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

Acoustical Society of America
162nd Meeting Session 4pNS
Noise and Physical Acoustics: Launch Vehicle Noise II
November 3, 2011

Magda B. Vargas
All Points Logistics/ESTS Group
Douglas Counter
NASA Marshall Space Flight Center
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
Sensors

• 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

Sound Pressure Level (dB)

[Graph showing sound pressure level vs. frequency with different line styles for various configurations.]

Lee, E.

B&K Grid

Resonance

1/3 Octave Band Analysis

Test 13, Zone 8 minus 9
Test 14, Zone 8 minus 9
Test 17, Zone 8 minus 9

LOA Microphone - No Grid

LOA Microphone - Grid

M. Vargas / D. Counter

7
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

M. Vargas / D. Counter
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)
• 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
Sound Pressure Level (dB)

Tower IOP Mount Tube Resonance
1/3 Octave Band Analysis

Calculated Mount Resonance ~ 4,500 Hz

IOP Mount Resonance

Frequency (Hz)

Sound Pressure Level (dB)

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

GA (G06) Vert9 South Tower Level 2 (Recessed)
GA (G07) Vert9 South Tower Level 2 (Flushed)
GA (G08) Vert9 South Tower Level 2 (Recessed)
GA (G09) Vert9 South Tower Level 2 (Recessed)
GA (G10) Vert9 South Tower Level 2 (Recessed)
GA (G25) Vert9 South Tower Level 2 (Flushed)

M. Vargas / D. Counter
Mounting Effects – IOP Cavity

Vehicle IOP Mount Cavity Resonance

1/3 Octave Band Analysis

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

- IOP Vert9 92in 270° (Cavity)
- IOP Vert9 100in 270° (Cavity)
- IOP Vert9 112in 270° (Cavity)
- LOA Vert9 Zone4 270° (Flushed)
- LOA Vert9 Zone6 270° (Flushed)

Frequency (Hz)

Sound Pressure Level (dB)
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)

M. Vargas / D. Counter
Mounting Effects – SC Cavity

Vehicle SC Cavity Resonance
1/3 Octave Band Analysis

Calculated Mount Resonance ~ 22,300 Hz

Sound Pressure Level (dB)

Frequency (Hz)

M. Vargas / D. Counter

ESI Group
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

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

c = speed of sound (in/sec)
S = neck area (in²)
L = neck length (in)
D = neck diameter (in)
V = chamber volume (in³)
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
        • $2.9 \times 10^{-9}$ for measurements in psi
        • $2 \times 10^{-5}$ for measurements in Pa
      • N Average: 3
PRODUCT DATA

1/2" DeltaTron® Pressure-field Microphones — Types 4944-A and 4944-B

Types 4944-A and 4944-B are 1/2" Pre-polarized Pressure-field Microphones laser welded to 1/2" DeltaTron preamplifiers.

The preamplifier connects to CCLD input conditioning and supports IEEE P1451.4V 99 TEDS (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: 46 dB(A) – 120 dB
• Temperature: –20 to +100°C (–4 to +212°F)

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 optimised to allow measurements of high sound pressure levels without clipping in 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 micro CD. This micro CD carries all individual calibration data as well as random-noise and free-field corrections. The influence of 1/4" Nose Cone UA-0386 is also available.

Calibration
The sensitivity can be calibrated at 250 Hz using PurpleGnome Type 4228 with 1/4" Adaptor DP-0775. The pressure-field response can be measured using Actuator UA-0033 with Adaptor DB-0204. The pressure-field response is equal to the actuator response.

Brüel & Kjær

M. Vargas / D. Counter 23
**Data Processing Parameters**

| Model Number | PRESSURE SENSOR, ICP® | Revision C  
|--------------|----------------------|--------------|

<table>
<thead>
<tr>
<th><strong>Performance</strong></th>
<th><strong>ENGLISH</strong></th>
<th><strong>SI</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Range (for ±10 V output)</td>
<td>±100 psi</td>
<td>±690 kPa</td>
</tr>
<tr>
<td>Useful Overrange (for ±10 V output)</td>
<td>±100 psi</td>
<td>±690 kPa</td>
</tr>
<tr>
<td>Sensitivity (±15 %)</td>
<td>100 mV/psi</td>
<td>14.5 mV/kPa</td>
</tr>
<tr>
<td>Resolution</td>
<td>1 mpsi</td>
<td>0.007 kPa</td>
</tr>
<tr>
<td>Resonant Frequency</td>
<td>≥250 kHz</td>
<td>≥250 kHz</td>
</tr>
<tr>
<td>Rise Time</td>
<td>≤2.0 μsec</td>
<td>≤2.0 μsec</td>
</tr>
<tr>
<td>Low Frequency Response (±5 %)</td>
<td>0.50 Hz</td>
<td>0.50 Hz</td>
</tr>
<tr>
<td>Non-Linearity</td>
<td>≤1.0 % FS</td>
<td>≤1.0 % FS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Environmental</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration Sensitivity</td>
<td>≤0.002 psi/g</td>
<td>≤0.0014 kPa/(m/s²)</td>
</tr>
<tr>
<td>Temperature Range (Operating)</td>
<td>-100 to +275 °F</td>
<td>-73 to +135 °C</td>
</tr>
<tr>
<td>Temperature Coefficient of Sensitivity</td>
<td>±0.06 %/°F</td>
<td>±0.108 %/°C</td>
</tr>
<tr>
<td>Maximum Flash Temperature</td>
<td>3900 °F</td>
<td>2150 °C</td>
</tr>
<tr>
<td>Maximum Shock</td>
<td>20000 g pk</td>
<td>19600 m/s² pk</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Electrical</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Polarity (Positive Pressure)</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Discharge Time Constant (at room temp)</td>
<td>≤1.0 sec</td>
<td>≤1.0 sec</td>
</tr>
<tr>
<td>Excitation Voltage</td>
<td>22 to 30 VDC</td>
<td>22 to 30 VDC</td>
</tr>
<tr>
<td>Current Excitation</td>
<td>2 to 20 mA</td>
<td>2 to 20 mA</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>≤100 ohm</td>
<td>≤100 ohm</td>
</tr>
<tr>
<td>Output Bias Voltage</td>
<td>8 to 14 VDC</td>
<td>8 to 14 VDC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Physical</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing Geometry</td>
<td>Compression</td>
<td>Compression</td>
</tr>
<tr>
<td>Sensing Element</td>
<td>Quartz</td>
<td>Quartz</td>
</tr>
<tr>
<td>Housing Material</td>
<td>17-4 Stainless Steel</td>
<td>17-4 Stainless Steel</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Invar</td>
<td>Invar</td>
</tr>
<tr>
<td>Scaling</td>
<td>Welded Hermetic</td>
<td>Welded Hermetic</td>
</tr>
<tr>
<td>Electrical Connector</td>
<td>10-32 Coaxial Jack</td>
<td>10-32 Coaxial Jack</td>
</tr>
<tr>
<td>Weight (with clamp nut)</td>
<td>0.21 oz</td>
<td>0.6 gm</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** | 10 ohm |
- **Supplied Accessories**: Model 065A08 Isolation ring, 0.250" OD x 0.218" ID x 0.027" thick, anodized aluminum
- **Supplied Accessory**: Model 065A22 Isolation Seal, 0.250" OD x 0.218" ID x 0.015", Torlon of Ventral
- **H - Hermetic Seal**
  - Sealing | Welded Hermetic |
  - J - Ground Isolated |
- **N - Negative Output Polarity** |
- **S - Stainless Steel Diaphragm** | 316L Stainless |
- **W - Water Resistant Cable** |
  - Supplied Accessory: Model 060A03 Clamp nut, 5/16-24 A thd, 1/4" hex, stainless steel (for Series 111, 112 and 113) |
  - WM - Water Resistant Cable |
  - Supplied Accessory: Model 060A05 Clamp nut, M7 x 0.75-65 thd (for Series 111, M112 and 113) |

**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 P9223 for details.
4. For sensor mounted in thread adaptor, see adaptor installation drawing for supplied accessories.
5. Used with optional mounting adaptor.
6. Clamp nut installed prior to cable attachment.

**Supplied Accessories**

- 060A03 Clamp nut, 5/16-24 A thd, 1/4" hex, stainless steel (1)
- 060A05 Clamp nut M7 x 0.75-65 thd (1)
- 065A02 Seat ring, sensor flush mount, 0.248" OD x 0.219" ID x 0.015" thick, brass (3)
- 065A05 Seat sleeve sensor recess mount 0.248" OD x 0.221" ID x 0.240" thick 17-7 (1)

**Entered BLS** | Engineer: NJL | Sales: RWM | Approved: ES | Date: 02/24/2009 | 6476
---|---|---|---|---|---
**Date** | 02/24/2009 | 02/13/2009 | 02/22/2009 | 02/23/2009 | 6476

**PCB Piezotronics**

3425 Walden Avenue, Depew, NY 14043
UNITED STATES
Phone: 888-664-0011
Fax: 716-668-9129
E-mail: pressure@pcb.com
Web site: www.pcb.com

**Jacobs ESTS Group**

M. Vargas / D. Counter

24
Data Processing Parameters

**Kulite**

RUGGEDIZED AUTOMOTIVE IS™ PRESSURE TRANSDUCERS

**XTL-123B-150 (M) SERIES**

- Easy Installation
- High Reliability
- 10-32 UNF or M 5 x 0.8 Thread
- Wide Temperature Range
- Compatible With All Automotive Fluids
- Immersion Safe Patent Leadless Technology Applications Available (e.g., IS-XTL-123B-150 or IS-XTL-123C-150)

**XTL-123C-150**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>XTL-123B-150</td>
<td>Ruggedized Automotive IS™ Pressure Transducer</td>
</tr>
<tr>
<td>XTL-123C-150</td>
<td>Ruggedized Automotive IS™ Pressure Transducer</td>
</tr>
</tbody>
</table>

**PRODUCT SPECIFICATIONS**

- **Pressure Range**
  - 15, 25, 50, 100, 250, 500, 1000, 2000 PSI
  - Absolute, Gaged, Absolute, Gaged

- **Operational Mode**
  - Absolute, Gaged

- **Over Pressure**
  - 3 Times Rated Input
  - 3 Times Rated Input

- **Input Impedance**
  - 1000 Ohms (Max.), 600 Ohms (Max.)

- **Output**
  - 1000 ± 500 Ohms
  - 100 ± 10 mV

- **Electrical Uplag**
  - ± 0.05% Full Scale (Typ.)

- **Humidity**
  - ± 0.05% Full Scale (Typ.)

- **Thermal Drift**
  - ± 0.1% FS/°F (Typ.)

- **Linearization**
  - 10% Full Scale

- **Power Requirements**
  - 12V DC, 50 mA

- **Environmental**
  - Operating Temperature Range: -40°F to +122°F (-40°C to +50°C)
  - Compressed Temperature Range: -40°F to +266°F (-40°C to +130°C)

- **Mounting**
  - Fully Active-Fuse Arm Wheelbase Bridge Transducer/Thick Film on Silicon-Patried Leadless Technology

**NOTES:**

- This product specification is accurate at the time of publication. Changes may occur due to improvements or modifications that are not reflected in this document.

KULITE SEMICONDUCTOR PRODUCTS, INC. • One Willow Trail Road • Lincroft, New Jersey 07738 • Tel 732-246-4000 • Fax 732-246-4406 • http://www.kulite.com

M. Vargas / D. Counter 25
# Data Processing Parameters

## Kulite High Temperature Miniature IS+ Pressure Transducer

### XCEL-100 Series

- **-1/8” Diameter**
- **Patented Leakproof Technology**
- **Ideal For Turbine Engine Probes**
- **Designed For Both Static and Dynamic Measurement**
- **-65°F to 126°F Temperature Capability**

The XCEL-100 design features Kulite’s patented leakproof technology that allows for a very rugged package suited for turbine, pressure lines and other similar field applications. This transducer is well-suited for dynamic and static pressure measurements in harsh environments. It wide operating temperature range (-65°F to 126°F) makes it ideal for numerous applications in aerospace and other areas of industry.

### Table: Data Processing Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Pressure Range</strong></td>
<td>0.25 to 1000 psi</td>
</tr>
<tr>
<td><strong>Operational Mode</strong></td>
<td>Absolute, Gauge</td>
</tr>
<tr>
<td><strong>Over Pressure</strong></td>
<td>3 Times Rated Pressure</td>
</tr>
<tr>
<td><strong>Rated Pressure</strong></td>
<td>15 VDC</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>1000 mW</td>
</tr>
<tr>
<td><strong>Output Voltage</strong></td>
<td>100 mV</td>
</tr>
<tr>
<td><strong>Fatigue Life (5,000)</strong></td>
<td>1,000,000 cycles</td>
</tr>
<tr>
<td><strong>Corrosion Resistance</strong></td>
<td>± 0.1% FS (SS 316)</td>
</tr>
<tr>
<td><strong>Electrical Insulation</strong></td>
<td>10 MΩ at 100 VDC</td>
</tr>
<tr>
<td><strong>Environmental Temperature</strong></td>
<td>-40°F to 126°F</td>
</tr>
<tr>
<td><strong>Compressed Temperature Range</strong></td>
<td>-40°F to 126°F</td>
</tr>
<tr>
<td><strong>Thermal Shift</strong></td>
<td>± 0.1% FS (Typ.)</td>
</tr>
<tr>
<td><strong>Stability (1 hour, 100° C)</strong></td>
<td>± 0.1% FS (Typ.)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>1000 grams</td>
</tr>
</tbody>
</table>

**Note:** Custom pressure ranges, acabages and mechanical configurations are available. Contact the factory for details. Dimensions and parameters are subject to change.

---

M. Vargas / D. Counter