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: 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

<table>
<thead>
<tr>
<th>Test</th>
<th>Objective</th>
<th>Location</th>
<th>Water Systems</th>
<th>Total Water (gpm)</th>
<th>Rainbird Ww/Wp</th>
<th>Test Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>IOP Series. Hold down case without water bags.</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>3</td>
<td>IOP Series. Dry case. Test primarily for IOP measurements.</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>4</td>
<td>Elevation Series. Purpose is to find the elevation of max SPL. No rainbird water. IOP measurements not necessary.</td>
<td>2.5 (50)</td>
<td>4.625</td>
<td>Yes</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>5</td>
<td>Elevation Series. Purpose is to find the elevation of max SPL. No rainbird water.</td>
<td>5 (100)</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>6</td>
<td>Elevation Series. Purpose is to find the elevation of max SPL. No rainbird water.</td>
<td>7.5 (150)</td>
<td>8.375</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>7</td>
<td>Elevation Series. Repeat at max SPL.</td>
<td>5</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>8</td>
<td>Rainbird Series. Purpose is to find effective flow rate of rainbirds at max SPL.</td>
<td>5</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>9</td>
<td>Rainbird Series. Purpose is to find effective flow rate of rainbirds at max SPL.</td>
<td>5</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>10</td>
<td>Modified Rainbird Series (No LM)</td>
<td>5</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>11</td>
<td>Modified Elevation Series (No LM, No Rainbird)</td>
<td>5</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>12</td>
<td>Modified Rainbird Series (No LM)</td>
<td>5</td>
<td>6.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>13</td>
<td>No Drift (No LM)</td>
<td>5</td>
<td>0</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>14</td>
<td>No Drift (No LM) No Rainbirds</td>
<td>5</td>
<td>0</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>16</td>
<td>Modified Rainbird Series (No LM)</td>
<td>10</td>
<td>9.875</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
<tr>
<td>17</td>
<td>Contingency (Dry at 5')</td>
<td>5</td>
<td>0</td>
<td>No</td>
<td>873</td>
<td>291</td>
</tr>
</tbody>
</table>
Instrumentation

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

- Sensor naming convention:
  - \[Gxx.Lz\]
    - 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

Gxx_Tz

Not to Scale

North

Gxx_Mz

Not to Scale

North
Instrumentation Layout

Mobile Launcher View from Underside

Gxx_Fz

View from Underside of Mobile Launcher

North

Mobile Launcher

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Not to Scale
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 anomalies
- 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
  \[ \frac{256,000}{65,536} \rightarrow \text{low freq limit} = 4 \text{ Hz} \ (0.2 \text{ Hz full scale}) \]
- 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

![Bar Chart]

- Level 1
- Level 2
- Level 3
- Level 4
- Level 5

Test: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17

OASPL
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
- 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

TOWER LEVEL 4, SOUTH FACE

One-third Octave Frequency, Hz

TOWER LEVEL 5, SOUTH FACE

One-third Octave Frequency, Hz

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

TOWER LEVEL 4, SOUTH FACE

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

TOWER LEVEL 5, SOUTH FACE

Test5- OASPL=148.1 dB
Test8- OASPL=145.5 dB
Test10- OASPL=142.4 dB
Test12- OASPL=142.8 dB
Ares I – Drift Effects

TOWER LEVEL 4, SOUTH FACE

One-third Octave Frequency, Hz

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

TOWER LEVEL 5, SOUTH FACE

One-third Octave Frequency, Hz

Test07: OASPL=148.7 dB
Test08: OASPL=147.6 dB
Test10: OASPL=143.8 dB
Test13: OASPL=142.4 dB
Ares I – Launch Mount Effects

TOWER LEVEL 4, SOUTH FACE

One-third Octave Frequency, Hz

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

TOWER LEVEL 5, SOUTH FACE

One-third Octave Frequency, Hz

Test05-- OASPL=149.7 dB
Test11-- OASPL=149.2 dB
Test09-- OASPL=146.3 dB
Test10-- OASPL=143.9 dB

Test05-- OASPL=148.1 dB
Test11-- OASPL=147.4 dB
Test09-- OASPL=144.7 dB
Test10-- OASPL=142.5 dB
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