AN EXPERIMENTAL INESTIGATION OF THE SEISMIC SIGNAL PRODUCED BY HYPERVELOCITY IMPACTS. J. E. Richardson[1] and S. Kedar[2], [1]Dept. of Earth, Atmospheric, & Planetary Sciences, 550 Stadium Mall Drive, Purdue University, West Lafayete, IN 47907, richardson@purdue.edu, [2]Geodynamics and Space Geodesy Group, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Ms 238-600, Pasadena, CA 91109.

Motivation: The possibility of using meteoritic impacts as a seismic source for the seismic exploration of Mars has been raised in the past, and has also been considered in the context of a future Mars seismic network mission. The concept is particularly appealing because impacts add a substantial number of seismic sources to an otherwise seismically quiet planet, whose natural quake rate is estimated to be ~1000 times lower than on Earth [1, 2, 3]. Moreover, such additional, naturally occurring sources would not only enhance the science return from a network mission, but would also translate into a shorter mission duration and lower cost.

Determining whether meteoritic impacts can be used as seismic sources for studying the Martian interior depends directly upon two fundamental parameters: (1) the rate of transfer of momentum to the elastic medium as defined by the impact source time function (its power spectrum); and (2) the efficiency with which the kinetic energy of the impacting body is transferred to seismic energy. Nearly all previous investigations into this topic date back to the Apollo era, and modern experimental approaches and numerical modeling techniques will greatly improve our understanding of these poorly-determined parameters.

Introduction: It has been over 40 years since a series of impact experiments were performed to investigate the seismic signal produced by impacts. These experiments used analog equipment of limited sensitivity and signal fidelity, coupled with simplified data reduction techniques [1]. In June of 2012, we conducted a series of verification and follow-up impact experiments relative to this earlier work, using modern seismic sensors, digital data-logging equipment, current data reduction and analysis techniques, and a target material analogous to the Martian surface. These experiments were conducted at the *NASA Ames Vertical Gun Range (AVGR)*, the only facility in the country capable of the wide range of velocities necessary to sufficiently explore variations in impact speed with hyper-velocity impacts (i.e. impacts at greater than sound speed in the target).

Experiment Setup: Figure 1 shows a simplified diagram of our test setup, which consisted of a 6' diameter by 3' high fiberglass tank, filled with unconsolidated 0.1-0.2 mm grain size silica sand or pumice (both were used), and containing 26 shallow- and deeply-buried, high-frequency accelerometer stations, positioned below and around the impact point in the uprange, downrange, and cross-range directions. Three stations in the seismic setup had three accelerometers, recording vertical, radial, and azimuthal motion; seven stations had two accelerometeters, recording vertical and radial motion, and three buried stations had only one accelerometer, recoding only vertical motion. In a given run, 15 channels of the 26 possible outputs were feed into an external digital data-logger for recording at a sample rate of 100 k s^{-1}. Having multiple sensors in each direction at different distances from the impact point permited us to observe signal attenuation with distance and thus determine the seismic quality factor Q of the test medium..

The test bed was purposefully as large as the vacuum chamber (and access door) would permit, for two reasons: (1) it reduced the effects of signal contamination from seismic wave reflection off the tank boundaries, both by delaying their arrivals and attenuating their magnitude to the maximum extent possible; and (2) it permitted the accelerometers to be placed as far from the impact point as possible, to prevent clipping of the sensors, while enabling the testing of asymmetrical effects of oblique impact (increasing incidence angle) on an impact's seismic signal. The original McGarr et al. [1] investigation (also conducted at the AVGR) obtained useful data from sensors located 2.0' and 2.5' from the impact point, where accelerations of up to 2.13g were experienced from impacts into a quartz sand target bed. Our sensors had a maximum dynamic range of +/- 10 g, giving us a comfortable dynamic margin at those same distances. All surface level sensors were shallowly buried to ensure good seismic coupling with the target medium and protection from hits by impact ejecta particles.

Experiment Campaign: For our first targe material, we used a loose, silica sand, a material that is well-known in the experimental impact literature, and to establish experimental consistency with the McGarr et al. [1] study. Volcanic pumice, our second target substance, was both readily available in large volume and roughly similar in composition, grain size, and density to the Johnson Space Center (JSC) Mars-1 Regolith Simulant [5]. Note that a `hard' target (rock or cemented aggregate) used in the original McGarr et al. [1] study was not used in this campaign, because the elastic wave-speed in such a target is so high (of order 2-5 km/sec) that the initial impact seismic waveform would likely be missed, and the normal vibrational modes of the target would dominate thereafter [1]. Consequently, we selected targets with elastic wave-speeds of only a few hundred m/sec, allowing the impact seismic waveform to be captured in full, prior to target boundary reflections and the onset of normal mode resonances from tank and bedding.

The experimental impact campaign consisted of 22 total impacts:

- Sand target, 90^o incidence (vertical), 0.3, 0.5, 1.0, 3.0, 5.0, 7.0 km/sec (6 shots),
- Sand target, 15^o, 30^o, 45^o, 60^o, 75^o incidence, 3.0 km/sec (5 shots),
- Pumice target, 90^o incidence, 0.3, 0.5, 1.0, 3.0, 5.0, 7.0 km/sec (6 shots),
- Pumice target, 15^o, 30^o, 45^o, 60^o, 75^o incidence, 3.0 km/sec (5 shots),.

The sand shots were performed under near-vacuum conditions (< 1.0 torr), providing us with an airless, silicate-body baseline dataset that is consistent with McGarr et al. [1]. The pumice (Martian regolith stimulant) shots were performed at Mars atmospheric pressures (~5-10 torr), emulating the environment of interest for this phase of the study.

This campaign took a total of 10 days of dedicated AVGR time, as follows: Day 1 for sand target setup and equipment test shots; Days 2-4 for sand shots (~4 shots per day); Day 5-6 for the change-over to pumice target; Days 7-9 for pumice shots (~4 shots per day); and Day 10 for experiment and test bed breakdown.

All shots (except those at the highest speeds) used a common, non-metallic, pyrex glass projectile of ~1/4" diameter, selected in consultation with the AVGR team and fine-tuned based upon the initial test shots.

Data Analysis: Following data collection, the seismic recordings are in the process of being analyzed to investigate the impact seismic efficiency factor η, and the impact seismic signal power spectrum, as a function of:

- Impact speed (0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0 km/sec),
- Impact incidence angle (15^o, 30 ^{o}, 45 ^{o}, 60 ^{o}, 75^o, 90^o),
- Axial sensor position (uprange, downrange, cross-range), and
- Target type (sand w/ vacuum and pumice w/ thin atmosphere).

The seismic efficiency factor η, will be calculated using the expressions developed in Richardson et al. [6, 7], as well the expressions of McGarr et al. [1] for comparison, preliminary results to be presented at the

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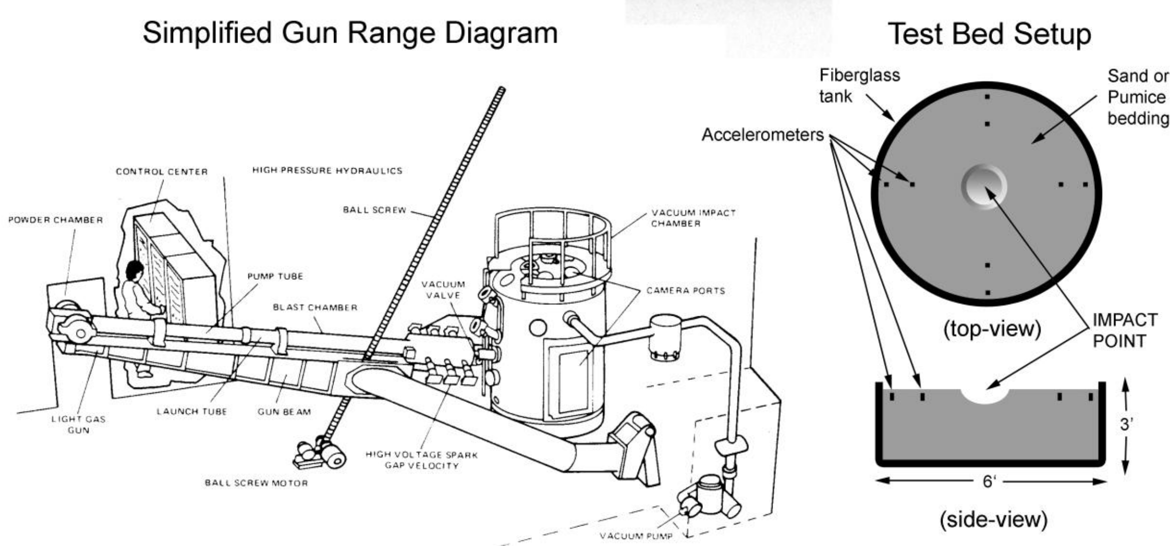

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Figure 1: *(left) A simplified diagram of the NASA Ames Vertical Gun Range (AVGR), showing the "wishbone" mounted gun (only the near fork is depicted), which can be positioned via the long ball-screw to impact angles ranging from 0o to 90o incidence in 15o increments. The vacuum chamber, within which the test bed is placed, is 8' in diameter by 10' tall. (right) A simplified diagram of our proposed test bed setup, showing the large, fiberglass tank, the sand or pumice target bed, and eight shallow-buried accelerometers.*