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.

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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.**

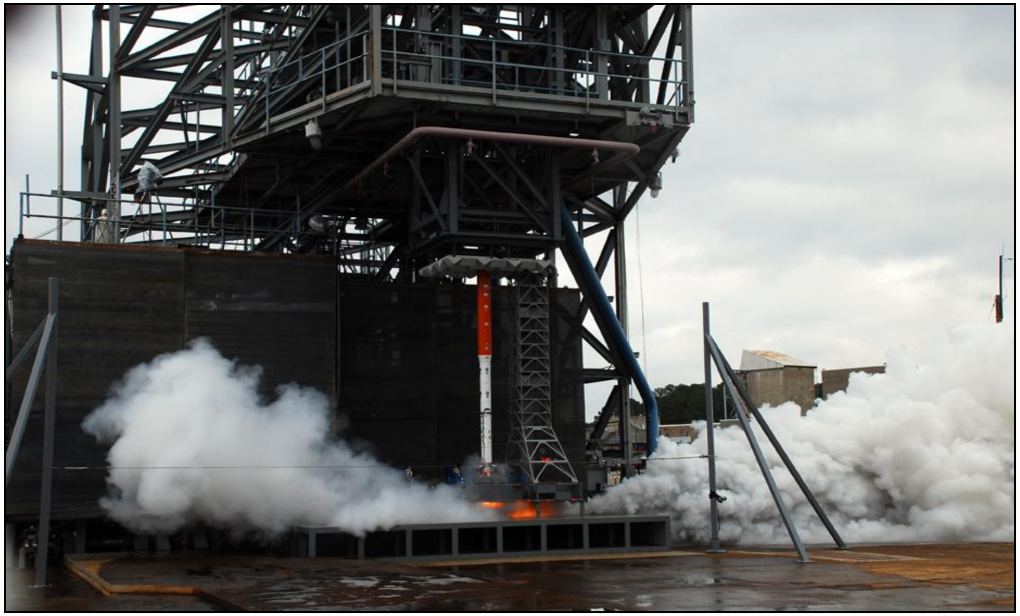
Ares I at Kennedy Space Center Launch Complex

- **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

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

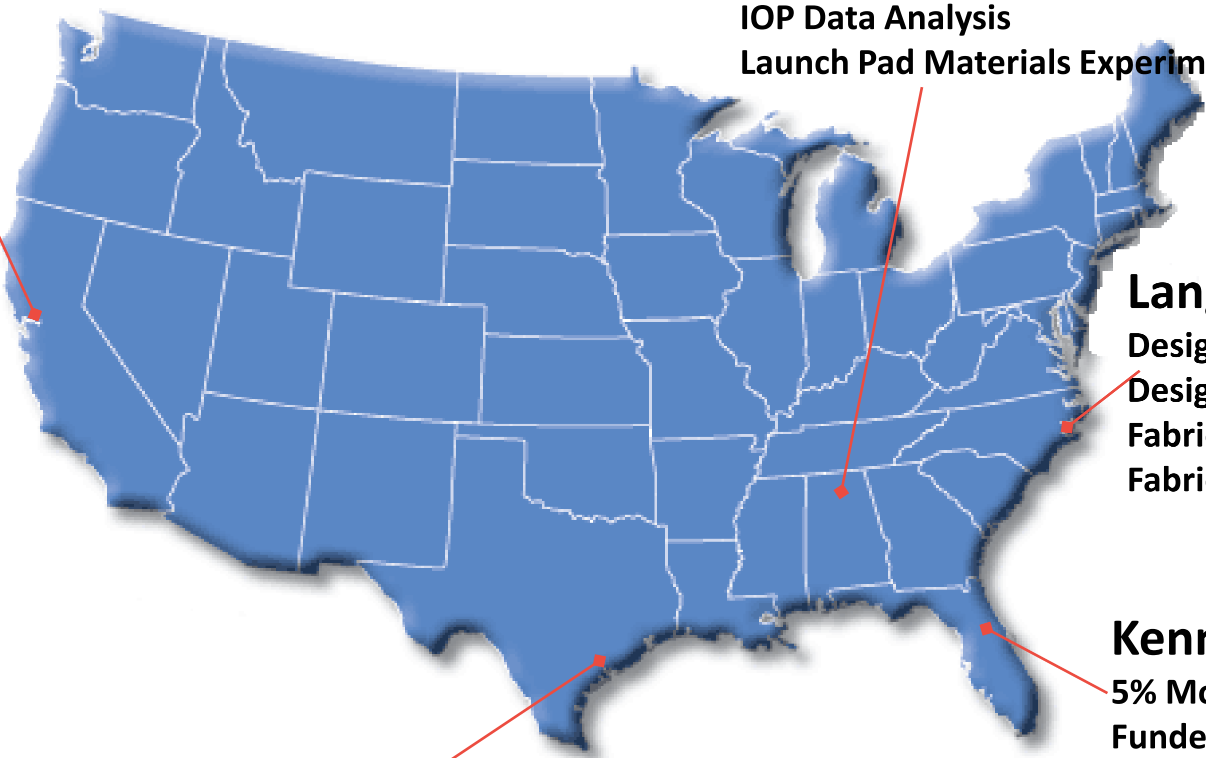
Test Matrix

IOP Tests	VERT1: 0 ft + No Drift + Launch Mount + Water Bags + Below Deck Water
	VERT2: 0 ft + No Drift + Launch Mount + Below Deck Water
	VERT3: 0 ft + No Drift + Launch Mount
Elevation Tests	VERT4: 2.5 ft + Drift + Launch Mount + Below Deck Water
	VERT5: 5 ft + Drift + Launch Mount + Below Deck Water
	VERT6: 7.5 ft + Drift + Launch Mount + Below Deck Water
	VERT7: 5 ft + Drift + Launch Mount + Below Deck Water
	VERT11: 5 ft + Drift + Below Deck Water
	VERT15: 10 ft + Drift + Below Deck Water
Rainbird Tests	VERT8: 5 ft + Drift + Launch Mount + Below Deck Water + Rainbird Water at 2 flow rate
	VERT9: 5 ft + Drift + Launch Mount + Below Deck Water + Rainbird Water at 3.5 flow rate
	VERT10: 5 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate
	VERT12: 5 ft + Drift + Below Deck Water + Rainbird Water at 4.5 flow rate
	VERT16: 10 ft + Drift + Below Deck Water + Rainbird Water at 3.5 flow rate
No Drift Tests	VERT13: 5 ft + No Drift + Below Deck Water + Rainbird Water at 3.5 flow rate
	VERT14: 5 ft + No Drift + Below Deck Water
	VERT17: 5 ft + No Drift

Teaming Across NASA

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

Ames Research Center
Installed & calibrated SC sensors
Phased Array
WALLE



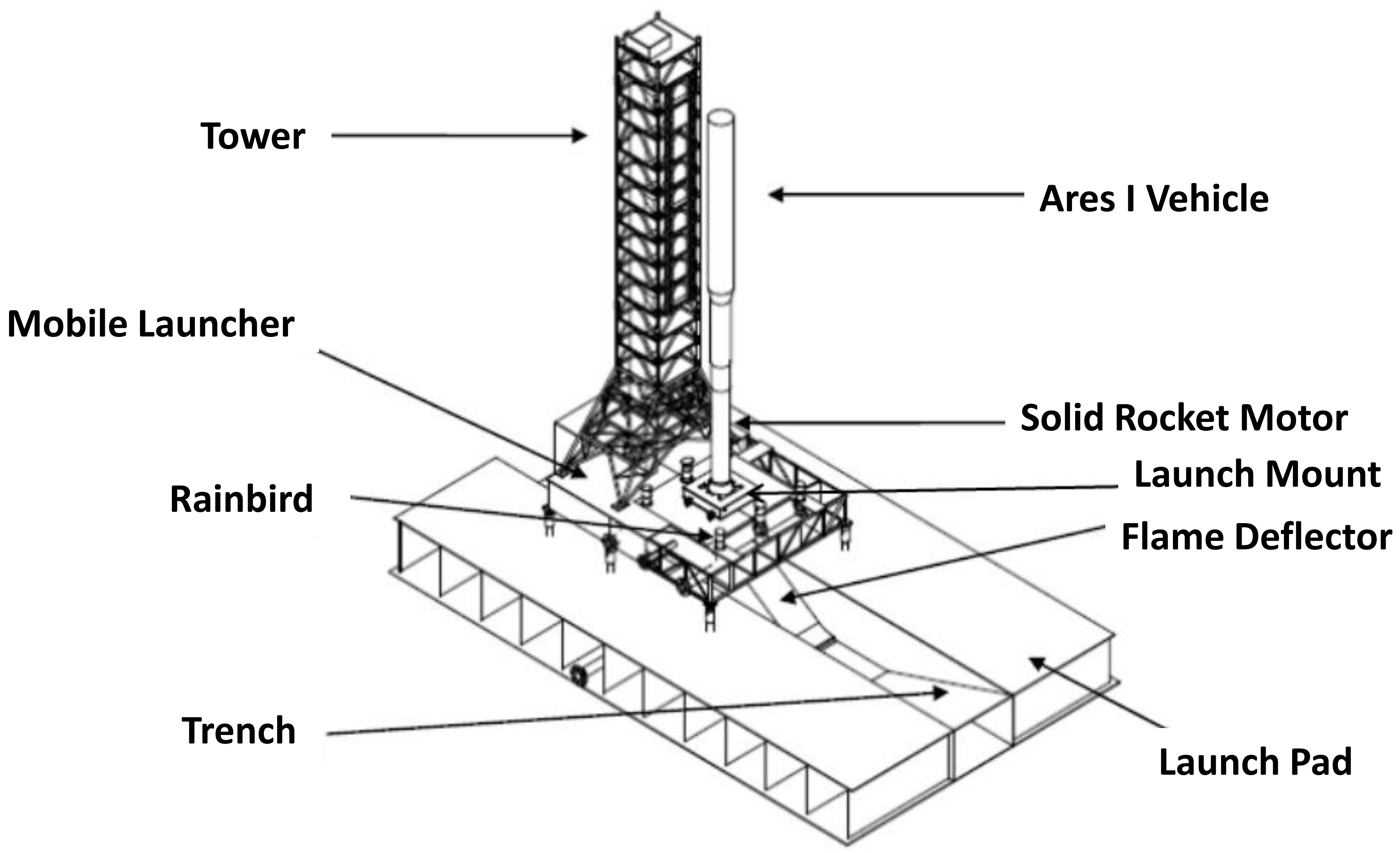
Langley Research Center
Designed ASMAT vehicle
Designed ASMAT tower
Fabricated vehicle & tower
Fabricated nozzle extension

Kennedy Space Center
5% Mobile Launcher drawings
Funded water bag tests
Funded Ground Acoustic (GA) sensors
GA Data Analysis
Radiometers

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

ASMAT DESIGN
TEST ARTICLE CONFIGURATION

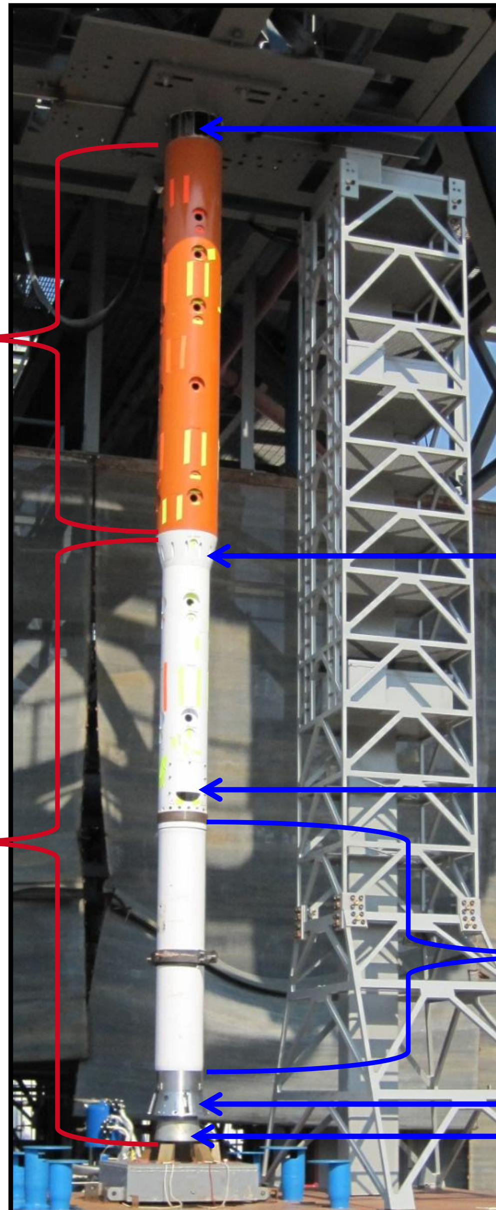
5% ASMAT Configuration



ASMAT Vehicle Model

2nd Stage

1st Stage



Upper Attachment

Frustum

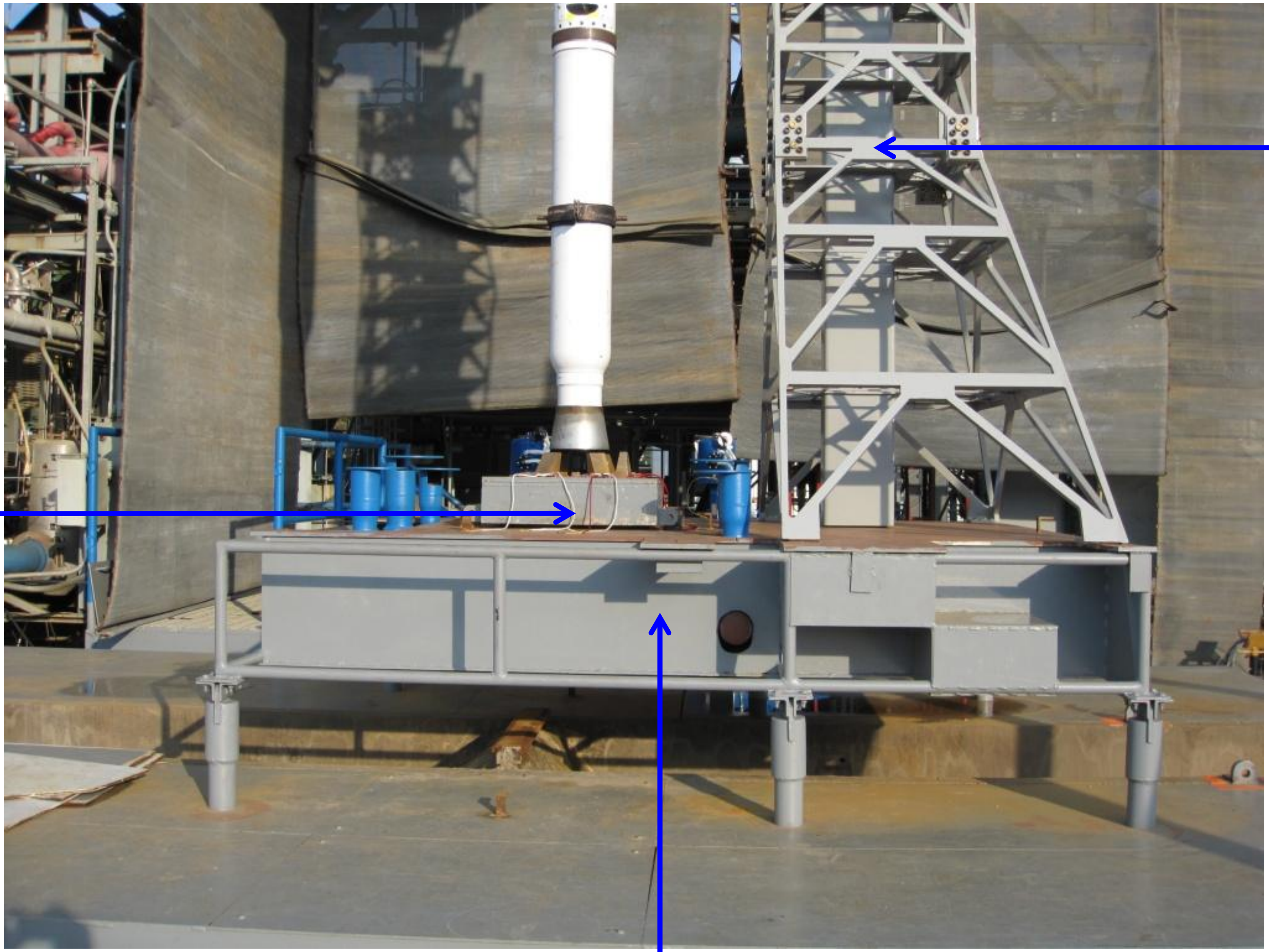
Thrust Mount (Milk Stool)

Solid Rocket Motor

Aft Skirt

Nozzle Extension

Mobile Launcher



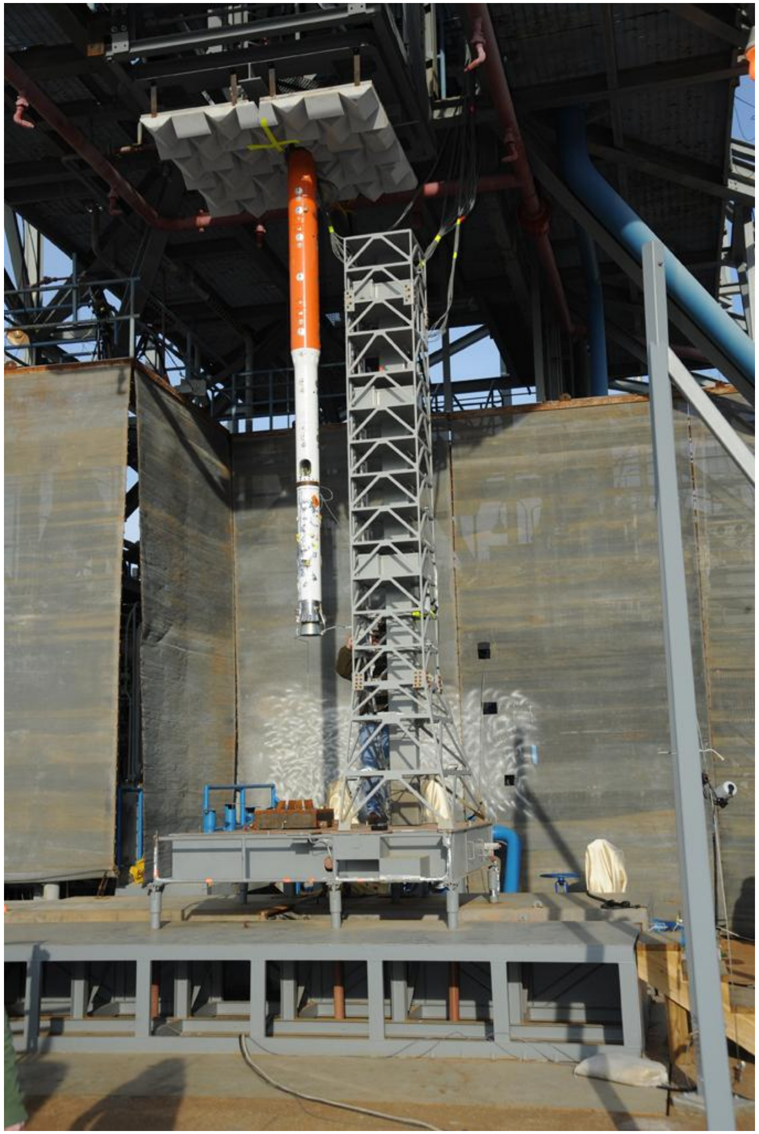
Tower

Launch Mount (LM)

Mobile Launcher (ML)

Mobile Launcher Tower

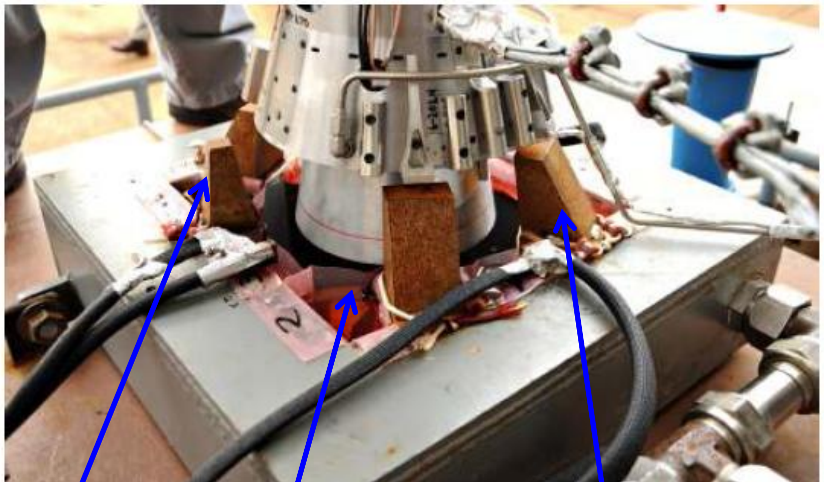
Truncated Tower for VERT1-3
0 ft and no drift



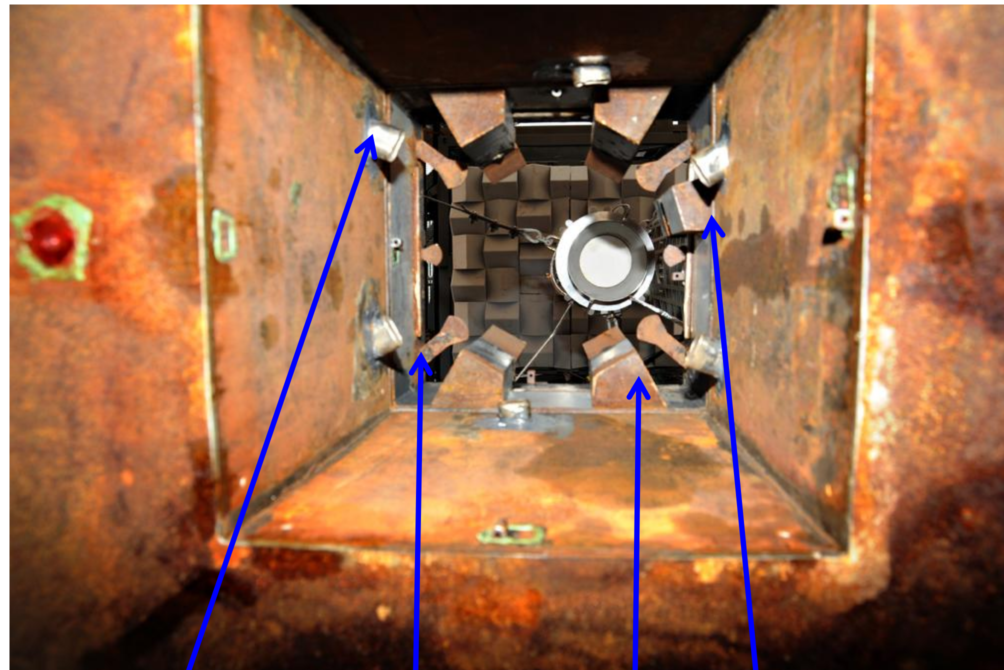
Complete Tower for VERT4-17
Elevated 5 ft and drifted

ML and LM Subassemblies

Top of Launch Mount



View of Mobile Launcher and Launch Mount from deflector



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: LM Water

Below Deck: ML Water

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

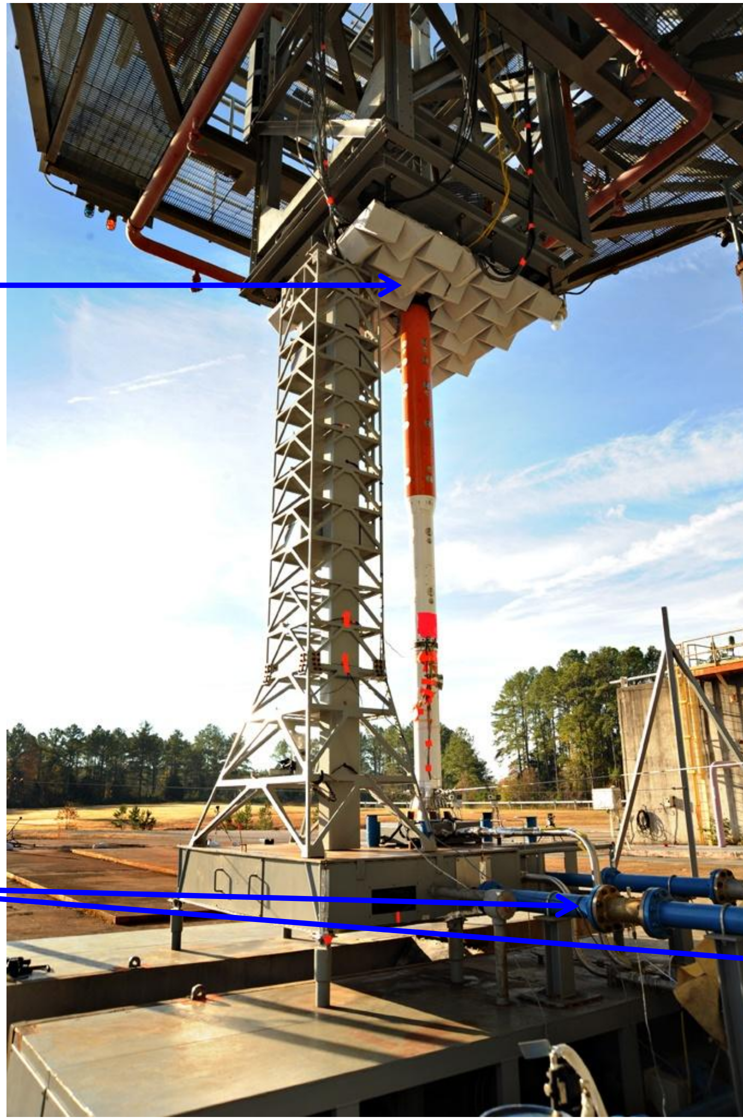
Drift Plate

Blast Curtains

Side Restraint System

Ground Support Equipment Continued

Foam



Water
Supply
System

Looking Southeast

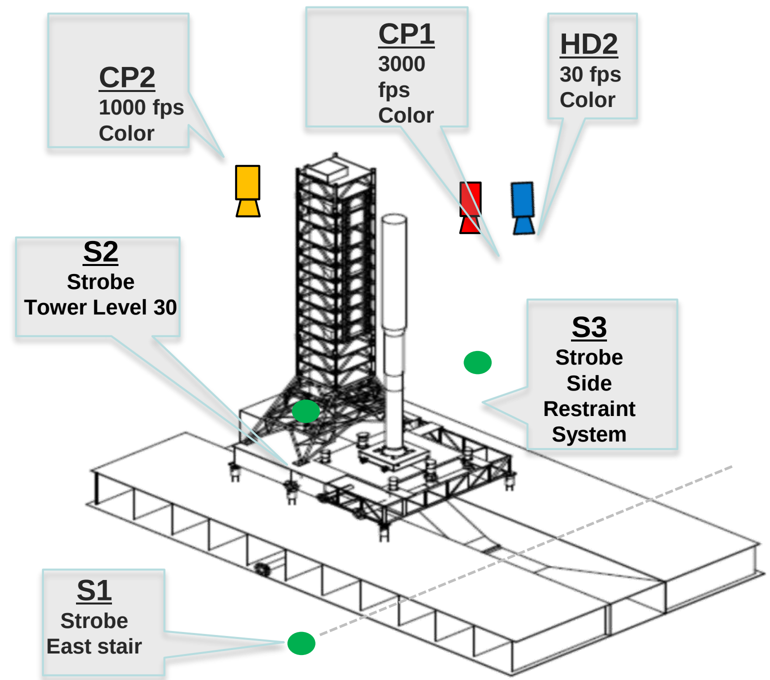
- ♦ **Water Supply System**
- ♦ **Foam**
  - Open-cell Soundfoam ML HY - Hydrophobic Melamine Foam was installed for its sound absorption and water resistant properties

Looking Down

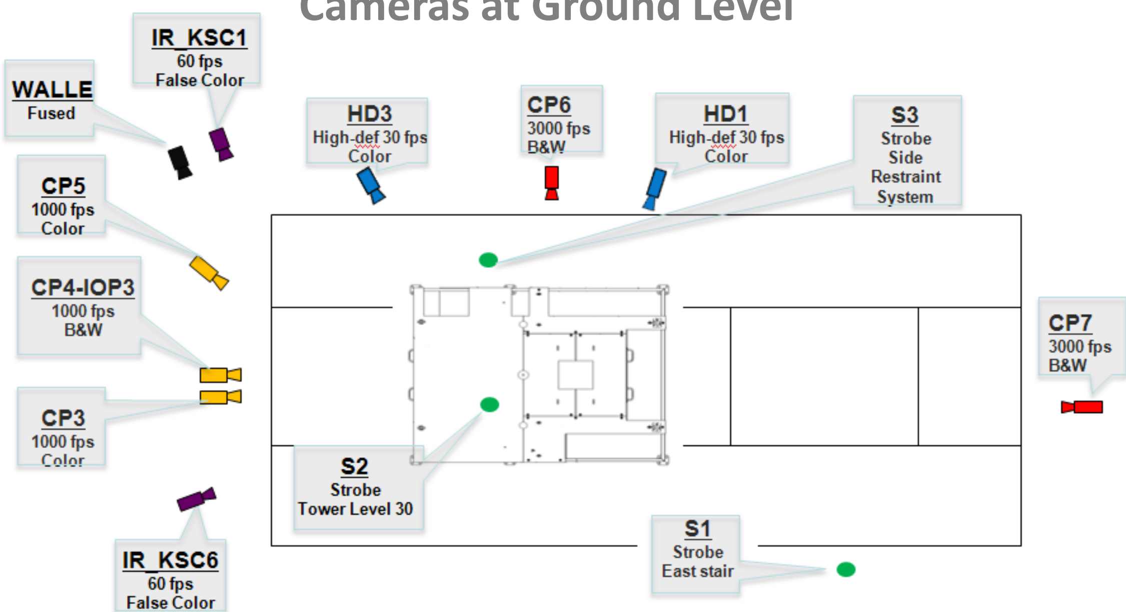
Additional Test Resource: Photography

- **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



ASMAT INSTRUMENTATION

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

LOA & GA microphone

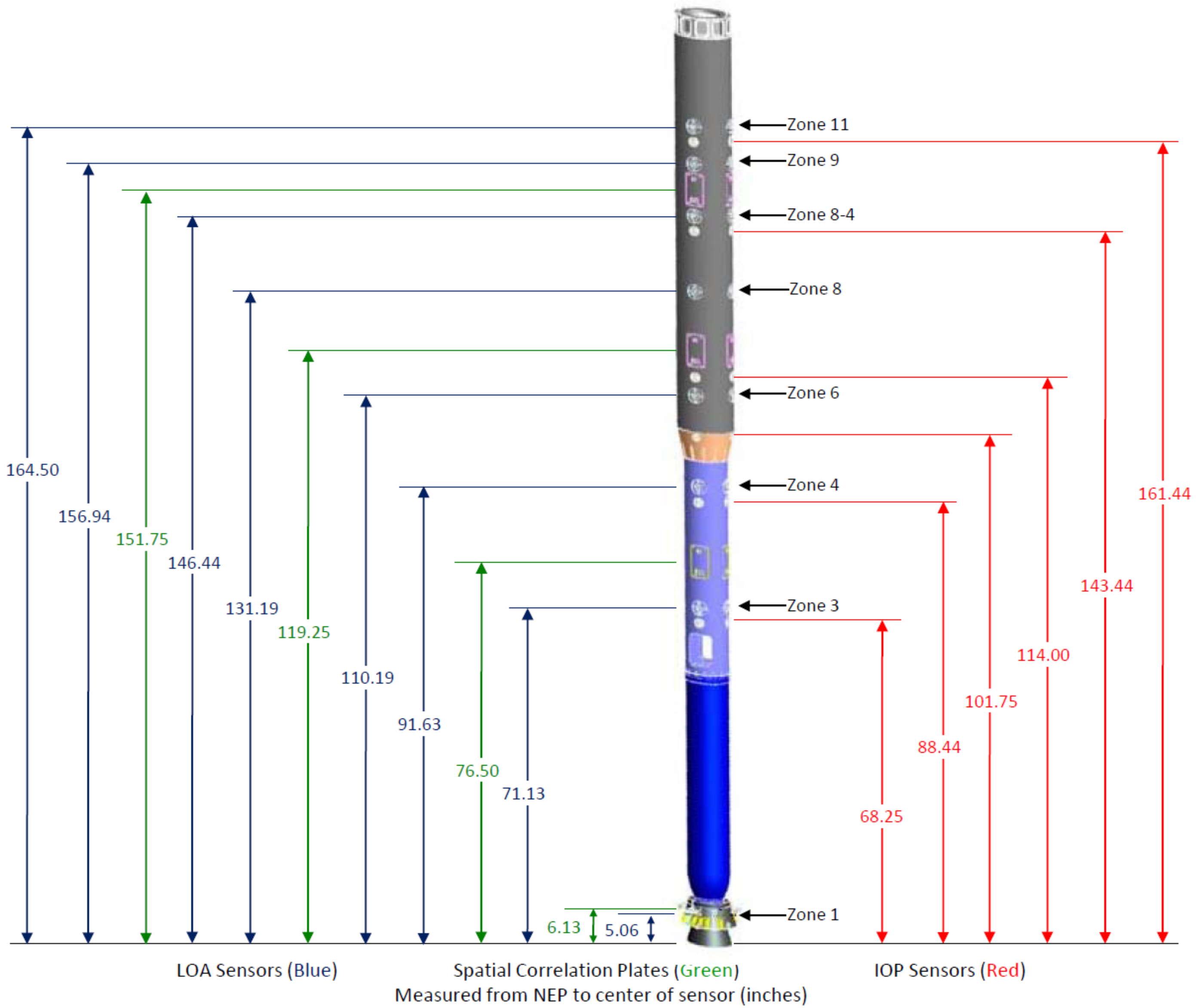
IOP pressure transducer

SC pressure transducer

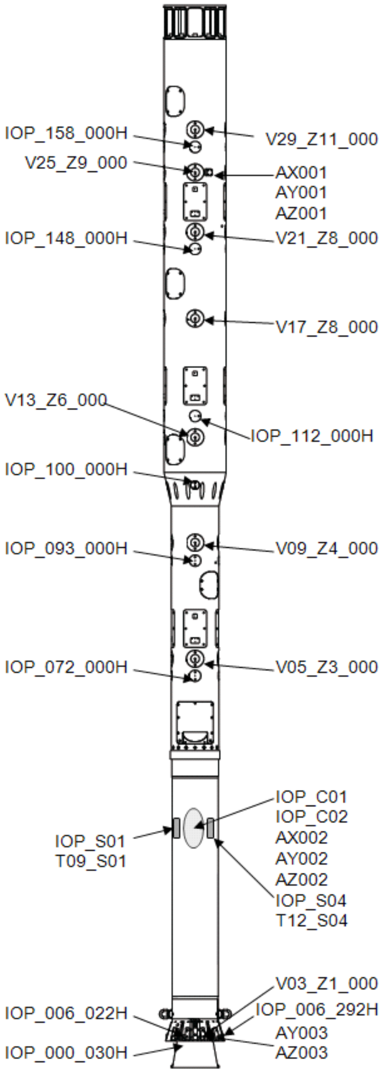
200+ sensors per ASMAT firing

Each ASMAT firing had a specific instrumentation configuration

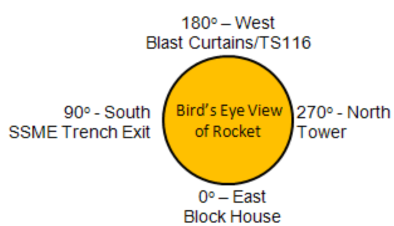
ASMAT Vehicle Instrumentation



Example: Vehicle Instrumentation

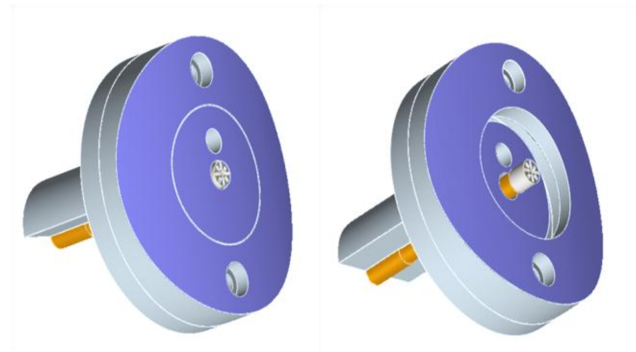


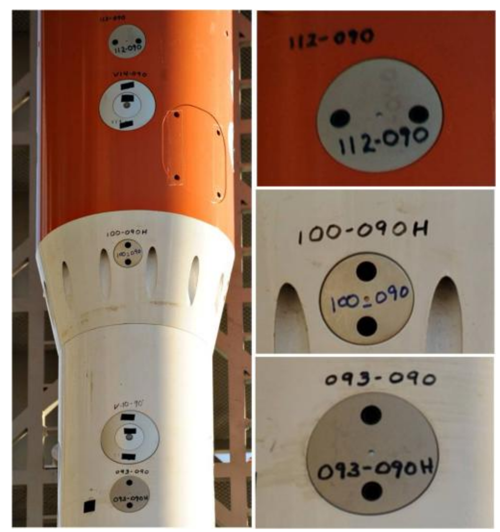
Vehicle Model Orientation - 0 Degrees			
MSID	**Sensor Location**	**MSID**	**Sensor Location**
IOP_000_030H	Thermal Curtain (0 in.)	V01_Z1_000	Aft Skirt (Zone 1)
IOP_006_022H	Aft Skirt (6 in.)	V05_Z3_000	4th SRM Seg. (Zone 3)
IOP_006_292H	Aft Skirt (6 in.)	V09_Z4_000	Fwd Skirt (Zone 4)
IOP_072_000H	Forward Center (68 1/4 in.)	V13_Z6_000	Interstage (Zone 6)
IOP_093_000H	Forward End (88 7/16 in.)	V17_Z8_000	Upper Stage (Zone 8)
IOP_100_000H	Frustum (101 3/4 in.)	V21_Z8_000	Upper Stage (Zone 8-3)
IOP_112_000H	Forward Skirt (114 in.)	V25_Z9_000	Orion Adapter (Zone 9)
IOP_148_000H	CM Interface (143 1/2 in.)	V29_Z11_000	Crew Module (Zone 11)
IOP_158_000H	Orion Fairing (161 7/16 in.)	AY003	Aft Skirt (Y axis)
AX001	Top of Model (X axis)	AZ003	Aft Skirt (Z axis)
AY001	Top of Model (Y axis)	IOP_C01	Chamber Pressure
AZ001	Top of Model (Z axis)	IOP_C02	Chamber Pressure
AX002	RATO Head End (X axis)	IOP_S01	Motor Hoop Strain (45 deg)
AY002	RATO Head End (Y axis)	IOP_S04	Motor Hoop Strain (315 deg)
AZ002	RATO Head End (Z axis)	T09_S01	Strain Monitoring T.C. (S01)
		T12_S04	Strain Monitoring T.C. (S04)



Vehicle Instrumentation for 0 degree side

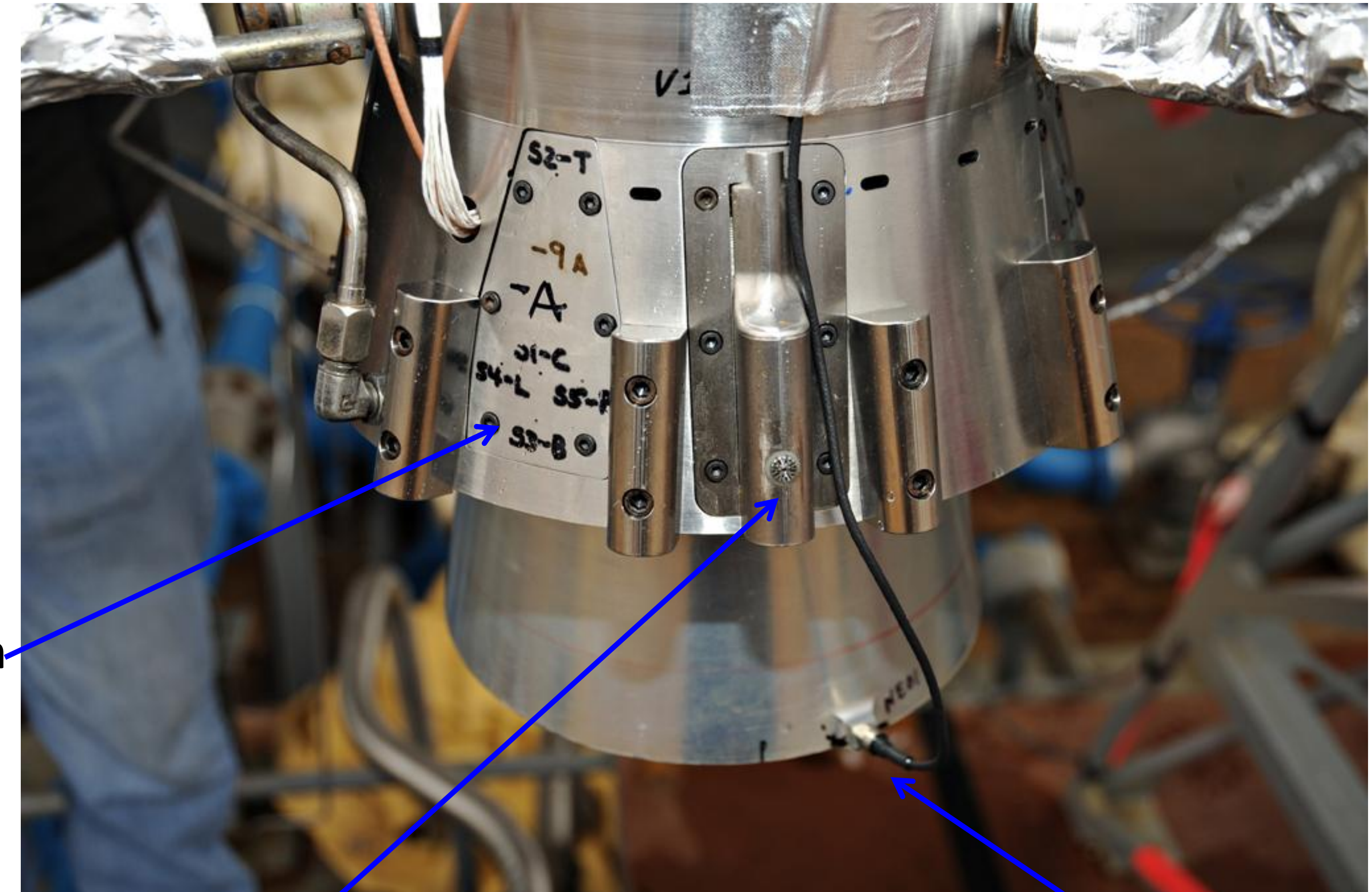
Retracting LOA Mount





3 Types of IOP Vehicle Mounts

Example: Aft Skirt Instrumentation

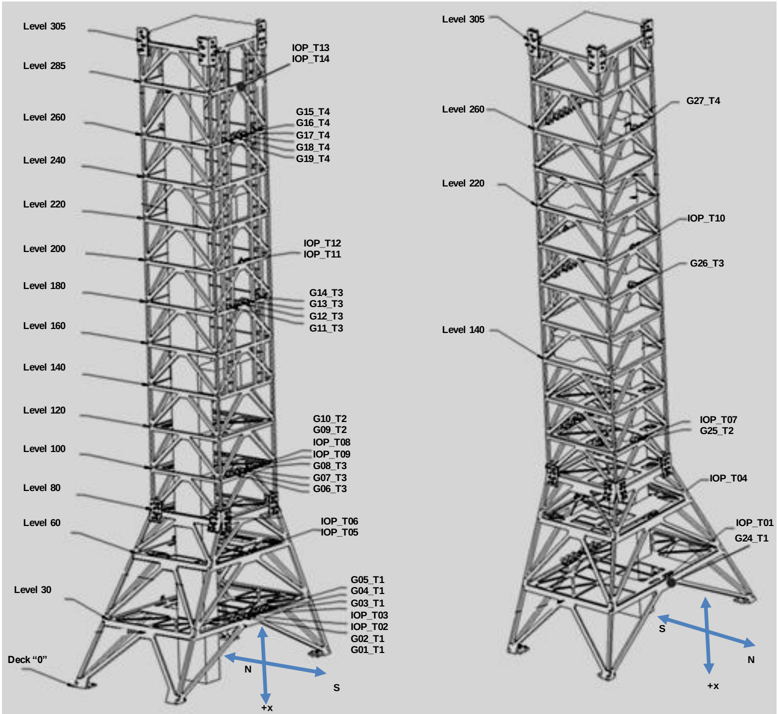


Spatial Correlation Sensors

Microphone installed in Booster Deceleration Motor

IOP Kulite installed at Nozzle Extension exit plane

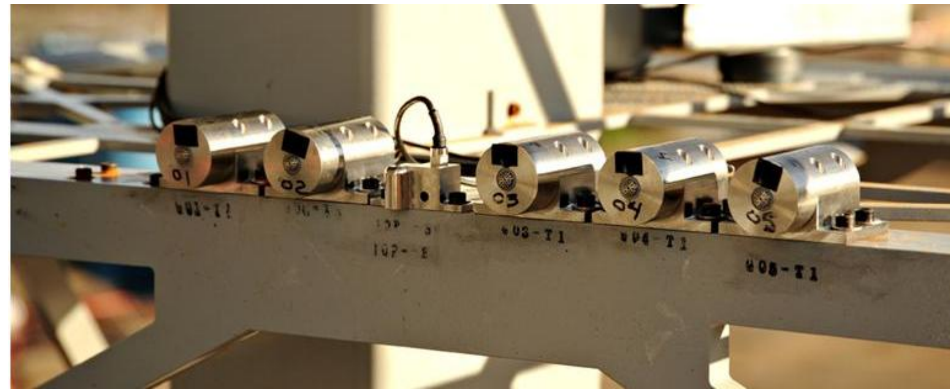
Example: Tower Instrumentation

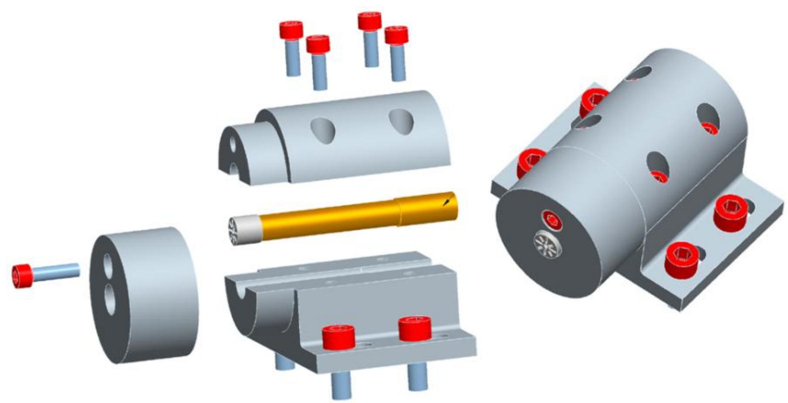


MSID	Sensor Location	MSID	Sensor Location	MSID	Sensor Location	MSID	Sensor Location
G01_T1	S Tower Level 30	G10_T2	S Tower Level 100	G19_T4	S Tower Level 260 Same height as Zone 8-3 sensors	IOP_T05	S Tower Level 60 Pointed S Capture hole overpressure
G02_T1	S Tower Level 30	G11_T3	S Tower Level 180 Same height as Frustum sensors	G24_T1	N Tower Level 30	IOP_T06	S Tower Level 60 Pointed down Capture hole overpressure
G03_T1	S Tower Level 30	G12_T3	S Tower Level 180 Same height as Frustum sensors	G25_T2	N Tower Level 100	IOP_T07	N Tower Level 100 Pointed N Capture duct overpressure
G04_T1	S Tower Level 30	G13_T3	S Tower Level 180 Same height as Frustum sensors	G26_T3	N Tower Level 180 Same height as Frustum sensors	IOP_T08	S Tower Level 100 Pointed S Capture duct overpressure
G05_T1	S Tower Level 30	G14_T3	S Tower Level 180 Same height as Frustum sensors	G27_T4	N Tower Level 260 Same height as Zone 8-3 sensors	IOP_T09	S Tower Level 100 Pointed down Capture duct overpressure
G06_T2	S Tower Level 100	G15_T4	S Tower Level 260 Same height as Zone 8-3 sensors	IOP_T01	N Tower Level 30 Pointed N Capture duct overpressure	IOP_T10	N Tower Level 200 Pointed N Capture duct overpressure
G07_T2	S Tower Level 100	G16_T4	S Tower Level 260 Same height as Zone 8-3 sensors	IOP_T02	S Tower Level 30 Pointed S Capture hole overpressure	IOP_T11	S Tower Level 200 Pointed S Capture duct overpressure
G08_T2	S Tower Level 100	G17_T4	S Tower Level 260 Same height as Zone 8-3 sensors	IOP_T03	S Tower Level 30 Pointed down Capture hole overpressure	IOP_T12	S Tower Level 200 Pointed down Capture duct overpressure
G09_T2	S Tower Level 100	G18_T4	S Tower Level 260 Same height as Zone 8-3 sensors	IOP_T04	N Tower Level 60 Pointed N Capture duct ovepressure	IOP_T13	S Tower Level 285 Same height as Zone 11 sensors Pointed S Capture duct overpressure
						IOP_T14	S Tower Level 285 Same height as Zone 11 sensors Pointed Down Capture duct overpressure

Instrumentation for North and South Tower

GA and IOP sensors installed on Tower Level 1



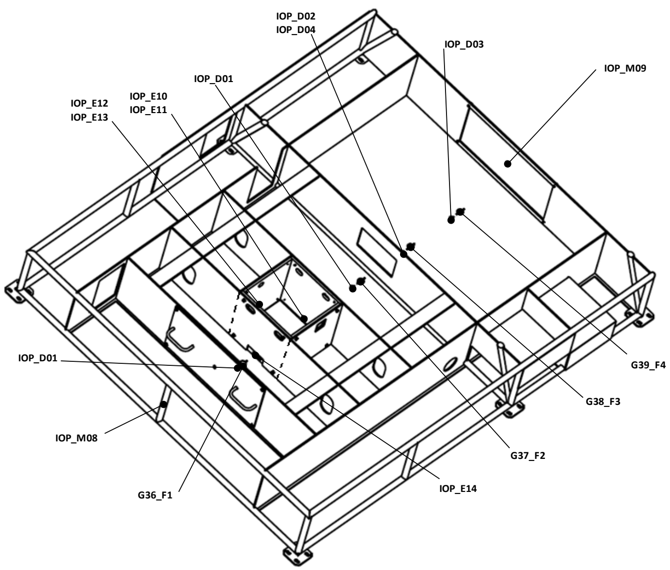


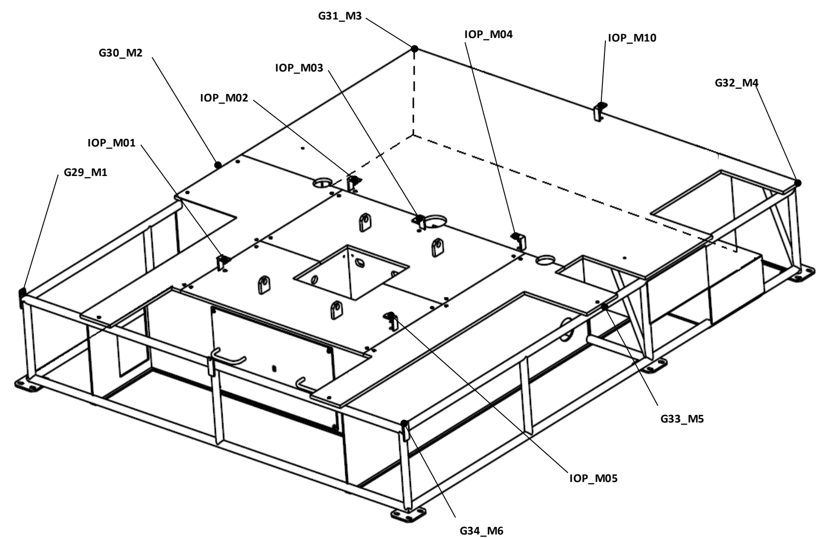
Exploded view of GA sensor tower mount

Example: Mobile Launcher Instrumentation

Installed IOP sensors on ML underside

ML IOP sensor L-bracket





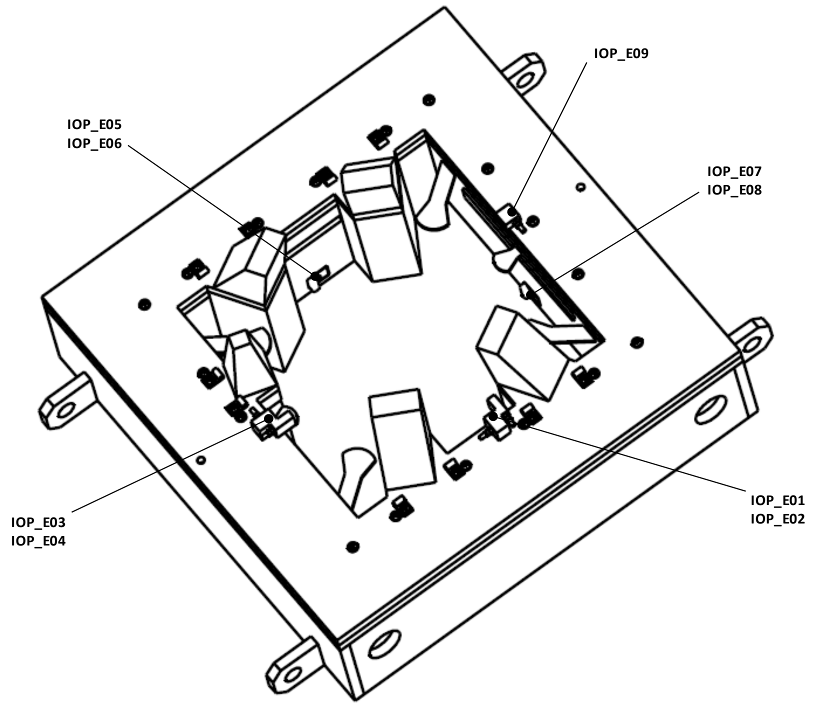
G36_F1	ML Underside S Trench Facing Down	IOP_D01	ML Underside N Trench Near Deflector Facing Down	IOP_D05	ML Underside S Trench Facing Down	IOP_E13	W Exhaust Duct Facing Down
G37_F2	ML Underside N Trench Near Deflector Facing Down	IOP_D02	ML Underside N Trench Center Facing Down	IOP_E10	N Exhaust Duct Facing South	IOP_E14	S Exhaust Duct Facing North
G38_F3	ML Underside N Trench Center Facing Down	IOP_D03	ML Underside N Trench Near Exit Facing Down	IOP_E11	N Exhaust Duct Facing Down	IOP_M08	S Side ML Facing South
G39_F4	ML Underside N Trench Near Exit Facing Down	IOP_D04	ML Underside N Trench Center Facing South	IOP_E12	W Exhaust Duct Facing East	IOP_M09	N Side ML Facing North

MSID	Sensor Location	MSID	Sensor Location	MSID	Sensor Location
G29_M1	SW ML Corner Facing UP	G33_M5	E Side ML Facing Up	IOP_M03	N ML Top Deck Facing Up
G30_M2	W Side ML Facing Up	G34_M6	SE ML Corner Facing Up	IOP_M04	NE ML Top Deck Facing Up
G31_M3	NW ML Corner Facing Up	IOP_M01	SW ML Top Deck Facing Up	IOP_M05	SE ML Top Deck Facing Up
G32_M4	NE ML Corner Facing Up	IOP_M02	NW ML Top Deck Facing Up	IOP_M10	N Side Top ML Facing Up

Instrumentation for ML underside

Instrumentation for ML topside

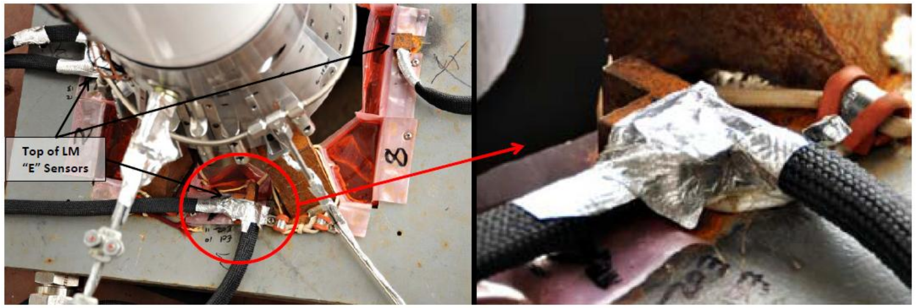
Example: Launch Mount Instrumentation



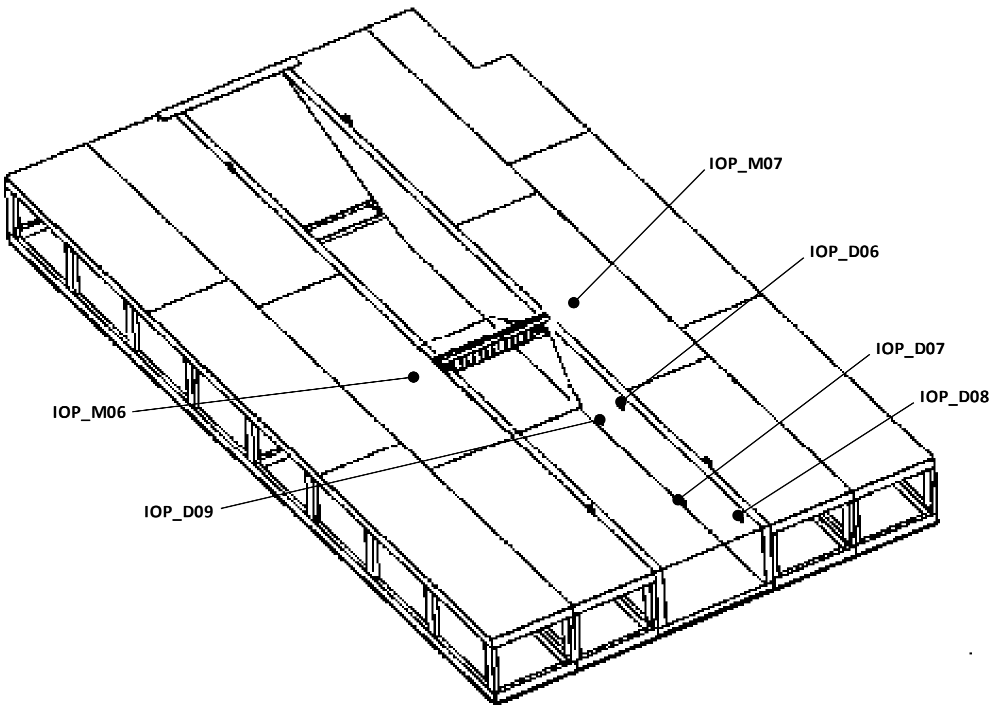
MSID	Sensor Location	MSID	Sensor Location	MSID	Sensor Location
IOP_E01	W Side Top LM Facing East	IOP_E04	N Side Top LM Facing South	IOP_E07	S Side Bottom LM Facing North
IOP_E02	W Side Top LM Facing Down	IOP_E05	E Side Bottom LM Facing West	IOP_E08	S Side Bottom LM Facing Down
IOP_E03	N Side Top LM Facing Down	IOP_E06	E Side Bottom LM Facing East	IOP_E09	S Side Top LM facing North

Instrumentation for LM (Deck and Duct)

Installed IOP Sensor on LM Dec



Example: Launch Pad Trench Instrumentation



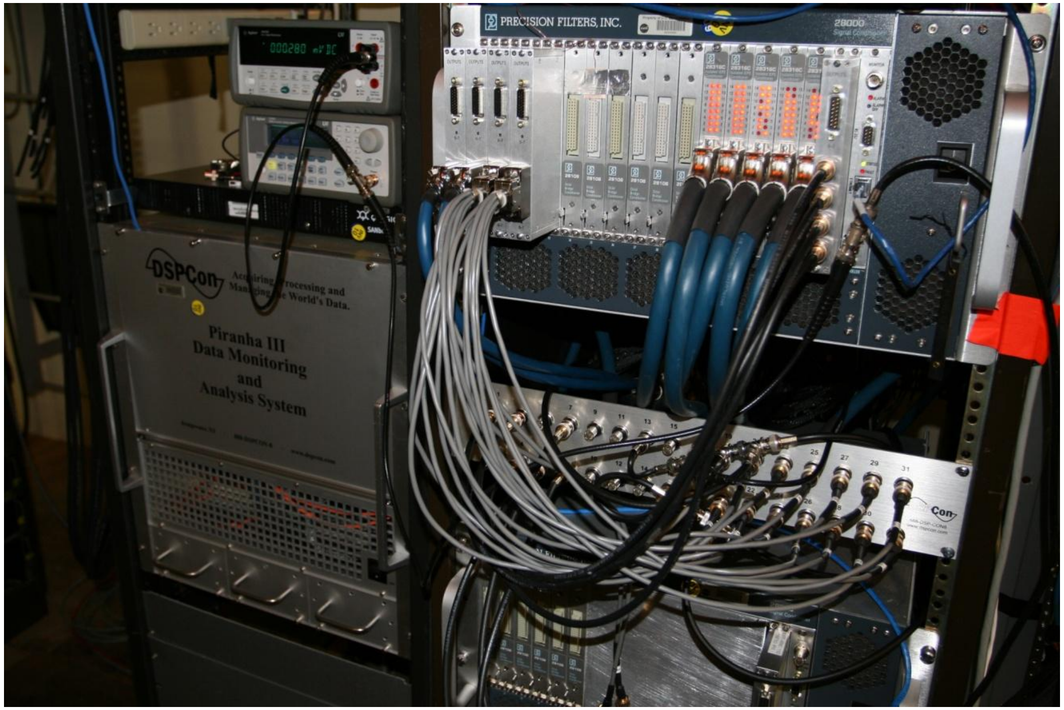
MSID	Sensor Location	MSID	Sensor Location
IOP_D06	N Trench Wall Top Near Deflector	IOP_D09	N Trench Wall Bottom Near Deflector
IOP_D07	N Trench Wall Bottom Near Exit	IOP_M06	LPT West Side Facing Up
IOP_D08	N Trench Wall Top Near Exit	IOP_M07	LPT East Side Facing Up

Instrumentation for LPT

IOP Trench Sensor Mount

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



DSPCon Piranha III

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
    - 1st Vertical Firing
      - November 5, 2010
    - 17th and last Vertical Firing
      - July 12, 2011
- **Satisfied ASMAT Program Objectives**
  - Verified LOA environments
  - Verified IOP environments
  - Determined noise reduction due to rainbirds