Launch Pad Vibroacoustics Research at NASA / KSC

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Rocket Noise and KSC

- KSC's role as a premier launch site dictates reliability and availability of pad and ground support equipment
- Structural vibration is consequent to launch acoustics, both air-borne and structure-borne
- Resonance is always present, due to wide band acoustic excitation
- Noise and Vibration measurements are key to launch readiness
Characteristics of Noise

- Space Shuttle launch environment (plume pressures, acoustics, strains, vibration) are random, nonstationary, non-gaussian, and wideband
- Amplitude and frequency vary widely
- Significant variability exists between short duration and long duration data collection and processing thereof
- Large sample size needed (we have over 100 launches)

Noise...Generation

- Space Shuttle noise: 180 dB - 2.8 psi
- Space Shuttle Lift-off:
  - Creates intense noise
  - Noise source is supersonic exhaust
  - Turbulent eddies created due to mixing of hot gases with ambient air...lead to shock
  - Shock strongest source of noise (see 5)

Noise...Impact

- Vibroacoustics effect on the vehicle and its valuable payload
- Effect on Astronauts inside vehicle
- Influence on pad and ground structures
- Impact on wildlife and ecosystem in close proximity of the pad
- Physiological and psychological effect on humans and surrounding community
- Sonic boom related issues
Noise...SSME Ignition
- Loud roar and heavy vibrations in the cockpit - driving a car down a railroad track or sitting close to speakers at a rock concert
- SSME's produce close to a million pounds thrust; since rocket is held to the pad via bolt/nut arrangement
- Noise is LOUD and teeth-rattling

Sounds...SRB Ignition
- Noise and vibration increase significantly; one cannot simulate such noise and shaking in the laboratory
- Vibrations and noise are not so bad that Astronauts cannot read instruments; noise does not prevent them from hearing fellow Astronauts (they use intercom for communication)

Noise...in Space
- Sound does not travel in vacuum, so it is not possible to talk in space. During EVA, Space walkers use radio
- Explosions occurring outside cannot be heard inside
- Talking inside Space Shuttle or ISS is same as on Earth; Air inside Shuttle is similar to ground
- N2 = 80%, O2 = 20%, Sea Level pressure = 14.7 psi similar to Earth

Noise at and during Liftoff
- Vibrations steadily increase up to Mach 1, the speed of sound, where shock waves add to the shaking; vibrations moderate as the Shuttle rises into thinner air as it ascends
- When SRB's burn out and are separated a dramatic change occurs; marked by a bang due to explosive bolts being fired; noise and vibration end at last

Noise at and during Liftoff
- SRB separation occurs around 25 miles; air is very thin here for wind noise or shock waves to shake the Astronauts
- SRB separation occurs 2 minutes after liftoff (after T-0 seconds)
- Even though SSME's are still operating there is virtually no noise or vibrations during the rest of the ascent until External tank ejection (around 8.5 minutes after liftoff)
Noise... Characterization

- Typical: Time history, OASPL, and FFT
- At NASA, we use Probability Density Distributions, Power Spectral Density, Cross-Power Spectral Density, Pressure Correlation Lengths, Coherences, etc.
- AJ factors – Vibroacoustic coupling between the sound field and structure of consequence
Rocket vs. Common Noise

- 0 dB - Threshold of hearing
- 55 dB - Normal conversation
- 85 dB - Exposure must be < 8 hours
- 140 dB - Jet Engine (Pain threshold)
- 158 dB - Australian Cicada at 3 feet
- 180 dB - Shuttle lift-off at 10 feet
- 194 dB - Highest noise level (14.7 psi)

Loudness: Records

- 188 dB: Loudest Animal Sound
- 182 dB: Loudest Instrument
- 158 dB: Loudest Insect
- 145 dB: Loudest Animal
- 128 dB: Loudest Scream
- 122 dB: Loudest Whistle
- 121 dB: Loudest Shout
- 93 dB: Loudest Snoring

Launch Systems Test bed
Cold Jet (GN2) Simulation with closed duct

Future Hot Combusting Jet (GH2+GOX) Simulation

Trajectory Simulation Mechanism
Data Acquisition System
**Noise...Design Application**
- What you don't hear...hurts you (20 Hz)
- Define acoustic load in terms of Static Equivalent Load (Architectural use)
- Dynamic Load: Enhance SEL analysis by conducting modal tests, response analysis; include considerations for stress, fatigue, and fracture mechanics

**Vibroacoustics Objectives**
- Rocket Noise Models
  - Characterize acoustics environment
  - Bridge gap between test and analysis
  - Develop innovative analysis
- Vibration Response Analysis
  - Reliable Structural analysis method
  - Test project for verification
  - Implement system for use

**Vibroacoustics...needs**
- ESL approach is crude; leads to over design – does not account for higher order modes
- Future launch vehicles have higher mechanical power – no experience
- Lower costs for new structures and modifications of older structures
- New measurement based analysis systems are needed coupled with FEA
Response Analysis Methods

- Probabilistic Method (1967)
  - Based on classical random vibration
  - Transient – simulated as steady state
  - White Noise PSD, WN decay is CPSD
- Deterministic Method (1987)
  - Based on non-stationary data (Shuttle)
  - Low frequency response analysis - key
  - Response Spectra and PCL, CPD, etc
  - True simulation of rocket response
Concluding Remarks

- Critical structures... bridges, oil rigs, aircrafts, rockets, and launch pads all require new techniques for design
- Dynamic loads... aerodynamic, earthquake, ocean waves, acoustic pressures... require random analysis
- Kobe earthquake... similar to water waves overlapping... cancel or additive
- Vibroacoustic coupling, launch exhaust management analysis... state of the art from a Ground Structures perspective
Delivery to Launch

Hardware Delivery at KSC
Installation into Canister
Payload Installation at Pad
Canister Rotation Facility

Kennedy Space Center
"I'm not afraid of storms... for I am learning to sail my ship."

Louisa May Alcott

"Every great achievement in science has issued from a new abrasion of the imagination."

John Dewey

"Smooth seas do not make skillful sailors."

Anonymous

"We must become the change we want to see."

Gandhi