Tracking Sound and Vibration
Levels Using RFID

Presented by -
Rudolph J. Werlink
Ravi N. Margasahayam
NASA John F. Kennedy Space Center

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Endeavour – on Pad LC 39A
Case Study - Highlights

- **Goal:** Record launch-induced Sound and Vibration
- **Existing:** Extensive Wired systems/ no Wireless
- **Microstrain:** Embedded sensors showed promise
- **RFID type:** Active - signals over extended range
- **Wireless:** Monitors large area/complex situations
- **Issues:** RFI affecting People, Systems, Mission
- **Deployment:** Battery, Line-of-Sight, Large Data
- **Environmental:** Weather, Power, Far-field
- **Inception to data:** 3-6 months; Shuttle launch
- **Phase II:** Near-field data, High Sample Rate
Resonance Causes Bridge Failure

- http://www.youtube.com/watch?v=Az503VJ6kHw
Resonance – Self-contained Loads

- http://kzo.net/log/aeroelasticity-structural-vibrations
Resonance – External Loads

http://www.youtube.com/watch?v=JDnNmLkQ3Bc
Mode Shapes of SSME
**Human Body Resonances**

**Eyeball, Intraocular Structure (20-90 Hz)**

**Head (axial mode) (20-30 Hz)**

**Shoulder Girdle (4-5 Hz)**

**Chest wall (50-100 Hz)**

**Arm (5-10 Hz)**

**Hand (30-50 Hz)**

**Abdominal Mass (4-8 Hz)**

**Spinal column (axial mode) (10-12 Hz)**

**Abdominal mass mode (around 5 Hz)**
NASA KSC – A Wildlife Refuge
Acoustics and Vibration

Input Forces + System Response (Mobility) = Vibration

Forces caused by:
- Imbalance
- Shock
- Friction
- Acoustic

Structural Parameters:
- Mass
- Stiffness
- Damping

Vibration Parameters:
- Acceleration
- Velocity
- Displacement
Noise Analysis Considerations
Noise Measurement Challenges
RF Controls for Manned Space Flight

• The Radio Frequency (RF) environment is managed to avoid RFI issues that could harm People, Systems or the Mission.

• RF emitter evaluation is based on device frequency, power and distance relative to RF sensitive systems – pyrotechnics, communications and control systems.

• Direct and harmonic frequencies as well as the potential to swamp the receive circuits of existing devices using a close frequency.

• NASA frequency manager reviews frequency utilization for license requirements from the FCC
Wing Leading Edge Application

Hardware:
- 44 sensor units, 22 per wing, mounted in 2 locations
- Each unit has 3 accelerometer channels & 1 thermal sensor
- 132 accelerometers mounted inside wing spare panel


**Orbiter Stinger Application**

- Microphone on OMS/RCS Stinger Inboard Side Access Door
- Microphone on OMS/RCS Stinger Aft Access Door
- Approved Accelerometer Side Access Door Internal Lower Aft Corner (same as installed on OV-104)
- Existing Microphone on Drag Chute Stinger
- Microphone Base Heatshield Center (V08Y9686H)
Holding Pond Water Level System
Microstrain – Background

- Founded in 1987 in Vermont; wireless sensors since 1996
- Has COTS systems for strain, pressure, load, displacement, acceleration, tilt, etc
- Developing the next generation of cutting-edge wireless systems for Navy and Army helicopters and fixed wing aircraft
- Used in automotive, aerospace, industrial manufacturing, semiconductor, alternative energy, environmental monitoring, oil & gas, power generation, civil structures and defense markets.
Microstrain Wireless System

Cloud Computing
everything and the kitchen sink
Deployed Wireless Technology

- 2.4 GHz active RFID tags with built-in sensors and signal conditioning for external sensors
- Easy to configure/deploy using Node Commander GUI
- Scalable network support hundreds of synchronized wireless nodes
- Comprised of G-Link accelerometer nodes, a SG-Link strain node, a Wireless Sensor Data Aggregator base Station (WSDA-Base), and SensorCloud, a web data management platform
- SensorCloud - Tool to remotely visualize and manage data and to isolate and interpret launch event data - key for test analysis correlation.
- Qualifies and meets requirements for use at NASA
What is a Wireless Node?

- Sensor Inputs
  - Sensor signal conditioning
    - multiplexer, PG instrumentation amplifier
  - Lithium thionyl chloride battery
    - low power, microcontroller
      - 12, 16 or 24 bit A/D converter
        - Radio Frequency (RF) transceiver
          - Flash EEPROM for sensor logging
Health Monitoring Apps
Aerospace Applications
Plume-induced Vibroacoustics
Test Article and Test Design Issues

- Pad 39B location – far-field, historical data exists, linear acoustics laws, SVETA (test article)
- Accessibility of test site 24 hours prior to launch
- Plate dynamics - easy to model and build
- Plate weight – does not affect modal behavior
- Wireless systems would not affect sensitive Shuttle communications during pad clear to launch
- Sensor installation – access, support, environment
- Base station – inside building, line-of-sight issues
- Computer – location, Ethernet, remote access
- Launch issues – access, pad closeout, safety
SVETA Laboratory Setup
SVETA on Pad 39B Camera Mount
Space Shuttles on Pads 39 A & B
SVETA w/ Pad 39B and Pad 39A
SVETA—Line of Sight - WSDA
Atlantis - Liftoff to SRB Separation
Space Shuttle Lift-off Sequence
Test Analysis Correlation Method

- **TOA, Shape, Frequency, and Magnitude**
- **Time of Arrival** - tells us when the Rocket lifted off at Pad 39A and when SVETA experiences the load (speed of sound)
- **Shape** - Vibration signature be similar in shape (less in magnitude – distance effect)
- **Frequency** - Modal (Static test), FE computer Analysis, Shuttle Lift-off – should be same from all 3 methods
- **Magnitude of Vibration** - actually measured g’s and then backtracked PSI and dB load (it would have been easier to measure acoustics)
- **Pressure load (PSI)** is converted to dB and compared with **historical data from NASA Master Planning**
**Acoustic Levels - SVETA Test**

<table>
<thead>
<tr>
<th>G Loads @ lift-off on SVETA</th>
<th>Equivalent PSI and dB</th>
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<tbody>
<tr>
<td>0.5</td>
<td>(0.0075psi) = 128.2 dB</td>
</tr>
<tr>
<td>0.6</td>
<td>(0.0090psi) = 129.5 dB</td>
</tr>
<tr>
<td>0.7</td>
<td>(0.0108psi) = 130.8 dB</td>
</tr>
<tr>
<td>0.8</td>
<td>(0.0120psi) = 132.2 dB</td>
</tr>
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Future Wireless Applications
Future Wireless Applications
Future Wireless Applications

40” Tank:
• Titanium liner (0.104” thick) and boss
• Overwrap: Kevlar-49 fibers in Epoxy (0.739” thick)

Composite carries ~70-80% of load (at operating pressure)
Conclusions & Observations

- 2.4 GHz RFID tags with built-in sensors from Microstrain were used to measure launch vibrations.
- Verified time of arrival of rocket noise data and Vibroacoustics implications of a rocket launch.
- Launch Vibration data is used to assess loads/stresses imposed by rocket noise on structures/useful life.
- Test data is vital to study safety and operational readiness and to predict impending failures of GSE.
- Helps monitor pressurized, hazardous systems operating at high temperatures with access issues.
- Developed a tool to evaluate Safety, Reliability, and Maintainability of structures via condition monitoring.
Questions?