Background

The SonicBoom/BM project (Sonic Boom Resistant Earthquake Warning System) is a collaborative effort between Seismic Warning Systems, Inc. and NASA Dryden Flight Research Center. This project aims to evaluate the effects of sonic booms on Earthquake Warning Systems in order to prevent such systems from experiencing false alarms due to sonic booms. The area above the Antelope Valley, California includes the High Altitude Supersonic Corridor and the Black Mountain Supersonic Corridor. These corridors are among the few places in the US where supersonic flight is permitted, and sonic booms are common in the region.

NASA conducts regular supersonic flight experiments in the vicinity of Edwards Air Force Base, and accelerometers were positioned to record during these three experiments. The first, Sonic Booms on Big Structures (SonicBOBS), took place in the fall of 2010. This experiment generated 60 distinct sonic booms that were recorded in and around the Consolidated Facilities Area, large building at Edwards AFB. The second, the Superboom Caustic Analysis and Measurement Project (SCAMP) occurred in May 2011 near Cuddeback Dry Lake in the Mojave Desert. This experiment generated 70 sonic booms, of which 37 were recorded by accelerometers. Finally, in October 2011 five sonic booms were recorded at Building 4800 on the NASA Dryden campus as part of the Waveform and Signal Processing and Response (WSPR) experiment. In all, 24 distinct sonic booms have been recorded to date, with at least 15 from these dedicated SonicBoom/BM flights anticipated in the future.

High Quality Observations of Sonic Booms

Surface Response to Pressure Wave

Sonic booms from space shuttle re-entry are readily detectable on modern seismometers [Kanamori et al., 1991; Sorrells et al., 2002]. The figure on the right shows a record of a space boom from May 17 at Edwards AFB. The trace above is a microphone at the free field, and the green trace is the vertical displacement from nearby CISN station EDW2. The displacement is integrated from velocity and inverted to overlay with the microphone record. The sonic boom phase, however, has a characteristic shape which is easily discernible in displacement when integrated from velocity.

The figure on the right shows a sonic boom recorded on the SCAMP array. Again the blue trace is a microphone record. The green trace is recorded by an accelerometer resting on the desert surface. The record has to be digitally integrated to arrive at displacement, and this process reduces the fidelity of the ground motion record. As a result the seismic record does not mirror the microphone record as closely when recorded on a velocity sensor.

Implications for Earthquake Warning Systems

Seismic Warning Systems and NASA Dryden intend to collaborate on establishing a regional Earthquake Warning System (EWS) for the Antelope Valley. The map above outlines the proposed deployment. Red triangles represent potential instrument sites, and the smaller black triangles represent the public schools in the region as well as several government properties which would be protected by the regional system.

Because of the nature of flight activities in the Antelope Valley, the proposed EWS needs to be protected against false positives due to sonic booms. Part of the purpose of these tests is to determine whether the booms produce ground-motion comparable to an EWS from an earthquake of significant size. To determine this, we integrate the acceleration record to velocity and take the ratio from Wurman et al. [2005] for magnitude a function of peak velocity.

\[ M = 1.63 \log_{10}(PGV) + 4.40 \log_{10}(R) + 1.65 \]

where \( M \) is the apparent distance. We set this distance to 10 km as a reference to determine if an EWS system based on peak displacement algorithms can be spoofed by a sonic boom under realistic conditions. We find that sonic booms approaching 10 psf of overpressure can generate ground motions comparable to an M 3 at 10 km distance. However, a 10 psf boom is fairly extreme; the typical overpressure from the re-entry of the space shuttle was less than about 1.5 psf [Sorrells et al., 2002]. This value corresponds to slightly less than an M 5 at 10 km.

In addition, we observed during the SonicBoom/BM experiment that sensors positioned inside a building experience significantly attenuated accelerations (blue and red data below). We also note that, due to the high frequency content of the sonic booms, a lower sample rate (200 sps, 1-kHz sample rate) is significant. We use the right side of the graph to attenuate in these levels.

Superboom Caustic Analysis and Measurement Project

The Superboom Caustic Analysis and Measurement Project (SCAMP) is a NASA project designed to characterize the spatial evolution of a sonic boom head wave (or caustic) along a 3 km array of microphones. The experiment was set up near the Guardabosque Dry Lake in the Antelope Valley, beneath the northern edge of the Black Mountain Supersonic Corridor. Over the course of two weeks, NASA T3 research aircraft performed supersonic passes over the array, generating 70 sonic booms in total.

Over the course of this experiment, four high rate accelerometers were deployed in various array configurations. Of the 70 sonic booms generated for the experiment, 60 accelerometers successfully recorded (1 accelerometer was not deployed on all days). One configuration was a monostatic array with 16 in separation between the sensors. Another two were orthomodal arrays with baseline lengths of 38 and 66 in., including broadband of equal depth. In one configuration, each sensor was excited in different conditions; one in a 44 in hole, one in a 36 in hole, a third on the natural desert surface, and the fourth on the concrete foundation of a demolished building. This array produced data on the response of the ground to the sonic boom.

We drilled two boreholes for the SCAMP experiment in an effort to find a depth at which a sensor could be mounted, such that the seismic signature of the sonic boom will be attenuated enough to record. This turned out to be a challenge. As seen in this figure below, using the accelerometers on the bottom of a 36 in hole provides a significant effect on ground accelerations relative to bare ground (green data). In fact, recording from a sensor placed at the bottom of a 44 in hole (blue data) results in amplification of overpressures by around a factor of 5. We suspect this is actually due to pressure wave regressing in the course of the slowness hole. However, we were unable to eliminate the effect by plugging the top of the borehole with foam.

An interesting result is that the sensor resting on the concrete slab (black data) exhibited a factor of 5 lower ground motions than the adjacent bare ground sensor. This is counterintuitive in that we expected the ratio to be roughly equal to 4 and, instead, the signal on the pressure over its entire surface. However, the pressure wave does not cross the entire slab simultaneously, but rather propagates across it over the course of ~60 ms. As a result, we suspect the slab's highly orthotropic axis to attenuate in vertical direction rather than amplifying it.

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Conclusions

We have identified 70 sonic booms with high-rate accelerometers recording up to 1000 samples per second. At least 15 noise booms are scheduled before the conclusion of the project. The dataset includes sonic booms ranging from 0.1 to 10 psf overpressures recorded with various array configurations. These results will help determine the best locations for hardened an Earthquake Warning System against false positives from sonic booms.

References