The Effect of Sonic Booms on Earthquake Warning Systems

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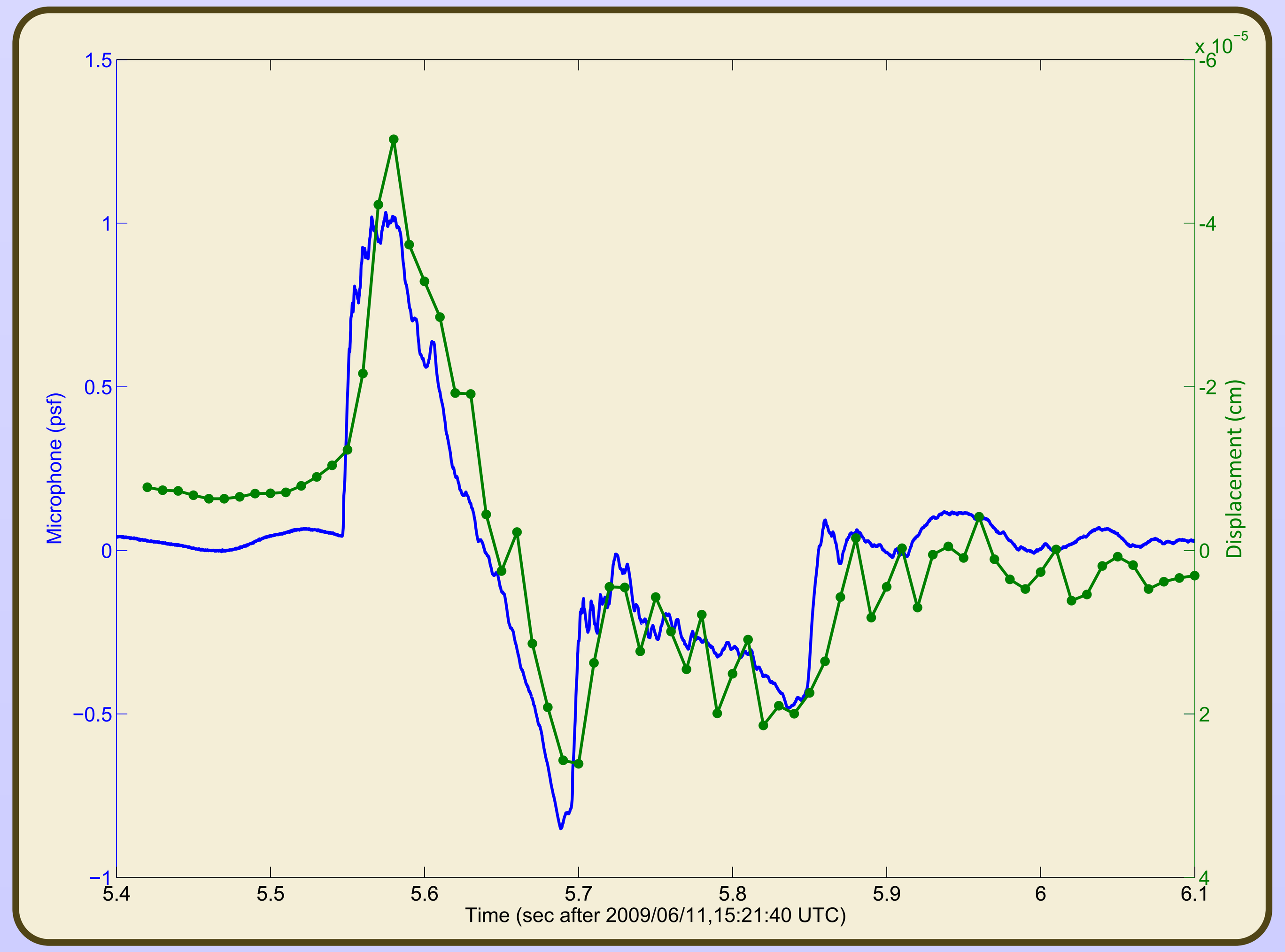
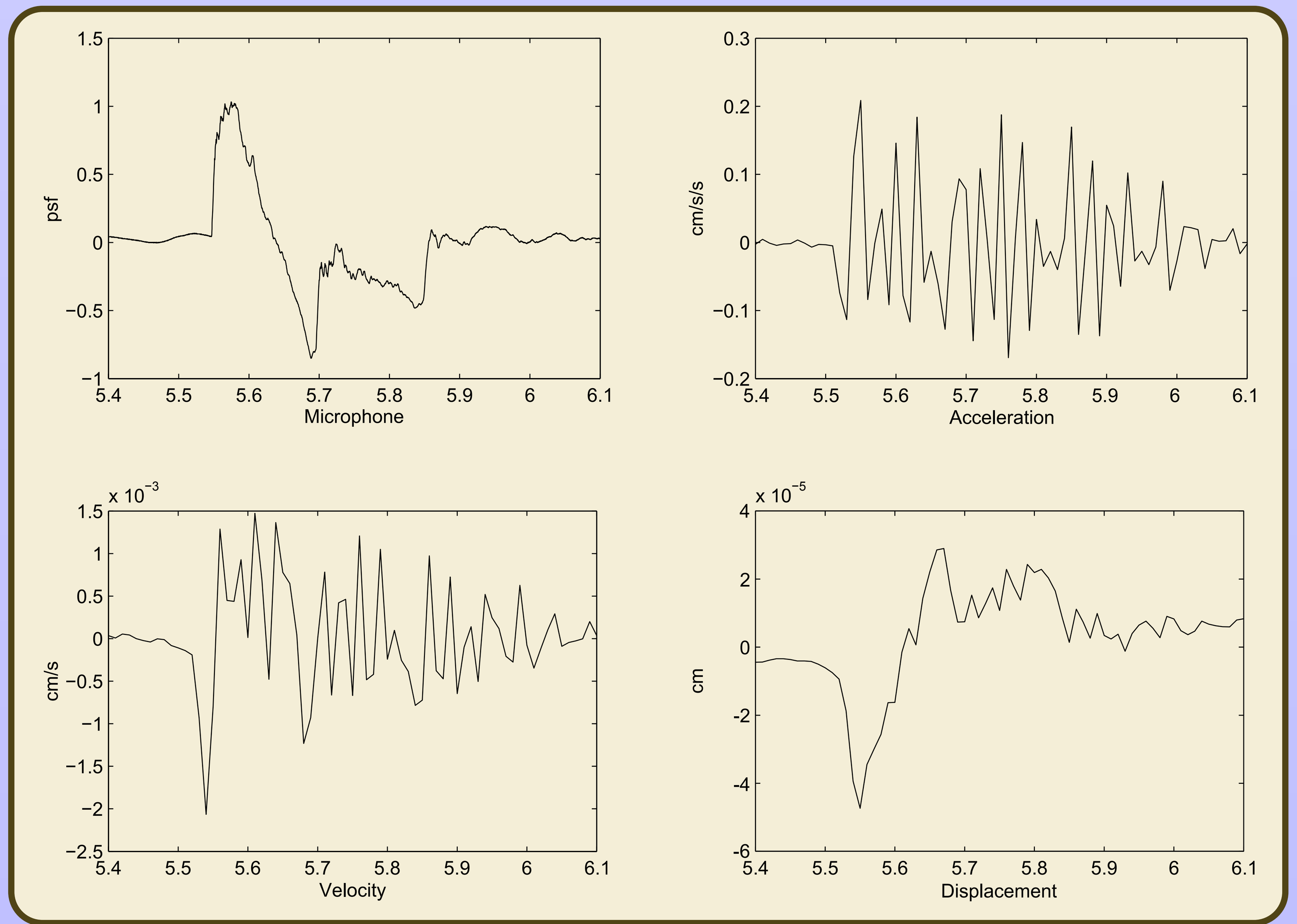
Background

Several aerospace companies are designing quiet supersonic business jets for service over the United States. These aircraft have the potential to increase the occurrence of mild sonic booms across the country. This leads to interest among earthquake warning (EQW) developers and the general seismological community in characterizing the effect of sonic booms on seismic sensors in the field, their potential impact on EQW systems, and means of discriminating their signatures from those of earthquakes. The SonicBREWS project (Sonic Boom Resistant Earthquake Warning Systems) 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 EQW sensors.

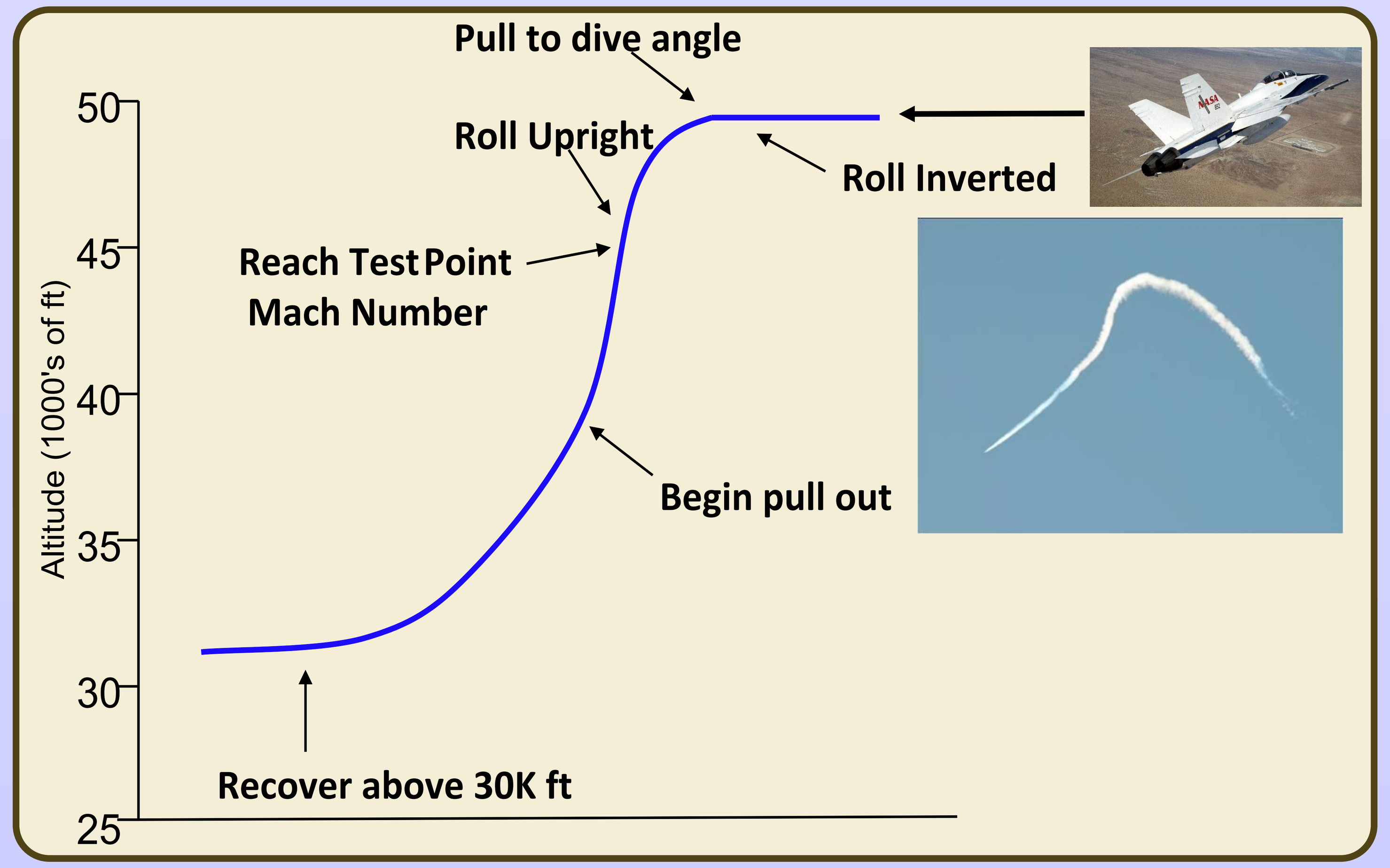


Sonic booms from space shuttle re-entry are readily detectable on modern seismometers [*Kanamori et al.*, 1991; *Sorrell et al.*, 2002]. The figure shows a record of a sonic boom from an F-18 at Edwards AFB. The blue trace is a microphone in the free field, and the green trace is the vertical displacement from nearby CISN station EDW2. The displacement is integrated from velocity and inverted to overlay with the microphone record. The initial sonic boom phase, the N-wave, has a characteristic shape which is easily discernible in displacement, but is far less obvious in velocity or acceleration as in the figures below.

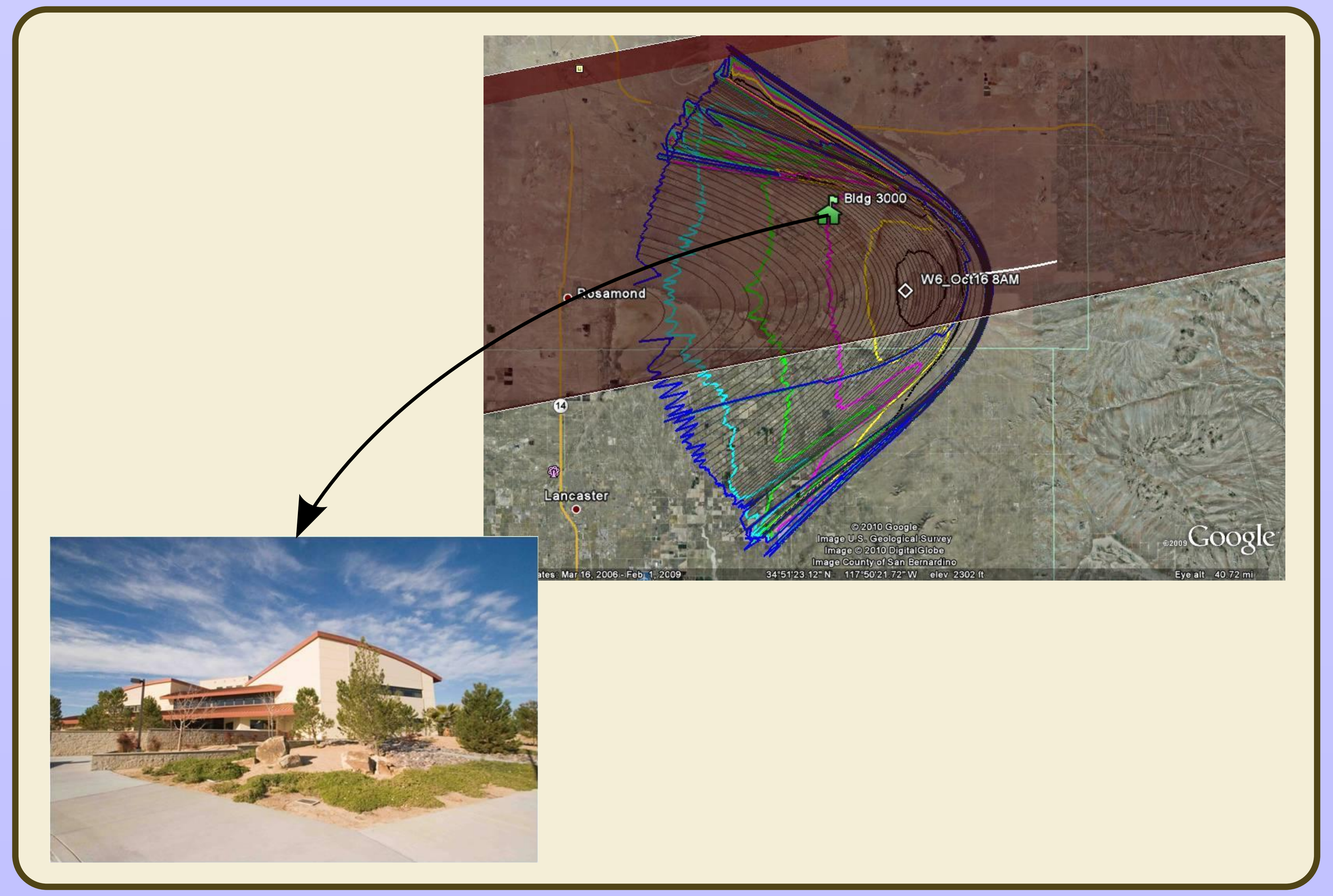


Sonic Booms on Big Structures (SonicBOBS)

Because flight time on NASA's F-18 research aircraft is a limited resource, we took advantage of SonicBOBS, an ongoing NASA study of the perception of sonic booms in large buildings, to gather initial data. We used the F-18s to initiate sonic booms with overpressures ranging from 10 to 50 Pa (0.2 to 1 psf) over Edwards AFB. By comparison, boom overpressures from space shuttle re-entry range from about 30 to 120 Pa [*Garcia et al.*, 1985]. The flight profile, described in the figure below, is designed to mimic the low-amplitude sonic booms expected from future supersonic business jets. By varying the dive point the amplitude of the sonic boom can be carefully controlled.



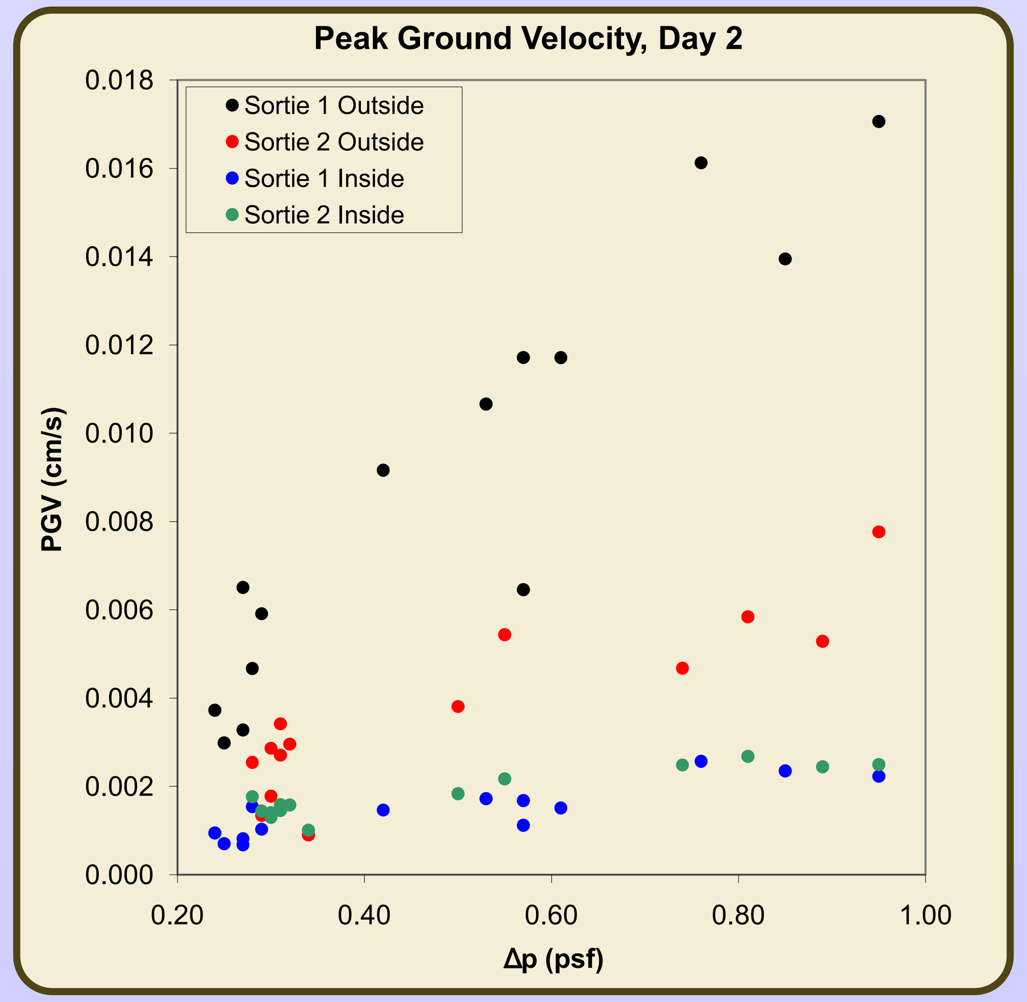
We deployed two Reftek 131A low-noise strong-motion accelerometers recording to a Reftek 130 datalogger. The accelerometers recorded the coupling of the sonic boom to the ground and surrounding structures, while microphones recorded the acoustic wave above ground near the sensor. The sensors were deployed at the Consolidated Services Facility at Edwards AFB. One accelerometer was located on the ground floor near an exterior wall, and another was placed approximately 15 meters outside the building.



The SonicBOBS experiment took place over two days, with one sortie (14 booms) on day 1 and two sorties (28 booms) on day 2. We set the sampling rate to 200 sps on day 1, and noting significant aliasing in the records we increased the rate to 1000 sps (the instrument's limit) for day 2. Due to a cabling problem, only the indoor accelerometer was recording on day 1.

Early Results from SonicBOBS

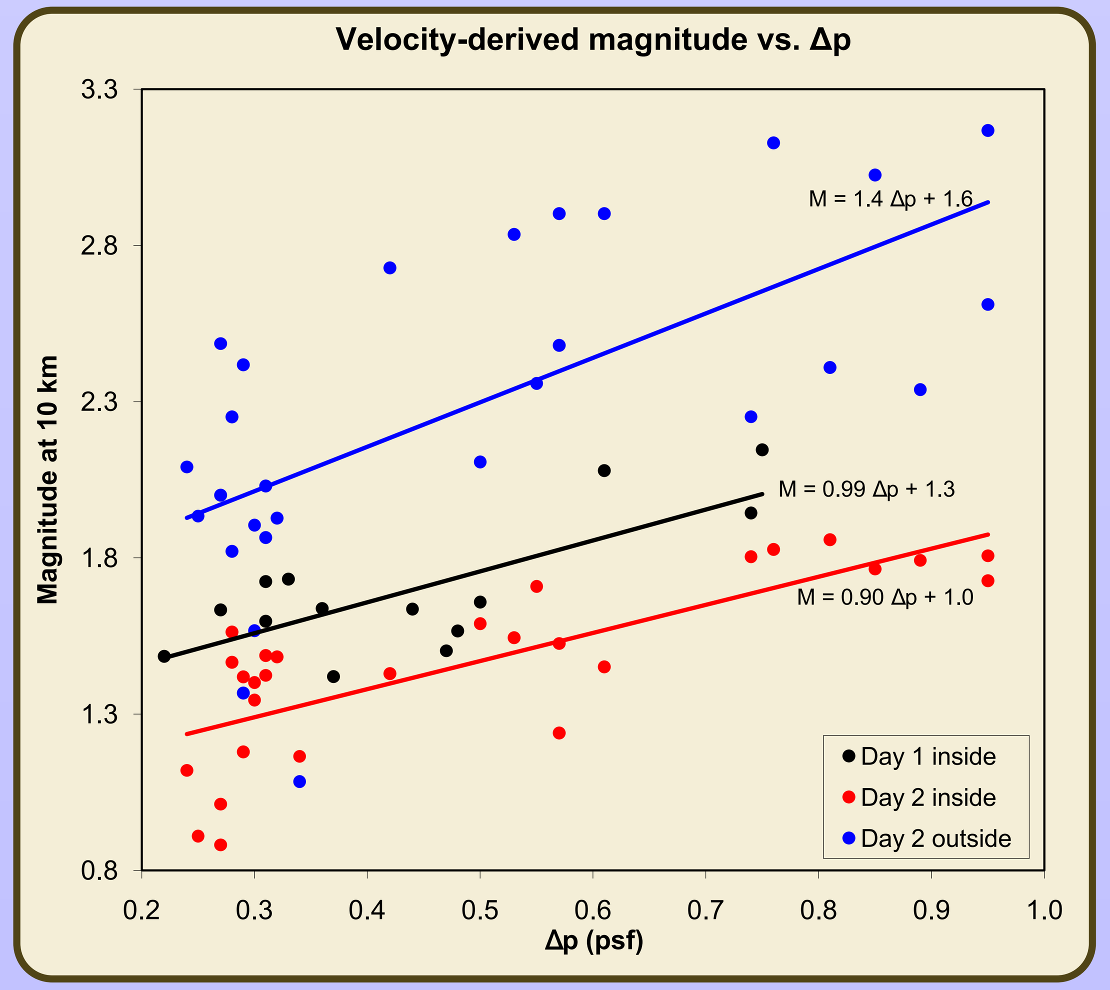
The Reftek accelerometers exhibit variation of sensitivity with temperature. Between sortie 1 and sortie 2 on the second day, the outside temperature increased from the mid-70s to mid-90s resulting in a factor of 2 reduction in sensitivity. By comparison the indoor sensor, at a constant temperature around 70 degrees, showed no change from sortie 1 to sortie 2.



We integrate the acceleration record to velocity and take the relation from *Wurman et al.* [2007] for magnitude as a function of peak P-wave velocity:

$$M = 1.63\ \mathrm{Log}_{10}(\mathrm{PGV}) + 4.40\ \mathrm{Log}_{10}(R) + 1.65$$

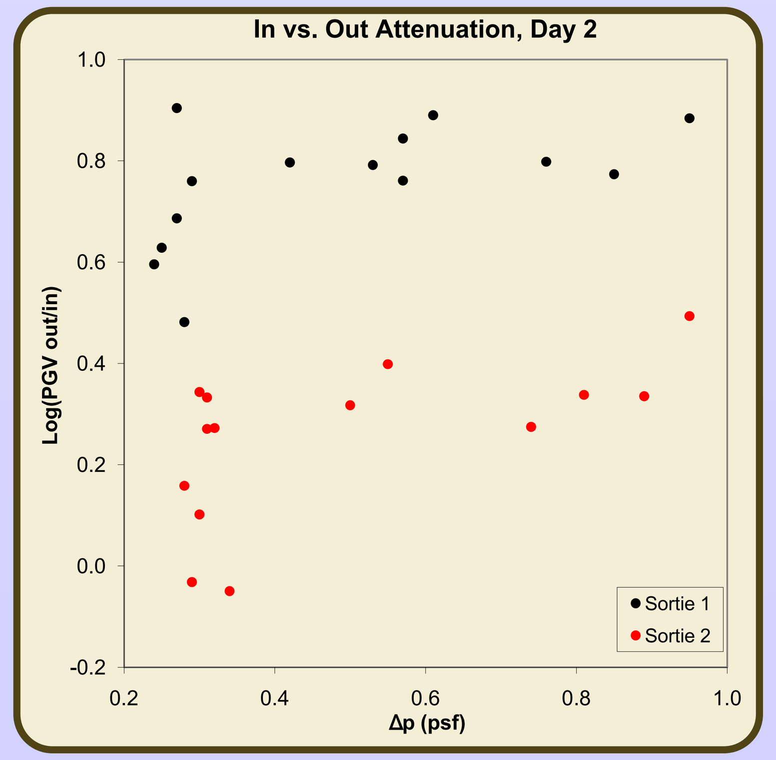
where R is the epicentral distance. We set this distance to 10 km as a reference to determine if an EQW system based on peak displacement algorithms can be spoofed by a sonic boom under realistic conditions. We find that sonic booms approaching 1 psf overpressure can generate ground velocities comparable to a M 3 at 10 km distance.



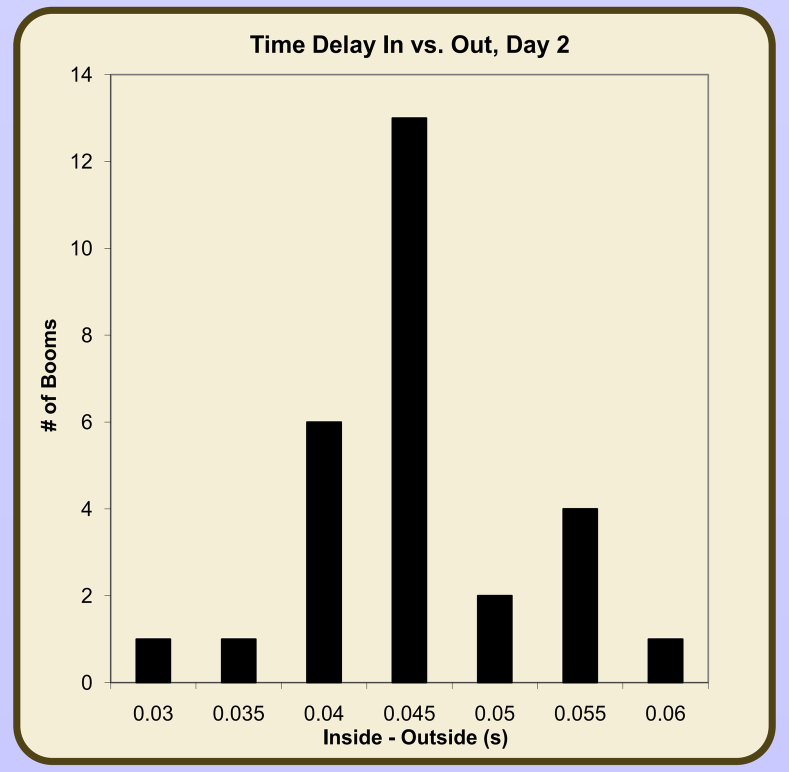
Sonic booms are broadband signals with more high-frequency content than earthquakes. Even a 1000 sps accelerometer will produce a significantly aliased record. Thus the observed peak ground velocity is strongly dependent on the sampling rate, and increases as the sampling rate is reduced. This can be seen in the difference between the magnitude vs. Δp relations from day 1 and day 2.

Strategies for Rejecting Sonic Booms

Several possible avenues exist for discriminating and rejecting sonic booms for EQW. The least robust is to shield the sensors. The attenuation between the accelerometer outside and inside is almost a factor of 10 when sensor temperatures are comparable, but a sufficiently intense boom can still spoof the sensors.



The time delay between the boom onset at the two sensors is consistent with a sound wave travelling at 300 m/s rather than a seismic wave. This discriminant requires two sensors and breaks down if the boom is normally incident to the array.



Because of the enhanced high-frequency component, sonic booms may be discernible from earthquakes by use of spectral methods such as τ_p [*Allen and Kanamori,* 2003; *Allen,* 2004 and 2007] in comparison with amplitude methods. Finally, it may be possible to discriminate the booms from earthquakes by collocating acoustic sensors (microphones) with the seismometers, though care must be taken not to erroneously exclude actual seismoacoustic signals. Again, the enhanced high-frequency component of the boom can help in this determination.

Next Steps

In May 2011 we will deploy 4 accelerometers in arrays at Cuddeback dry lake during the Superboom Caustic Analysis and Measurement Program to test the response of high-amplitude (600 Pa) sonic booms. We will also fly three dedicated SonicBREWS flights, during which we will test specific boom cases like vertical incidence on a building.

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