Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing **September 2010 Newsletter**

Cue the Sun

This month's newsletter continues with the space exploration theme.

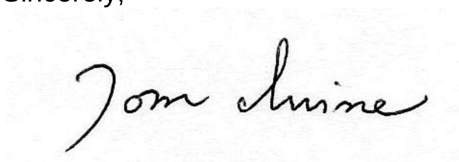
The Orion spacecraft is being designed to carry four to six astronauts. The Launch Abort System is mounted atop the Orion. This system underwent an unmanned test flight last May at White Sands, New Mexico.

The plume from the four abort motor nozzles impinged on the adapter cone, driving the sound pressure levels up to 170 dB in this zone. A number of other interesting vibroacoustic effects occurred including a prolong abort motor tail-off pressure oscillation with a frequency of 685 Hz. These effects are given in the first article.

Note that the Orion spacecraft is being designed for the Ares I launch vehicle. The U.S. Senate, House, and the presidential administration are still debating the future of the Ares I vehicle, the Orion spacecraft and the manned space program.

The second article presents the Space Shuttle Twang oscillation which occurs at liftoff. Enjoy.

Sincerely,



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Feature Articles

Orion Launch Abort System PA-1 Test by Tom Irvine

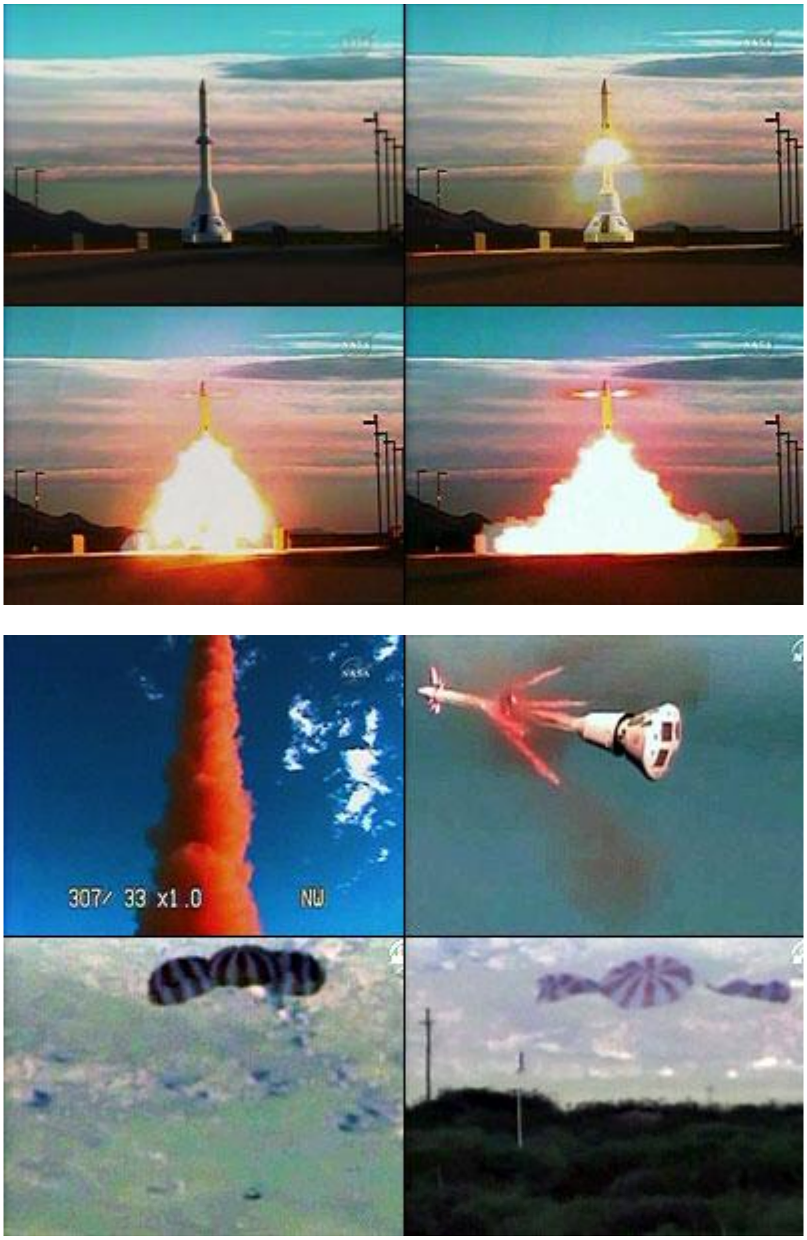

Figure 1. Pad Abort Test 1, Unmanned

<u>Introduction</u>

The purpose of the Launch Abort System (LAS) is to pull the Orion Crew Module and its astronauts safely away from the launch vehicle in the event of an emergency on the launch pad or during ascent.

An unmanned test of this system was performed at White Sands Missile Range, New Mexico, on May 6, 2010, as shown in Figure 1. The image in the right column, third from the top, shows the elongated exhaust plumes from the four abort motor nozzles, as well as the small plumes from the eight nozzles of the Attitude Control Motor (ACM).

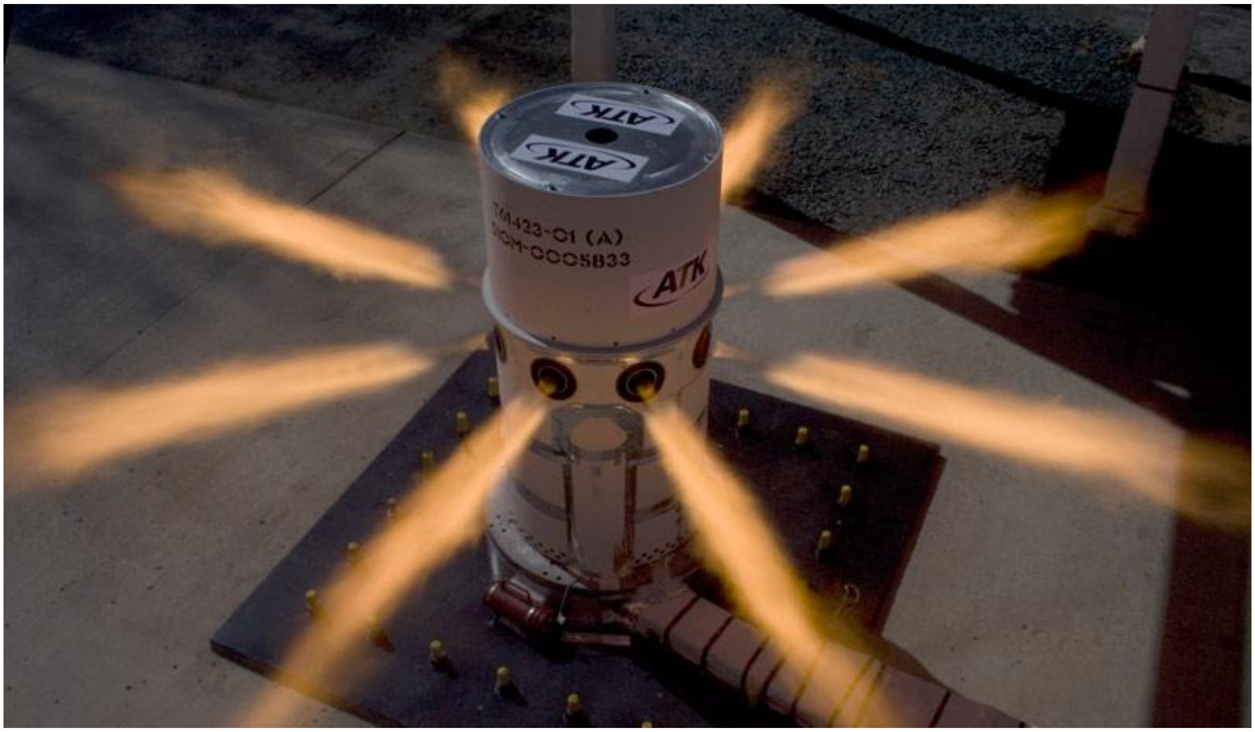

Figure 2. Ground Static Fire Test of the Attitude Control Motor

Microphones and accelerometers were mounted in the LAS for the pad abort test. The purpose of this article is to present the some flight data from these sensors and to provide interpretation. Note that the test vehicle may have had a different Outer Mode Line (OML) than that which would be used for an actual flight vehicle. Nevertheless, the test flight data provides a useful reference.

<u>Animations and Actual Video Footage</u>

The following videos provide an excellent visual reference of the test flight.

http://www.youtube.com/watch?v=cd--3KgoUzo&NR=1

http://www.youtube.com/watch?v=c2GLaRZGyJQ&feature=related

http://www.youtube.com/watch?v=5lK9kkMP5yE&feature=related

Pad Abort 1 Test Configuration

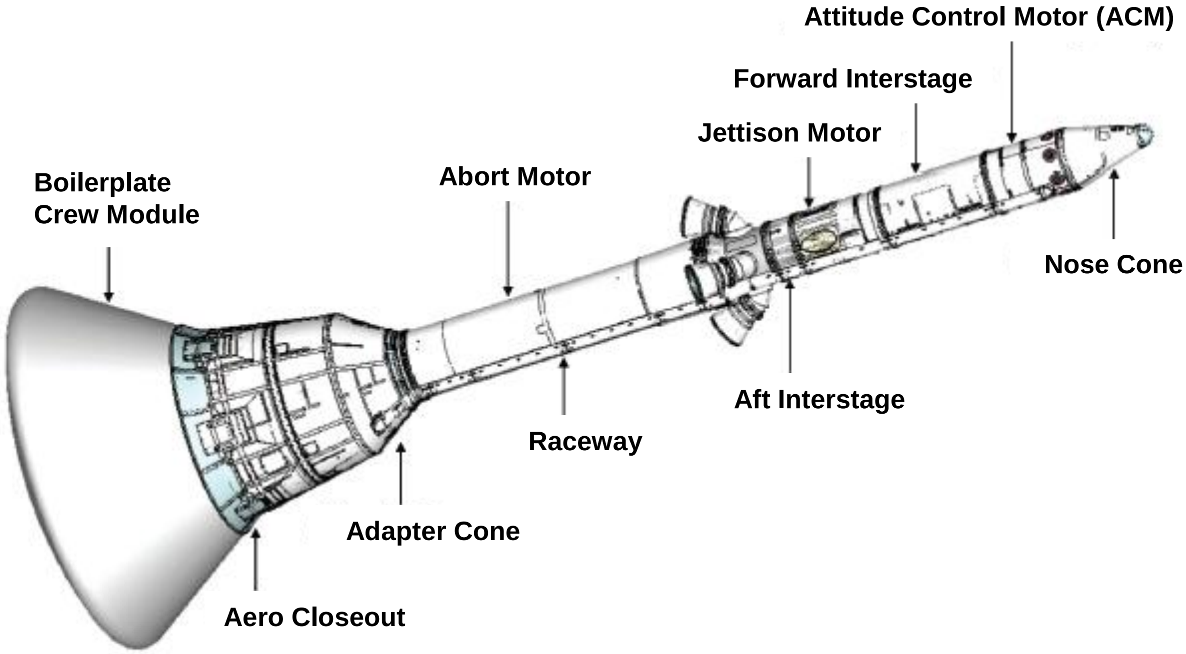

Figure 3. Launch Abort System and Crew Module

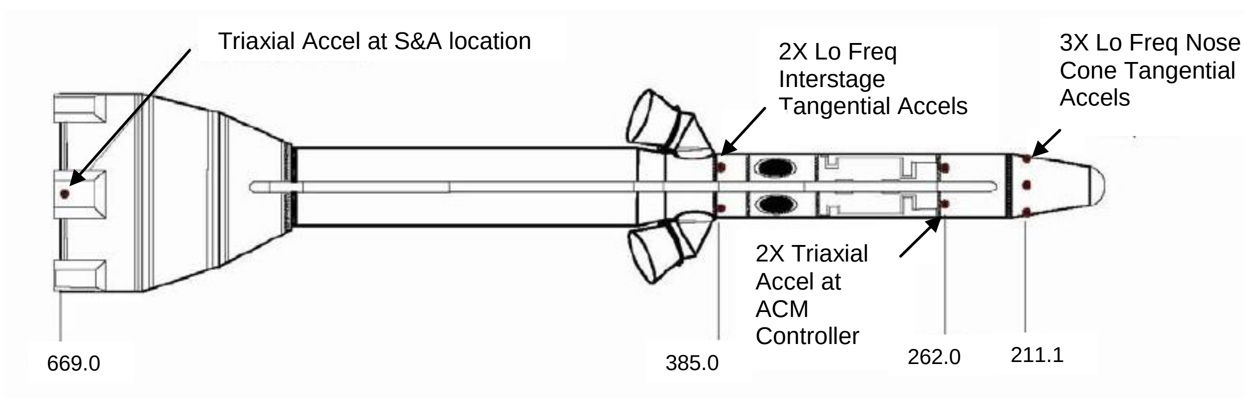

Figure 4. Accelerometer Locations

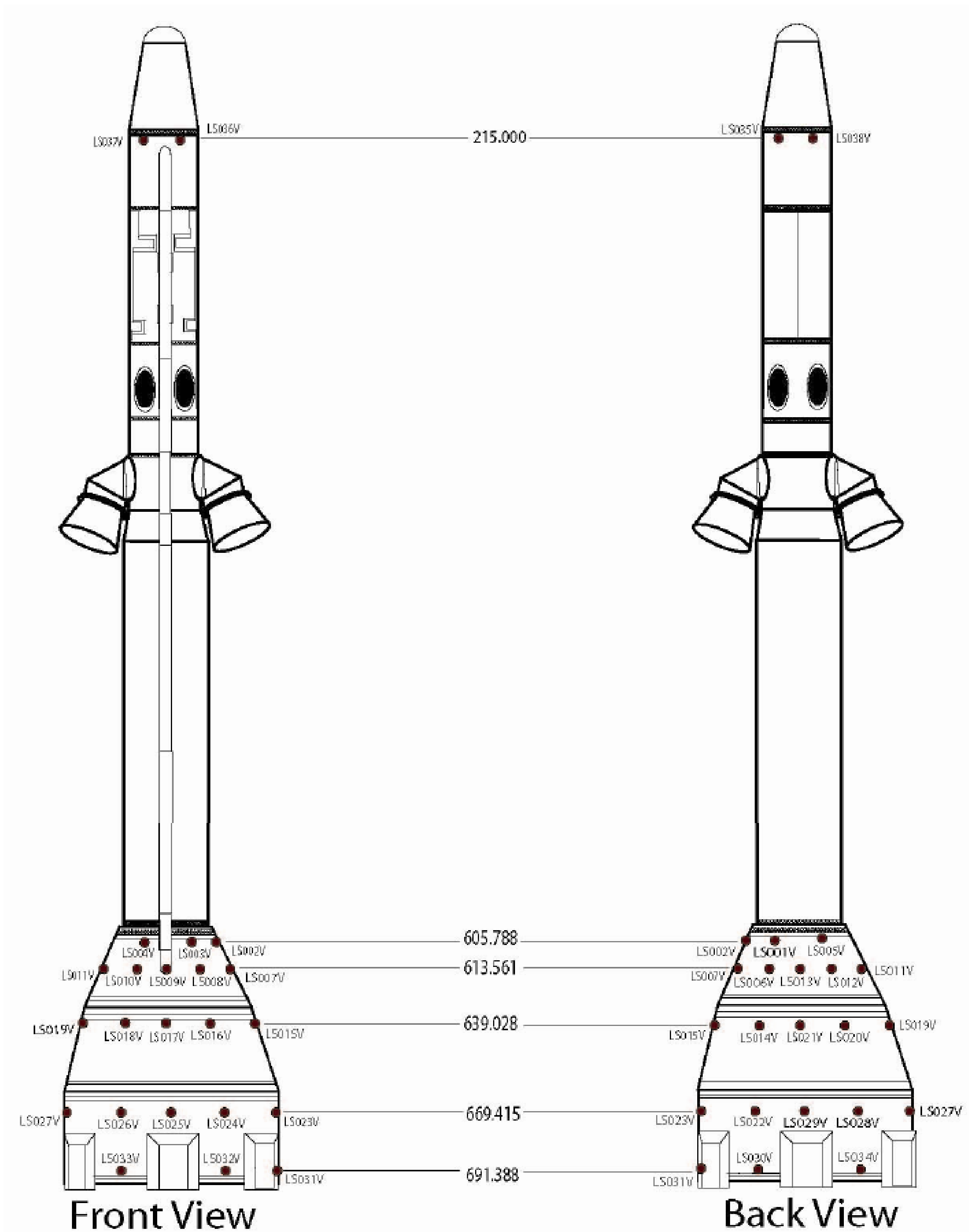

Figure 5. Microphone Locations

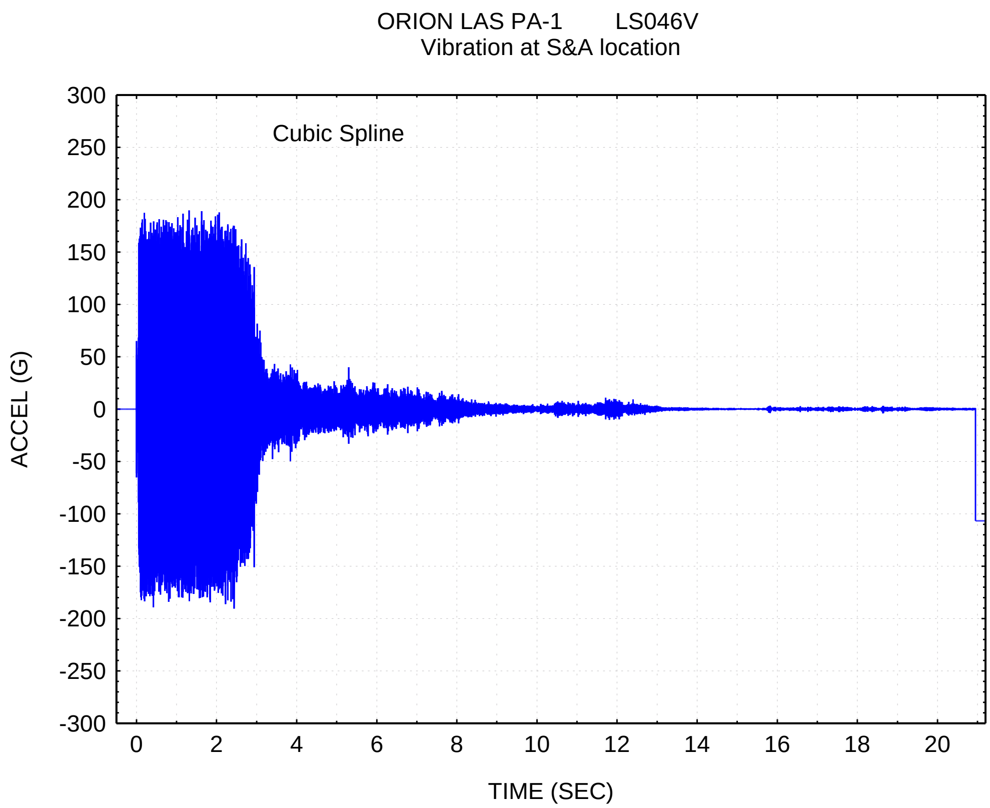

Figure 6.

The time history in Figure 6 shows that the instantaneous time history could have reached nearly 190 G.

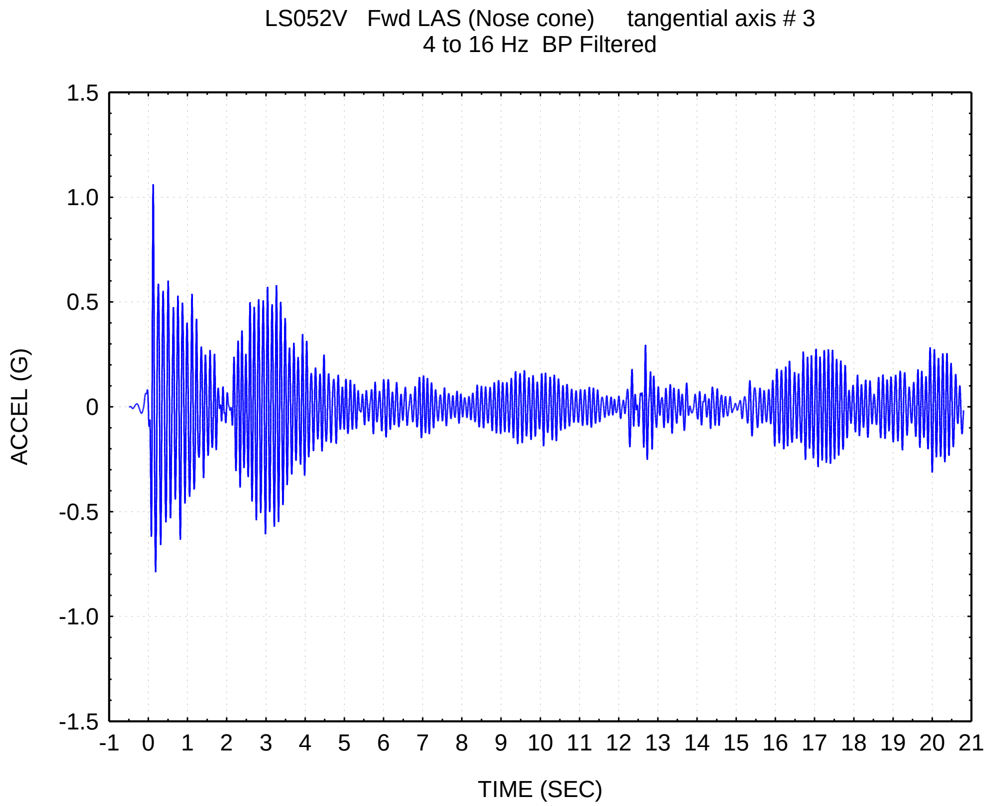

Figure 7.

The acceleration data is bandpass filtered to focus on the fundamental body-bending mode.

The mode was driven by an offset of the abort motor thrust vector from the centerline and by the ACM thrust vectoring and maneuvers.

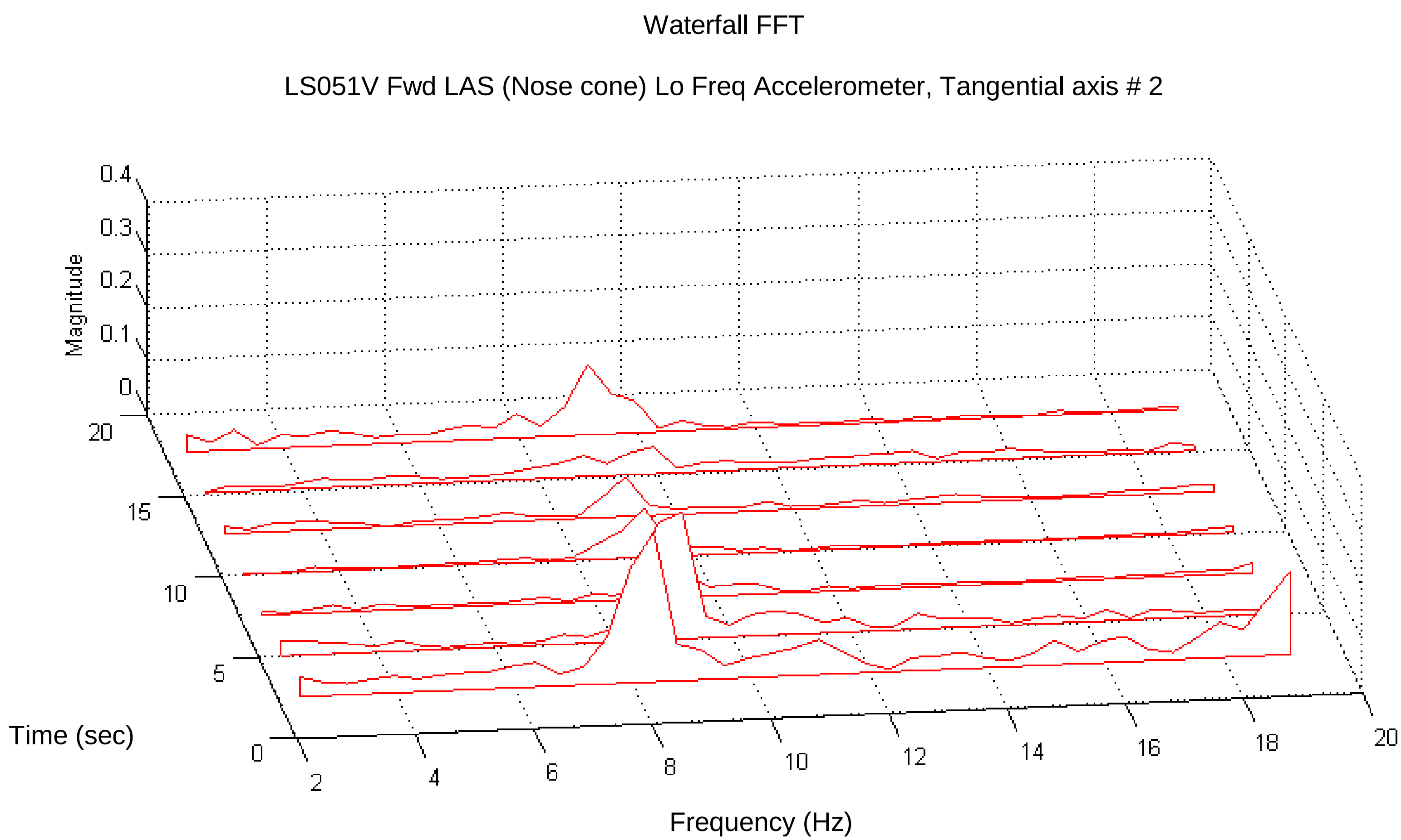

Figure 8.

The fundamental body-bending frequency begins near 8 Hz and gradually increases over time due to the decrease in propellant mass.

Waterfall FFT   Vibration at S&A Location   LS045V

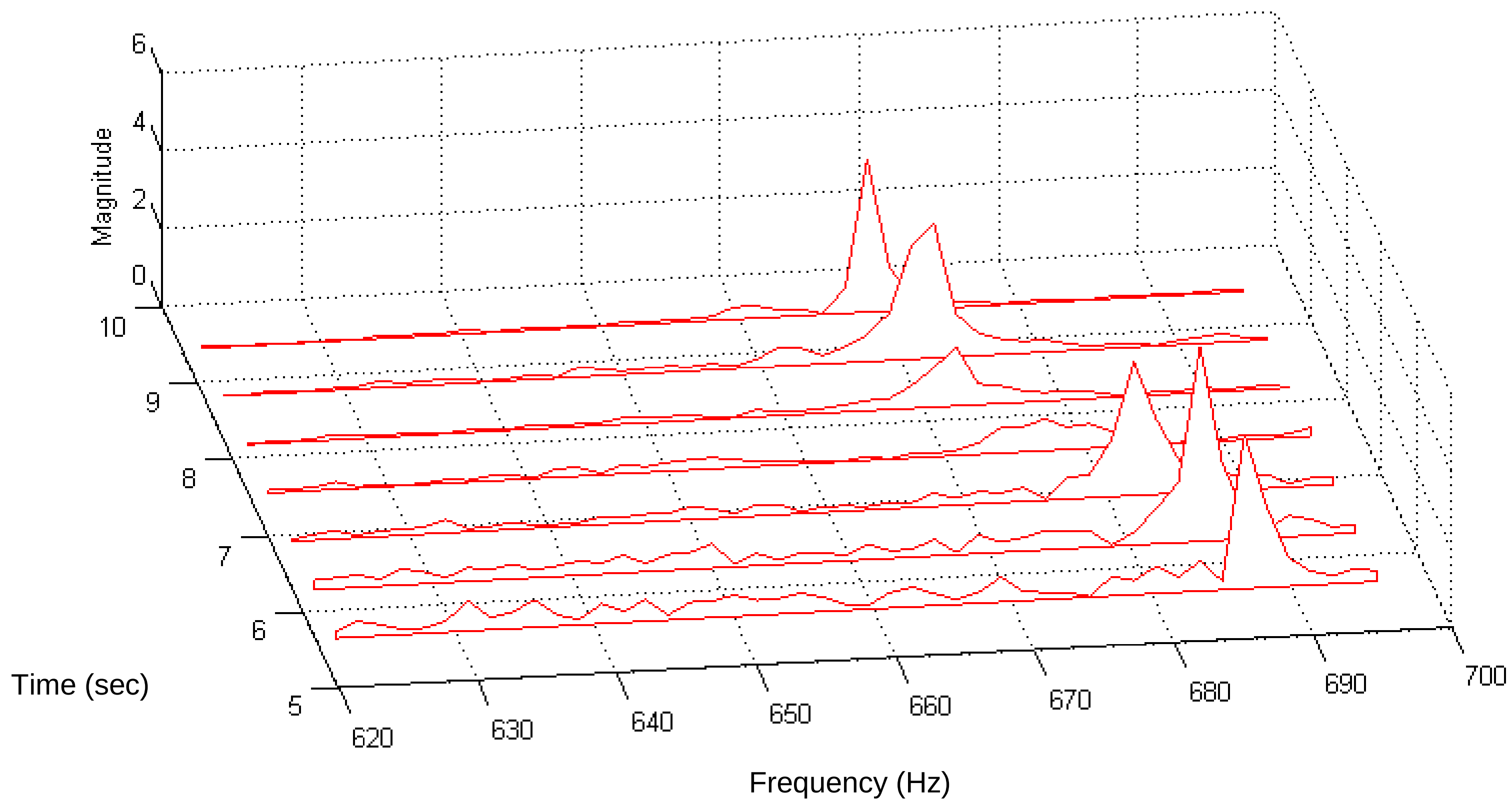

Figure 9.

The abort motor had an oscillation which swept downward in frequency from 685 to 670 Hz during the tail-off. This resonance is considered to be a phenomenon of the low pressure end of burn gas dynamics of the reverse flow motor.

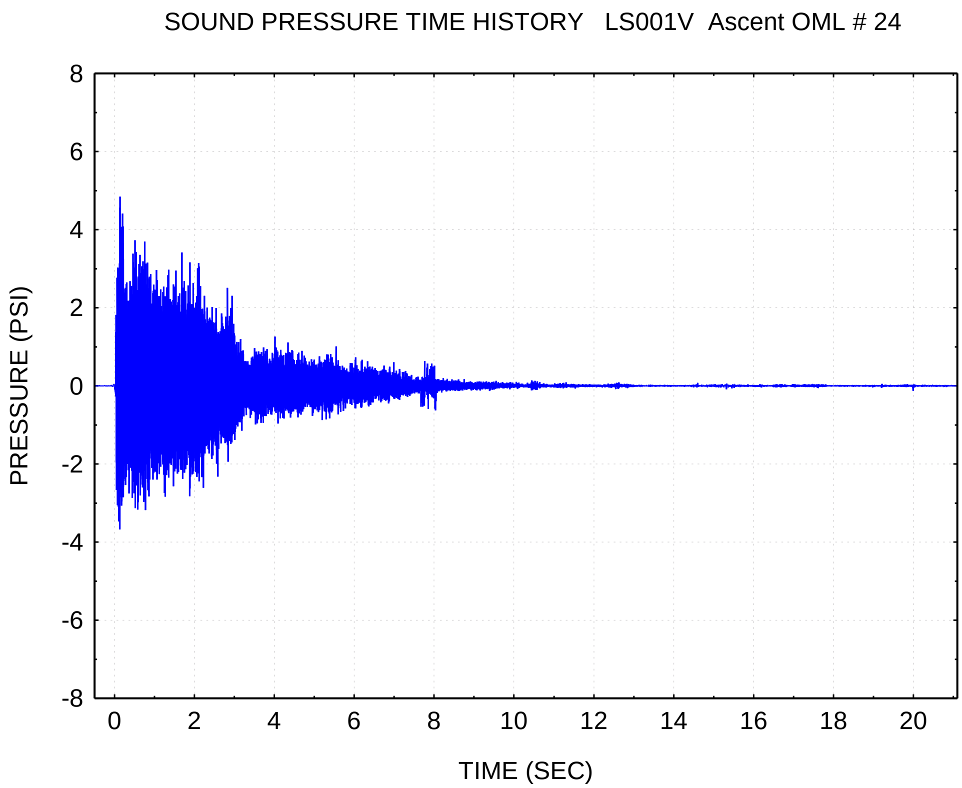

Figure 10.

The adapter cone connects the aft end of the launch abort system to the crew module.

The time histories are somewhat uniform. The peak acoustic excitation for these locations usually occurred during the first one-second interval due to combined liftoff acoustics and plume impingement effects.

The levels remained high during the 3-second abort motor burn, driven by plume impingement. There was some lingering excitation during the tail-off from 3 to 10 seconds. Thereafter, the levels were relatively benign.

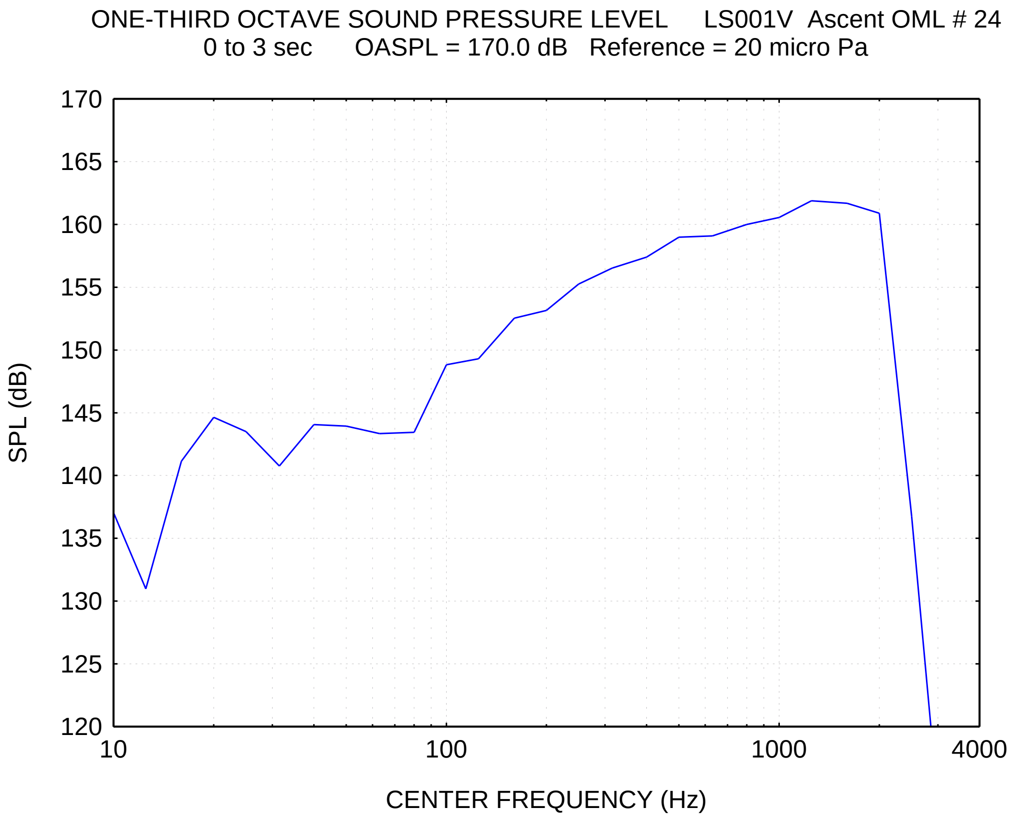

Figure 11.

The sound pressure levels for the adapter cone microphones ranged from 169.4 to 171.4 dB. The levels were taken over a duration of zero to 3 seconds, which corresponds to the abort motor burn.

The peak excitation occurred over the domain from 1000 to 2000 Hz.

Note that the overall levels would have been higher if the instrumentation had been set to measure up to 20 KHz.

Space Shuttle Twang by Tom Irvine

Figure 1. Space Shuttle Liftoff

The Space Shuttle propulsion system generates about 188 dB on the launch platform. A water suppression system is used to attenuate the resulting acoustic environment, creating billowing clouds of steam.

Introduction

The Space Shuttle has three main engines (SSMEs) which are started at T minus 6.6 seconds.

The main engines ignite at 120 milliseconds intervals per a programmed sequence. The Shuttle's flight computers require that the engines reach 90% of their rated performance to complete the final gimbal of the main engine nozzles to liftoff configuration.

Note that the Shuttle has multiple computers for redundancy.

All three SSMEs must reach the required 100% thrust within three seconds to prevent an abort. Otherwise, the engines are shutdown.

If the thrust criterion is met, then the eight pyrotechnic nuts holding the vehicle to the pad are detonated. There are two interfaces between the vehicle and the pad, located at the aft end of each solid rocket booster (SRB). Each interface has four hold-down posts.

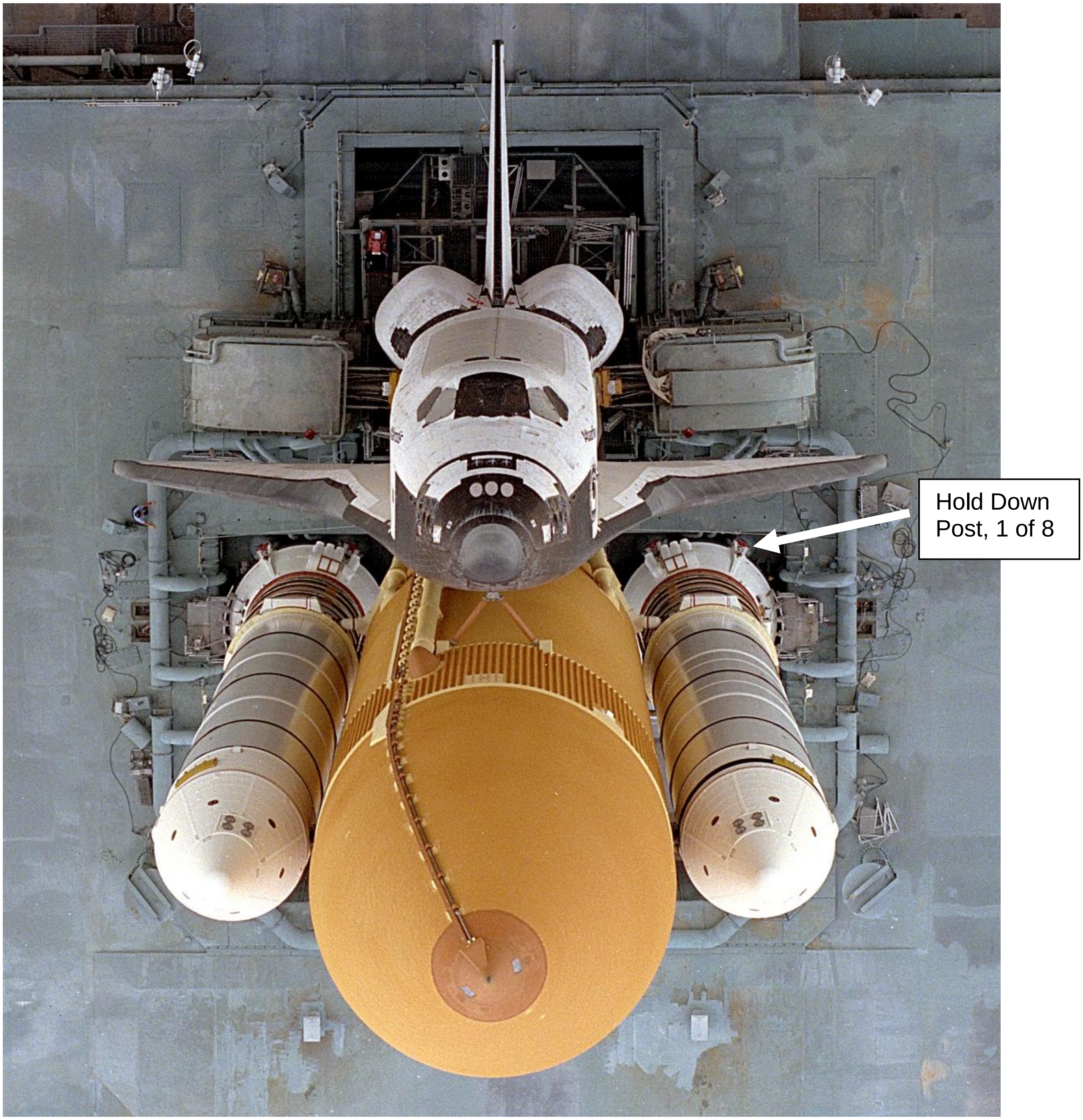

Figure 2. Space Shuttle Atlantis (STS-79) Atop the Mobile Launcher Platform (MLP) and Crawler-Transporter 1996.

Then the two solid rocket boosters are ignited. The boosters go to full power in two-tenths of a second. The Shuttle lifts off from the pad.

Note that the solid boosters cannot be shut down after ignition. Thus, the vehicle is committed to launch once the boosters are ignited.

Twang Event

The Space Shuttle stack consists of the boosters, external tank and the orbiter. The orbiter's SSMEs are offset from the vehicle stack's center of gravity.

The offset thrust from the Shuttle's three main engines causes the entire launch stack to pitch down about 2 meters at cockpit level, after the main engines start, but while the solid rocket boosters are still clamped to the pad.

This motion is called the "twang."

The boosters then flex back into their original shape due to internal stiffness forces. The launch stack pitches slowly back upright. This back-and-forth motion takes approximately six seconds.

At the point when the vehicle stack is perfectly vertical again, the hold-down post pyrotechnic nuts are ignited, the boosters ignite and the vehicle lifts off the pad.

The twang is shown in the following video:

http://www.youtube.com/watch?v=xmLeGBIj6kw

Ascent

The Shuttle clears the tower and begins a combined roll, pitch and yaw maneuver that positions the orbiter head down, with wings level and aligned with the launch pad.

The Shuttle flies upside down during the ascent phase. This orientation allows an angle of attack that is favorable for aerodynamic loads during the region of high dynamic pressure. This maneuver results in a net positive load factor, as well as providing the flight crew with use of the ground as a visual reference.

The vehicle climbs in a progressively flattening arc, accelerating as the weight of the SRBs and main tank decrease. More horizontal than vertical acceleration is required to achieve low orbit. This is not visually obvious, since the vehicle rises vertically and is out of sight for most of the horizontal acceleration.

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Figure 3. Space Shuttle Flight Profile, courtesy of Wikipedia

The vehicle then reaches its maximum dynamic pressure condition, or Max Q, where the aerodynamic forces are at their maximum. The SSMEs are temporarily throttled back to 65% to avoid overspeeding, which would overstress the engines and vulnerable structures such as the wings.

At *T*+70 seconds, the main engines throttle up to their maximum cruise thrust of 104% rated thrust.

The SRBs are released at *T*+126 seconds after launch, via explosive bolts. The SRBs parachute back to the ocean to be reused.

The main engines are throttled down at *T*+7.7 minutes to keep the acceleration below 3 G so that the vehicle is not overstressed.

The SSMEs are shut down at *T*+8.5 minutes, at which point the Space Shuttle achieves initial orbit.

The external tank is jettisoned at *T*+9 minutes. It burns up upon re-entry into the atmosphere.

The Shuttle’s Orbital Maneuvering System (OMS) engines are fired for the final orbital insertion.

The orbital altitude above the Earth is between 200 and 385 miles, depending on mission requirements.

The orbital speed is about 17,500 miles per hour.