ATK Launch Vehicle (ALV-X1) Liftoff Acoustic Environments: Prediction vs. Measurement

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The ATK Launch Vehicle (ALV-X1) provided an opportunity to measure liftoff acoustic noise data. NASA Marshall Space Flight Center (MSFC) engineers were interested in the ALV-X1 launch because the First Stage motor and launch pad conditions, including a relativity short deflector ducting, provide a potential analogue to future Ares I launches.

This paper presents the measured liftoff acoustics on the vehicle and tower. Those measured results are compared to predictions based upon the method described in NASA SP-8072 "Acoustic Loads Generated by the Propulsion System" and the Vehicle Acoustic Environment Prediction Program (VAEPP) which was developed by MSFC acoustics engineers. One-third octave band sound pressure levels will be presented. This data is useful for the ALV-X1 in validating the pre-launch environments and loads predictions. Additionally, the ALV-X1 liftoff data can be scaled to define liftoff environments for the NASA Constellation program Ares vehicles.

Vehicle liftoff noise is caused by the supersonic jet flow interaction with surrounding atmosphere or more simply, jet noise. As the vehicle's First Stage motor is ignited, an acoustic noise field is generated by the exhaust. This noise field persists due to the supersonic jet noise and reflections from the launch pad and tower, then changes as the vehicle begins to liftoff from the launch pad. Depending on launch pad and adjacent tower configurations, the liftoff noise is generally very high near the nozzle exit and decreases rapidly away from the nozzle. The liftoff acoustic time range of interest is

typically 0 to 20 seconds after ignition. The exhaust plume thermo-fluid mechanics generates sound at ~10 Hz to 20 kHz. Liftoff acoustic noise is usually the most severe dynamic environment for a launch vehicle or payload in the mid to high frequency range (~ 50 to 2000 Hz).

This noise environment can induce high-level vibrations along the external surfaces of the vehicle and surrounding launch facility structures. The acoustic pressure fluctuations will induce severe vibrations in relatively large lightweight structures. Consequently, there is the potential for failure of the structure or attached electrical components. Due to these potential failures, the liftoff acoustic noise is one of the noise source inputs used to determine the vibro-acoustic qualification environment for a launch vehicle and its components.

Predicted liftoff acoustic environments were developed by both NASA MSFC and ATK engineers. ATK engineers developed predictions for use in determining vibro-acoustic loads using the method described in the monograph NASA SP-8072. The MSFC ALV-X1 liftoff acoustic prediction was made with the VAEPP. The VAEPP and SP-8072 methods predict acoustic pressures of rocket systems generally scaled to existing rocket motor data based upon designed motor or engine characteristics. The predicted acoustic pressures are sound-pressure spectra at specific positions on the vehicle.

The ALV-X1 launched from the Mid-Atlantic Regional Spaceport (MARS) Pad 01B on August 22, 2008. The MARS Pad 01B consists of a launch mount approximately 33 ft in height, with an open J-deflector. There is no water sound suppression. Adjacent to Pad 01B is an open frame launch tower.   This launch configuration provided an opportunity to acquire liftoff acoustic data from a solid motor in a J-deflector at the baseline worst case (i.e. with no sound suppression).

The liftoff noise was measured by multiple sensors. An Endevco 8510-B pressure transducer was installed on the ALV-X1 at a location ~37 ft above the nozzle exit plane and oriented horizontally at 20 degrees azimuth from the J ducted exhaust flow. The pressure transducer was functional during the liftoff event. The flight pressure transducer was acquired at 5,000 samples per second (sps).   Additionally, four PCB106B5 ICP microphones were installed on the Pad 01B tower at 33, 53, 78 and 88 ft above ground (referred to as G1, G2, G3 and G4 respectively). The tower mounted microphone data were acquired at 51,200 sps. Figure 1 shows the relative position of the tower sensor locations to the vehicle sensor location.
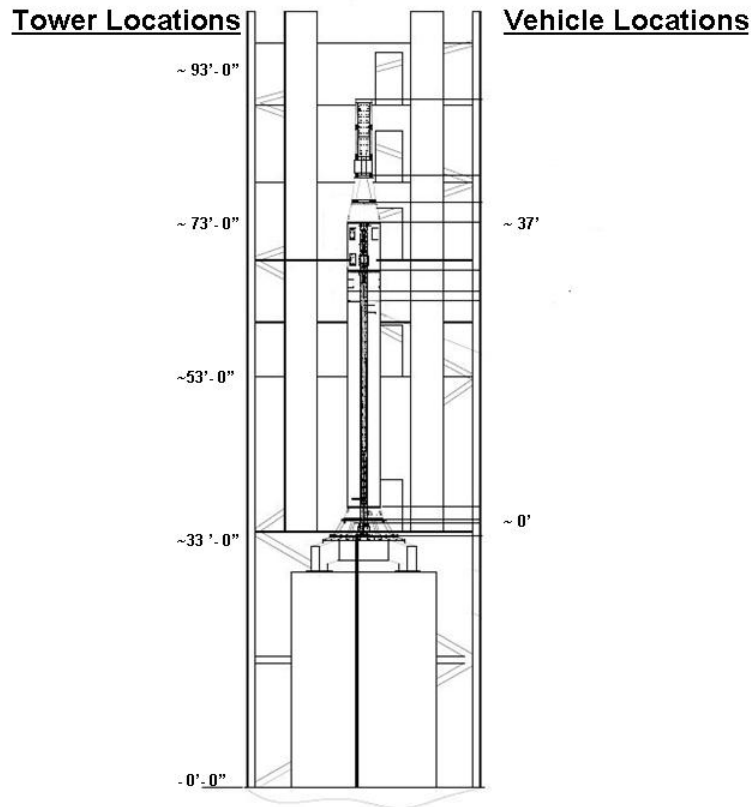
Figure 1. Relative locations of the tower sensors to the vehicle sensor.

The vehicle measurement validates the VAEPP prediction method. Figure 2 shows one-third octave and overall sound pressure levels comparisons between the VAEPP method and the ALV-X1 measured data. No corrections have been applied to the measured data. Various time windows were chosen within the liftoff data and all the analyzed results are shown. There is very good comparison in terms of the overall sound pressure levels (OASPLs) and the shape of the spectra. However, the VAEPP method, with no margin, is not conservative.
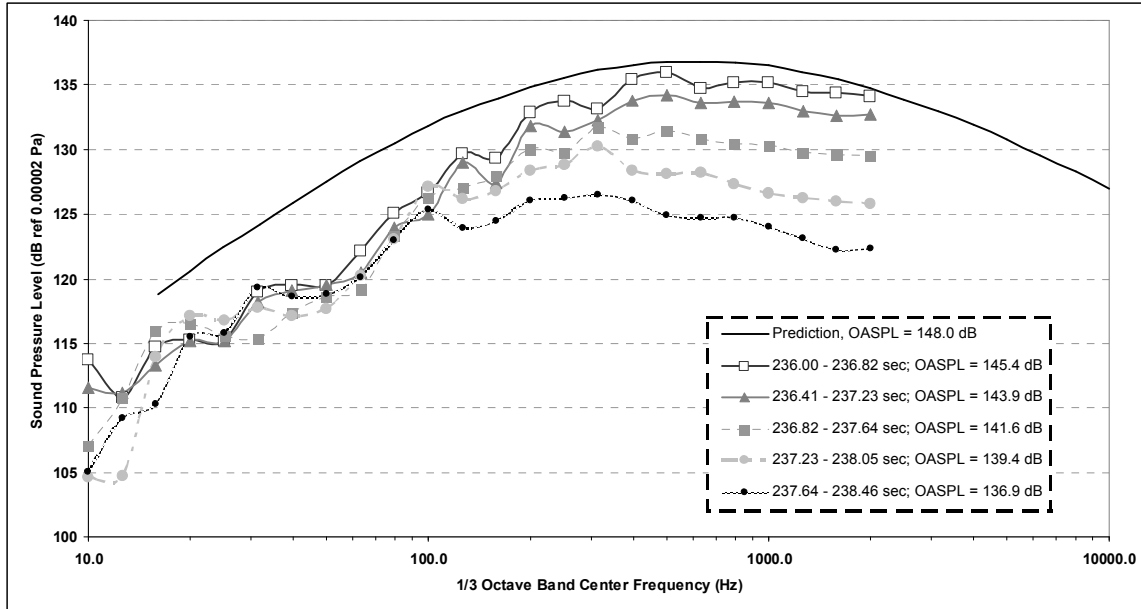
Figure 2. One-third octave and overall sound pressure level comparisons between the VAEPP method and the ALV-X1 measured data.

For the tower measurements, an individual time slice was chosen in which the root-mean-square pressure versus time exhibits a 3 dB roll-off from the peak pressure value. This method allows for a consistent process for each measurement with the goal being to compare the maximum OASPLs. The one-third octave bands are averaged in one-second intervals. The one-third octave bands and overall sound pressure levels are shown in Figure 3. No corrections have been applied to the measured data. There is a 3 dB difference between the four tower measurements, with the lowest overall sound pressure level of 156.9 dB measured at G1, the location nearest the nozzle exit plane, and the highest overall sound pressure level measured of 159.6 dB at G4. It is interesting to note that the OASPLs of the tower measurements are significantly higher, ~ 11 dB, than the vehicle OASPL.
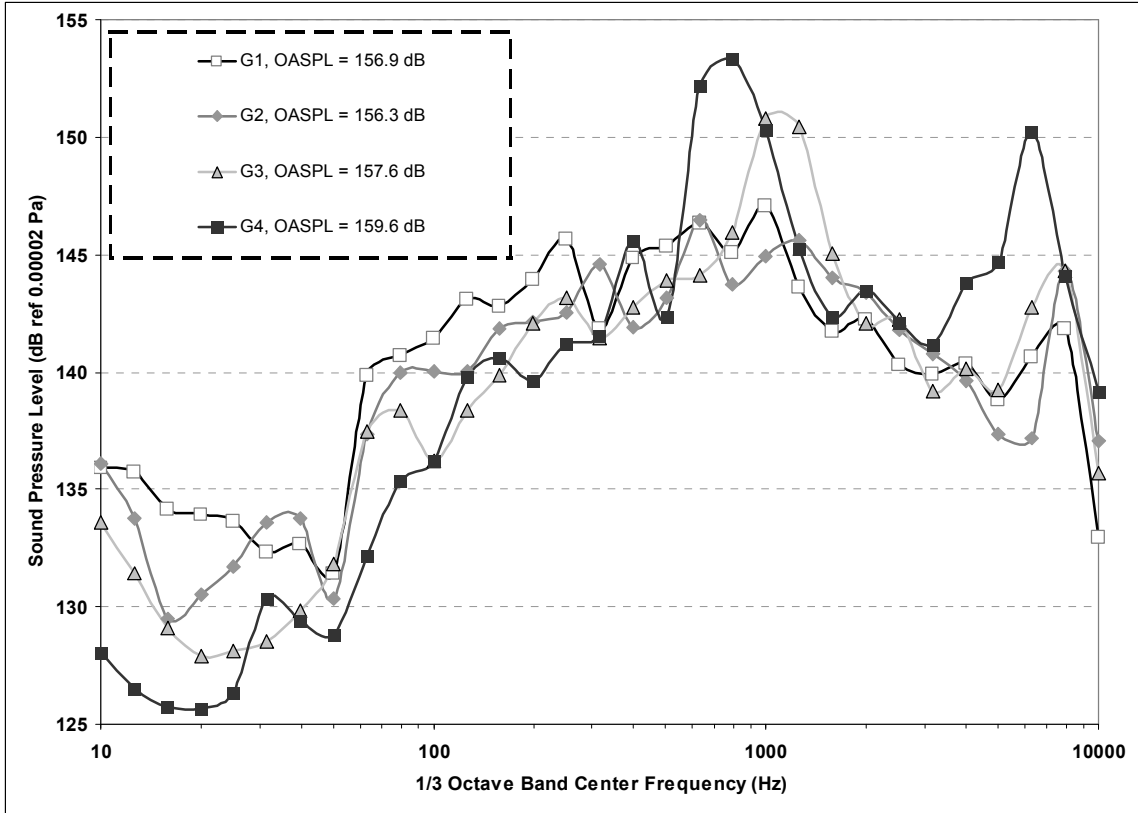
Figure 3. One-third octave and overall sound pressure level comparisons for the tower sensors.