AN ACOUSTIC PARTICLE SIZE ANALYZER FOR PLANETARY SURFACES. J. Marshall[1], L. Mason[2], P. Thompson[3], [1]SETI Institute, 515 N. Whisman Rd. Mountain View, CA 94043 (jmarshall@seti.org), [2]Lockheed, 12257 S Wadsworth Blvd, Littleton, CO (larry.w.mason@lmco.com), [3]N-Science, 6155 W 54 Ave Arvada, CO 80002.

An acoustic method of determining the size of loose particles has been developed at the breadboard level. This is intended as a precursor to a planetary flight instrument that can conduct grain-size analyses using a highly miniaturized sensor head requiring no complex sample processing or handling. When a particulate material (sand, dust) in actively being crushed, it emits a sound or acoustic signature that is diagnostic of the particle size distribution of the material, as well as the hardness of the grains. This principle has been applied in the breadboard development which has confirmed the ability of the technique to discriminate between samples based on their size distribution. A brief anecdotal comparison serves to illustrate the principle underlying the proposed instrument. It has probably been most people's experience that sugar spilled on a tabletop creates a distinctive crunching sound if a cup is pressed down onto it. But if flour is spilled on the tabletop, the same cup will generate only a muffled "squeaky" sound. The human ear can readily distinguish the sound of crushing sugar, salt, and flour without having to see what the cup is sitting on. In other words, this simple tabletop "experiment" can do first order grain-size discrimination by registering *diagnostic acoustic signatures* for each material. We are proposing to take the next, considerably more sophisticated step by replacing the human ear with highly sensitive acoustic transducers that can explore both audible and non-audible frequencies.

From a science perspective relating to geological or astrobiological exploration, particle size is a valuable parameter for defining the degree of material sorting, and therefore provides indications of fluid transport. Indications of water transport in particular are clearly of direct relevance to paleohydrology and issues of microbial habitability on Mars. For example, well-sorted silt and mud sediments can indicate particle settling in a lacustrine/playa environment, and well-sorted sand can indicate fluvial action (possible aeolian origins notwithstanding).

From the standpoint of human exploration, particle-size data are critical for understanding the likely effects of soil and dust interaction with both humans and equipment (Mars/Moon). Fine dust and silt particles pose a threat to machinery through abrasive wear and penetration of moving components. They can also degrade airlock seals and the joints and fabric of spacesuits. Dust-size particles in particular are hazardous surface contaminants by their highly adhesive nature (as a result of electrostatic and van der Waals forces --which are aided by low gravity on Moon and Mars). Particles of dust that are suspendable for long periods in air can become respirable materials, with all the attendant health hazards for astronauts. Particle size is also important for determining the reactivity potential of materials if they come in contact with moisture (in machinery, electronics, or human lungs). Reactivity increases with decreasing particle size and increasing particle angularity. By the same token, knowledge of particle size can be valuable in determining how efficiently a mineral ore can be caused to react, for example, in attempts to extract oxygen from iron oxides on the Moon.

Rigorous particle size analysis has never been conducted on any planetary mission. Size analysis has long posed a challenge for in situ instrumentation. Sieving and weighing techniques are unwieldy and generally impractical, while cascade-impactor type techniques only work for fine dust (also true for other trapping or settling techniques). It is also difficult to apply microscopy to the problem. We believe that the innovative acoustic technique being reported here is unique and has the potential for being packaged as a portable, lightweight, and power-conservative instrument for planetary applications.

Figure 1 shows the breadboard arrangement with a motor drive to grind the sample while under load from a series of weights. Directly beneath the ground sample is a microphone coupled to an acoustic signal (Fast Fourier Transform) analyzer.

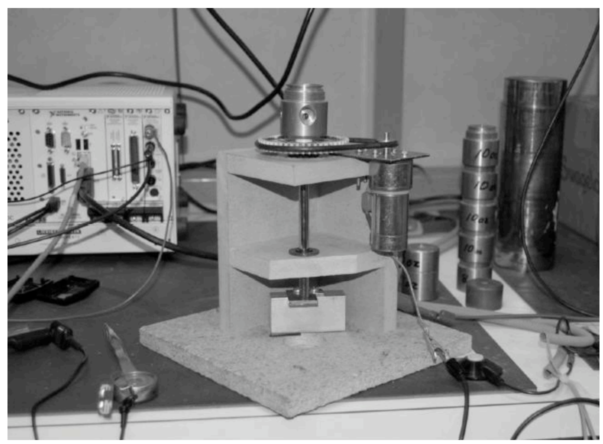
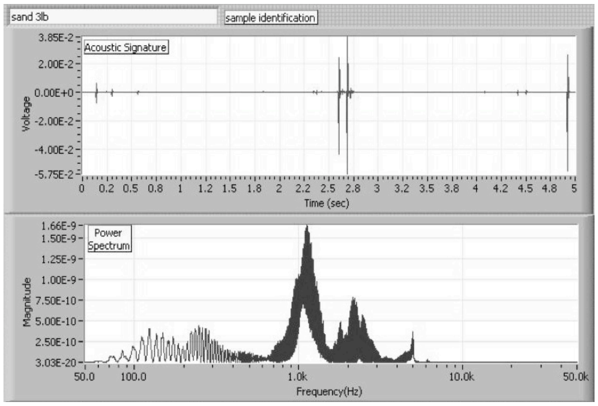


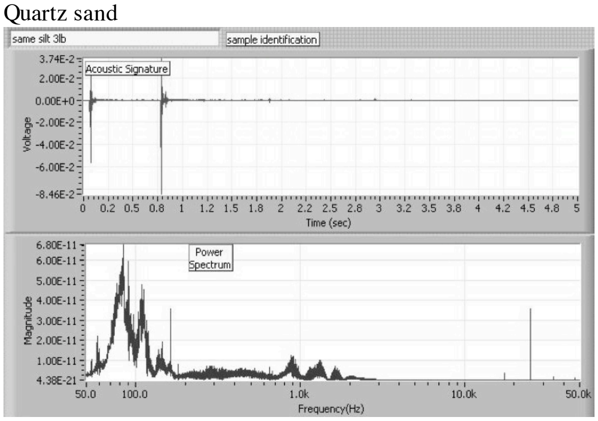
Figure 1: *Breadboard of acoustic size analyzer*

Sample results from this breadboard are seen in Figure 2 for sand-size material (quartz), silt-size material (quartz/clay mix), and dust (powder)-size material (baking soda). Many more tests were conducted, but this selection highlights the very distinct difference between samples. The upper plot indicates the 'raw' acoustic signature, while the lower plot indicates a derivative power spectrum. Although we have not fully determined what differentiates the signals between samples, it is nevertheless clear that acoustic signatures provide a means of sample differentiation.

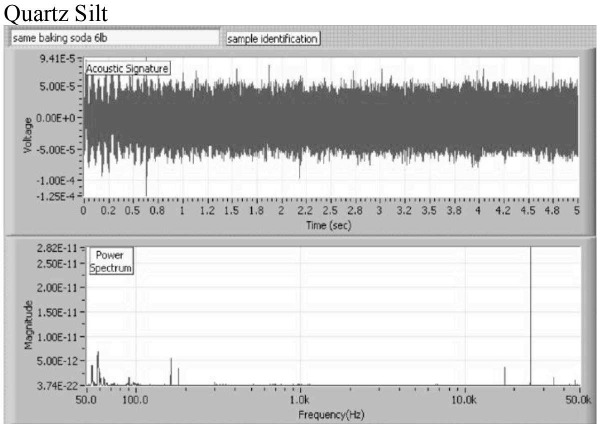
Figure 3 shows a strawman concept for a potential flight instrument. The whole unit is about 10 cm in diameter and would weight ~ 1.5 kg. A sample of soil or dust is placed inside a small cup or anvil of approximately 1 cm internal diameter. The amount of material need only be a fraction of a gram. A plunger is then slowly brought down on the sample with sufficient force to gradually crush the particles over a period of several minutes. As each particle fractures, an acoustic signature is generated that is a function of the ***initial*** size of the material. This signature is detected by a sensitive transducer embedded in the anvil. Because the sample is being pressed into the anvil, there is a good elastic contact to facilitate the transmission of acoustic energy across the sample/anvil interface. While the plunger is crushing the particles by translational motion, a second actuator is rotating



Quartz sand



Quartz Silt



Baking Soda

Figure 2: *Acoustic spectral analysis of different size granular materials. Note the difference in scales between the figures.*

the plunger to create a grinding action. In the concept illustrated, the translational and rotational actions can be operated separately or simultaneously, with the ability to control the applied forces and rates of motion. The anvil will be designed so that it is acoustically decoupled from the rest of the instrument, and will have a resonant frequency much different from the acoustic signatures we intend to measure. The transducers will be chosen to respond to auditory and ultrasonic frequencies, and acoustically coupled to the anvil.

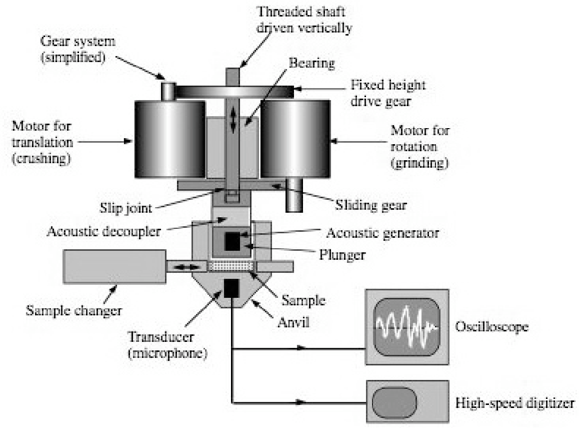


Figure 3: *Strawman design for an acoustic particle-size analyzer.*

As particle disintegration proceeds, the acoustic waveform data will be acquired from the instrument by a high speed digitizer that operates at several hundred kilohertz, a much higher frequency than the ultrasonic signatures. Data from this can be analyzed, visualized, and stored for future use. An oscilloscope will additionally be used to visualize the waveforms. The acoustic data will be analyzed using Fast Fourier Transform (FFT) signal analysis techniques to resolve the characteristic frequencies and associated power spectrum. The measured frequencies will then be compared to samples of known size distribution for correlation.

The amplitude and frequency of the acoustic waves will be a function of particle size, and we suspect them to also be a function of the physical properties of the material such as brittleness, hardness, crystallinity, etc because the propagation of fractures through elastic solids is a function of all these parameters. And indirectly, these physical properties potentially reveal something about the composition of the bulk sample.