Ares I Scale Model Acoustic Test
Instrumentation for Acoustic and Pressure Measurements

Acoustical Society of America
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Noise and Physical Acoustics: Launch Vehicle Noise II
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Agenda

- Overview and Scope
- Sensors
- Sensor Effects
- Mounts
- Mount Effects
- Conclusions
- Backup
Overview and Scope

• Ares I Scale Model Acoustic Test (ASMAT) is a 5% scale model test of the Ares I vehicle, launch pad and support structures conducted at MSFC to verify acoustic and ignition environments and evaluate water suppression systems

• Test design considerations
  • 5% measurements must be scaled to full scale requiring high frequency measurements
  • Users had different frequencies of interest
    • Acoustics: 200 - 2,000 Hz full scale equals 4,000 - 40,000 Hz model scale
    • Ignition Transient: 0 - 100 Hz full scale equals 0 - 2,000 Hz model scale
  • Environment exposure
    • Weather exposure: heat, humidity, thunderstorms, rain, cold and snow
    • Test environments: Plume impingement heat and pressure, and water deluge impingement

• Several types of sensors were used to measure the environments
• Different instrument mounts were used according to the location and exposure to the environment
• This presentation addresses the observed effects of the selected sensors and mount design on the acoustic and pressure measurements
Overview and Scope

• 5% ASMAT model includes
  • Vehicle
  • Tower
  • Mobile Launcher (ML)
  • Launch Mount (LM)
  • Launch Pad Trench (LPT)

• ASMAT measurements included
  • Liftoff Acoustics (LOA): 4,000-40,000 Hz
  • Ignition Overpressure (IOP) and transient wave: 0-2,000 Hz (10,000 Hz for CFD)
  • Ground Acoustics (GA): 4,000-40,000 Hz
  • Spatial Correlations (SC): 4,000-40,000 Hz
A combination of microphones and pressure sensors were used throughout the model to measure the environments

- **Microphone**
  - B&K 4944B – LOA and GA

- **Pressure Transducers**
  - Kulite XTL 123B-190-30 SG and -65 SG – IOP
  - PCB 122A22 - GA
  - Kulite XCEL-12-100-2D - SC
Sensor Effects

• Each instrument used has a diaphragm resonant frequency above the frequency of interest
  • B&K 4944B – 60 KHz
  • Kulite XTEL-123B-190 – 175 kHz
  • PCB 112A22 – ≥250 kHz
  • Kulite XCEL-12-100-2D – ≥150kHz

• Protective screens introduced additional resonances
  • B&K 4944B – 31.5 kHz peak
  • Kulite XTEL-123B-190 - 41kHz peak
Sensor Effects – B&K Grid

B&K Grid Effects
1/3 Octave Band Analysis

Measured Grid Resonance ~ 31,500 Hz

B&K Grid Resonance

LOA Microphone - No Grid

LOA Microphone - Grid

ASMAT_gridAssessment.fig

Lee, E.

Sensor Effects – B&K Grid

B&K Grid Effects
1/3 Octave Band Analysis

Measured Grid Resonance ~ 31,500 Hz

B&K Grid Resonance

LOA Microphone - No Grid

LOA Microphone - Grid

ASMAT_gridAssessment.fig

Lee, E.

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B&K Grid Effects
1/3 Octave Band Analysis

Measured Grid Resonance ~ 31,500 Hz

B&K Grid Resonance

LOA Microphone - No Grid

LOA Microphone - Grid

ASMAT_gridAssessment.fig

Lee, E.
Sensor Effects – Kulite Grid

Kulite Grid Effects
1/3 Octave Band Analysis

Measured Grid Resonance ~ 41,000 Hz

Kulite Grid Resonance

- Sound Pressure Level (dB)
- Frequency (Hz)

IOP Vert2 ML North Side Bottom
IOP Vert2 ML South Side
IOP Vert2 ML North Side Top
IOP Vert2 North Tower Level 1

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Mounts

- Instrument mounts were designed according to the model location

LOA Vehicle Mount (Diaphragm Flushed)

GA Tower Mount (Flushed) and IOP North Tower Mount (Protruding)

IOP Vehicle Mount (Cavity)

IOP ML Mount (Tube)

SC Vehicle Mount (Cavity)
Mounting Effects

• Some of these mounts introduced either cavity or tube resonances in the measurements
  • Calculated Tube Resonances
    • IOP: South Side Tower Blocks - ~4,500 Hz
    • IOP: Mobile Launcher Underside Blocks - ~5,000 – 5,500 Hz
    • IOP: Launch Mount Blocks – 3,300 – 6,300 Hz
    • IOP: Launch Pad Trench Blocks - ~ 5,100 Hz
    • IOP: Exhaust Hole Blocks - ~5,000 – 5,500 Hz
    • GA*: 1/8” Recessed - ~14,300 Hz
  • Calculated Cavity Resonances
    • IOP: Vehicle Mounts - ~27,500 – 29,200 Hz
    • GA**: Covers - ~9,300 Hz
    • SC: All Mounts - ~22,300

Note:
*GA 1/8” Recessed only during Vert9 South Side Tower Level 1 and 2 except for G02 and G07 which were flushed
**GA Covers only for Vert7 G02 and Vert8 South Side Tower Level 1 and 2
Mounting Effects – IOP Tube

Tower IOP Mount Tube Resonance
1/3 Octave Band Analysis

Calculated Mount Resonance ~ 4,500 Hz

IOP Mount Resonance

Sound Pressure Level (dB)

Frequency (Hz)

IOP Vert9 North Tower Level 2 (Protruding)
IOP (T08) Vert9 South Tower Level 2 (Tube)
IOP (T09) Vert9 South Tower Level 2 (Tube)

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Mounting Effects – IOP Tube

ML IOP Mount Tube Resonance
1/3 Octave Band Analysis

Calculated Mount Resonance ~ 5,000 – 5,500 Hz

IOP Mount Resonance

Sound Pressure Level (dB)

Frequency (Hz)

VERT2 - ML Kulite North Side Top (Protruding)
VERT2 - ML Kulite North Side (Tube)
VERT2 - ML Kulite North Side Bottom (Tube)

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Mounting Effects – GA Tube

Tower GA 1/8" Tube Resonance
1/3 Octave Band Analysis

GA 1/8" Recessed only during Vert9 South Side Tower Level 1 and 2 except for G02 and G07 which were flushed

Calculated Mount Resonance ~ 14,300 Hz

Sound Pressure Level (dB)
Frequency (Hz)
Vehicle IOP Mount Cavity Resonance
1/3 Octave Band Analysis

Calculated Mount Resonance ~ 27,500-29,200 Hz

IOP Mount Resonance

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Mounting Effects – GA Cavity

Tower GA Cover Cavity Resonance
1/3 Octave Band Analysis

GA Covers only for Vert7 G02 and Vert8 South Side Tower Level 1 and 2

Calculated Mount Resonance ~ 9,300 Hz

Sound Pressure Level (dB)

Frequency (Hz)

GA (G06) Vert8 South Tower Level 2 (Cover)
GA (G07) Vert8 South Tower Level 2 (Cover)
GA (G08) Vert8 South Tower Level 2 (Cover)
GA (G09) Vert8 South Tower Level 2 (Cover)
GA (G10) Vert8 South Tower Level 2 (Cover)
GA (G25) Vert8 North Tower Level 2 (Flushed)
Vehicle SC Cavity Resonance

1/3 Octave Band Analysis

Calculated Mount Resonance ~ 22,300 Hz

Sound Pressure Level (dB)

Frequency (Hz)

SC Mount Resonance

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Conclusions

- Appropriate sensors were selected for the measurements
  - IOP Kulite grid and mount resonances occurred beyond the frequency range of interest.
  - LOA measurements will be corrected to remove the grid resonance.
  - GA and SC sensor resonances beyond the frequencies of interest.

- Proper mount design
  - Mount induced resonances occur beyond the user’s frequency of interest.
  - The mounting measures used during the ASMAT program protected most of the sensors exposed to the plume environments and resulted in low sensor loss.
  - Attempts to protect the GA sensors from the plume environments resulted in mount induced resonances that limited the frequency range of useful data.

- The measured and calculated resonances agree; the data can be corrected for both grid and mount induced resonances.
Questions
Backup

- Resonance Equations
- Data Acquisition Parameters
- Data Processing Parameters
- Sensor Spec Sheets
Resonance Equations

- **Tube Resonance**

  \[ f = \frac{c}{4(L + 0.4D)} \]

  - \( c \) = speed of sound (in/sec)
  - \( L \) = tube length (in)
  - \( D \) = tube diameter (in)

- **Cavity Resonance**

  \[ f = \frac{c}{2\pi \sqrt[3]{\frac{S}{(L + 0.4D)V}}} \]

  - \( c \) = speed of sound (in/sec)
  - \( S \) = neck area (in\(^2\))
  - \( L \) = neck length (in)
  - \( D \) = neck diameter (in)
  - \( V \) = chamber volume (in\(^3\))
Data Acquisition Parameters

• Coupling
  • DC - IOP and SC measurements
  • AC – LOA and GA measurements

• Sample Rates
  • 4000 sps – IOP
  • 256000 sps – LOA, IOP, GA and SC

• Data converted and delivered in engineering units
  • IOP and SC – psi
  • LOA and GA - Pa
Data Processing Parameters

- DC component removed during post processing
- Processing parameters selected according to sample rate in order to keep a consistent number of blocks
  - 256,000 sps
    - Time Domain
      - Time Window: -0.5 – 4.492 seconds
      - Reduction Time: 0.032 seconds
    - Frequency Domain
      - 1/3 Octave Band Range (Center Frequency): 50 – 128,000 Hz
      - Frequency Resolution: 1.953 Hz
      - Fast Fourier Transform Block Size: 131,072 samples
      - Frequency Analysis Time Window: 0.5 – 2.036
      - Window Type: Rectangular
      - Reference Pressure
        - 2.9x10⁻⁹ for measurements in psi
        - 2x10⁻⁵ for measurements in Pa
    - N Average: 3
PRODUCT DATA

1/4" DeltaTron® Pressure-field Microphones — Types 4944-A and 4944-B

Types 4944-A and 4944-B are 1/4" Pre-polarized Pressure-field Microphones laser welded to 1/4" DeltaTron premillimeters.

The preamplifier connects to CCLD input conditioning and supports IEEE P1451.4 V-09/EDS (Transducer Electronic Data Sheet).

USES
- High-level measurements
- High-frequency measurements
- Flush mounting

FEATURES
- Sensitivity: 0.9 mV/Pa
- Frequency: 16 - 70000 Hz
- Dynamic Range: 48 dB(A) - 140 dB
- Temperature: -20 to +100°C (-4 to +212°F)

TEDS: IEEE P1451.4
- 5/16 or 1/2 UNF socket
- Connects to CCLD input

Description

Uses of Types 4944-A and 4944-B

A pressure-field microphone is designed to be used in small closed couplers close to hard reflective surfaces or flush-mounted. The sensitivity has been optimized to allow measurements of high sound pressure levels without clipping to the built-in DeltaTron preamplifier.

Design and Robustness

The shape of the microphone front ensures excellent microphone performance when flush-mounted. The laser-welded diaphragm on the microphone housing ensures that the sensitivity is resistant to rough handling during flush mounting.

Microphone Data CD

The microphone is supplied with a mini CD. This mini-CD carries all individual calibration data as well as random-incidence and free-field corrections. The influence of 1/4" Noise Cone UA-0385 is also available.

Calibration

The sensitivity can be calibrated at 250 Hz using Pitotphone Type 4228 with 1/4" Adaptor DP-0775. The pressure-field response can be measured using Actuator UA-0003 with Adaptor DB-0264. The pressure-field response is equal to the actuator response.

Brüel & Kjær
Data Processing Parameters

<table>
<thead>
<tr>
<th>Model Number</th>
<th>112A22</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRESSURE SENSOR, ICP®</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Measurement Range</td>
<td>360 psi 345 kPa</td>
</tr>
<tr>
<td>Useful Overrange</td>
<td>660 psi 600 kPa</td>
</tr>
<tr>
<td>Sensitivity (±15 %)</td>
<td>100 mV psi 14.5 mV/kPa</td>
</tr>
<tr>
<td>Maximum Pressure</td>
<td>500 psi 3450 kPa</td>
</tr>
<tr>
<td>Resolution</td>
<td>1 mV 0.007 kPa</td>
</tr>
<tr>
<td>Resonant Frequency</td>
<td>≥250 kHz ≥250 kHz</td>
</tr>
<tr>
<td>Rise Time</td>
<td>≤2.0 μsec ≤2.0 μsec</td>
</tr>
<tr>
<td>Low Frequency Response (±5 %)</td>
<td>0.50 Hz 0.50 Hz</td>
</tr>
<tr>
<td>Non-Linearity</td>
<td>≤1.0 % FS ≤1.0 % FS</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
</tr>
<tr>
<td>Acceleration Sensitivity</td>
<td>≤0.002 psi/g ≤0.0014 kPa/(m²/s)</td>
</tr>
<tr>
<td>Temperature Range (Operating)</td>
<td>-100 to +275 °F -73 to +315 °C</td>
</tr>
<tr>
<td>Temperature Coefficient of Sensitivity</td>
<td>±0.05 °F/°F ±0.108 °C/°C</td>
</tr>
<tr>
<td>Maximum Flush Temperature</td>
<td>1050 °F</td>
</tr>
<tr>
<td>Maximum Shock</td>
<td>20000 g pk 196000 m/s² pk</td>
</tr>
<tr>
<td><strong>Electrical</strong></td>
<td></td>
</tr>
<tr>
<td>Output Polarity (Positive Pressure)</td>
<td>Positive</td>
</tr>
<tr>
<td>Discharge Time Constant (at room temp)</td>
<td>≤5 sec ≤5 sec</td>
</tr>
<tr>
<td>Excitation Voltage</td>
<td>≥22 to 30 VDC ≥22 to 30 VDC</td>
</tr>
<tr>
<td>Constant Current Excitation</td>
<td>2 to 20 mA 2 to 20 mA</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>≥100 ohm ≥100 ohm</td>
</tr>
<tr>
<td>Output Bias Voltage</td>
<td>6 to 14 VDC 6 to 14 VDC</td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td></td>
</tr>
<tr>
<td>Sensing Geometry</td>
<td>Compression</td>
</tr>
<tr>
<td>Sensing Element</td>
<td>Quartz</td>
</tr>
<tr>
<td>Housing Material</td>
<td>17-4 Stainless Steel</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Invar</td>
</tr>
<tr>
<td>Sealing</td>
<td>Welded Hermetic</td>
</tr>
<tr>
<td>Electrical Connector</td>
<td>10-32 Coaxial Jack 10-32 Coaxial Jack</td>
</tr>
<tr>
<td>Weight (with clamp nut)</td>
<td>0.21 oz 0.03 lb</td>
</tr>
</tbody>
</table>

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option may be used.)

- E - Entrainment coating
- Coating: Entrainment Entrainment
- Electrical Isolation: 10⁷ ohm
- Supplied Accessory: Model 065A08 Isolation ring, 0.250” OD x 0.219” ID x 0.027” thk, anodized aluminum
- Supplied Accessory: Model 065A22 Isolation Seal, 250° O.D. x 210” I.D. x 0.15”, Torlon of Vespol
- H - Hermetic Seal
- Sealing: Welded Hermetic Welded Hermetic
- J - Ground Isolated
- N - Negative Output Polarity
- S - Stainless Steel Diaphragm
- W - Water Resistant Cable
- W2 - Water Resistant Cable

Notes
1. For ±10 volt output, minimum 24 VDC supply voltage required. Negative 10 volt output may be limited by output bias.
2. Zero-biased, least-squares, straight line method.
3. See PCB Declaration of Conformance P823 for details.
4. For sensor mounted in thread adapter, see adapter installation drawing for supplied accessories.
5. Used with optional mounting adaptor.
6. Clamp nut installed prior to cable attachment.

Supplied Accessories
- 06A03 Clamp nut, 5/16-24 A thd, 1/4” hex, stainless steel (1)
- 06A05 Clamp nut M7 x 0.75-8g thd (1)
- 055A02 Seat ring, sensor flush mount, 0.240” OD x 0.219” ID x 0.015” thk, brass (3)
- 065A05 Seat sleeve sensor recess mount 0.240” OD x 0.221” ID x 0.240” thk 17-7 (1)

Entered: BL.S Engineer: NJL Sales: RWM Approved: ES Date: Date: Date: 02/24/2009 02/13/2009 02/22/2009 02/23/2009 6476

PCB PIEZOTRONICS
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E-mail: pressure@pcb.com
Web site: www.pcb.com
Data Processing Parameters
Data Processing Parameters

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### Data Processing Parameters

#### Kulite High Temperature Miniature IS+ Pressure Transducer

**XCEL-100 Series**

- 0.11" Diameter
- Patented Leadless Technology
- Ideal for Turbine Engine Probe
- Designed for Both Static and Dynamic Measurement
- 

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#### Technical Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>Absolute, gage, sealed gage, differentia</td>
</tr>
<tr>
<td>Over Pressure</td>
<td>2 Times Rated Pressure</td>
</tr>
<tr>
<td>Burst Pressure</td>
<td>3 Times Rated Pressure</td>
</tr>
<tr>
<td>Precision Media</td>
<td>All noncorrosive, noncondensing liquids or gases (noncondensing liquids and gases - please consult factory)</td>
</tr>
<tr>
<td>Rated Electrical Excitation</td>
<td>15 VDC/AC</td>
</tr>
<tr>
<td>Maximum Electrical Excitation</td>
<td>15 VDC/AC</td>
</tr>
<tr>
<td>Input Resistance</td>
<td>1000 Ohms (max)</td>
</tr>
<tr>
<td>Output</td>
<td>100 Ohms (nom)</td>
</tr>
<tr>
<td>Full Scale Output (FSO)</td>
<td>100 mV (nom)</td>
</tr>
<tr>
<td>Noise Voltage</td>
<td>±1 mV (typ)</td>
</tr>
<tr>
<td>Combined Non-linearity, Hysteresis and Repeatability</td>
<td>±0.15% FSO (δFSL) (Typ) ±0.25% FSO (Max)</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.0001</td>
</tr>
<tr>
<td>Natural Frequency (Typ)</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Accelerometer Sensitivity at 5g</td>
<td>1.5V/g</td>
</tr>
<tr>
<td>Cross-axis</td>
<td>0.5% FSO (%FS)</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-50°F to 350°F (-46°C to 176°C)</td>
</tr>
<tr>
<td>Environmental</td>
<td>60% RH at 101 kPa (50°C)</td>
</tr>
<tr>
<td>Thermal Drift</td>
<td>±0.1% FSO/°C (Typ) ±0.25% FSO/°C (Max)</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>0.01 W/°C (Typ)</td>
</tr>
<tr>
<td>Steady acceleration and Linear Velocity</td>
<td>1000g (Max)</td>
</tr>
<tr>
<td>Weight</td>
<td>3 g (Typ)</td>
</tr>
</tbody>
</table>

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**Note:** Custom pressure transducers, adapters and mechanical configuration are available. Please contact for more information. Dimensions are approximate, ±0.01" unless otherwise noted. All specifications subject to change without notice. (2) KULITE SEMICONDUCTOR PRODUCTS, INC. • One Willow Ave. • Iselin, New Jersey 08830 • Tel. 732-401-8000 • Fax 732-401-8010 • http://www.kulite.com

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