Tracking Sound and Vibration Levels Using RFID

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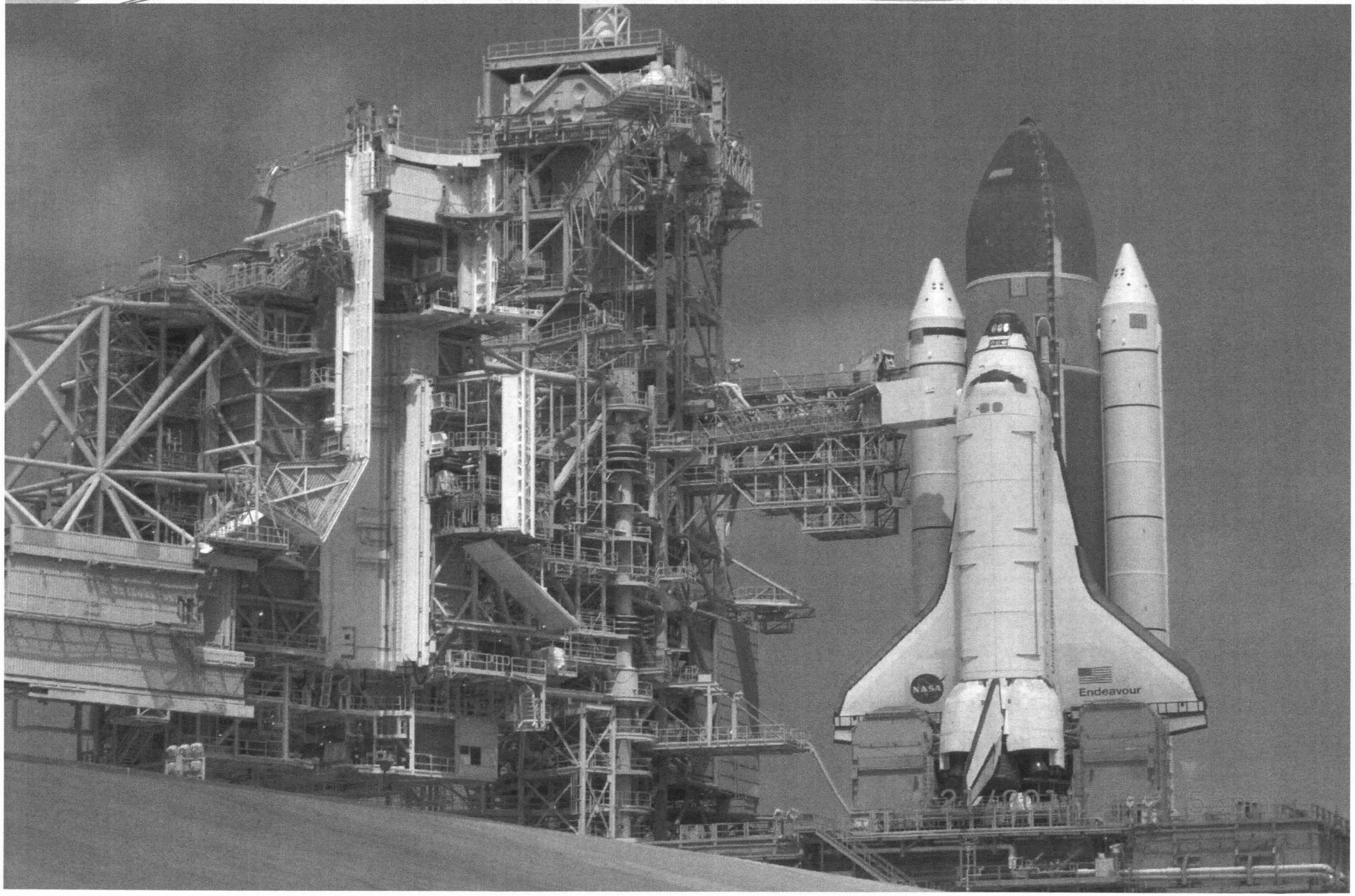
Endeavour – on Pad LC 39A



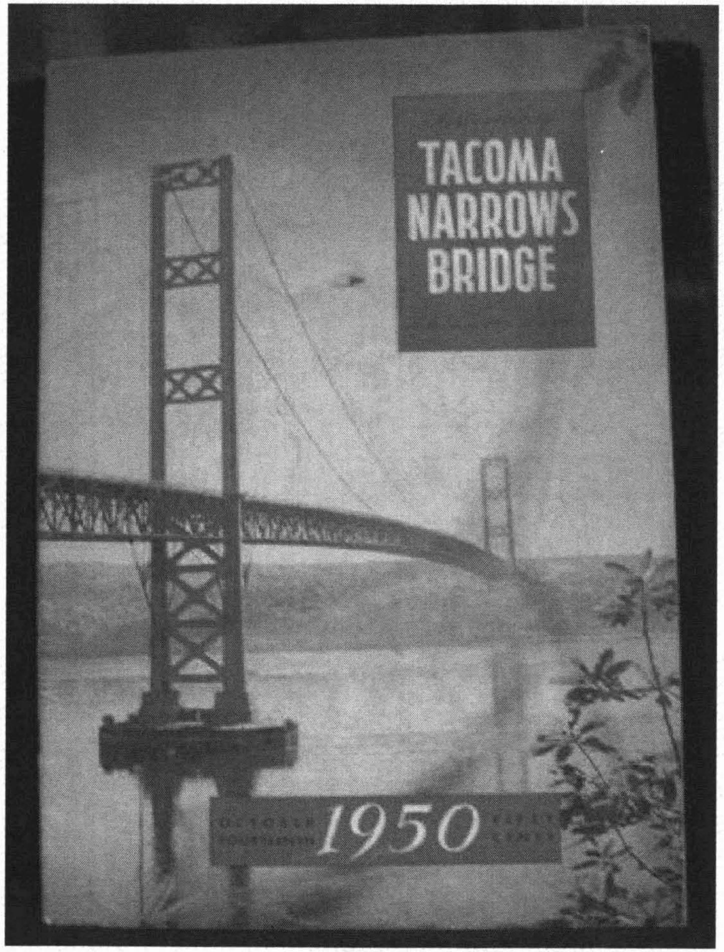
Case Study - Highlights

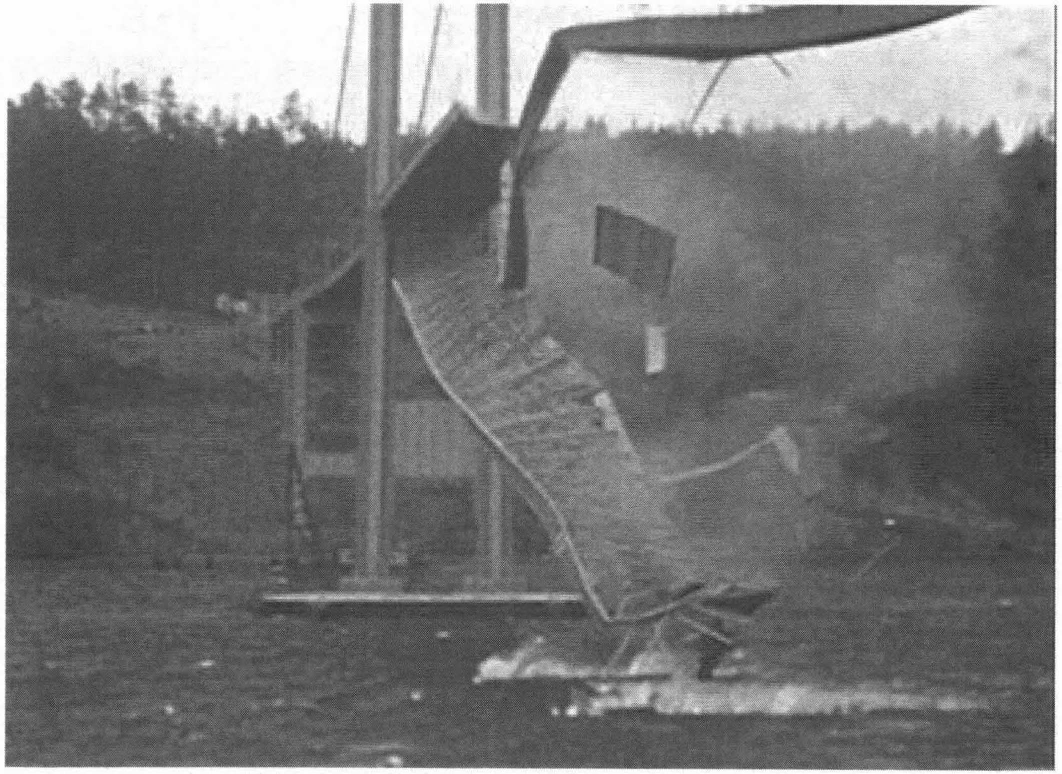
- Goal: Record launch-induced Sound and Vibration
- Existing: Extensive Wired systems/ no Wireless
- Microstrain: Embedded sensors showed promise
- RFID type: Active - signals over extended range
- Wireless : Monitors large area/complex situations
- Issues: RFI affecting People, Systems, Mission
- Deployment: 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

Space Shuttle Atlantis Lift-off

Resonance Causes Bridge Failure

- http://www.youtube.com/watch?v=Az503VJ6kHw

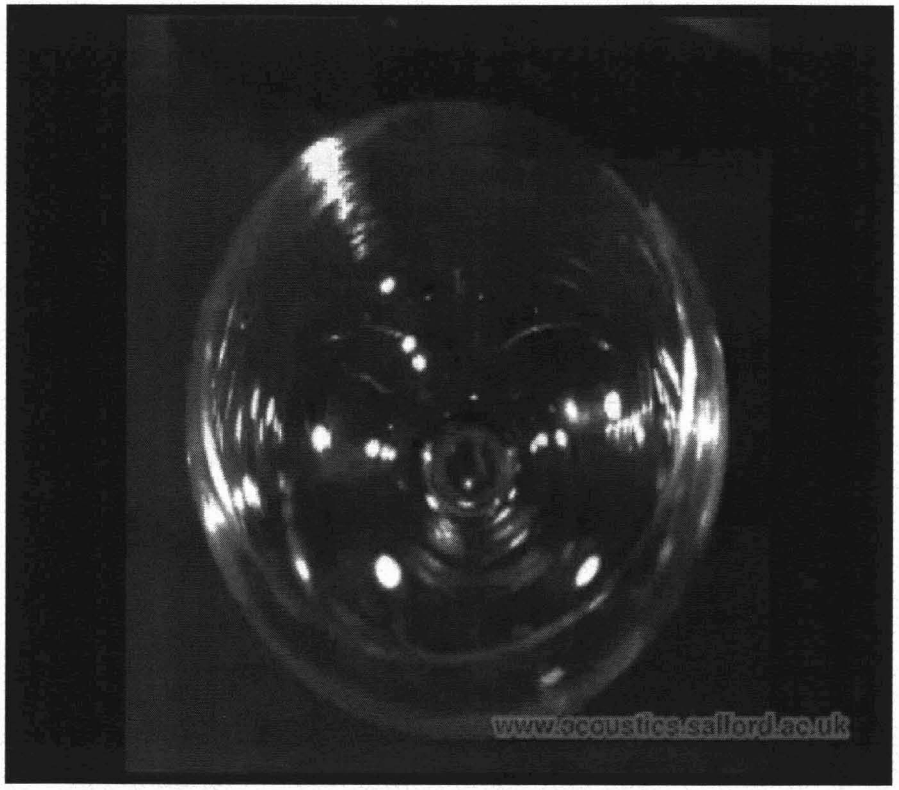


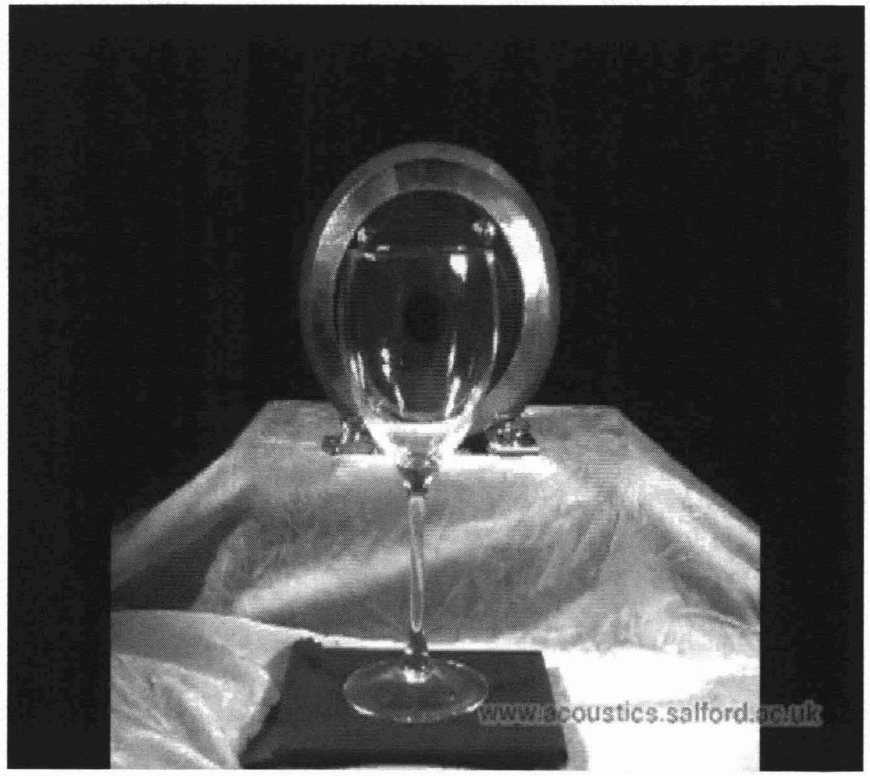


Resonance – Self-contained Loads

- http://kzo.net/log/aeroelasticity-structural-vibrations

Resonance – External Loads

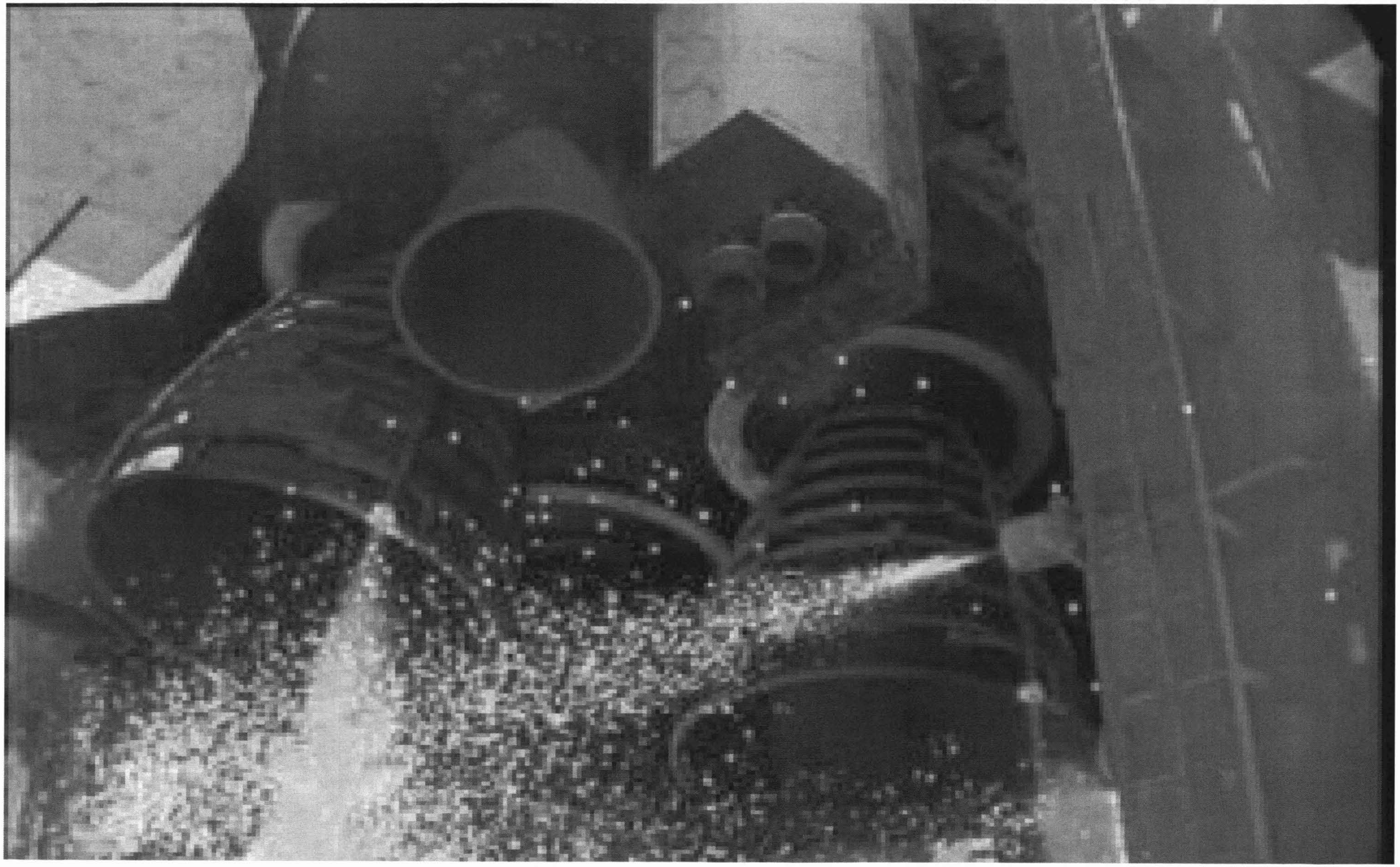




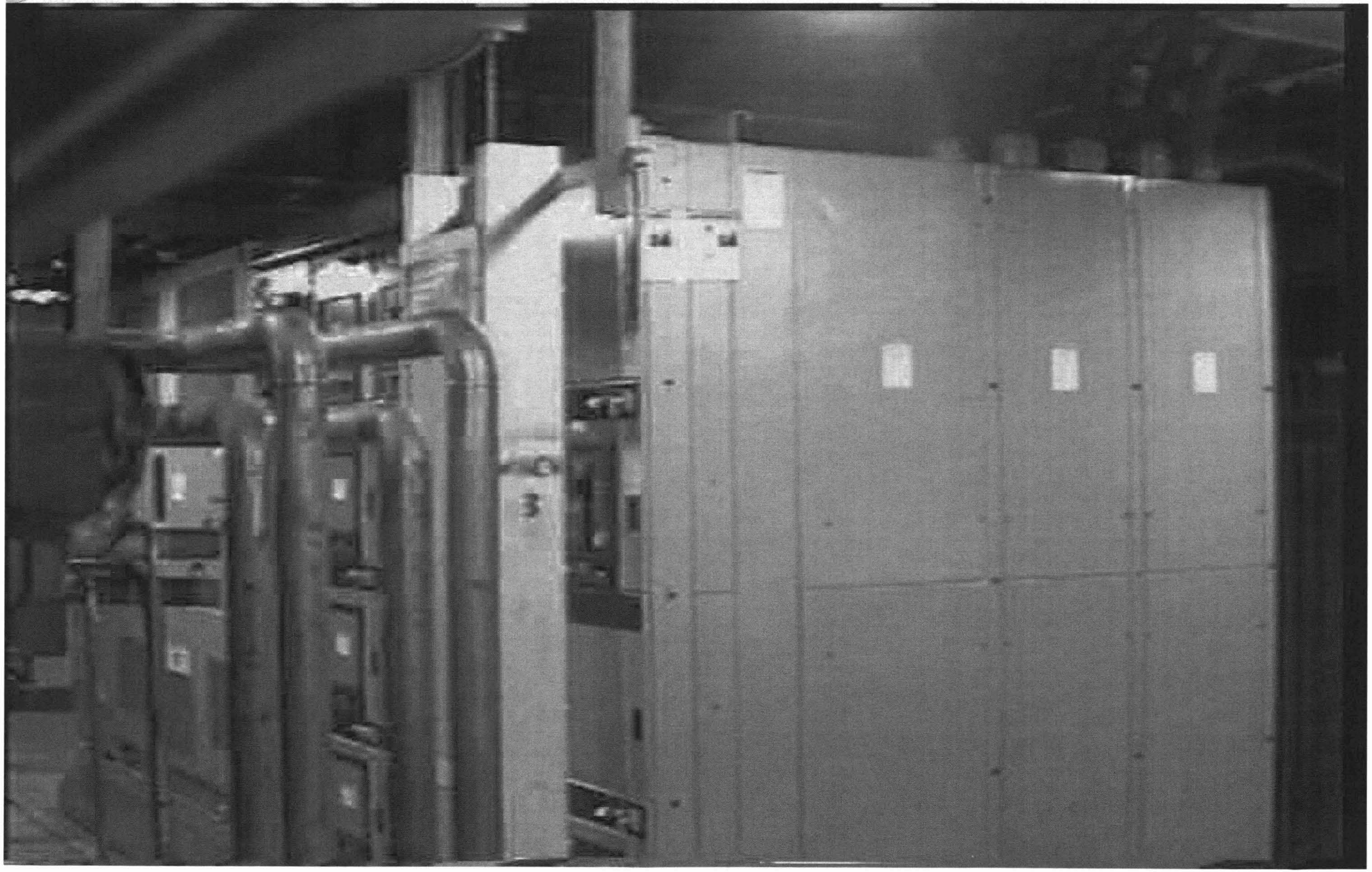
http://www.youtube.com/watch?v=JDnNmLkQ3Bc

Cockpit Vibrations @ Lift-off

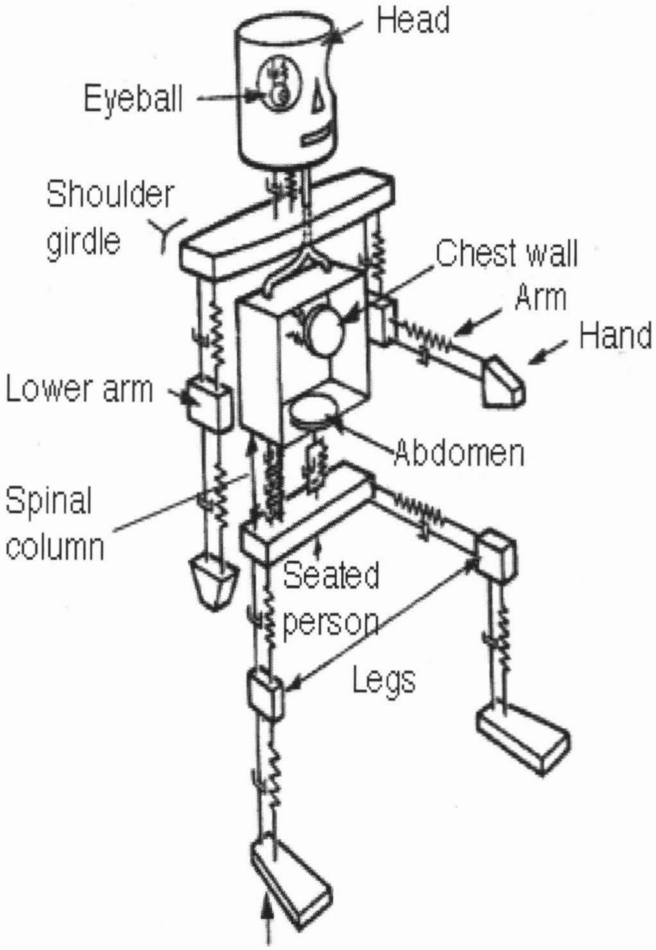
Mode Shapes of SSME



MLP Vibrations @ Lift-off

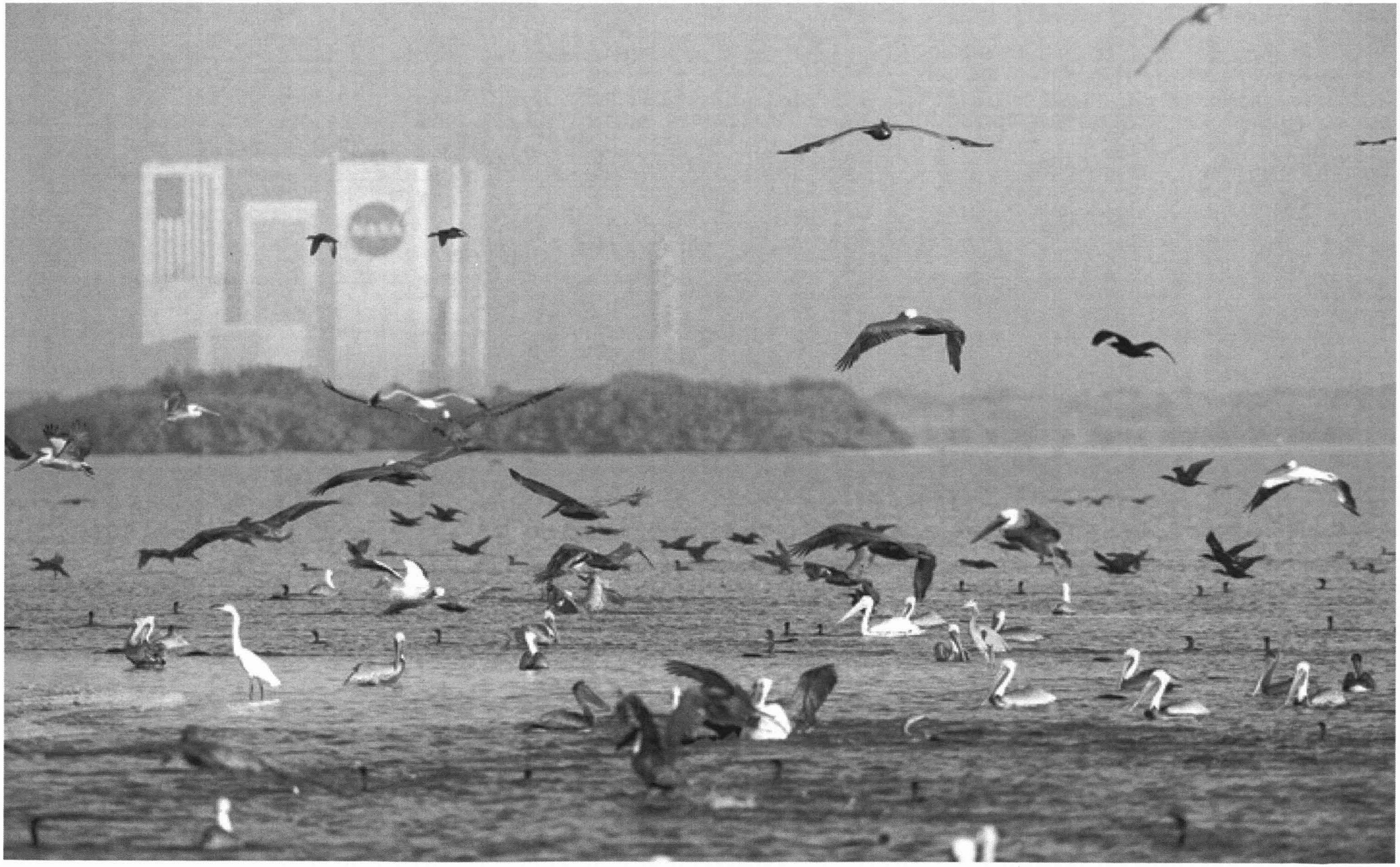


Human Body Resonances

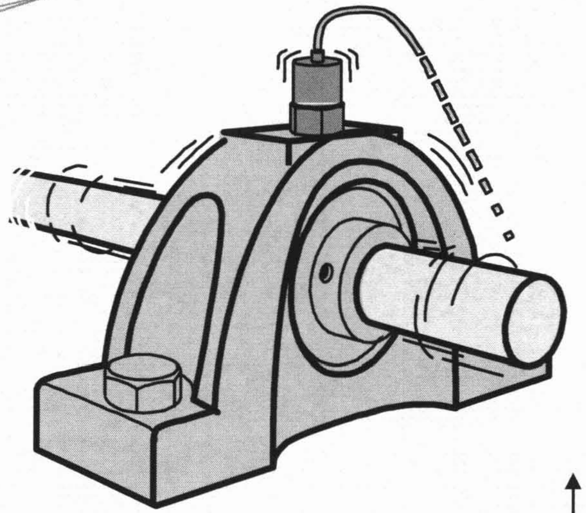


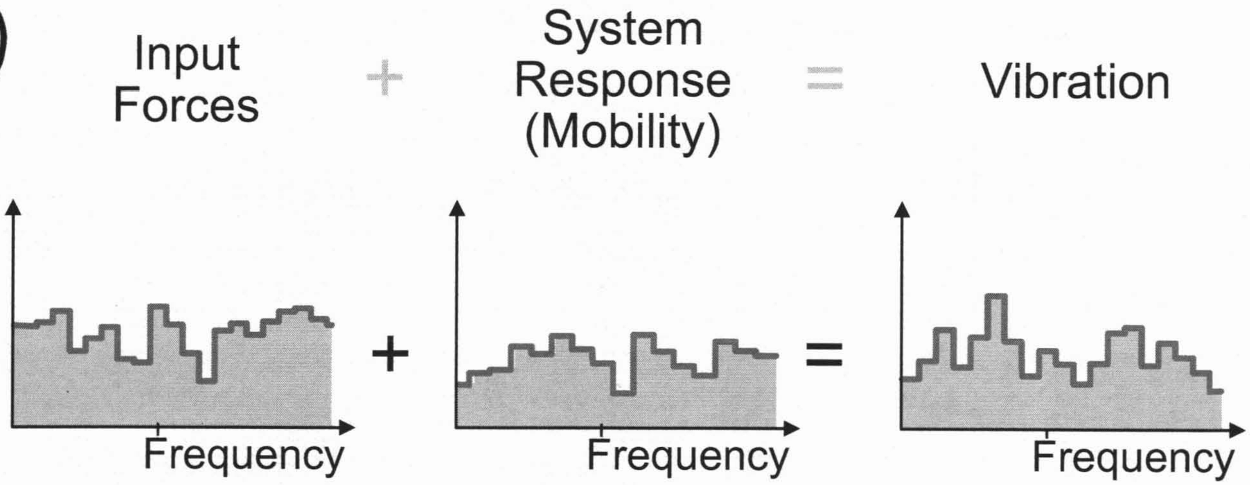
Eyeball, Intraocular Structure (20-90 Hz)
Head (axial mode) (20-30 Hz)
Shoulder Girdle (4-5 Hz)
Chest wall (50-100 Hz)
Arm (5-10 Hz)
Hand (30-50 Hz)
Abdominal Mass (4-8 Hz)
Spinal column (axial mode) (10-12 Hz)
Abdominal mass mode (around 5 Hz)

NASA KSC – A Wildlife Refuge



Acoustics and Vibration





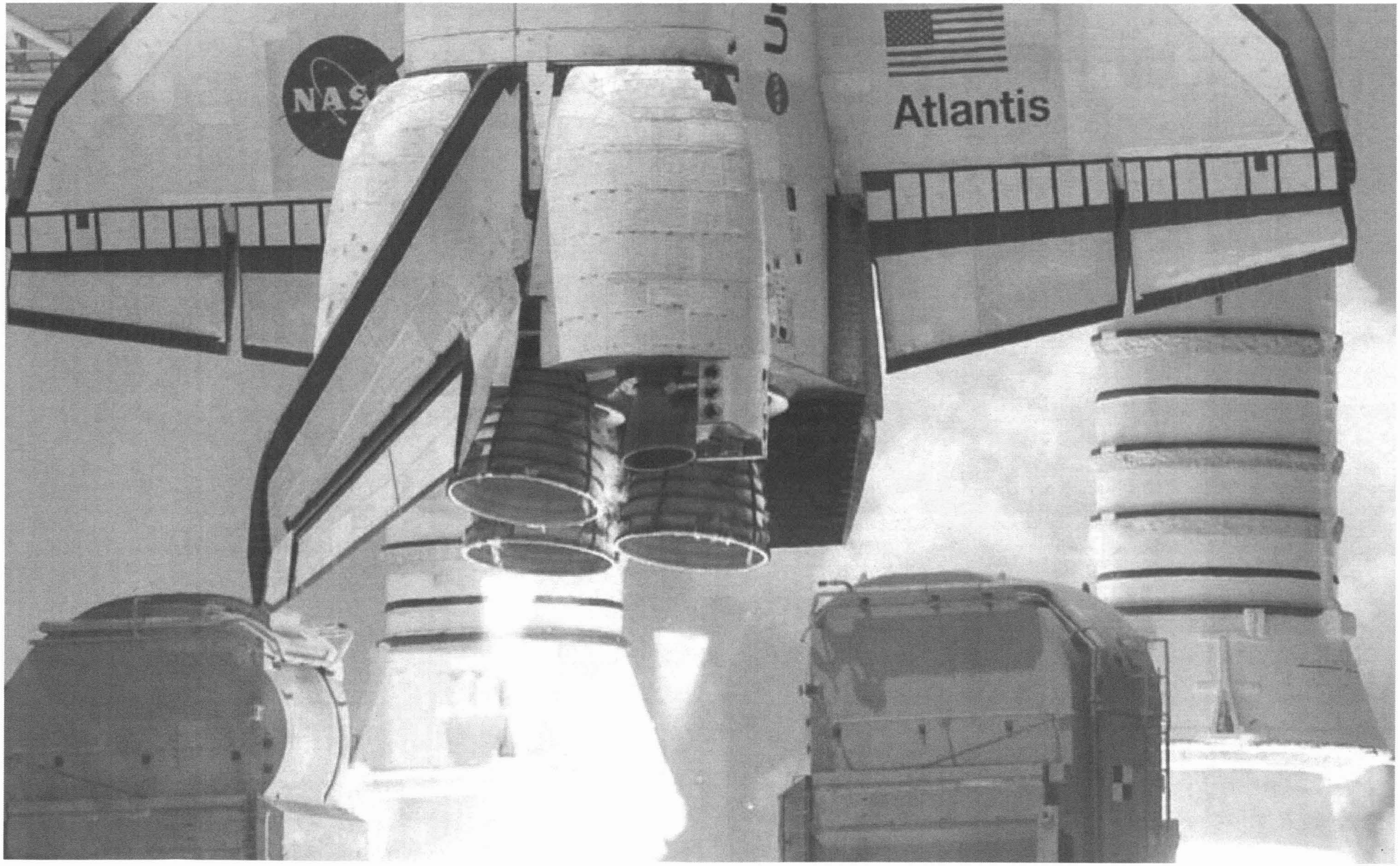
Forces caused by
Imbalance
Shock
Friction
Acoustic

Structural Parameters:
Mass
Stiffness
Damping

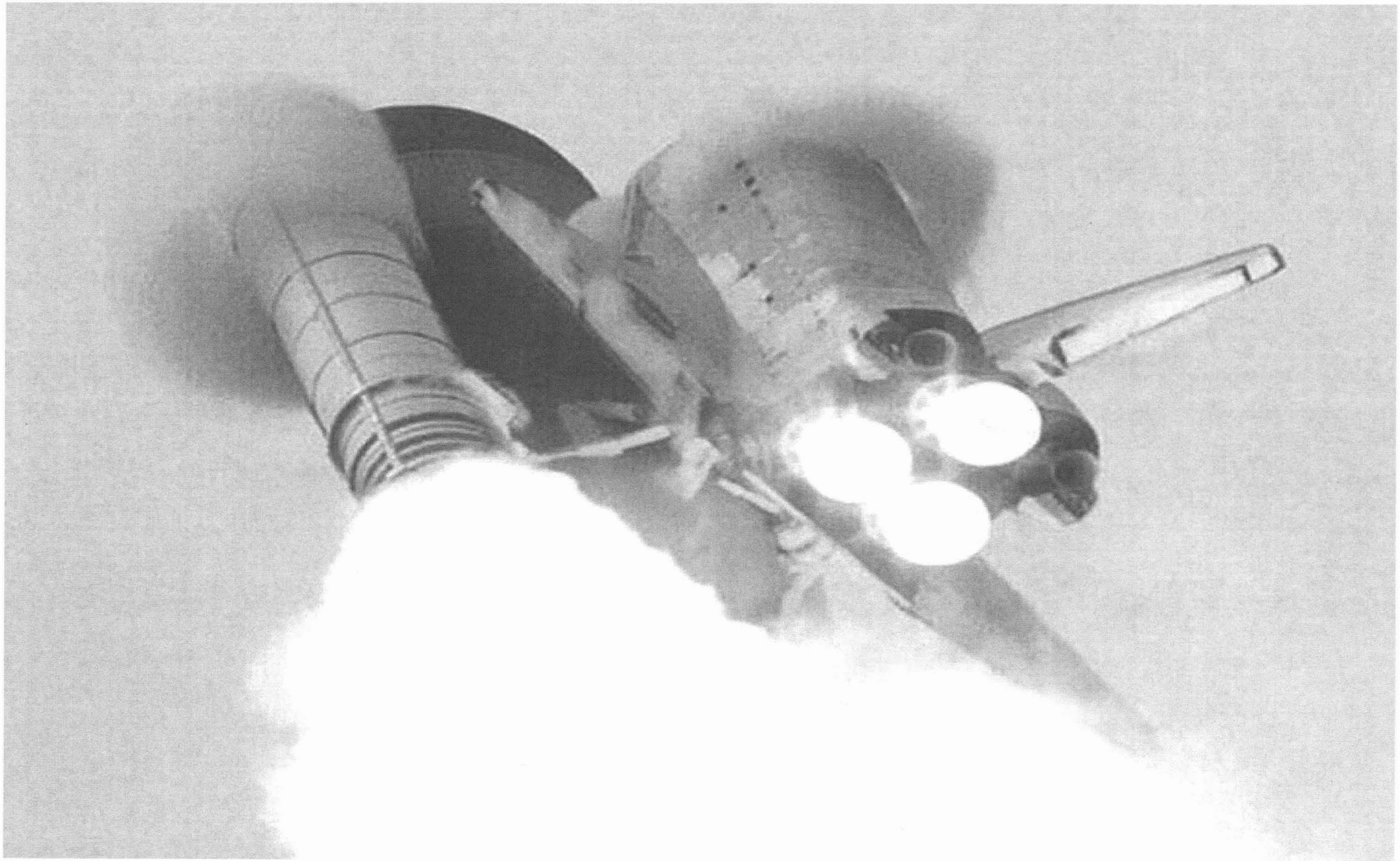
Vibration Parameters:
Acceleration
Velocity
Displacement

891875

Noise Analysis Considerations



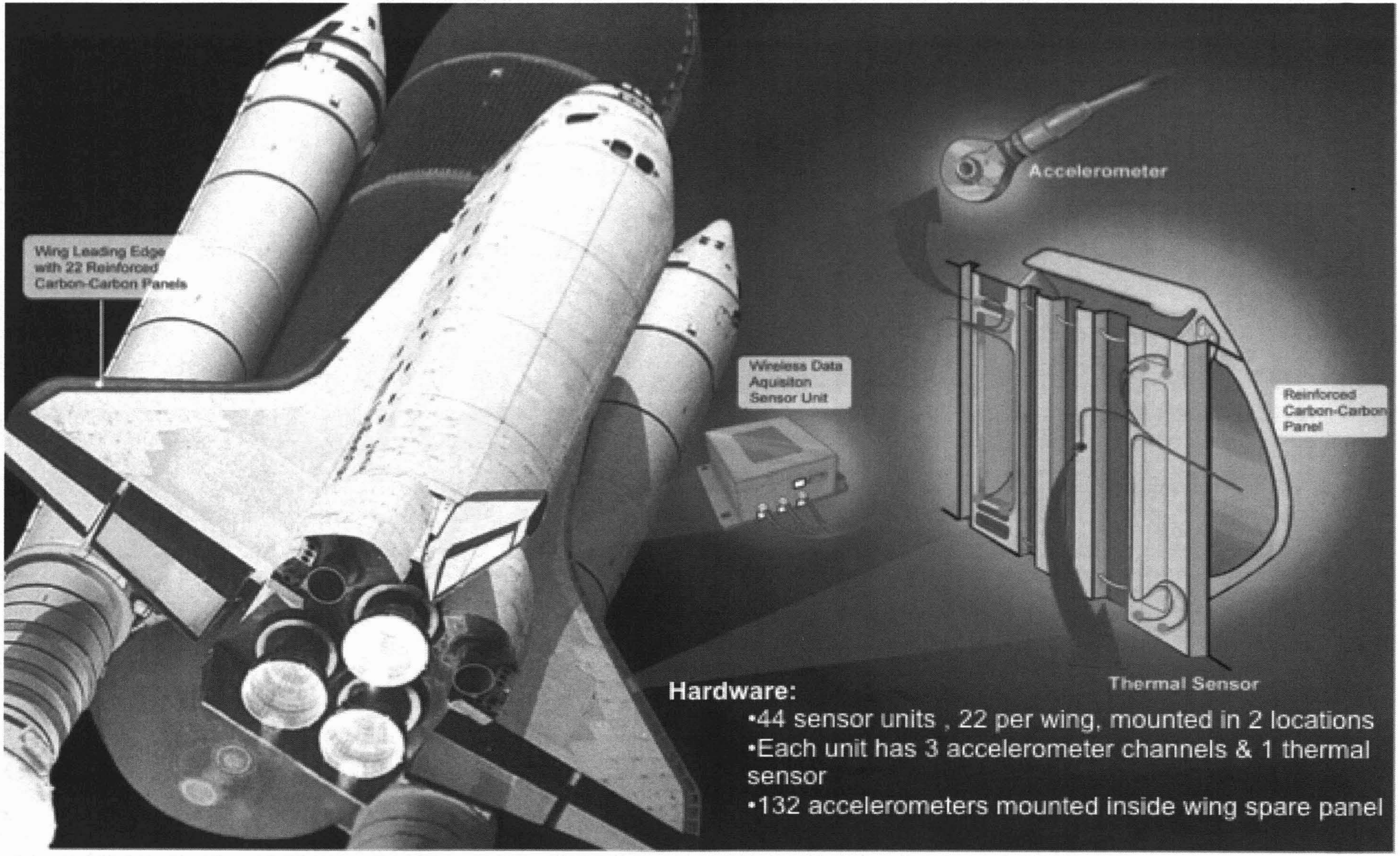
Noise Measurement Challenges



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

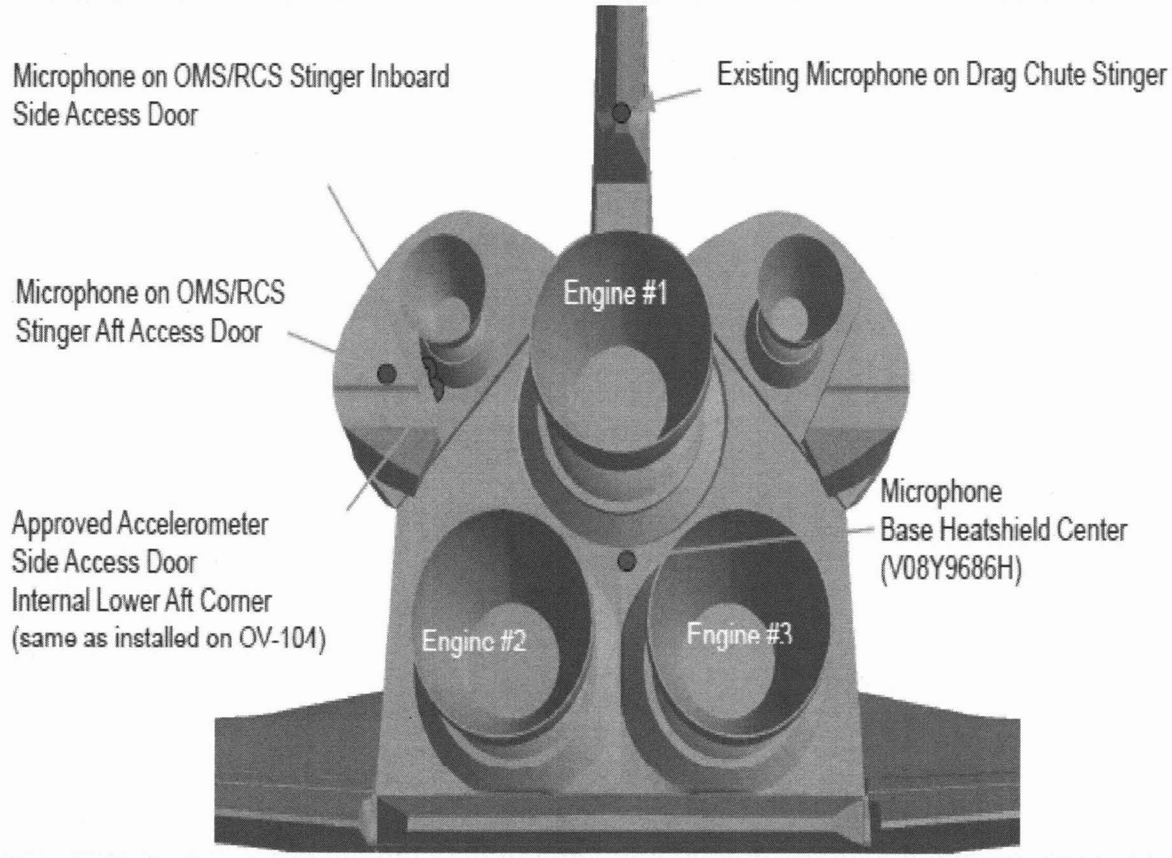
Wing Leading Edge Application

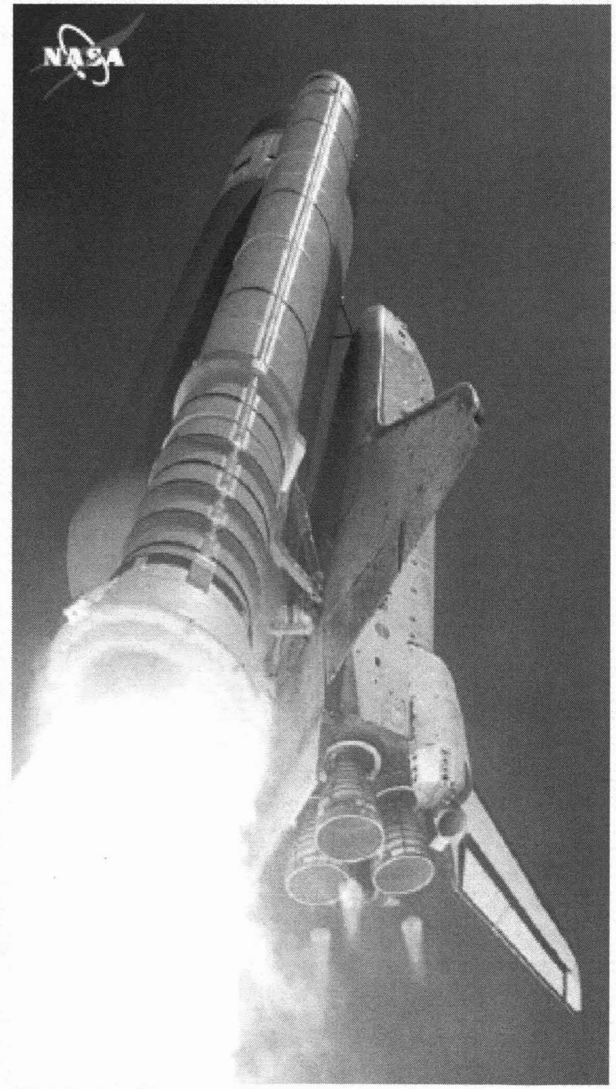


Hardware:

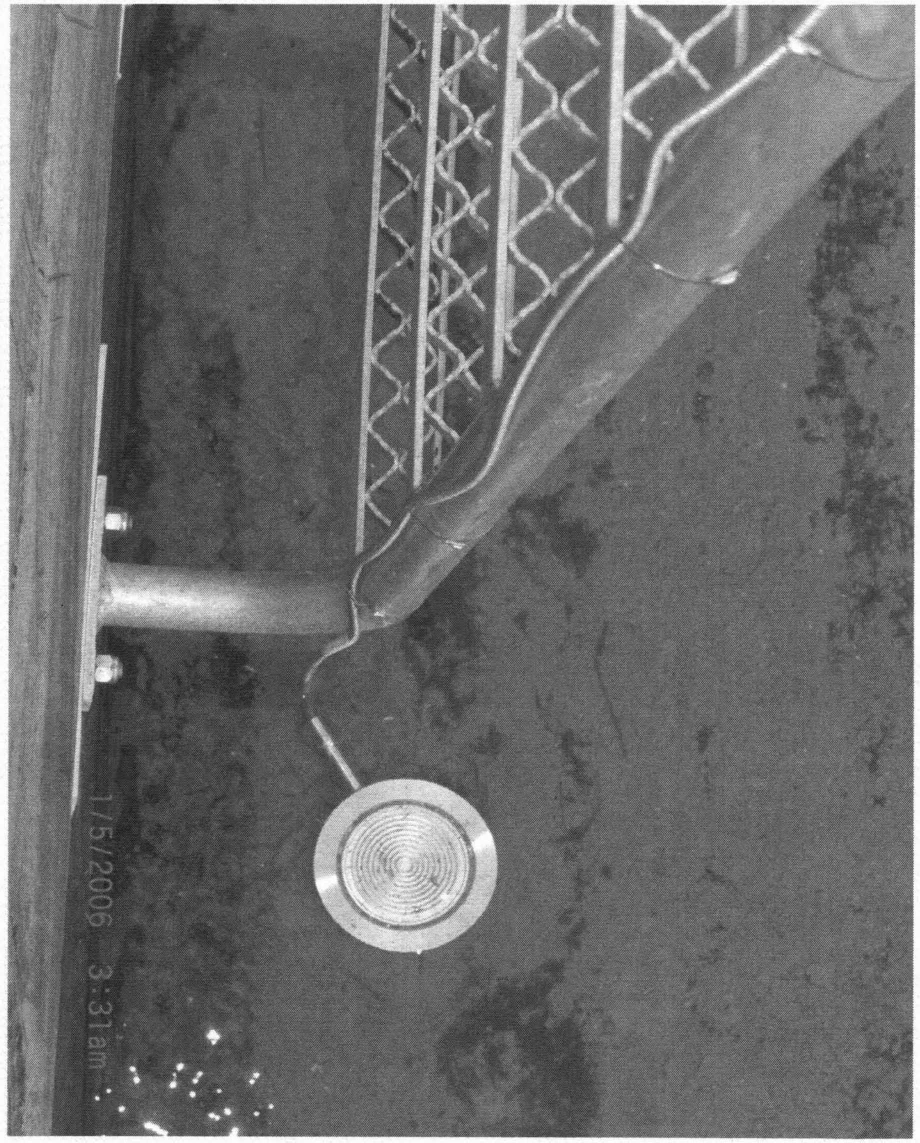
- 44 sensor units , 22 per wing, mounted in 2 locations
- Each unit has 3 accelerometer channels & 1 thermal sensor
- 132 accelerometers mounted inside wing spare panel

Orbiter Stinger Application





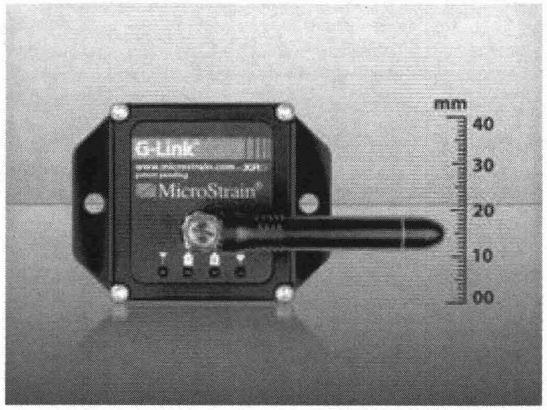
Holding Pond Water Level System

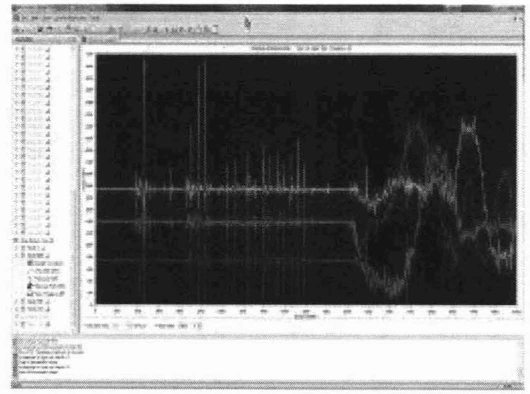


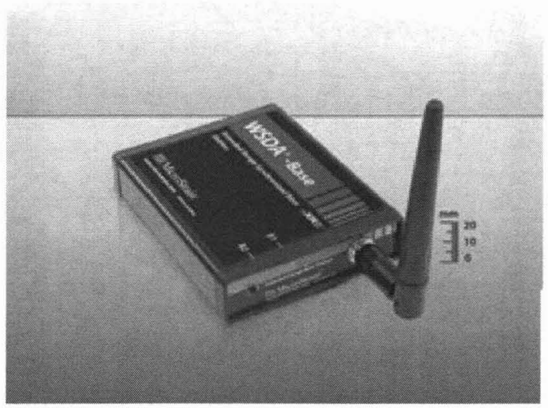
Microstrain – Background

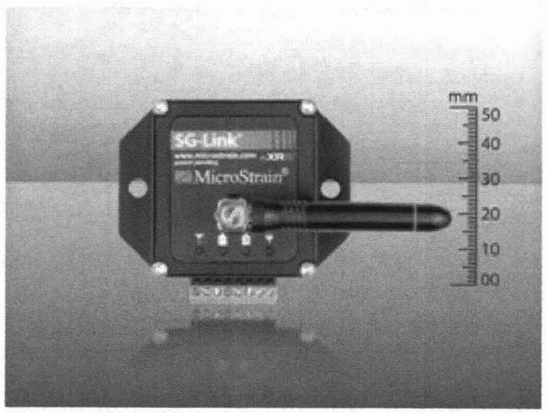
- Founded in 1987 in Vermont ; wireless sensors since 1996
- Has COTS systems for strain, pressure, load, displacement, acceleration, tilt, etc
- Developing the next generation of cutting-edge wireless systems for Navy and Army helicopters and fixed wing aircraft
- Used in automotive, aerospace, industrial manufacturing, semiconductor, alternative energy, environmental monitoring, oil & gas, power generation, civil structures and defense markets.
- Customers: Bell Helicopter, Sikorsky, Boeing, Caterpillar, Motorola, Johnson & Johnson, general Electric, Pratt & Whitney, Rolls Royce, Lockheed Martin, Ford, Intel, IBM, NASA, US Navy, US Army

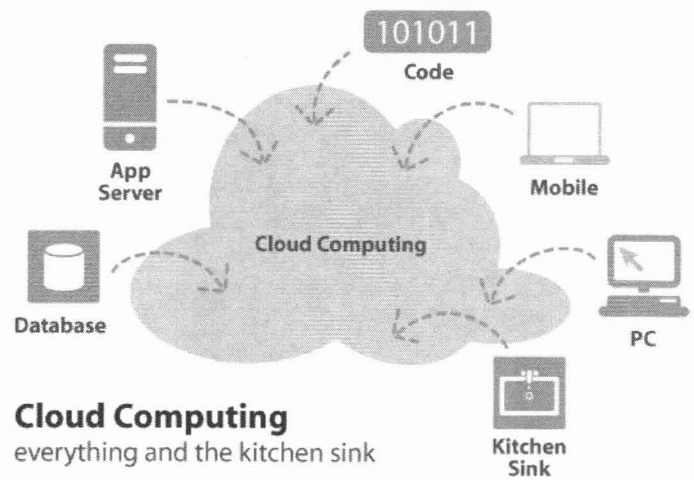
Microstrain Wireless System







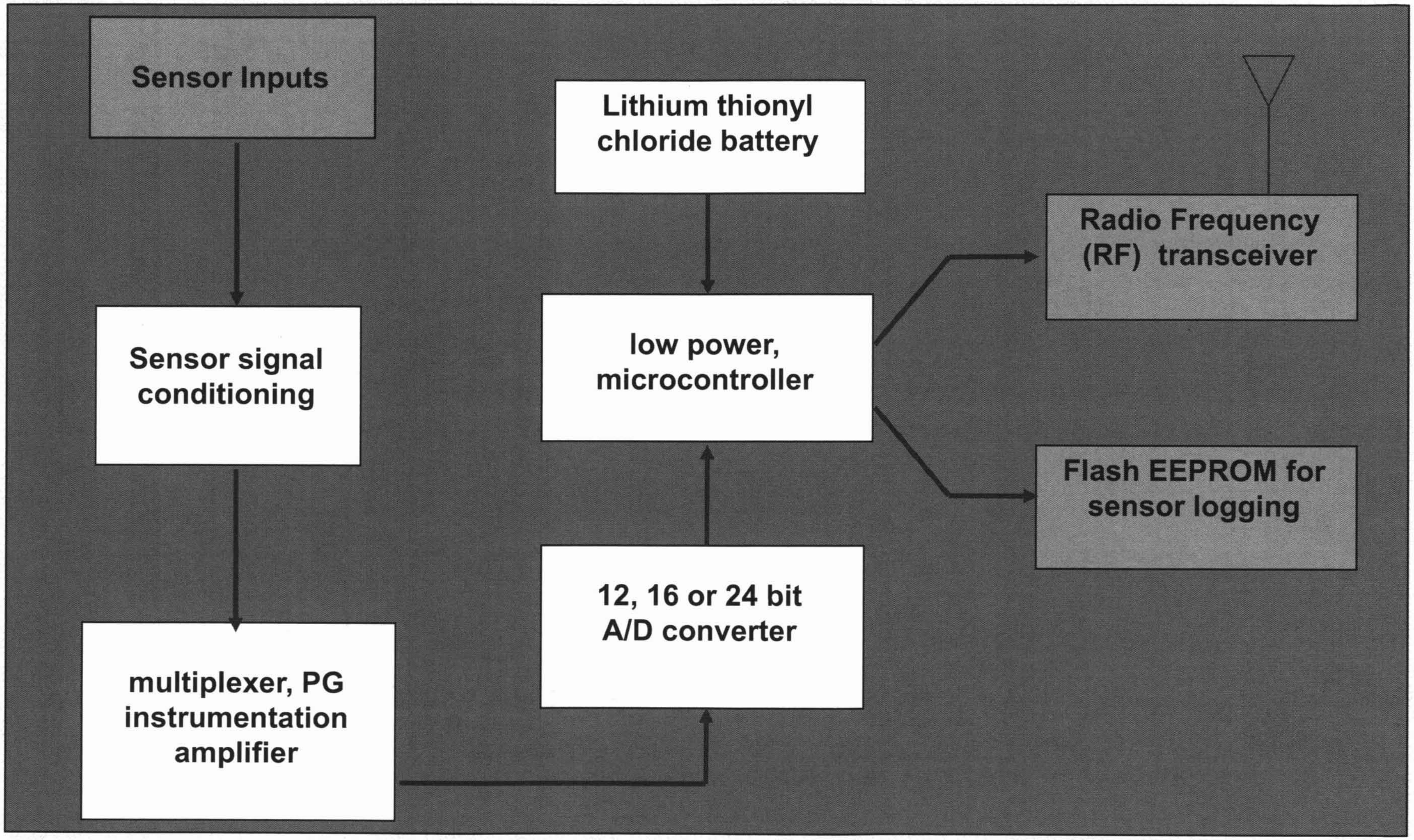




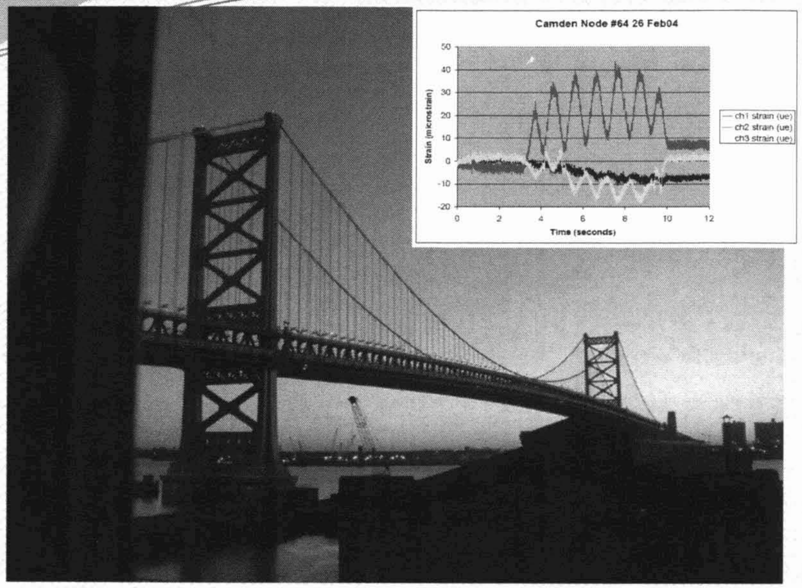
Deployed Wireless Technology

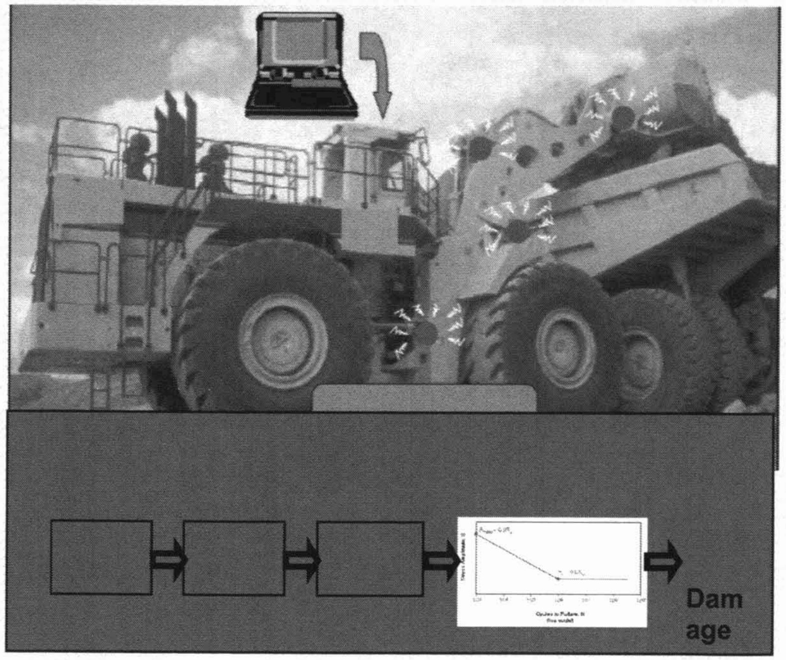
- 2.4 GHz active RFID tags with built-in sensors and signal conditioning for external sensors
- Easy to configure/deploy using Node Commander GUI
- Scalable network support hundreds of synchronized wireless nodes
- Comprised of G-Link accelerometer nodes, a SG-Link strain node, a Wireless Sensor Data 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

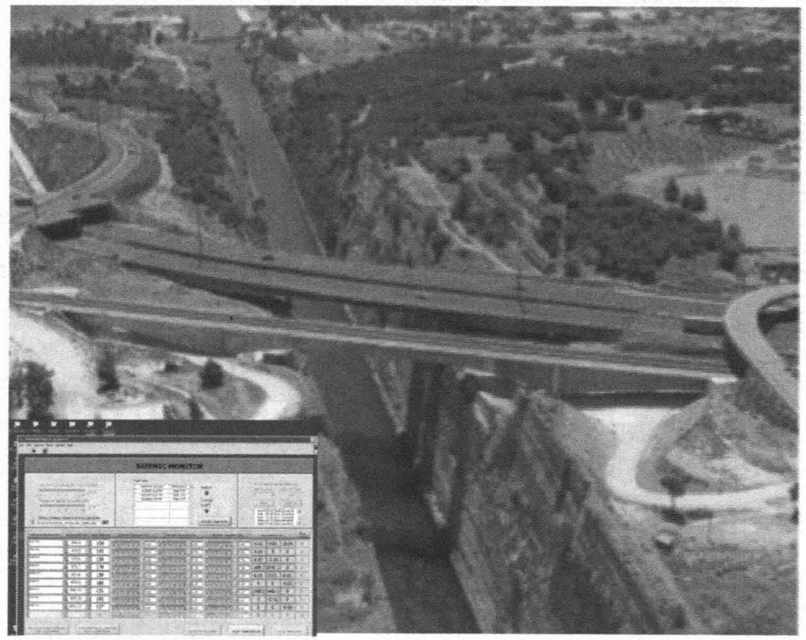
What is a Wireless Node?



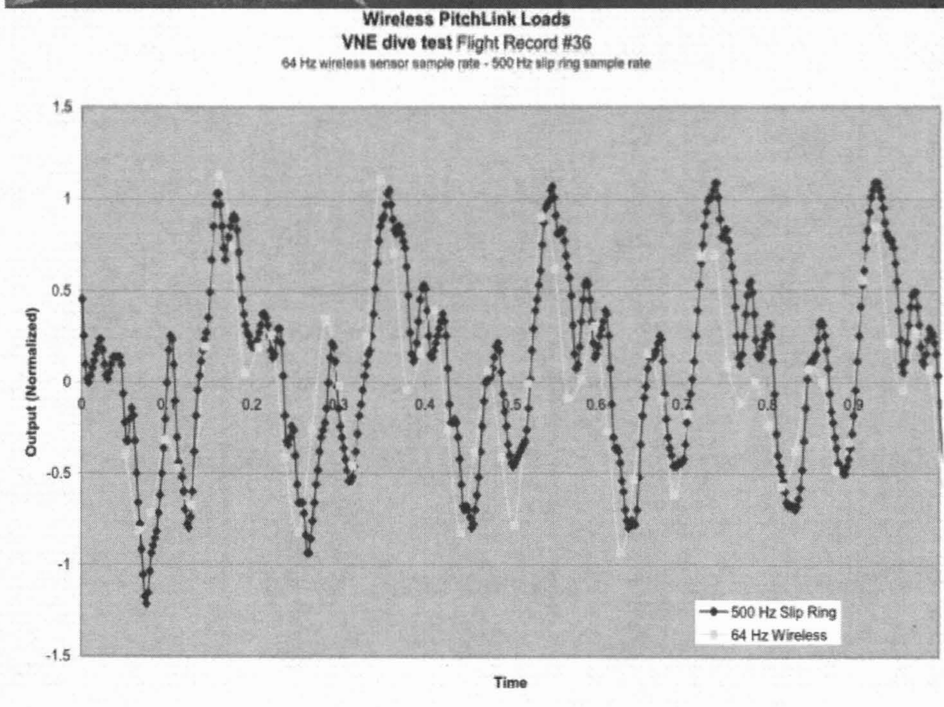
Health Monitoring Apps

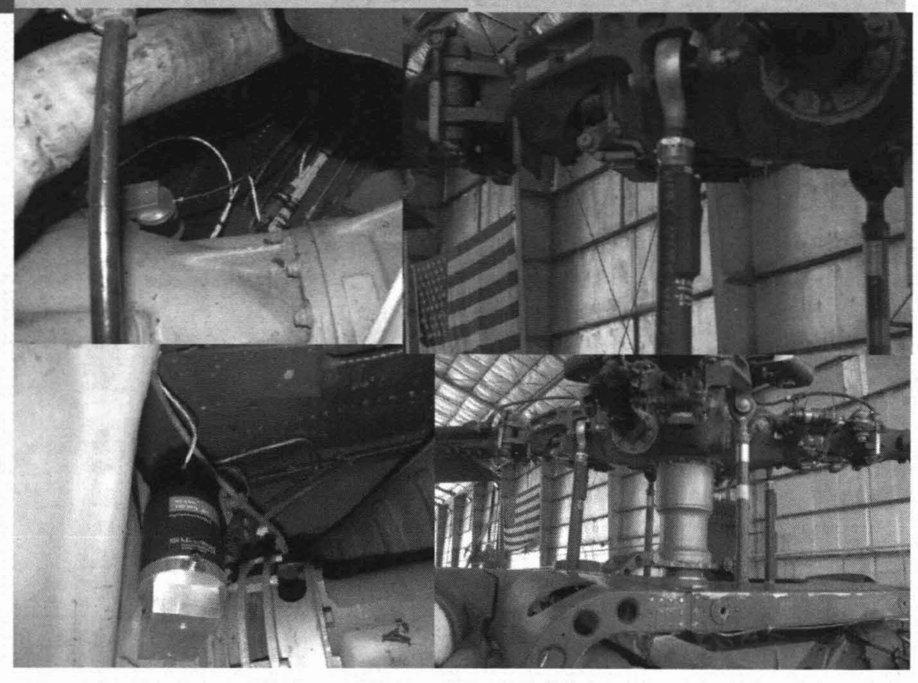






Aerospace Applications



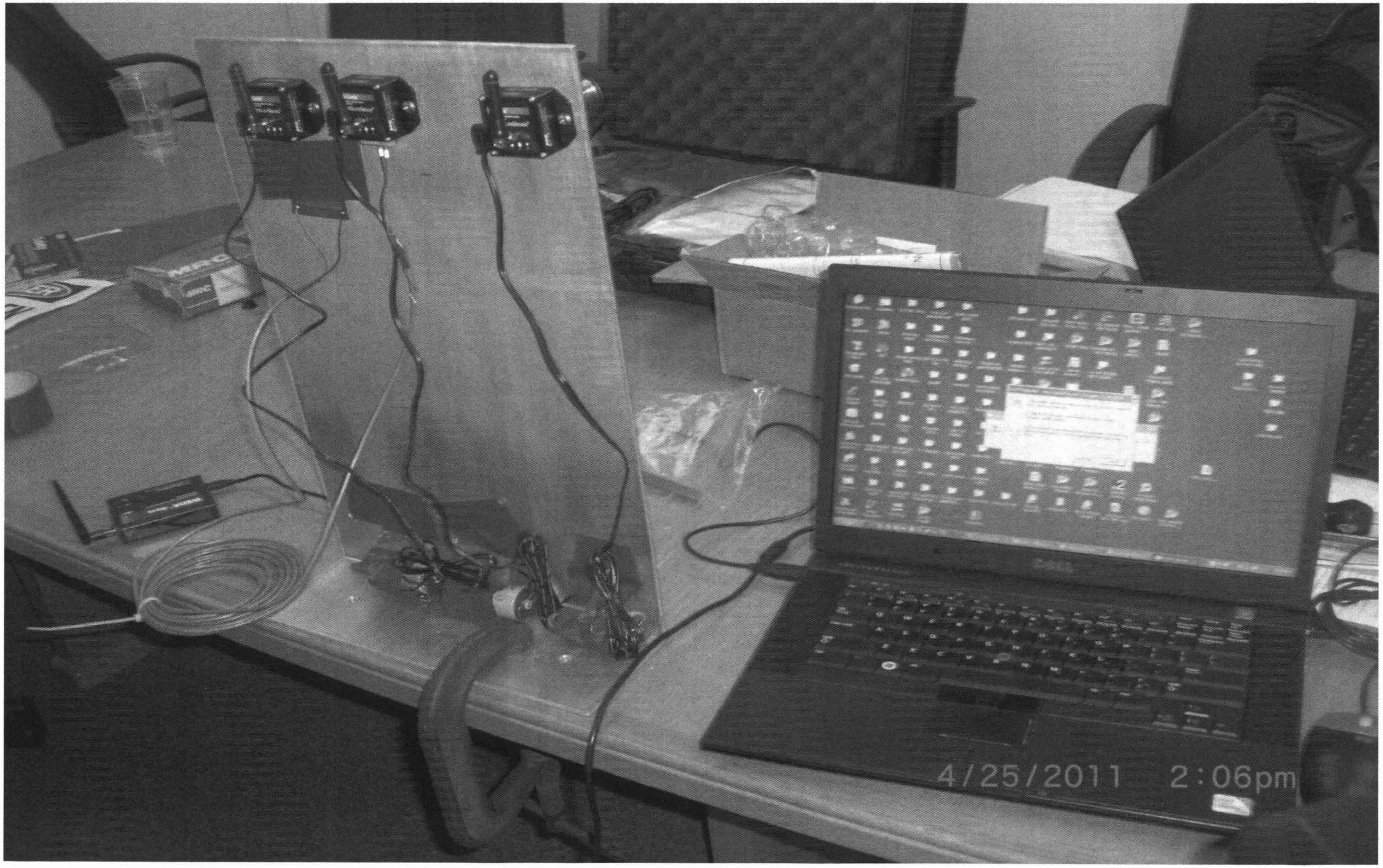


Plume-induced Vibroacoustics

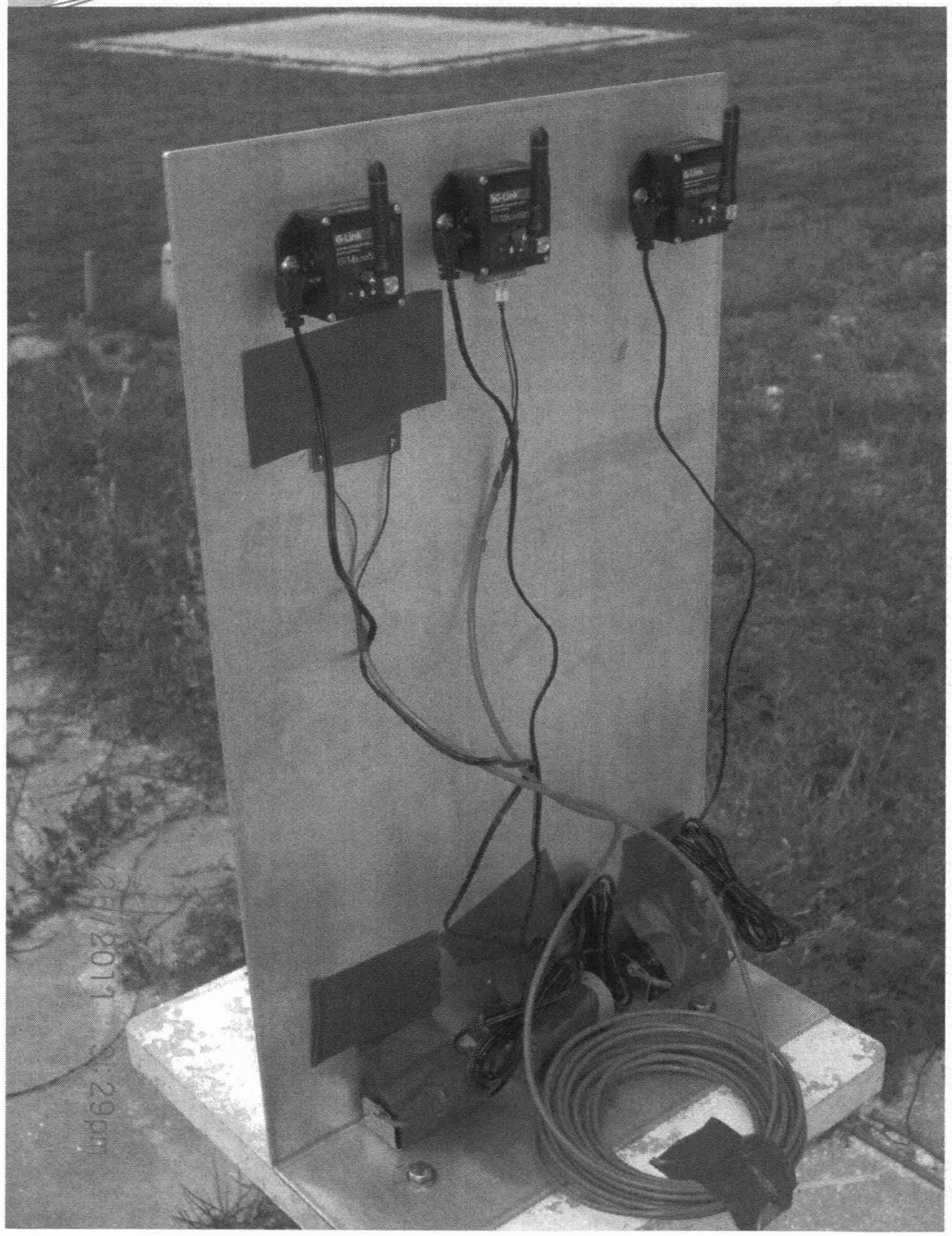
Test Article and Test Design Issues

- 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

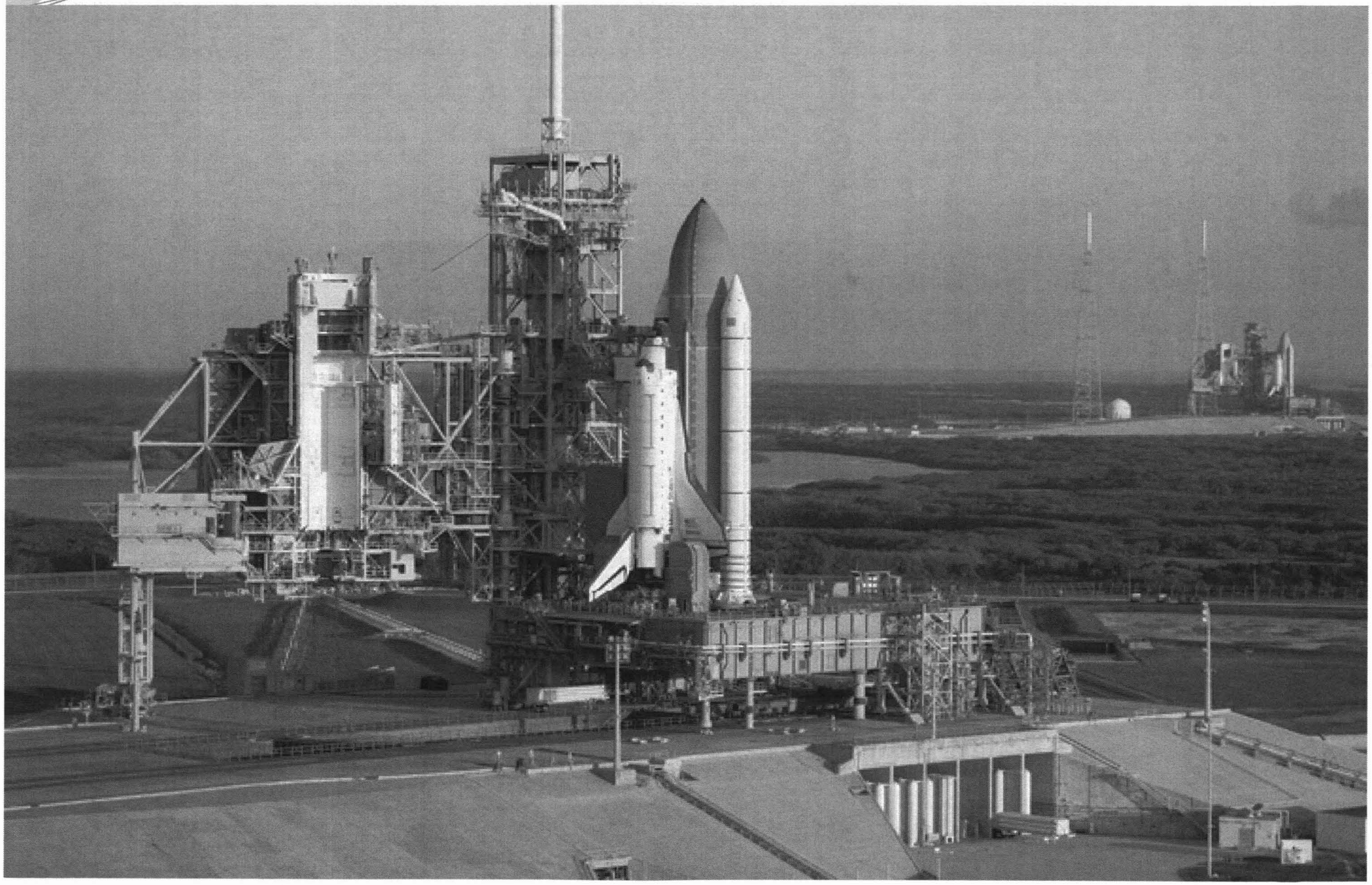
SVETA Laboratory Setup



SVETA on Pad 39B Camera Mount



Space Shuttles on Pads 39 A & B

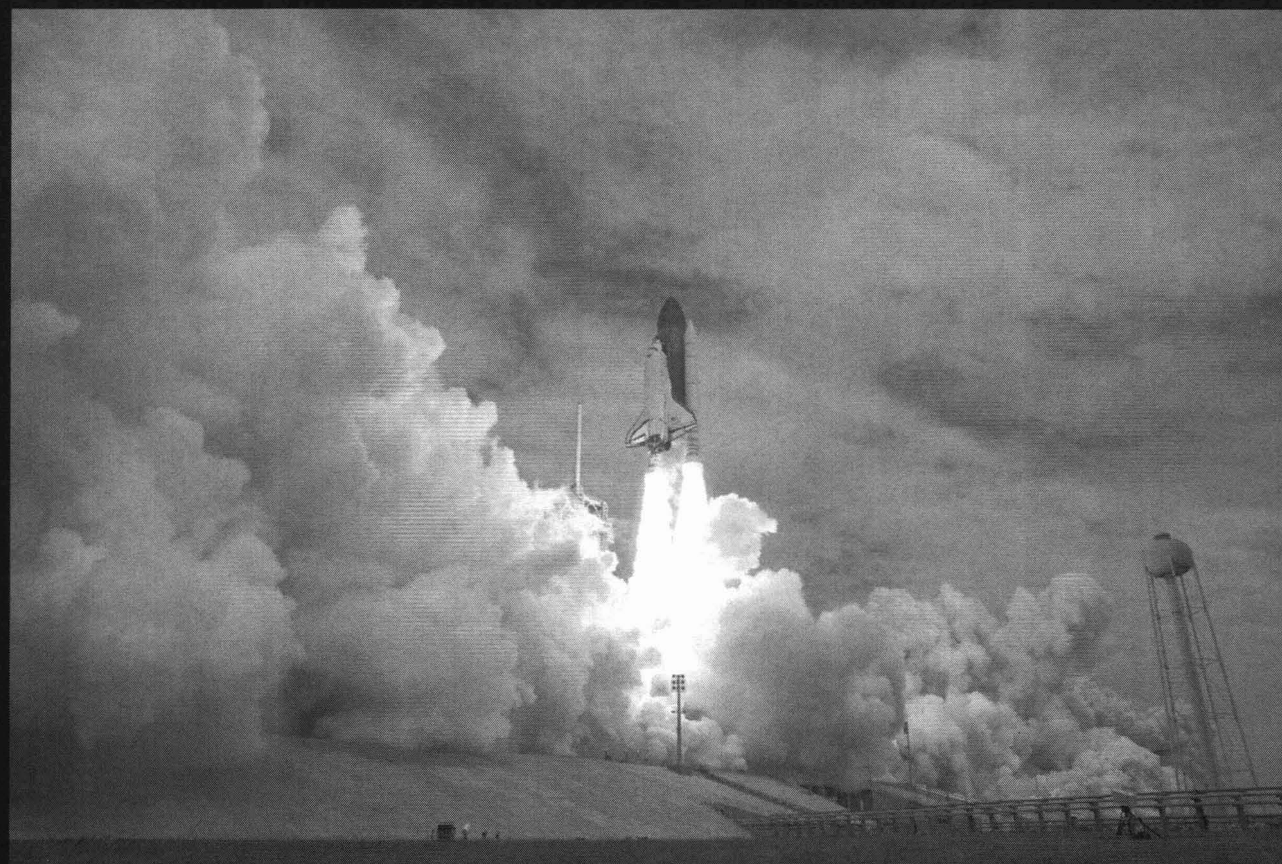


SVETA w/ Pad 39B and Pad 39A

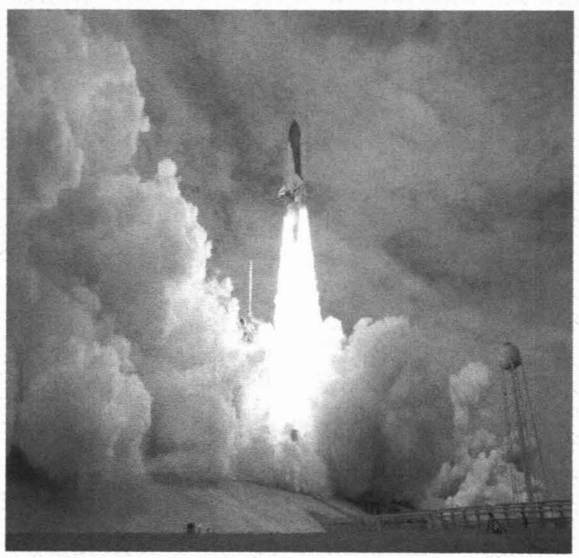
SVETA– Line of Sight - WSDA

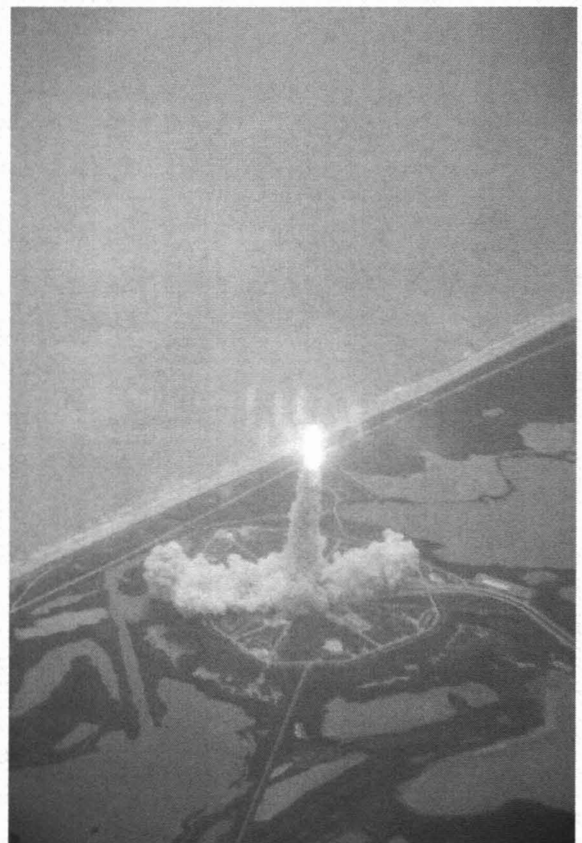
SVETA- Field Setup -WSDA

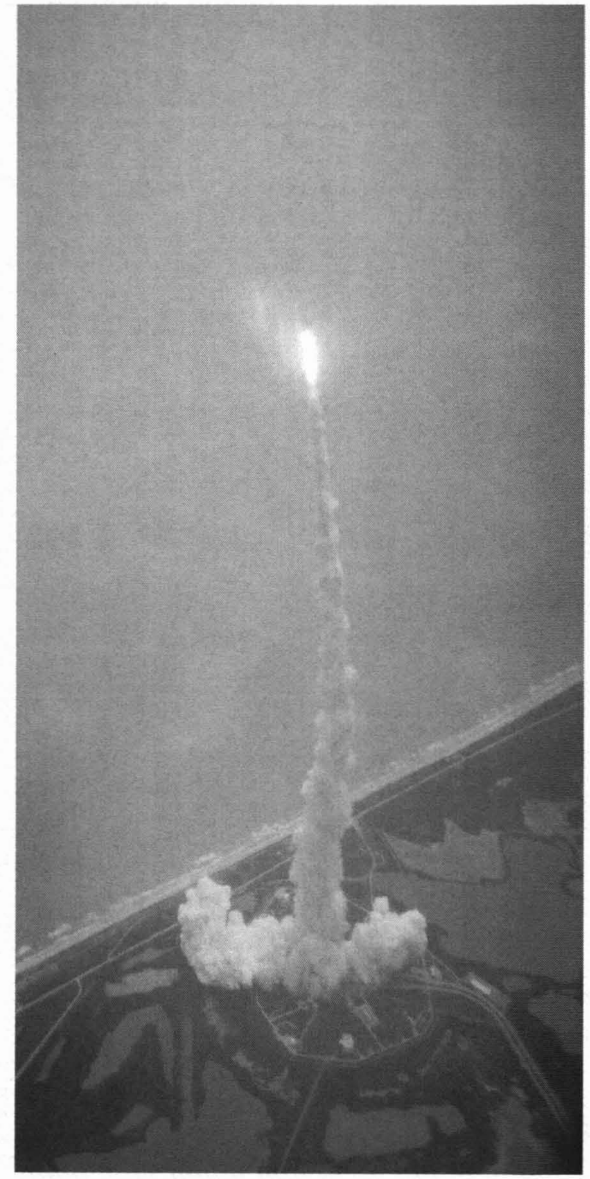
Atlantis - Liftoff to SRB Separation



Space Shuttle Lift-off Sequence







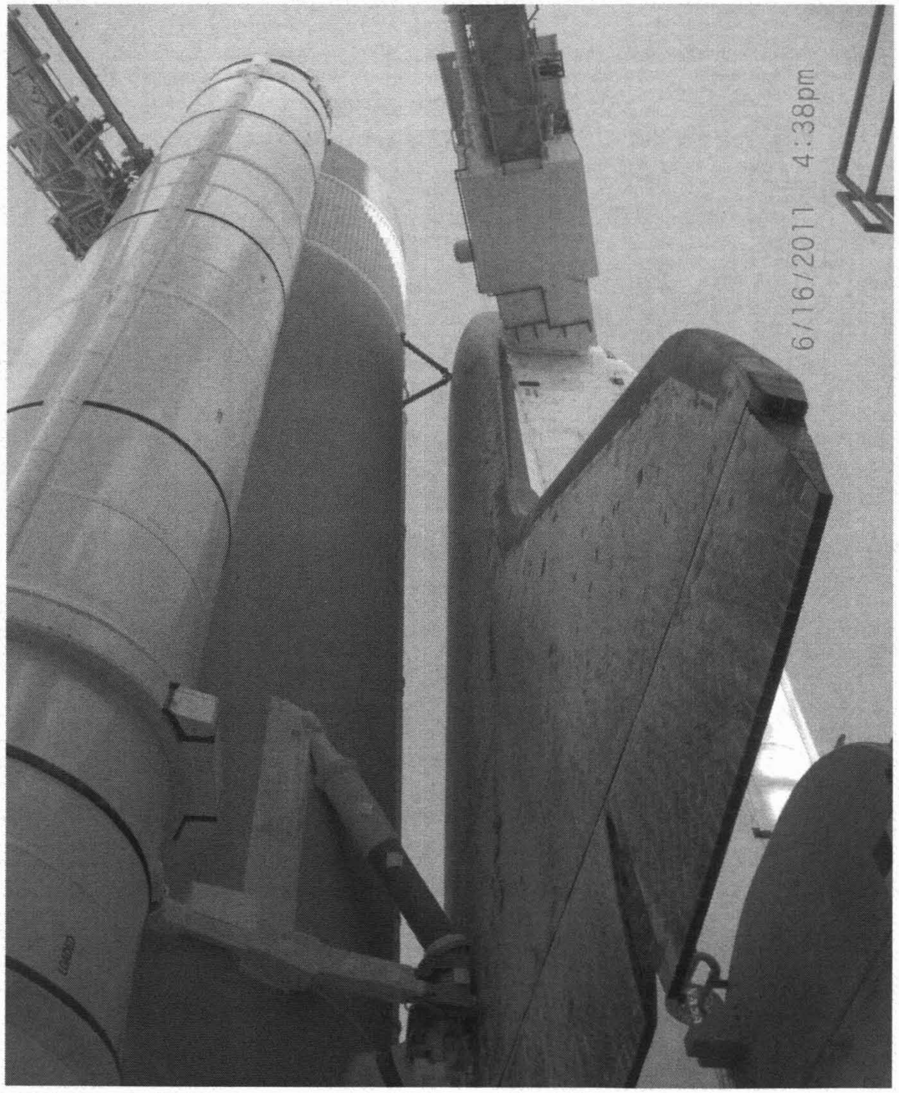
Test Analysis Correlation Method

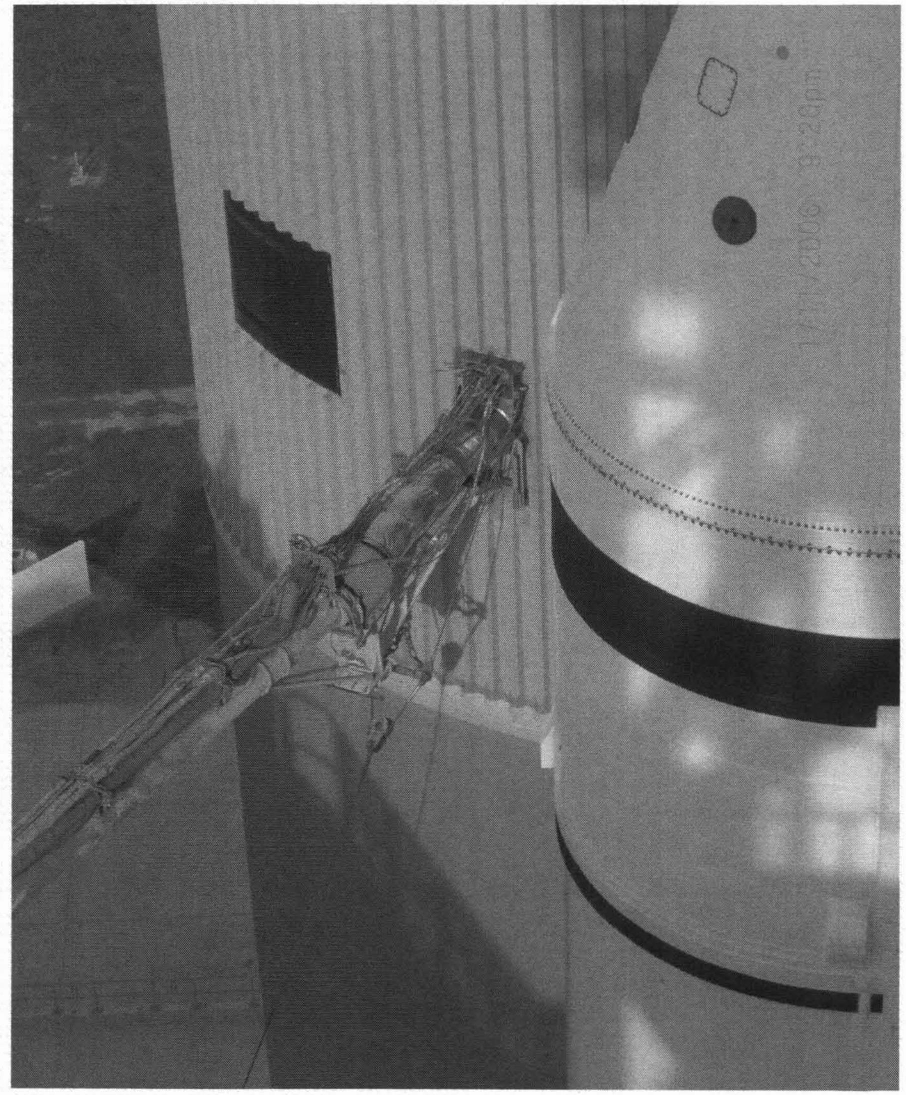
- TOA, Shape, Frequency, and Magnitude
- Time of Arrival – tells us when the Rocket lifted off at Pad 39A and when SVETA experiences the load (speed of sound)
- Shape – Vibration signature be similar in shape (less in magnitude – distance effect)
- Frequency– Modal (Static test), FE computer Analysis, 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

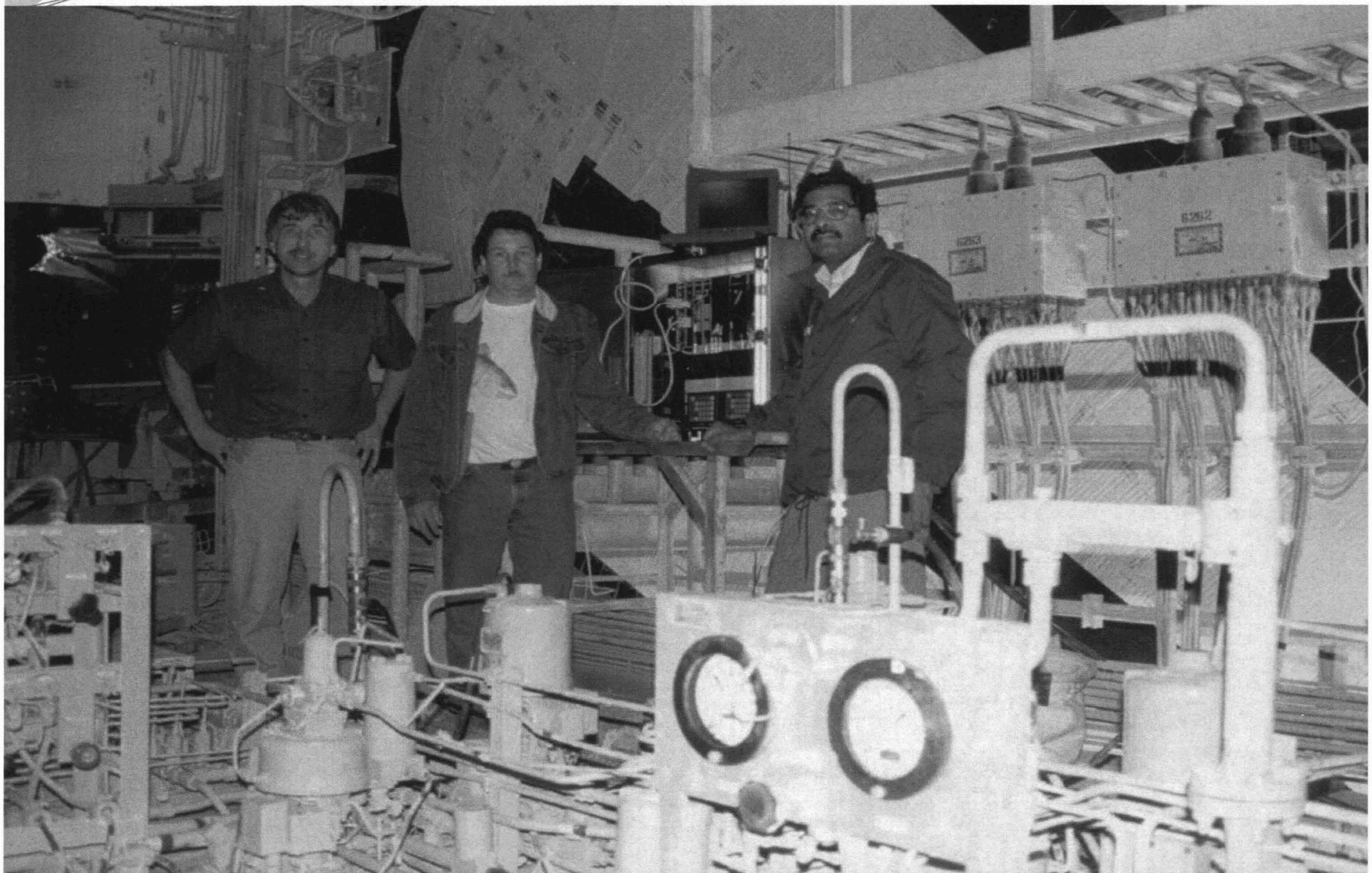
G Loads @ lift-off on SVETA	*Equivalent PSI and dB*
0.5	(0.0075psi) = 128.2 dB
0.6	(0.0090psi) = 129.5 dB
0.7	(0.0108psi) = 130.8 dB
0.8	(0.0120psi) = 132.2 dB

Future Wireless Applications

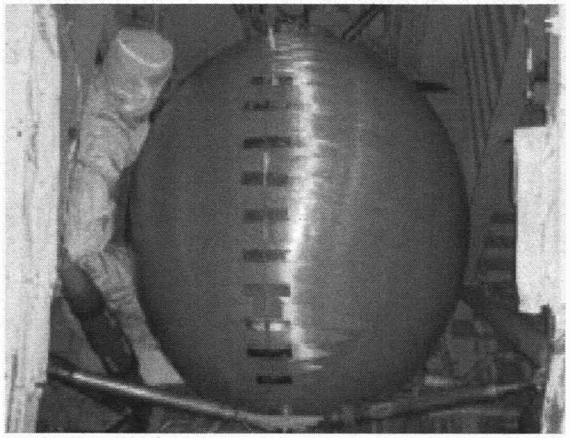


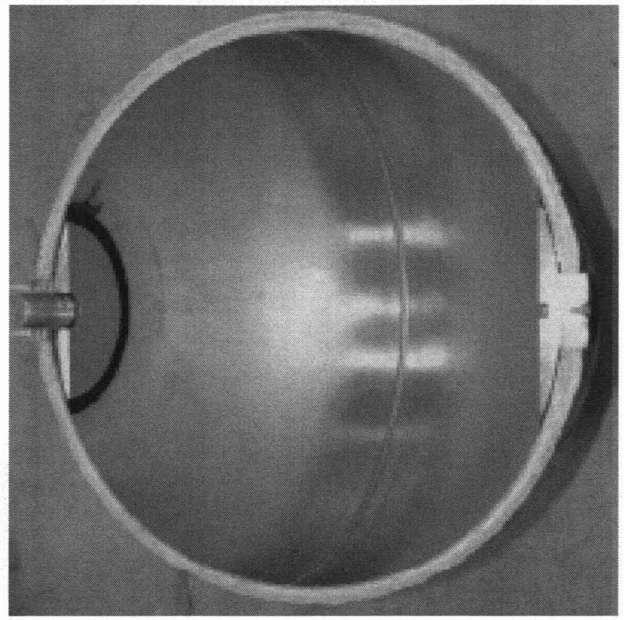


Future Wireless Applications



Future Wireless Applications





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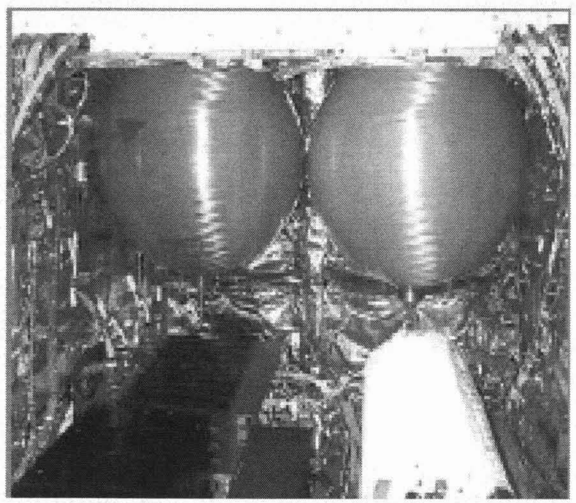
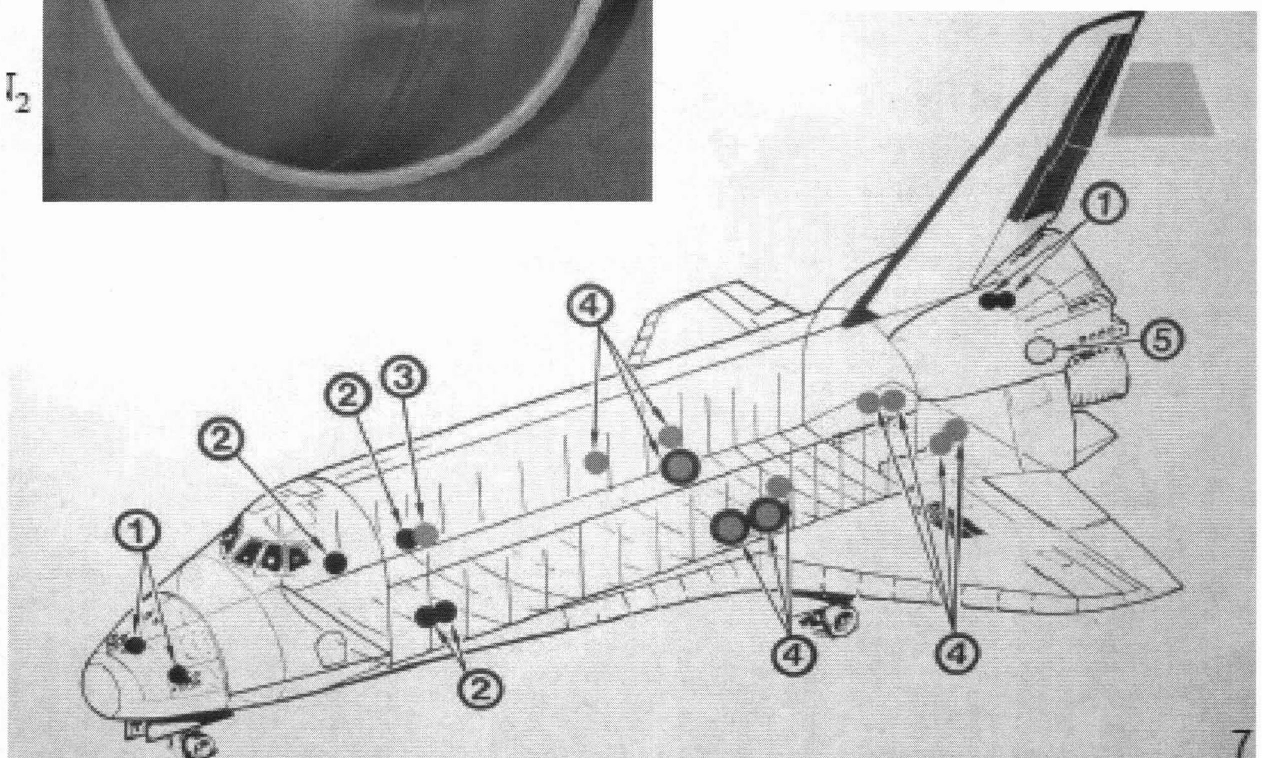


40" Tank:

- 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?