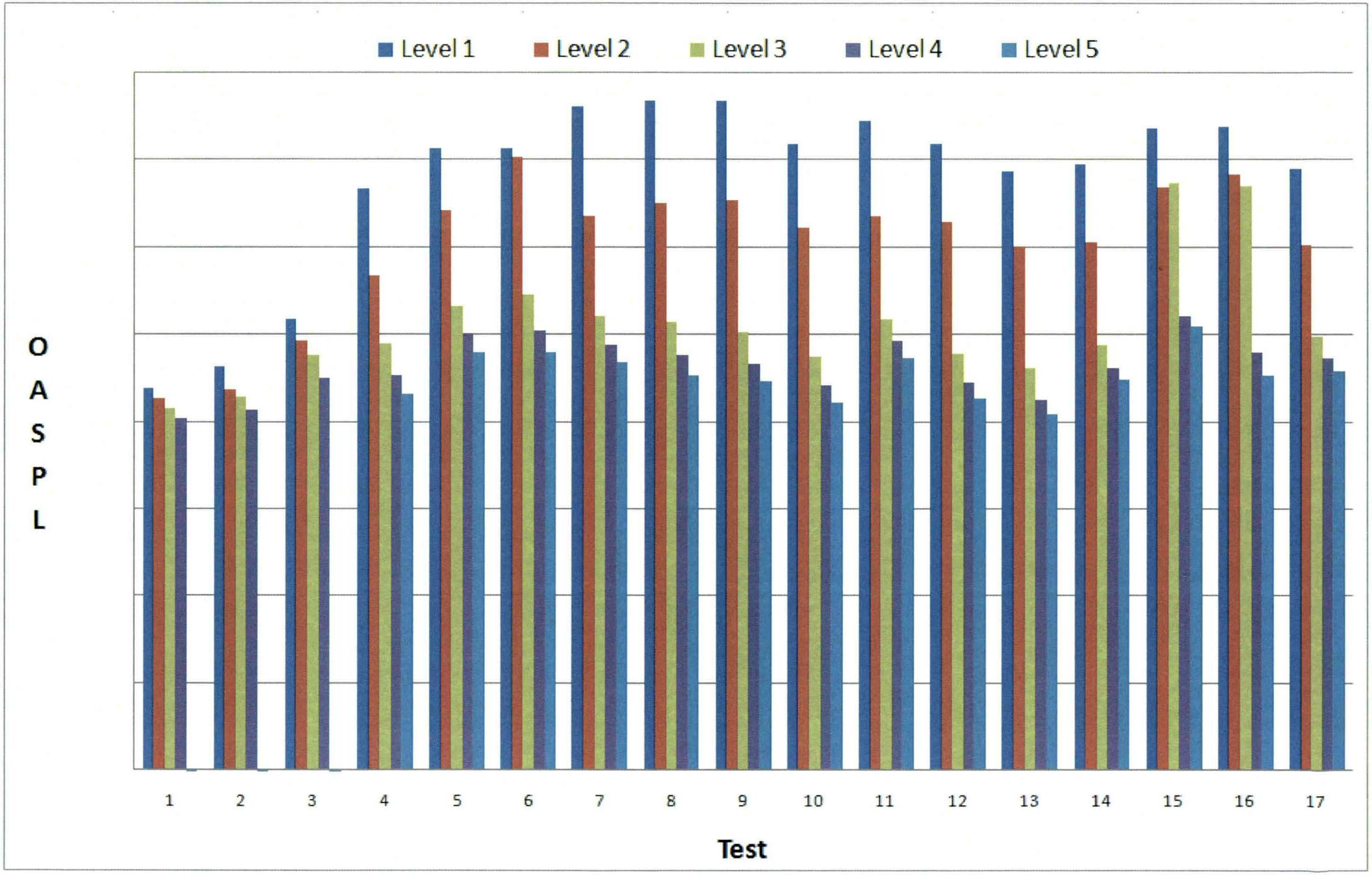




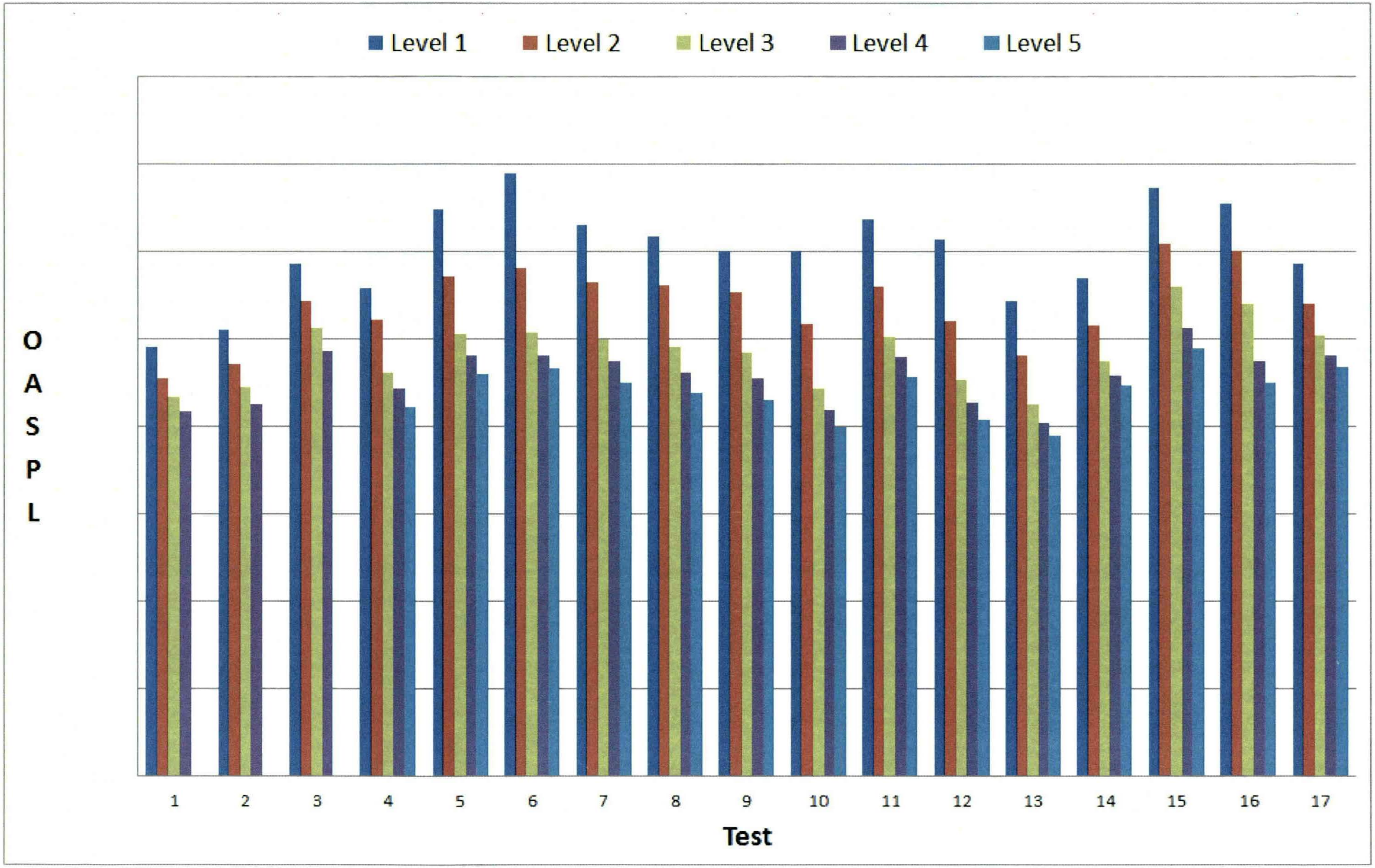
Data Processing

- Hann windowing
- Offset time = 1.0 sec
- Sampling rate = 256,000 samples per second
- Analysis time block= 0.5 sec → 128,000 samples
- FFT size = 2^{16}=65,536 samples
  256,000/65,536→ low freq limit=4 Hz (0.2 Hz full scale)
- Overlaps to improve statistics, N = 6
- 1/3 octave band number = 10-50 → f =10 Hz - 100 kHz
- Filter out early transient effects by excluding data prior to offset time
  (Filter time = 0.1-1.0 sec depending on the time-history data)

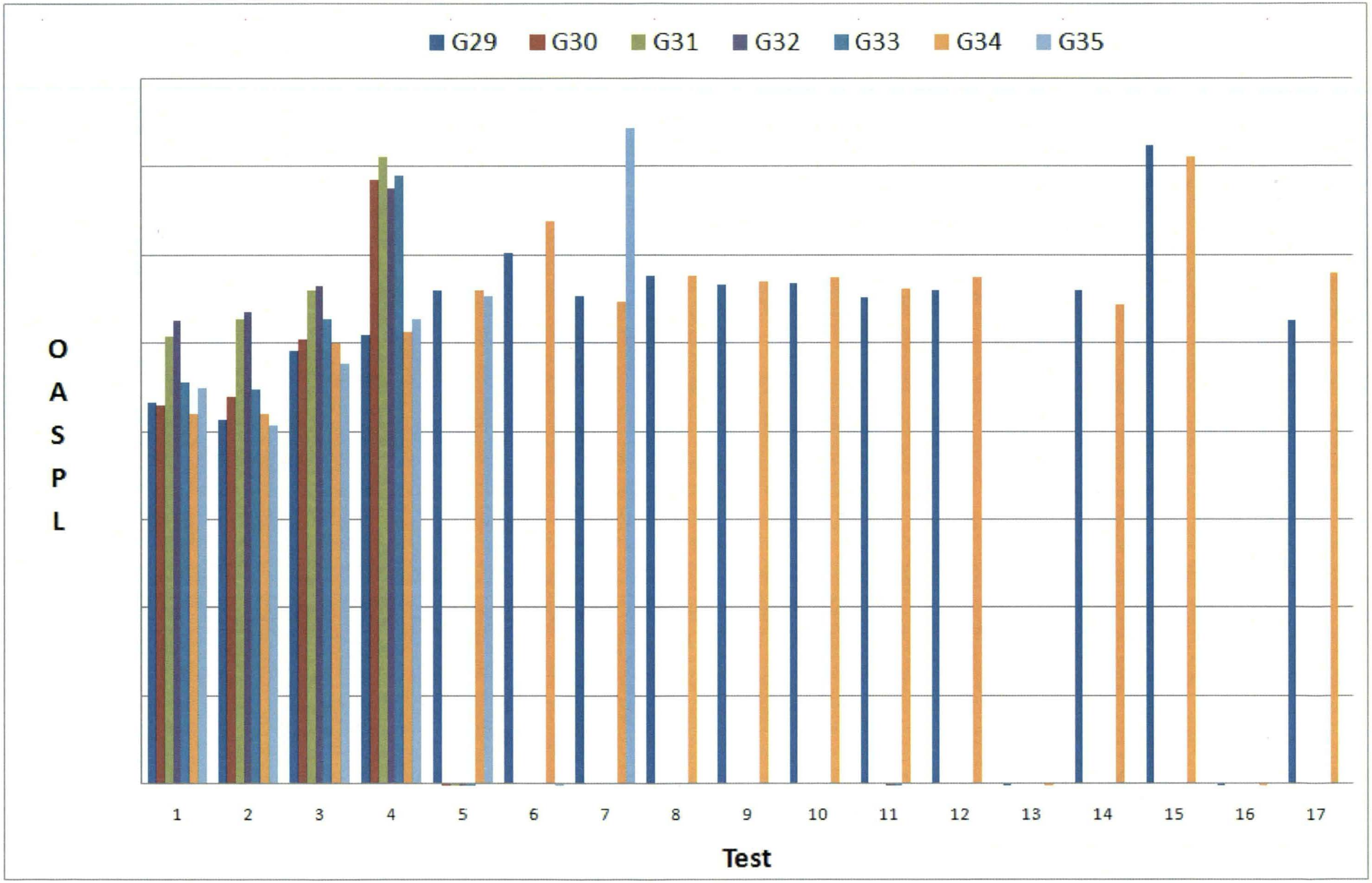
Average OASPL on ML Tower



OASPL on Tower North

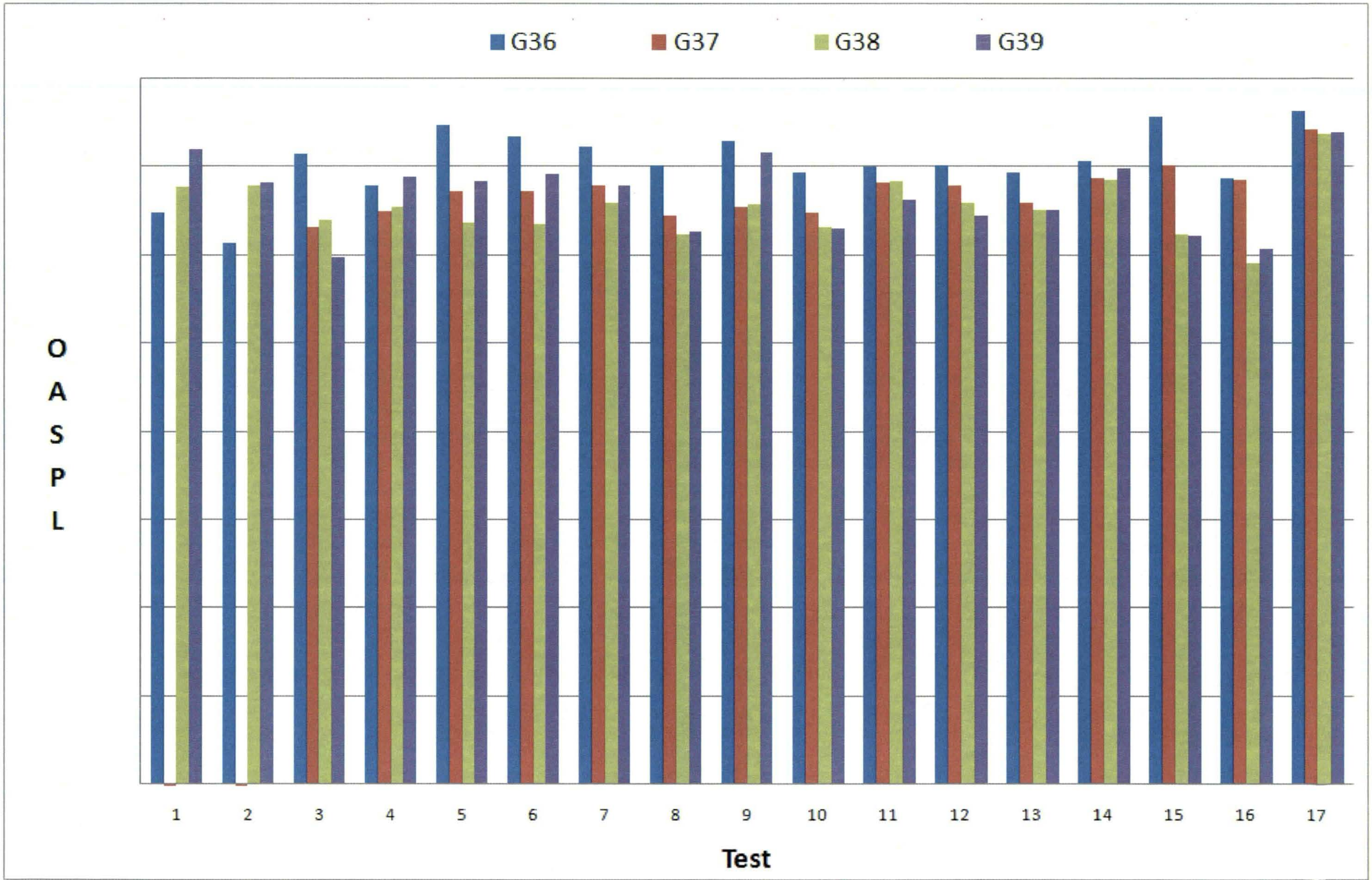


ML Deck



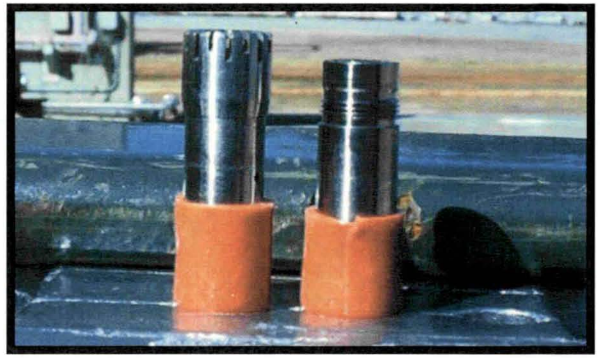
G29
G30
G31
G32
G33
G34
G35
OASPL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Test

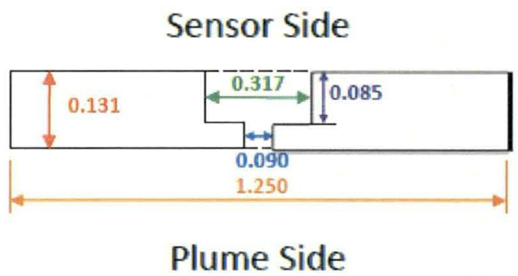
ML Underside

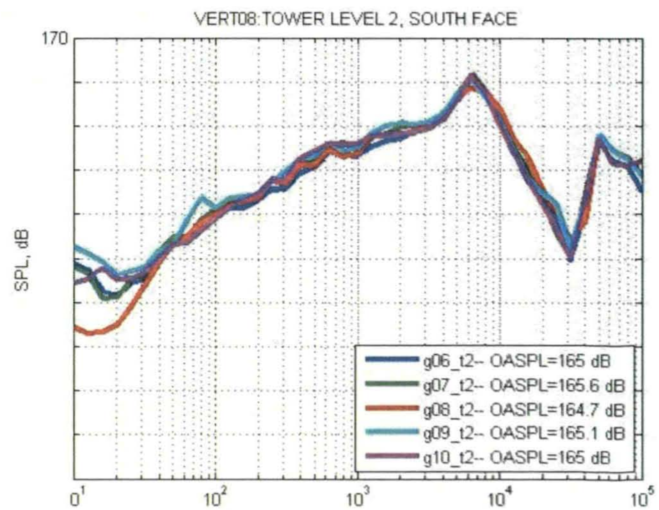


Grid Effect and Tube Resonance

- **B&K 4144 Microphone response defined without protective grid**
  - Frequency Response Function (FRF) measured for eight rocket firings (Bennett and Lee, 2010)
  - Statistical results
  - Not yet applied to ASMAT – will be for final analysis
- **Plume impingement failure of B&K mics at lower levels. Replace with PCB, and:**
  - Vert 7 and Vert 8: Protective caps on some T1 and T2 microphones
  - Vert 9: Some microphones recessed
  - Resonances from caps/recess need to be computed and applied







Cavity Tone (Chris Tam/FSU)

- **Outstanding Challenges**
  - Size of Computation Domain
  - Outflow Boundary Conditions
  - Turbulence Modeling

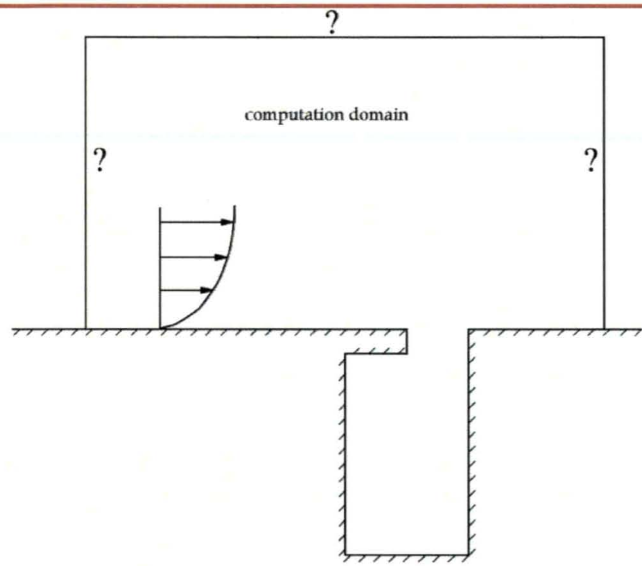


FIGURE 11 Computation domain for cavity tone problem

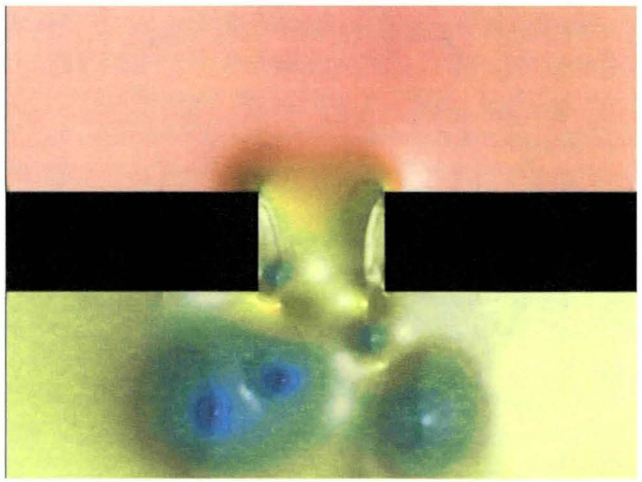


FIGURE 10a Vortex shedding at a 90° slit

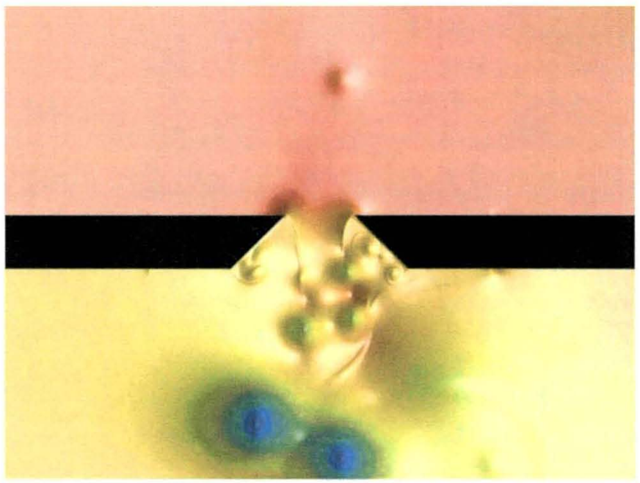


FIGURE 10b Vortex shedding and the development of thin shear layers and subsequent rolling up into vortices due to Kelvin-Helmholtz instability at a 45° beveled slit

Cavity Tone (Devos & Lafon/France)

- **Numerical Method**
  - 2-D Euler
  - 2nd order upwind TVD
  - 2nd order R-K time accurate

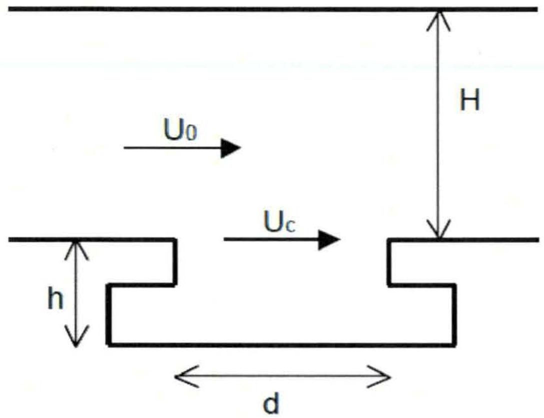


Figure 3 : the original cavity studied in this paper

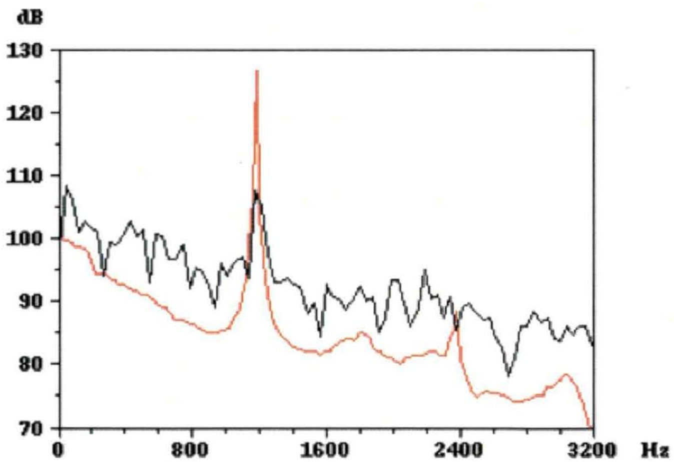
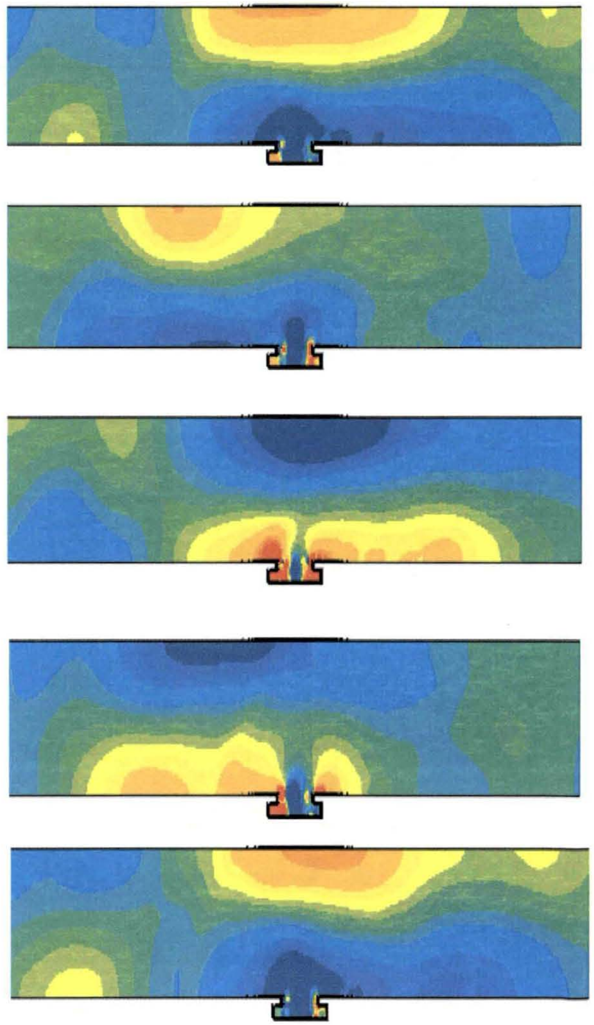
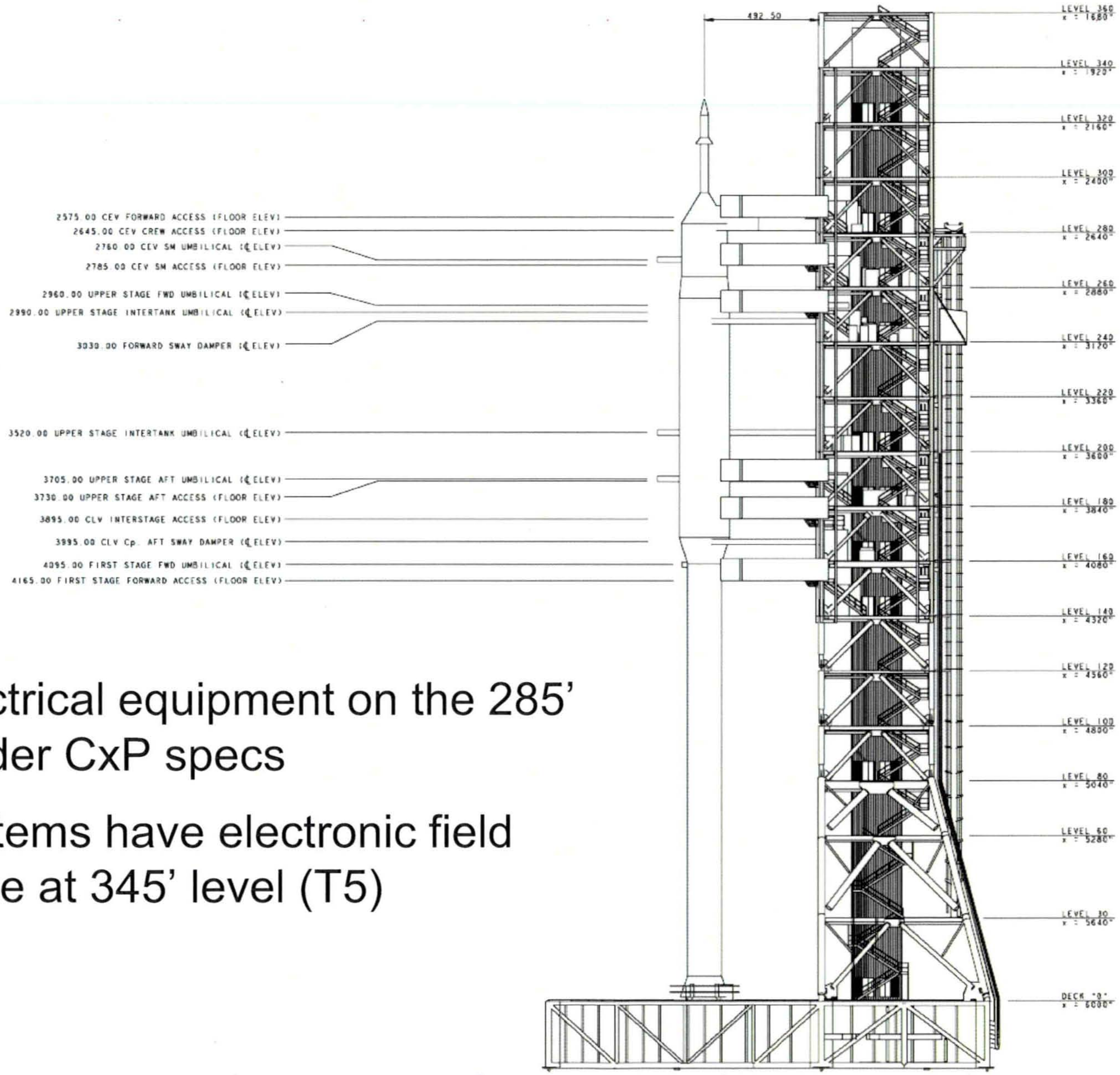


Figure 4 : pressure spectra in the cavity for the original cavity
- experiment : higher level for the tone frequency
- computation : higher level for broadband fluctuations



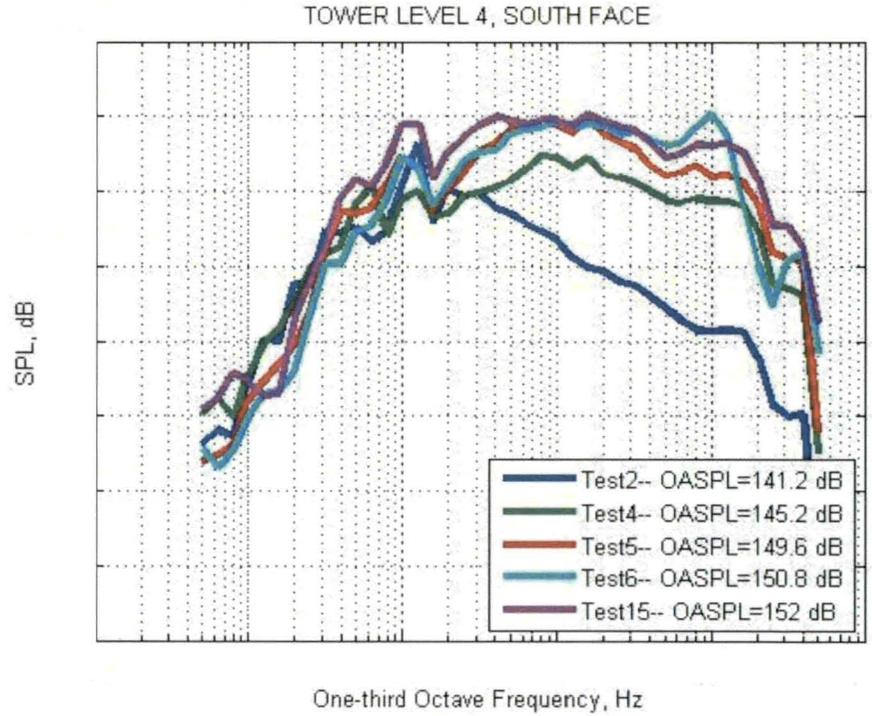
Pressure

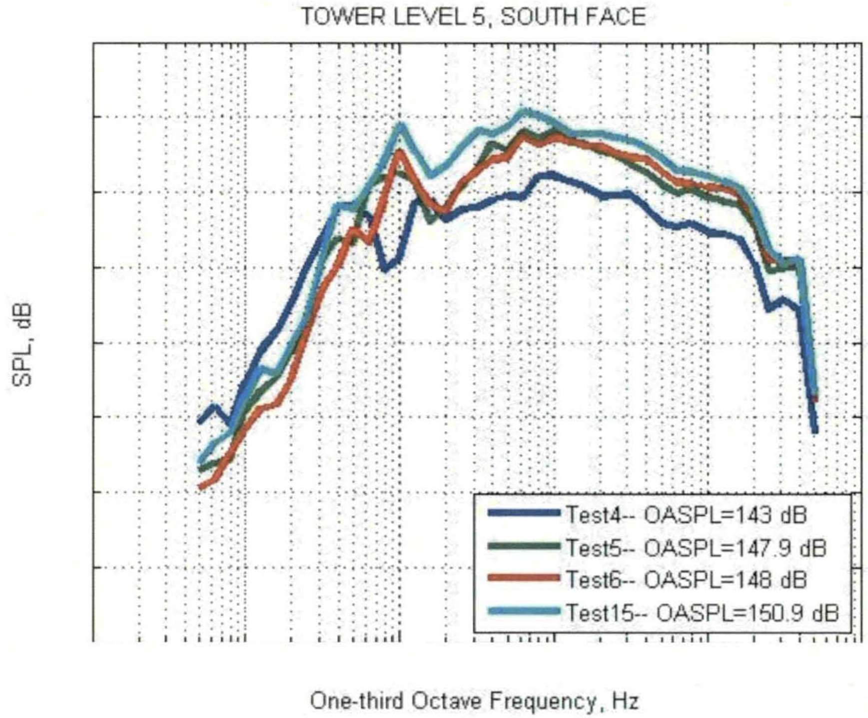
Levels of Interest



- CAA has electrical equipment on the 285' level (T4) under CxP specs
- Weather Systems have electronic field change device at 345' level (T5)

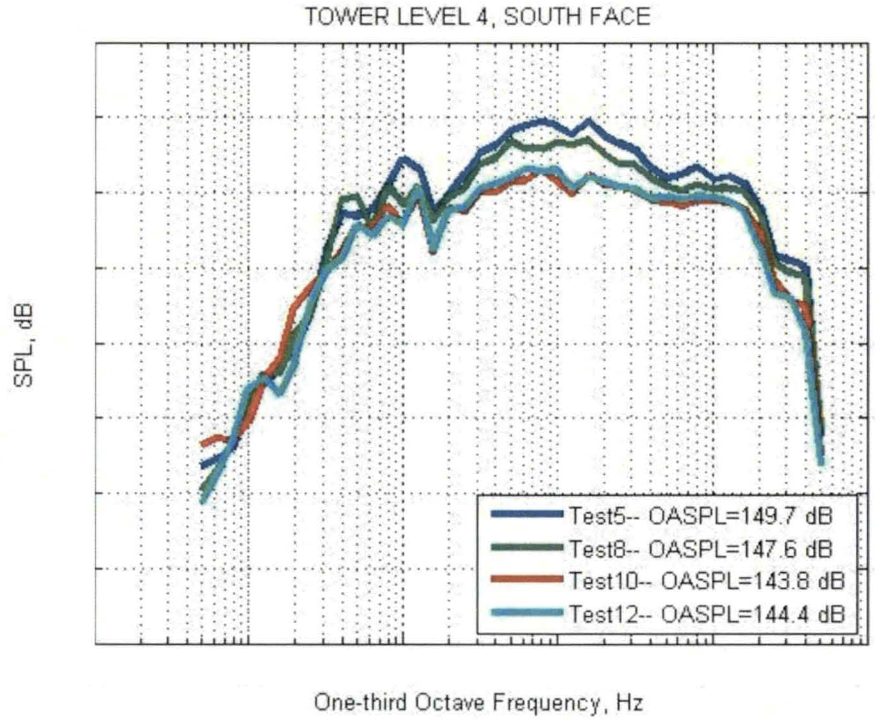
Ares I – Elevation Effects

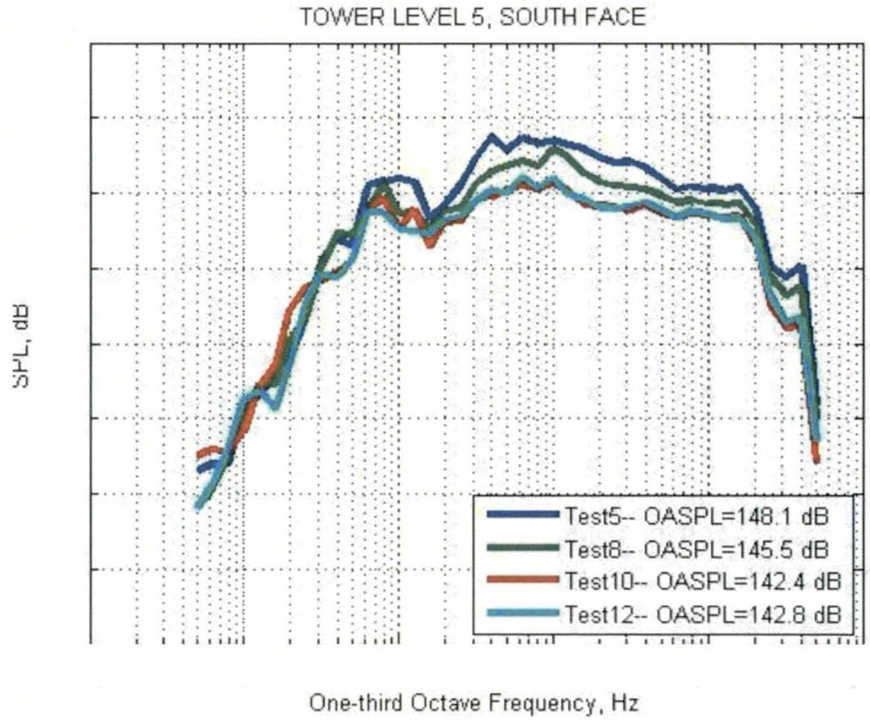




Test02: z=0.0', x=0.000", 0 gpm
Test04: z=2.5', x=4.625", 0 gpm
Test05: z=5.0', x=6.875", 0 gpm
Test06: z=7.5', x=8.375", 0 gpm
Test15: z=10.', x=9.975", 0 gpm

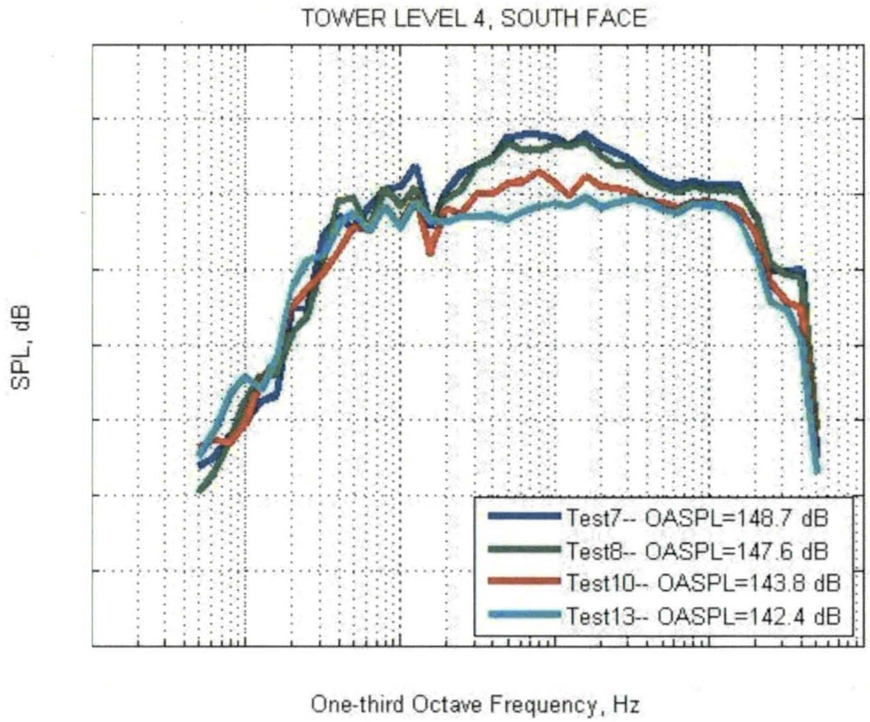
Ares I – Rainbird Effects

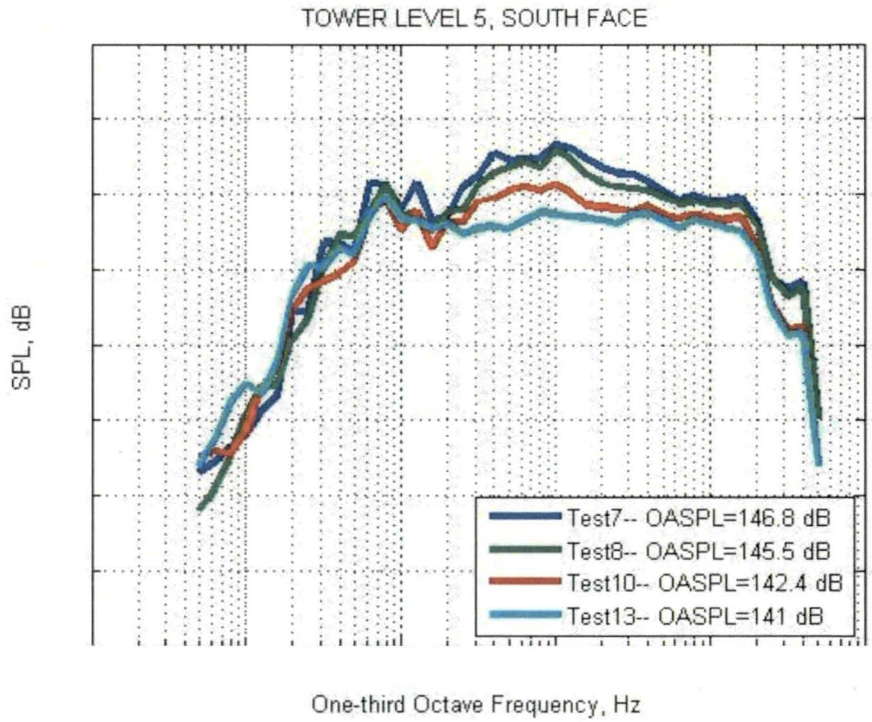




Test05:	z=5.0’,	x=6.875”,	0 gpm
Test08:	z=5.0’,	x=6.875”,	566 gpm
Test10:	z=5.0’,	x=6.875”,	991 gpm
Test12:	z=5.0’,	x=6.875”,	1275 gpm

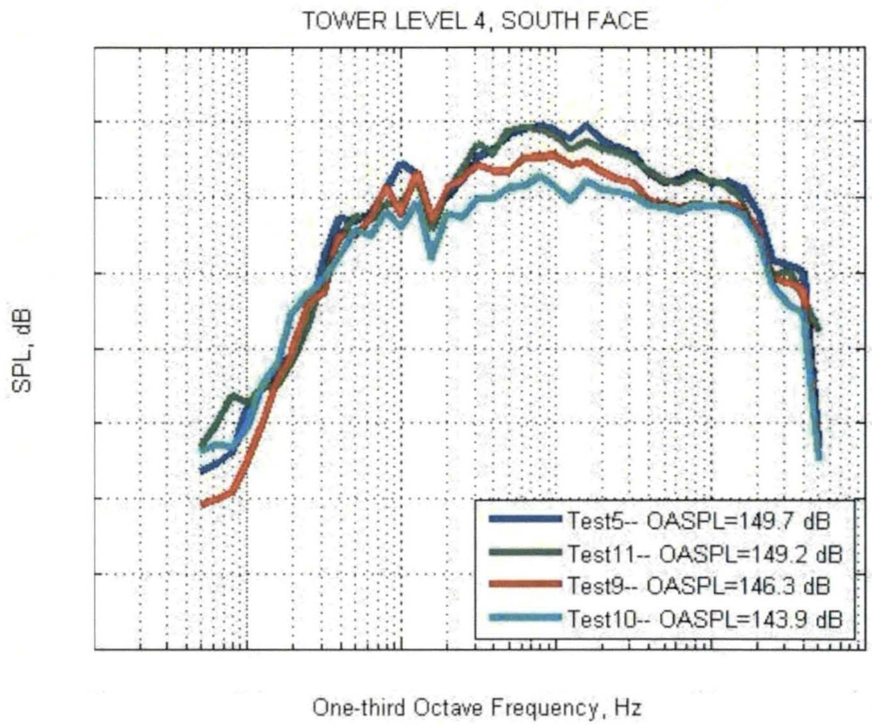
Ares I – Drift Effects

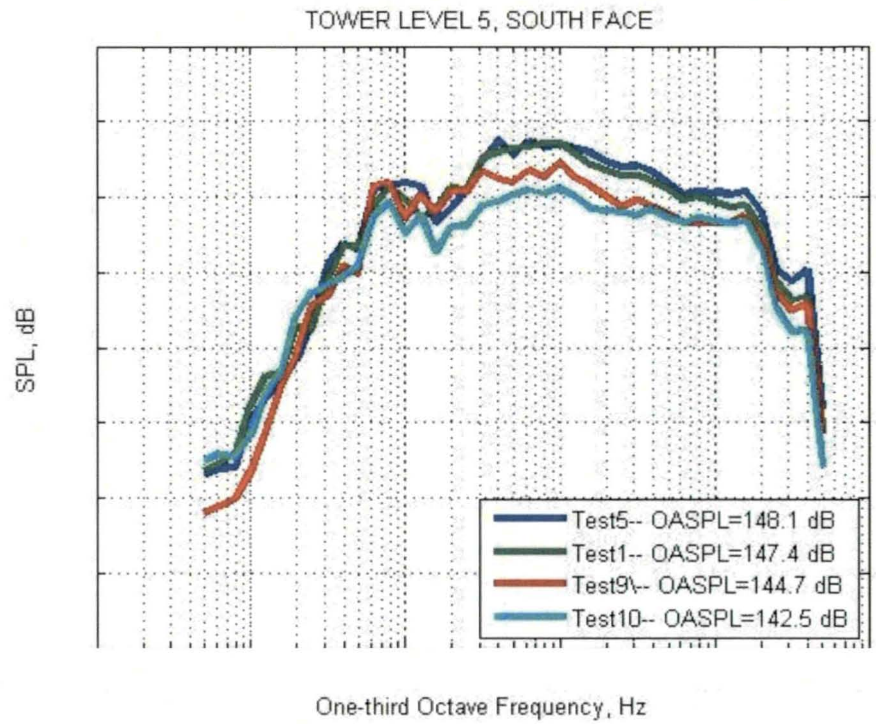




Test07:	z=5.0',	x=6.875",	0 gpm
Test08:	z=5.0',	x=0.0",	0 gpm
Test10:	z=5.0',	x=6.875",	991 gpm
Test13	z=5.0',	x=0.0:,	991 gpm

Ares I – Launch Mount Effects





Test05: z=5.0', x=6.875", 0 gpm, with LM
Test11: z=5.0', x=6.875", 0 gpm, no LM
Test09: z=5.0', x=6.875", 991 gpm, with LM
Test10: z=5.0', x=6.875", 991 gpm, no LM

Conclusion

- General trends, falloff with distance, as expected
- Plume impingement and IOP greatly affected acoustic measurements on the ML deck and Tower lower level below nozzle exit plane, making post-processing task difficult
  - ML Deck sensors (G29, G34) overloaded
  - All other sensors (ML Underside) probably overloaded, some were salvaged by filtering out the time window
- Maximum SPL occurred at relatively high vehicle altitude
- Rainbirds can reduce up to 6 dB at locations of interest
- Vehicle drift increases SPL, up to 1.4 dB OASPL
- Launch Mount increases SPL, up to 3 dB OASPL
- To be accomplished
  - Tube resonance analysis is required for recessed mics
  - Compare results with scaled Saturn-V and PAD predictions

Conclusion (cont'd)

- ASMAT provided valuable insights to the launch-induced environments
- Ground acoustic measurements remained a challenge; very difficult to collect data on the ML Base and lower Tower levels
- Environments were higher than predicted
- Beamforming results showed acoustics due to plume impingement to be different from NASA-SP-8072
- GSE should be placed on the North side of the Tower, if possible
- LM added adverse effects to the environments. Remove it if possible
- Vehicle drift only increased the environments slightly. Plume impingement is more of a concern during vehicle drift
- While rainbirds help reduce environments, ML Base and Tower can withstand the load without them