Overview of the Ares I Scale Model Acoustic Test Program

Launch environments, such as lift-off acoustic (LOA) and ignition overpressure (IOP), are important design factors for any vehicle and are dependent upon the design of both the vehicle and the ground systems. LOA environments are used directly in the development of vehicle vibro-acoustic environments and IOP is used in the loads assessment. The NASA Constellation Program had several risks to the development of the Ares I vehicle linked to LOA. The risks included cost, schedule and technical impacts for component qualification due to high predicted vibro-acoustic environments. One solution is to mitigate the environment at the component level. However, where the environment is too severe for component survivability, reduction of the environment itself is required.

The Ares I Scale Model Acoustic Test (ASMAT) program was implemented to verify the Ares I LOA and IOP environments for the vehicle and ground systems including the Mobile Launcher (ML) and tower. An additional objective was to determine the acoustic reduction for the LOA environment with an above deck water sound suppression system. ASMAT was a development test performed at the Marshall Space Flight Center (MSFC) East Test Area (ETA) Test Stand 116 (TS 116). The ASMAT program is described in this presentation.
Overview of the Ares I Scale Acoustic Model Test Program

Noise and Physical Acoustics: Launch Vehicle Noise II
Session 4pNS
November 3, 2011
Introduction: Rocket Liftoff Environments

- **Ignition overpressure (IOP)** is a significant transient low-frequency pressure event caused by the rapid pressure rise rate of the solid rocket motor.

- **Liftoff acoustics (LOA)** noise is caused by the supersonic steady jet flow interaction with surrounding atmosphere and launch complex, persisting for 0-20 seconds as the vehicle lifts off.

**Challenges for determining Ares I Rocket Liftoff Environments**

- New Solid Motor
  - Motor Sound Sources
- New Mobile Launcher
  - Launch Pad Deflector Effects
- New Tower
  - Plume Sound Reflections off of Launch Pad

Ares I at Kennedy Space Center Launch Complex
Rocket Liftoff Environments
Risks and Mitigation

♦ Vehicle Design
  • LOA - input for vibro-acoustics
  • IOP - input for loads

♦ If responses are high...
  • Mitigate at component or vehicle

♦ Vehicle mitigation is water sound suppression system provided by the ground system
  • Technical, cost and schedule risks for KSC Launch Complex

♦ Mitigation Pathfinder - scale model test
  • 5% Ares I Scale Model Acoustic Test (ASMAT)

♦ ASMAT objectives (risks)
  • Verify predicted liftoff acoustic environments
  • Verify predicted IOP environments

♦ Evaluate Water Sound Suppression Systems (mitigation)
  • Below Deck: Exhaust Hole & Trench Water
  • Above Deck: Water bags & Rainbirds

ASMAT at Marshall Space Flight Center Test Stand 116
# Test Matrix

<table>
<thead>
<tr>
<th>IOP Tests</th>
<th>Elevation Tests</th>
<th>Rainbird Tests</th>
<th>No Drift Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERT1: 0 ft + No Drift + Launch Mount + Water Bags + Below Deck Water</td>
<td>VERT4: 2.5 ft + Drift + Launch Mount + Below Deck Water</td>
<td>VERT8: 5 ft + Drift + Launch Mount + Below Deck Water + Rainbird Water at 2 flow rate</td>
<td>VERT13: 5 ft + No Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
</tr>
<tr>
<td>VERT2: 0 ft + No Drift + Launch Mount + Below Deck Water</td>
<td>VERT5: 5 ft + Drift + Launch Mount + Below Deck Water</td>
<td>VERT9: 5 ft + Drift + Launch Mount + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td>VERT14: 5 ft + No Drift + Below Deck Water</td>
</tr>
<tr>
<td>VERT3: 0 ft + No Drift + Launch Mount</td>
<td>VERT6: 7.5 ft + Drift + Launch Mount + Below Deck Water</td>
<td>VERT10: 5 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td>VERT17: 5 ft + No Drift</td>
</tr>
<tr>
<td>VERT7: 5 ft + Drift + Launch Mount + Below Deck Water</td>
<td>VERT7: 5 ft + Drift + Launch Mount + Below Deck Water</td>
<td>VERT12: 5 ft + Drift + Below Deck Water + Rainbird Water at 4.5 flow rate</td>
<td></td>
</tr>
<tr>
<td>VERT11: 5 ft + Drift + Below Deck Water</td>
<td>VERT11: 5 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td>VERT16: 10 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td></td>
</tr>
<tr>
<td>VERT15: 10 ft + Drift + Below Deck Water</td>
<td>VERT15: 10 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td>VERT13: 5 ft + No Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td></td>
</tr>
<tr>
<td>VERT16: 10 ft + Drift + Below Deck Water</td>
<td>VERT16: 10 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate</td>
<td>VERT17: 5 ft + No Drift + Below Deck Water</td>
<td></td>
</tr>
</tbody>
</table>
Teaming Across NASA

Ames Research Center
- Installed & calibrated SC sensors
- Phased Array
- WALLE

Marshall Space Flight Center
- Managed ASMAT
- Fabricated Mobile Launcher & Launch Pad Trench
- Executed Test
- Data Acquisition
- Post data processing
- LOA Data Analysis
- IOP Data Analysis
- Launch Pad Materials Experiment

Langley Research Center
- Designed ASMAT vehicle
- Designed ASMAT tower
- Fabricated vehicle & tower
- Fabricated nozzle extension

Johnson Space Center
- Funded Spatial Correlation (SC)
- SC Data Analysis

Kennedy Space Center
- 5% Mobile Launcher drawings
- Funded water bag tests
- Funded Ground Acoustic (GA) sensors
- GA Data Analysis
- Radiometers
ASMAT DESIGN
TEST ARTICLE CONFIGURATION
5% ASMAT Configuration

- Tower
- Mobile Launcher
- Rainbird
- Trench
- Ares I Vehicle
- Solid Rocket Motor
- Launch Mount
- Flame Deflector
- Launch Pad
ASMAT Vehicle Model

2nd Stage

1st Stage

Upper Attachment

Frustum

Thrust Mount (Milk Stool)

Solid Rocket Motor

Aft Skirt

Nozzle Extension
Mobile Launcher (ML)

Launch Mount (LM)

Tower

Mobile Launcher (ML)
Mobile Launcher Tower

Truncated Tower for VERT1-3
0 ft and no drift

Complete Tower for VERT4-17
Elevated 5 ft and drifted
ML and LM Subassemblies

Top of Launch Mount

- Water bag
- Electrical Umbilical
- Vehicle Support Post

View of Mobile Launcher and Launch Mount from deflector

- LM Splash Plate
- Electrical Umbilical
- ML Nozzle
- Vehicle Support Post
Launch Pad Trench Model: Deflector and Trench

South Side Deflector

North Side Deflector
Water Sound Suppression Systems

**Below Deck**
- Launch Mount Water
- Mobile Launcher Water
- Trench Water

**Above Deck (not baselined)**
- ASMAT to determine if Above Deck Water necessary
  - Water bags
  - Rainbirds
Below Deck Water: Trench/Deflector Water

South Side Deflector

North Side Deflector
Above Deck Water: Water Bags and Rainbirds

Water bags

Rainbirds
ASMAT GROUND SUPPORT EQUIPMENT
ASMAT Ground Support Equipment

- Telescoping Cage
- Drift Plate
- Blast Curtains
- Side Restraint System
Ground Support Equipment Continued

- Water Supply System
- Foam
  - Open-cell Soundfoam ML HY - Hydrophobic Melamine Foam was installed for its sound absorption and water resistant properties
Additional Test Resource: Photography

◆ Different photography needs
  • Record of the hotfire
  • Useful in case of failure
  • Aid in CFD modeling
  • Hotfire timing
    – All cameras had at least 1 strobe in field of view

Cameras at Overhead Level

Cameras at Ground Level

- CP2 1000 fps Color
- CP1 3000 fps Color
- HD2 30 fps Color
- S2 Strobe Tower Level 30
- S3 Strobe Side Restraint System
- S1 Strobe East stair
- CP7 3000 fps B&W
- IR_KSC1 60 fps False Color
- CP5 1000 fps Color
- CP4-IOP3 1000 fps B&W
- CP3 1000 fps Color
- HD3 High def 30 fps Color
- CP6 3000 fps B&W
- HD1 High def 30 fps Color
- S2 Strobe Tower Level 30
- S1 Strobe East stair
ASMAT
INSTRUMENTATION
There were four primary instrumentation suites

- **LOA**: 32 B&K 4944-B microphones on the vehicle, diaphragm flush mounted to vehicle surface
- **IOP**: ~78+ Kulite XTL-123B-190-30SG & -65SG pressure transducers on the vehicle, tower, mobile launcher
- **Ground Acoustics**: ~34+ B&K 4944-B microphones and PCB 112A22 pressure transducers on the tower, mobile launcher
- **Spatial Correlation**: 46 Kulite XCEL-12-100-2D pressure transducers on the vehicle

There were health/monitoring sensors:

- Accelerometers
- Strain Gages
- Thermocouples
- Flow Meters
- Chamber Pressure

There were special add-ons:

- Phased Array with stand-alone data acquisition system
- Radiometers
- Launch Pad materials experiment

200+ sensors per ASMAT firing
Each ASMAT firing had a specific instrumentation configuration
ASMAT Vehicle Instrumentation

- Zone 11
- Zone 9
- Zone 8-4
- Zone 8
- Zone 6
- Zone 4
- Zone 3
- Zone 1

LOA Sensors (Blue)
Spatial Correlation Plates (Green)
IOP Sensors (Red)

Measured from NEP to center of sensor (inches)
Example: Vehicle Instrumentation

<table>
<thead>
<tr>
<th>MSID</th>
<th>Sensor Location</th>
<th>Sensor Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP_000_030H</td>
<td>Thermal Curtain (0 in.)</td>
<td>V01_Z1_000 (Zone 1)</td>
</tr>
<tr>
<td>IOP_006_022H</td>
<td>Aft Skirt (6 in.)</td>
<td>V05_Z3_000 (Zone 3)</td>
</tr>
<tr>
<td>IOP_006_292H</td>
<td>Aft Skirt (6 in.)</td>
<td>V09_Z4_000 (Zone 4)</td>
</tr>
<tr>
<td>IOP_072_000H</td>
<td>Forw and Center (68 1/4 in.)</td>
<td>V13_Z6_000 (Zone 6)</td>
</tr>
<tr>
<td>IOP_093_000H</td>
<td>Forw and End (88 7/16 in.)</td>
<td>V17_Z8_000 (Zone 8)</td>
</tr>
<tr>
<td>IOP_100_000H</td>
<td>Frustum (101 3/4 in.)</td>
<td>V21_Z8_000 (Zone 8-3)</td>
</tr>
<tr>
<td>IOP_112_000H</td>
<td>Forw and Skirt (114 in.)</td>
<td>V25_Z8_000 (Zone 9)</td>
</tr>
<tr>
<td>IOP_148_000H</td>
<td>Orb Interface (143 1/2 in.)</td>
<td>V29_Z11_000 (Zone 11)</td>
</tr>
<tr>
<td>IOP_158_000H</td>
<td>Orbion Fairing (181.3/16 in.)</td>
<td>AY003 (Zone Y)</td>
</tr>
<tr>
<td>AX001</td>
<td>Top of Model (X axis)</td>
<td>AZ003 (Zone Z)</td>
</tr>
<tr>
<td>AY001</td>
<td>Top of Model (Y axis)</td>
<td>IOP_C01 (Zone 2)</td>
</tr>
<tr>
<td>AZ001</td>
<td>Top of Model (Z axis)</td>
<td>IOP_C02 (Zone 3)</td>
</tr>
<tr>
<td>AX002</td>
<td>RATO Head End (X axis)</td>
<td>IOP_S01 (Zone 4)</td>
</tr>
<tr>
<td>AY002</td>
<td>RATO Head End (Y axis)</td>
<td>IOP_S04 (Zone 5)</td>
</tr>
<tr>
<td>AZ002</td>
<td>RATO Head End (Z axis)</td>
<td>T09_S01 (Zone 6)</td>
</tr>
<tr>
<td>T09_S01</td>
<td>Strain Monitoring T.C. (S01)</td>
<td>T12_S04 (Zone 7)</td>
</tr>
</tbody>
</table>

Vehicle Instrumentation for 0 degree side

Retracting LOA Mount

3 Types of IOP Vehicle Mounts
Example: Aft Skirt Instrumentation

- Microphone installed in Booster Deceleration Motor
- IOP Kulite installed at Nozzle Extension exit plane
**Example: Tower Instrumentation**

GA and IOP sensors installed on Tower Level 1

**Instrumentation for North and South Tower**

<table>
<thead>
<tr>
<th>MSID</th>
<th>Sensor Location</th>
<th>MSID</th>
<th>Sensor Location</th>
<th>MSID</th>
<th>Sensor Location</th>
<th>MSID</th>
<th>Sensor Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>G01_T1</td>
<td>S Tower Level 30</td>
<td>G10_T2</td>
<td>S Tower Level 100</td>
<td>IOP_T01</td>
<td>N Tower Level 60</td>
<td>IOP_T10</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G02_T1</td>
<td>S Tower Level 30</td>
<td>G11_T3</td>
<td>S Tower Level 180</td>
<td>IOP_T02</td>
<td>S Tower Level 200</td>
<td>IOP_T11</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G03_T1</td>
<td>S Tower Level 30</td>
<td>G12_T3</td>
<td>S Tower Level 180</td>
<td>IOP_T03</td>
<td>S Tower Level 200</td>
<td>IOP_T12</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G04_T1</td>
<td>S Tower Level 30</td>
<td>G13_T3</td>
<td>S Tower Level 180</td>
<td>IOP_T04</td>
<td>S Tower Level 200</td>
<td>IOP_T13</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G05_T1</td>
<td>S Tower Level 30</td>
<td>G14_T3</td>
<td>S Tower Level 180</td>
<td>IOP_T05</td>
<td>S Tower Level 200</td>
<td>IOP_T14</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G06_T2</td>
<td>S Tower Level 100</td>
<td>G15_T4</td>
<td>S Tower Level 260</td>
<td>IOP_T06</td>
<td>S Tower Level 260</td>
<td>IOP_T15</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G07_T2</td>
<td>S Tower Level 100</td>
<td>G16_T4</td>
<td>S Tower Level 260</td>
<td>IOP_T07</td>
<td>S Tower Level 260</td>
<td>IOP_T16</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G08_T2</td>
<td>S Tower Level 100</td>
<td>G17_T4</td>
<td>S Tower Level 260</td>
<td>IOP_T08</td>
<td>S Tower Level 260</td>
<td>IOP_T17</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G09_T2</td>
<td>S Tower Level 100</td>
<td>G18_T4</td>
<td>S Tower Level 260</td>
<td>IOP_T09</td>
<td>S Tower Level 260</td>
<td>IOP_T18</td>
<td>S Tower Level 285</td>
</tr>
<tr>
<td>G10_T2</td>
<td>S Tower Level 100</td>
<td>G19_T4</td>
<td>S Tower Level 260</td>
<td>IOP_T10</td>
<td>S Tower Level 260</td>
<td>IOP_T19</td>
<td>S Tower Level 285</td>
</tr>
</tbody>
</table>

**Exploded view of GA sensor tower mount**
Example: Mobile Launcher Instrumentation

Installed IOP sensors on ML underside

ML IOP sensor L-bracket

Instrumentation for ML underside

Instrumentation for ML topside
Example: Launch Mount Instrumentation

Instrumentation for LM (Deck and Duct)

<table>
<thead>
<tr>
<th>MSID</th>
<th>Sensor Location</th>
<th>MSID</th>
<th>Sensor Location</th>
<th>MSID</th>
<th>Sensor Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP_E01</td>
<td>W Side Top LM Facing East</td>
<td>IOP_E04</td>
<td>N Side Top LM Facing South</td>
<td>IOP_E07</td>
<td>S Side Bottom LM Facing North</td>
</tr>
<tr>
<td>IOP_E02</td>
<td>W Side Top LM Facing Down</td>
<td>IOP_E05</td>
<td>E Side Bottom LM Facing West</td>
<td>IOP_E08</td>
<td>S Side Bottom LM Facing Down</td>
</tr>
<tr>
<td>IOP_E03</td>
<td>N Side Top LM Facing Down</td>
<td>IOP_E06</td>
<td>E Side Bottom LM Facing East</td>
<td>IOP_E09</td>
<td>S Side Top LM facing North</td>
</tr>
</tbody>
</table>

Installed IOP Sensor on LM Dec
Example: Launch Pad Trench Instrumentation

### Instrumentation for LPT

<table>
<thead>
<tr>
<th>MSID</th>
<th>Sensor Location</th>
<th>MSID</th>
<th>Sensor Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP_D06</td>
<td>N Trench Wall Top Near Deflector</td>
<td>IOP_D09</td>
<td>N Trench Wall Bottom Near Deflector</td>
</tr>
<tr>
<td>IOP_D07</td>
<td>N Trench Wall Bottom Near Exit</td>
<td>IOP_M06</td>
<td>LPT West Side Facing Up</td>
</tr>
<tr>
<td>IOP_D08</td>
<td>N Trench Wall Top Near Exit</td>
<td>IOP_M07</td>
<td>LPT East Side Facing Up</td>
</tr>
</tbody>
</table>
Data Acquisition

2 Data Acquisition Systems (DAQ)

- DSPCon Piranhas III / High Speed
  - Precision Filters, Inc 28000 Signal Conditioning
  - 160 Channels
  - Primary instrumentation suites
    - 256,000 and/or 4000 samples per second
- Neff 620 Data Systems Unit
  - 50 Channels
  - Health/monitoring sensors sample rates:
    - 100 samples per second
ASMAT HOTFIRES
Test Day Operations

♦ Prior to Firing Day
  • Performed in-situ calibrations
    – Pistonphone Checks for Microphones
    – Pressure Druck checks for limited number of pressure transducer

♦ Firing Day
  • Ensure all systems are “go”
  • Post test article inspection
    – Identified necessary repairs
  • Post test in-situ calibrations
    – Identified necessary sensor replacements
  • Channel by channel inspection of the data
  • Post test data processing
  • Release of data to analysts
  • Release of instrumentation plan and test article configuration for next firing

♦ 1-2 Days Post-Fire
  • Debrief held via telecon with analysts and debrief package (200+ pages) released
  • Each analyst presented preliminary results for all instrumentation suites
Movies

♦ Show movies
ASMAT CONCLUSION
Conclusions

♦ Successful Program
  • On average, test turnover was 1.5 weeks
    – 1\textsuperscript{st} Vertical Firing
      • November 5, 2010
    – 17\textsuperscript{th} and last Vertical Firing
      • July 12, 2011

♦ Satisfied ASMAT Program Objectives
  • Verified LOA environments
  • Verified IOP environments
  • Determined noise reduction due to rainbirds