A Review of Large Solid Rocket Motor Free Field Acoustics, Part I

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At the ATK facility in Utah, large full scale solid rocket motors are tested. The largest is a five segment version of the Reusable Solid Rocket Motor, which is for use on future launch vehicles.

Since 2006, Acoustic measurements have been taken on large solid rocket motors at ATK. Both the four segment RSRM and the five segment RSRMV have been instrumented.

Measurements are used to update acoustic prediction models and to correlate against vibration responses of the motor.

Presentation focuses on two major sections:

Part I) Unique challenges associated with measuring rocket acoustics

Part II) Acoustic measurements summary over past five years
# Off-Motor Acoustic Data Collection Efforts

## T-24 Test Stand

<table>
<thead>
<tr>
<th>Year</th>
<th>Motor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>TEM-13</td>
<td>Microphone array in far field (NASA, ATK, Wyle effort)</td>
</tr>
<tr>
<td>2008</td>
<td>FVM-2</td>
<td>Microphone array in far field (NASA, ATK, Wyle effort)</td>
</tr>
<tr>
<td>2008</td>
<td>FVM-2</td>
<td>4 microphones on a parallel path far field from motor</td>
</tr>
<tr>
<td>2008</td>
<td>FSM-15</td>
<td>Microphone array in far field (NASA, ATK, Wyle effort)</td>
</tr>
<tr>
<td>2010</td>
<td>FSM-17</td>
<td>Microphone sets on motor, 6ft, 30 ft from motor</td>
</tr>
</tbody>
</table>

## T-97 Test Stand ("hilly terrain")

<table>
<thead>
<tr>
<th>Year</th>
<th>Motor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>FSM-13</td>
<td>4 far field microphones on hillside</td>
</tr>
<tr>
<td>2007</td>
<td>FSM-14</td>
<td>4 far field microphones on hillside</td>
</tr>
<tr>
<td>2009</td>
<td>DM-1</td>
<td>4 far field microphones on hillside</td>
</tr>
<tr>
<td>2009</td>
<td>DM-1</td>
<td>Microphone arrays near and far field (with Dr. Kent Gee, BYU)</td>
</tr>
<tr>
<td>2010</td>
<td>DM-2</td>
<td>6 far field microphones at 4 locations (includes ground impedance measurements)</td>
</tr>
</tbody>
</table>
ATK Measurements
• Started with Endevco 8510B-5
• Now using 1/4” GRAS 40BD
• Data recorded at 100,000 samples/sec on a Genesis Recorder

NASA/ATK/Wyle Arrays
• 1/4” Microphones used for all locations
• Data recorded at 96,000 samples/sec on 24-bit system
• Wind, temperature, and relative humidity measured for corrections
• Ambient noise levels recorded
T-24 test site had flatter terrain / line of sight from microphone locations to motor plume compared to T-97

Several tests were run to evaluate T-24 and T-97 terrain effects on the measured data (Wyle Labs / ATK)

Additional tests were conducted to select best sensor type for this type of acoustic environment measurement (BYU / ATK)
Wyle Labs measured the ground impedance from soil to aid in correcting out any propagating wave interference / reflection effects.


Uses multi-microphone method to measure broadband noise source wave reflections at different heights from the ground.

Ground impedance value is 160 rayls. Used for any correction models.
Three measurements taken at a fixed location at the T-97 test site.

Looking to see general terrain effect between three measurements during same test.
Notable effect seen around 100 – 200 Hz, and 1000 Hz -> local effect only, no significant effect on OASPL

Simplest correction is to envelop octave bands to ‘smooth out’ the interference lines

**OASPL**
- Top position = 149 dB
- ~13 ft down from Top = 149 dB
- ~16 ft down from Top = 150 dB
- Envelop = 151 dB
T-97 Acoustic Free Field: Various Locations

Interference effect seen in other locations

Need terrain effects model to better accommodate for the interference

Can still use OASPL values for comparisons against prior datasets

*Notional Schematic; Not to scale
Microphone selection study

Needed to select best microphone for high amplitude rocket acoustic measurements

Several options available, but ultimately two types were chosen for further study

1) GRAS ¼ “ BH

2) Endevco 8510B with variable vent tube lengths

Study focused on side-by-side comparisons of GRAS and Endevco models at two separate firings, in addition to controlled lab work

Vent tube length varied using attached tubing

GRAS 40BH

Endevco 8510B-5
For this test objective, there were two arrays of instruments. One near the motor, and one far from the motor on a hillside. No instruments were positioned on the motor for this test.
Data from close to the motor

Vent tube studies showed short open, or no vent tube extensions distorted data in low frequencies.

Best results came from GRAS ¼” 40 BH responses, with 6” closed and 60” open vent tube responses being very similar.
Ground Impedance = 160 rayls

Ground reflection interference causes notable spectral dB changes in the 100-200 Hz and 1000 Hz ranges

- Care should be used in comparing spectral content against previous data without ground effects model corrections
- OASPL less affected by ground effects

Choice of microphone sensor type and installation greatly effects measurements
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Background

Acoustic data collected at two different test stands, T-97 and T-24.

T-24 test stand more amiable to free field acoustic data collection; T-97 had terrain complications addressed in Part I presentation

Part II focused on comparing the acoustic data collected between the two stands in terms of overall sound pressure levels (OASPL), spectral content, directivity, and relationship to motor operation
• First stage five-segment rocket motor offers performance improvement over four-segment predecessor
  • Total Impulse: 368.1 Mlbf-sec
  • Maximum thrust (60°F/vacuum): 3.55 Mlbf
  • Web time average thrust (60°F/vacuum): 3.13 Mlbf
  • Propellant weight: 1.385 Mlb
  • Grain geometry: 12 fin/CP
  • 56.86 in. diameter throat with 7.22 expansion ratio

Reusable Solid Rocket Motor = RSRM (4-segment)
Reusable Solid Rocket Motor V = RSRMV (5-segment)
Example Time Histories

Positive skewness of data
Potentially due to plume shock contributions

Prior RSRM measurement

24 nozzle diameters and 60° from nozzle exit plane
T-97 Test Stand

Recent RSRMV measurement

17 nozzle diameters and 90° from nozzle exit plane
T-24 Test Stand
Generally, the four and five segment motors have similar external acoustic characteristics.

While the measurements in the figure were taken at the same location test-to-test, the distance from the motor changed slightly between four and five segment motors.

4 segment: exit plane plus 171 ft
5 segment: exit plane plus 144 ft

-(Black) 4 segment motor measurements from two tests
-(Red) 5 segment motor measurements from two tests
Local acoustics sensitive to changing plume source strengths from associated thrust changes

OASPLs do not roll-off as thrust does at end of burn; plume (and sound sources) retreat towards measurement
DM-2 Duty Cycle Effects

Duty Cycle effects more pronounced for the far-field measurements than on motor

Measurements closer to downstream plume sources, in particular around 75-80 sec

*Notional Schematic; Not to scale
Near-field Data – Comparisons at 90-deg

Comparisons for prior (Endevco) and current (GRAS) sensors for same locations

Acoustic energy more wideband at 6ft with no apparent spectral roll-off

Acoustic energy peaks at 2000 Hz at 30ft with notable spectral changes at lower and higher frequencies

Difference is only 2 dB between measurement locations
Measurements Parallel to Plume Direction

Acoustic energy peak shifts from 2000 Hz down to 200 – 500 Hz by moving further away from the nozzle.

Octave band SPL peak rises as one moves from motor location to downstream of nozzle.
Results at T-97 – “Hill Site”; Spectral Shapes

Majority of acoustic energy located below 100 Hz

Spectral roll-off similar across different measurement locations and firings

Largest OASPL difference is 7 dB
Far-field vs. Near-field Directivity

Previous RSRM measurements had circular array at 79 nozzle diameters away from nozzle exit plane. Showed peak lobe occurs at approximately 50-deg throughout test.

Recent RSRMV measurements indicate that OASPLs have directivity, but not enough data was collected to define the directivity pattern in the near-field.

*Notional Schematic; Not to scale
Far-field vs. Near-field OASPL Reduction

Compared DM2 45deg spectra at 25\(D_e\) to the prior RSRM 45deg spectra at 79\(D_e\)

Notably good agreement above 100 Hz to \(~4000\) Hz; poor comparison between 10 – 100 Hz

‘Far-field’ definition frequency dependant? Coincidence?

\[79D_e; \text{OASPL} = 143 \text{ dB}\]

\[25D_e; \text{OASPL} = 151 \text{ dB}\]
Significance of the work

Time histories continue to show positive skewness

Spectral shapes strongly dependant on measurement location relative to nozzle exit origin

No apparent differences in spectral characteristics between 4 and 5-segment motor acoustic measurements at similar locations

Motor operation, specifically changing thrust level, plume length, and nozzle angle all influence the acoustic measurements.

- Apparent plume source strengths and locations relative to the measurement define the acoustic results

Collected data useful for empirical inputs into non-linear / linear acoustic models

- Free-field measurements: plume source definition and acoustic propagation
- On-motor measurements: near-surface acoustic environment and transmitted sound through panels -> vibration models
For more information about ATK’s test capabilities
Contact: Kevin Rees, Test Director
435.863.6471
Kevin.Rees@ATK.com

Rocket motor testing
Structural testing
Environmental testing
Dynamic testing
High reliability cable manufacturing
Custom measurement & transducer development
Control system design & fabrication
Warhead development & testing
BACKUP
Reusable Solid Rocket Motor (RSRM)

Thrust and nozzle diameter comparable to current Ares I booster design