Overview of the Space Launch System Transonic Buffet Environment Test Program

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Motivation for Buffet Testing
Buffet Test Program Objectives
Overview of Past SLS Buffet Environment Efforts
Space Launch System Model Design
  • Test Configurations
  • Instrumentation
Test Facility
Results
Conclusions
Buffet loads due to unsteady aerodynamic phenomena can excite vehicle bending modes and local shell/panel modes.

Transonic regime is typically most critical (max-Q next runner-up).

Buffet forcing functions are required for coupled loads analysis (CLA).

Pure analytical solution is not feasible.
- Experimental forcing functions (time domain)
- Experimental auto-spectra and cross-spectra (frequency domain)

Unsteady flow environment: shock oscillations, boundary layer separation, turbulence, vortex shedding
Buffet Test Program Objectives

Test Objective:
- Acquire time-correlated unsteady pressures on rigid model at transonic conditions
  - Up to 472 buffet pressure measurements: Full scale bandwidth to 60 Hz (770 Hz model scale)
  - Up to 64 aeroacoustic measurements: Full scale bandwidth to 2,000 Hz (26 KHz model scale)

Key Deliverable:
- Key deliverable is buffet forcing function (BFF) time histories at each longitudinal sensor

Cost of Failure:
- Lack of accurate BFFs for vehicle loads analyses may result in:
  - Over-prediction of buffet environment (heavier vehicle; less payload)
  - Under-prediction of buffet environment (compromised safety margins; vehicle failure)

Mercury-Atlas Test Flight (MA-1) August 1960
Panel buckling due to wake buffet of LAS tower and cone/cylinder junction

5% to 6% of launch vehicle failures can be attributed to structural failure
Launch Vehicle Failure Mode Database, Nickolas Demidovich, FAA, May 17, 2007
Overview of SLS Buffet Environment Efforts

Initial BFF Estimate (Feb 2012)
- Ares launch vehicle BFFs used as basis
- Scaled and mapped to SLS-10002
- Mach 0.95 provided for initial loads cycle

Buffet Test at TDT (Oct 2012)
- Three SLS configurations tested
- High buffet environments identified
- Buffet Loads Mitigation Task Team created

Ascent Aeroacoustic Test (Aug 2013)
- Ames Unitary Plan Wind Tunnel (UPWT)
- Primary goal: fluctuating pressure environments
- Buffet mitigation options (BMOs) tested

Buffet Test at TDT (May 2014)
- SLS-10005 configuration (Orion MPCV)
- Updated protuberances / Increased sensor ports
- Buffet mitigation options (BMOs) tested
3%-scale with 360 Unsteady pressure ports

SLS-10003 Vehicle Configuration
- 70-metric-ton payload (Orion)
- RS-25 engines (4)
- Enhanced 5-segment boosters (2)

SLS-11000 Vehicle Configuration
- 93-metric-ton payload (8.4m shroud)

SLS-13000/28000 Vehicle Configuration
- 93-metric-ton payload
Model Design: 2014 Test Configurations

3%-scale with 472 Unsteady pressure ports

SLS-10005 Vehicle Configuration
- 89-metric-ton payload (Orion)
- RS-25 engines (4)
- Enhanced 5-segment boosters (2)

- Updated Protuberances
  * Booster forward attach, LOX feed lines,
    GO2/GH2 press lines, cameras.

Refined versus Simplified Booster Forward Attachment Protuberance

2012 Test: Simplified

2014 Test: Refined
Booster Nose Cone Buffet Mitigation Options

- Canted Ogive
- Bent Bi-conic
- Canted Straight

Fence Buffet Mitigation Options

- Sharp Booster Fence
- Blunt Booster Fence
- Core Fence
Model Design: 2012 Test
Pressure Measurement Locations

- Static Pressure (64)
- Buffet Pressure (296)
- Aeroacoustic Pressure (64)

SLS-10003

SLS-13000

SLS-11000
Model Design: 2014 Test
Pressure Measurement Locations

Station with additional azimuthal orifices

SLS-10005

New longitudinal station

- Buffet Pressure (440)
- Aeroacoustic Pressure (32)
Model Pressure Instrumentation

- Kulite Semiconductor XCL-100/072 unsteady pressure sensors
- Integrated amplifier to reduce signal attenuation at high frequencies
- Very high channel counts
  - 360 Kulites for 2012 test (64 aeroacoustic)
  - 472 Kulites for 2014 test (32 aeroacoustic)
- 64 steady pressures on core and RSRB (2012)

Accelerometers and Q-flex Inclinometers

- Six accelerometers for model vibration response
- 3-axis Q-flex accels for model orientation (pitch/roll)
Facility Characteristics

- Closed-circuit, continuous flow, transonic pressure tunnel
- Test section: 16 feet x 16 feet
- R134a or air test medium
- Mach numbers up to 1.2
- Dynamic pressures up to 550 psf

SLS Tests

- Mach 0.7 – 1.2
- R134a test medium
- Dynamic pressures up to 480 psf
- Reynolds numbers up to
- Model Pitch: ±8° Model Roll: ±180°
- Over 10 terabytes of data
Comparisons of buffet environments made using $\Delta C_p, \text{rms}$

All results are presented without defined numerical scales

All results have 0.5-60 Hz bandpass filter applied (full-scale freq)

All results are presented for Mach 0.90 and pitch/roll of zero degrees

Data is presented versus vehicle longitudinal station at common azimuthal pressure port locations
$\Delta C_{p,rms}$ Trends on Core
Mach 0.90; 0/90/180/270 deg azimuths
$\Delta C_{p,\text{rms}}$ Trends on LSRB
Mach 0.90; 45/135/225/315 deg azimuths

Peak Buffet on LSRB at locations near core
Δ\(C_{p,\text{rms}}\) Trends on Core
Mach 0.90; 0/90/180/270 deg azimuths

SLS-10005 Core
0/90/180/270 deg
Bandpass 0.5–60Hz

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<th>M=0.90</th>
<th>(\theta=0) deg</th>
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$\Delta C_{p,\text{rms}}$ Trends on LSRB
Mach 0.90; 45/135/225/315 deg azimuths

SLS-10005 LSRB
45/135/225/315 deg
Bandpass 0.5–60Hz

Vehicle Station

Detailed

Simplified
$\Delta C_{p,\text{rms}}$ Trends on Core
Mach 0.90; 0/90/180/270 deg azimuths

SLS-10005 Core
0/90/180/270 deg
Bandpass 0.5–60Hz

Vehicle Station

Vehicle Station
$\Delta C_{p,\text{rms}}$ Trends on LSRB
Mach 0.90; 45/135/225/315 deg azimuths
$\Delta C_{p,\text{rms}}$ Trends on Core
Mach 0.90; 0/90/180/270 deg azimuths
$ΔC_{p,\text{rms}}$ Trends on LSRB
Mach 0.90; 45/135/225/315 deg azimuths

Canted straight and bi-conic results in increase on outboard booster
Space Launch System buffet test program development and project history has been presented.

Significant buffet model design characteristics which impact data quality have been discussed.

Comparisons of buffet environments made between various model configurations:
- Buffet environments defined for the SLS-10003 Orion, SLS-11000 Cargo, and SLS-13000 Orion configurations.
- High buffet environments observed in vicinity downstream of booster forward attachment.
- Buffet environments shown to be reduced with detailed forward attachment protuberance.
- Fence buffet mitigation options (BMOs) shown to be effective at reducing buffet environments:
  - Core fences slightly more effective.
- Nose cone BMOs shown to also be effective at reducing environments:
  - Canted ogive is slightly more effective.
2012 SLS Buffet Test

♦ Buffet Sensors (360 + 6 accels)
  • NEFF 730 A/D
  • 12 KHz scan rate
  • 4.5 KHz anti-alias filter

♦ Aeroacoustic Sensors (64)
  • DSPCon Piranha III A/D
  • 100 KHz scan rate
  • Anti-alias filter at 50 KHz

2014 SLS Buffet Test

♦ Buffet Sensors (472 + 6 accels)
  • Precision Filter 28000 + National Instruments PXI
  • 16 KHz scan rate
  • 6 KHz anti-alias filter

♦ Aeroacoustic Sensors (32)
  • Precision Filter 28000 + National Instruments PXI
  • 200 KHz scan rate
  • Anti-alias filter at 60 KHz
Buffet Kulite Installation: Sensor is sealed into hole with RTV

\[ F_{\text{Cavity}} = 15.9 \text{ KHz} \]

Aeroacoustic Kulite Installation: Precision insert and hand-worked to OML

\[ F_{\text{Cavity}} = 19.8 \text{ KHz} \]

Transducer Frequency Response In-Situ Testing