Creating a PZT Network Data Base for Detection of Low and High Velocity Impacts.

S. Rapp, J. Carmona-Reyes, M. Cook, J. Schmoke, J. Reay, L. Matthews, and T. Hyde

***Abstract*—Orbital space debris is becoming an alarming hazard for space flight. Since continued space exploration is in our national interest the resolution of this problem needs to come quickly. This paper describes a sensor system that is undergoing development at CASPER that can help monitor hypervelocity impacts from orbital space debris. Low velocity impact studies are used to calibrate a system for alternative hypervelocity impacts. In the initial phase of this project, the mapping of aluminum plates (similar to the outer covering of spacecraft) for frequency and amplitudes was archived for comparison with the second phase mapping of plates impacted by a light gas gun.**

Background: Outer space is a dangerous place. Orbital debris, whether it is man-made or natural, poses a huge threat to satellites and spacecraft, especially manned modules, such as the International Space Station. Every space vehicle is exposed to an onslaught of impacting meteoroid and space debris particles. These impacts occur at very high velocities, generally between 10 km/s and 20 km/s. The degree of damage to the target material depends on the type of material, the material thickness, how fast the particle is moving, and the size of the particle [1]. The impactor will puncture the target or cut through it if the target material is relatively thin (Fig. 1). Usually if the impactor is larger than about a third of the target material thickness the target will be punctured. The solar panels on the Solar Max satellite suffered several meteoroid impacts [2]. An impact crater can be seen in Fig. 2.

S. Rapp is with A. Linwood Holton Governor's School, One Partnership Circle, P. O. Drawer 1987, Abingdon, VA 24210 (phone: 276-619-4329; fax: 276-619-4328; email: srapp@hgs.k12.va.us).

J. Carmona-Reyes, M. Cook, J. Schmoke, J. Reay, L. Matthews, and T. Hyde are with CASPER (Center for Astrophysics, Space Physics and Engineering Research), Baylor University Summer RET Program, Waco, TX 76798

Figure 1. Photo of a Hubble Space Telescope (HST) solar cell that has been penetrated by space debris

Orbital debris may consist of many different objects such as fragmented rocket parts, meteoroids, spacecraft parts, micrometeoroids, satellite parts, and an estimated 100,000 untracked very small objects. About 40,000 metric tons of micrometeoroids enter the Earth's atmosphere each year. The mass of all this space debris is approximately 2,000,000 kg [3]. Fig. 3 illustrates the area and density of currently catalogued orbital debris [3]. Radar and optical telescopes are used to monitor objects larger than 1 m in geosynchronous (GEO) orbits. In low earth orbit (LEO) some sensitive radar can detect particles as small as 5 mm. Debris swarms

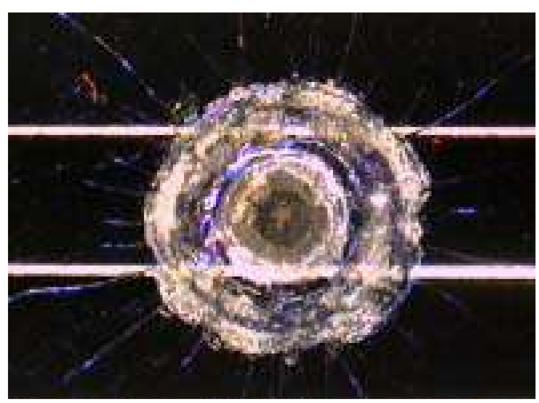

Figure 2. Meteoroid impact crater on a Solar Max solar panel; crater size: 3.5 mm, hole size .5 mm.

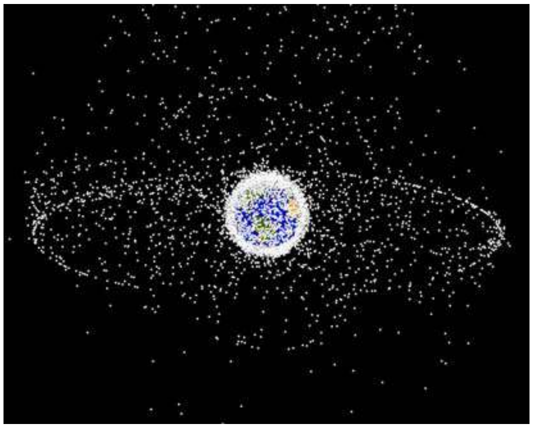

Figure 3: Depiction of catalogued orbital debris objects [3].

containing trillions of small particles are evident in the examination of objects that have been in orbit for extended periods such as the Long Duration Exposure Facility (LDEF) (Fig. 4) that was placed in orbit in the 1980s.

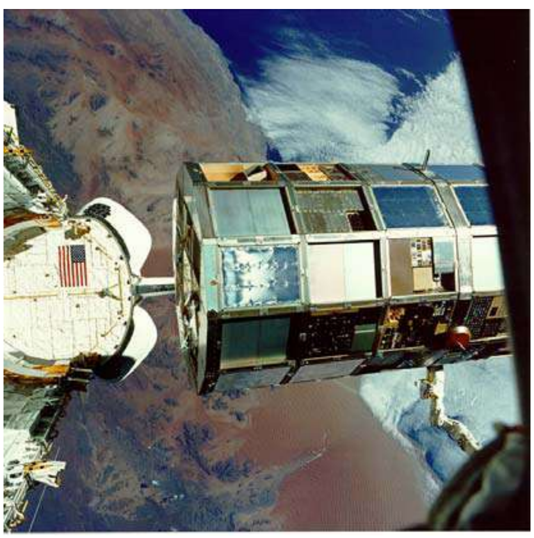

Figure 4: The LDEF, in orbit for 5.75 years, saw about 1 impact/m^2 which could have penetrated a typical 1.5 mm thick electronics box [4].

Damage from orbital debris can occur in many ways. Surface erosion can change thermal, electrical or optical properties. Sensors, mirrors, and windows can be seriously degraded (see Fig. 5). Even tiny impact craters on the Space Shuttle means the window has to be replaced. Of course, penetration of spacecraft walls and thermal insulation may lead to structural damage on inner subsystems (see Fig. 6).

Penetration of pressurized systems such as tanks and manned modules is especially serious. Space debris impacts may cut tethers, cables, or cause electrical short circuits that may endanger a mission. If the impacts occur in a charged environment, the possibility of plasmas being produced is great. This may cause electrical interference, disrupt current flow, or trigger electrostatic discharges [3].

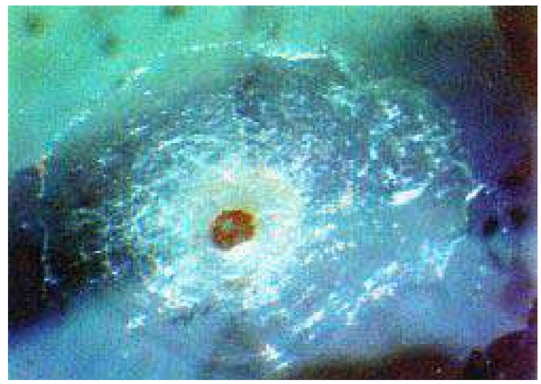

Figure 5: Impacts on Space Shuttle windshield result in serious damage that requires window replacement.

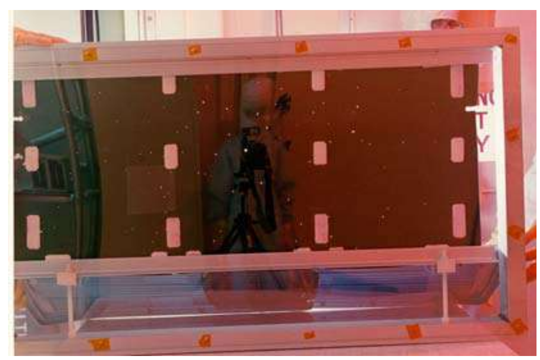

Figure 6: Several penetrations caused by space debris impact are seen in this image. This may result in internal structural damage.

Introduction: Since space exploration is vital to our national as well as commercial interests, the dangerous problem of orbital debris must be addressed. This project, a result of the Research Experience for Teachers (RET) program during the summer of 2005, is trying to address this problem. Teachers were involved in creating a database of mode frequencies and voltage amplitudes of impacts on sections of a plate. This database will be used for comparison to a plate damaged by projectile impacts to see if there is a shift in frequency and amplitude. It is hoped that a reliable monitoring system for detecting impact damage on spacecraft such as the Space Shuttle and the International Space Station will eventually result from this research.

Experiment: A 1.65 mm inch thick aluminum plate is attached by four rods (one rod at each corner) to a bottom aluminum plate of 3.18 mm thickness with 3 PZTs (piezoelectric lead zirconate titanate) clamped below the bottom plate (see Fig. 7).

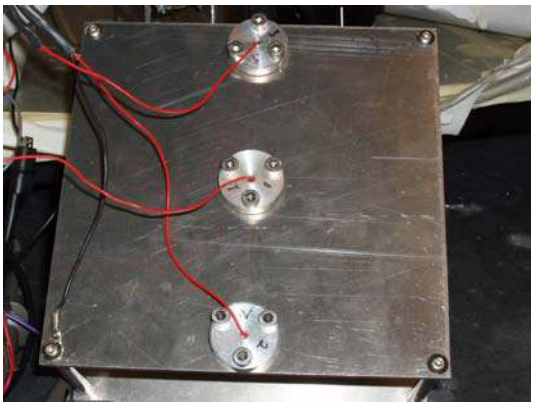

Figure 7: When the top plate is impacted by projectiles, a change in pressure is noted via the PZTs on the bottom plate. The change is recorded as an electric signal. The signal is then sent to an oscilloscope that is interfaced with a computer. The resonant frequency and the output voltage are determined.

The PZT in the middle is labeled PZT 1, PZT 2 is at the bottom of the plate, and PZT 3 is at the top. A PZT crystal is a type of sensor that can be used to find the momentum of a projectile at the time of impact [5]. The top plate (see Fig. 8) is mounted in one trial 6 cm from the bottom plate and 12 cm from the bottom plate in another trial.

Figure 8: The top plate was divided into 1.27 cm squares and labeled.

This simulates a Whiffle shield that is used in most spacecraft to maximize protection from space debris impacts.

The next step involves mapping the plate by dropping aluminum and chrome steel spheres on each section of the plate. A drop tower in which the projectiles could be dropped from a constant height of 25.8 cm was used for this purpose (see Fig. 9).

The mapping process has to be completed for each individual PZT as well as the whole PZT network. The first step involves the use of the drop tower, so that a low-velocity map can be created.. The result of one of the drops on one section of the plate is shown in Fig. 10. Each plate is divided into 144 sections.

Both projectiles have a diameter of 2.38 mm. The aluminum projectiles have a mass of 0.02 g and the chrome steel spheres have a mass of 0.05 g. Aluminum projectiles were dropped 10 times on each of 70 sections for a total of 700 drops. Chrome steel projectiles were dropped 5 times on each of 70 sections for a total of 350 drops. Since the four corner squares contain the bolts holding the plates together, they were not dropped on. LabVIEW was used to analyze data and Microsoft Excel was used to create a map of the frequencies and amplitudes.

The second step involves a higher-velocity mapping using a light gas gun [7]. At present enough data has not been collected to make accurate sensitivity maps for this apparatus.

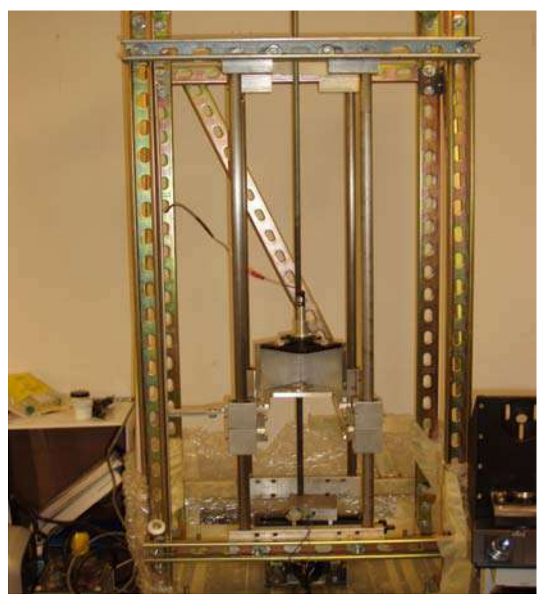

Figure 9: A laser guide, shown about midway in this photo, helps insure that the projectile is dropped on the correct square each time.

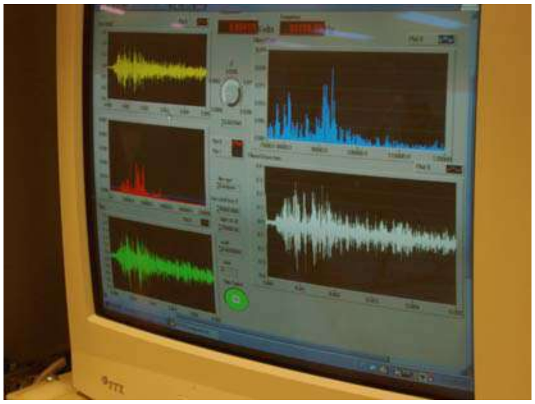

Figure 10: Display of signal responses from the PZTs.

Results: Maps were created for PZT 1, 2, and 3 for both aluminum projectiles and chrome steel projectiles. Only maps for PZT 1 frequencies and PZT 1 voltage amplitudes are presented in this paper respectively as Figures 11 and 12. The maps include data from the 12 cm plates using chrome steel projectiles.

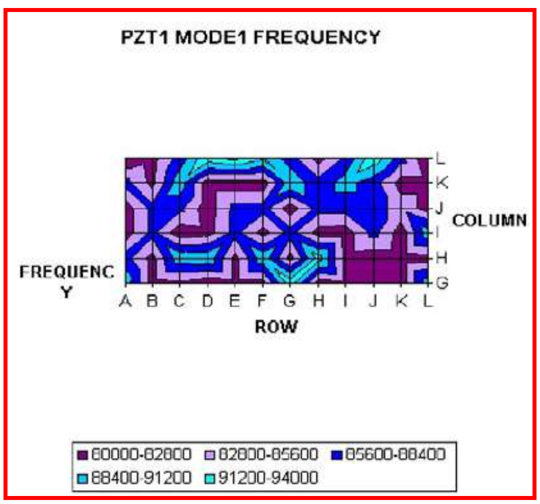

Figure 11: The mapped top plate for these impacts show a frequency range of 80 kHz to 94 kHz. The PZTs are 12 cm from the top plate on the bottom plate. These maps are for one half of the top plate.

These maps are for one half of the top plate as it was assumed that the second half of the plate is identical to the first due to symmetry.

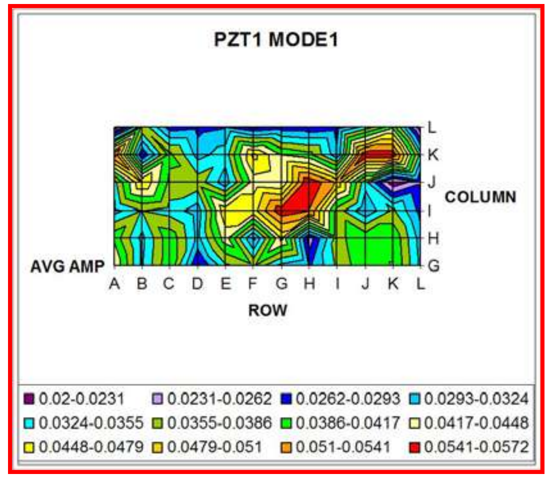

Figure 12: The chart above shows a map of voltage amplitudes. They range from .02 V to .0572 V.

A Light Gas Gun (LGG) (Fig. 13) is used to fire the projectiles at velocities between 100 and 500 m/s. The LGG was modified for this experiment to accommodate the double plate target as shown in Fig. 14. The plate was mounted inside the box (Fig. 15) and aligned with the beamline of the LGG. A wooden lid with a Plexiglas top was installed so the interior of the box could be lit for the camera. The video camera (Fig. 16) captured an image of the projectile as it struck the target (Fig. 17). The plate was impacted at velocities in the range of 120 m/s to 442 m/s. Damage to the plate is shown in Fig. 18.

Figure 13: The CASPER LGG uses helium at 500-1000 psi to fire projectiles up to 800 m/s. A laser fan is used to determine the velocity of the projectile. The LGG was run under normal atmospheric pressure rather than under vacuum as in previous experiments.

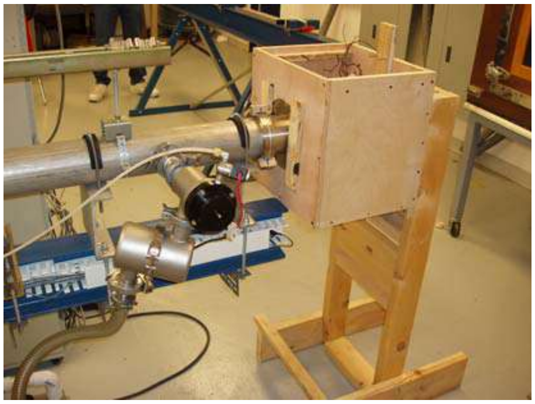

Figure 14: Accommodation for the double plate target.

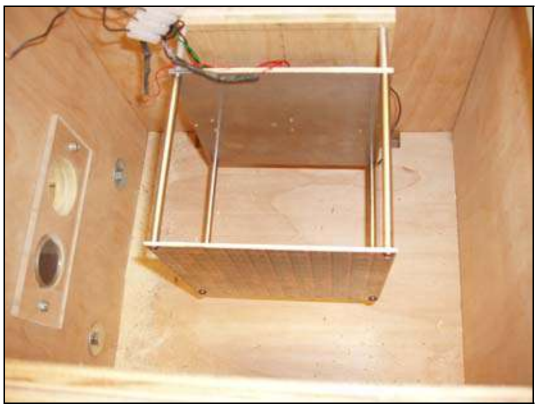

Figure 15: The plate is mounted directly in front of the beamline on an adjustable backing plate. Notice the camera lens at left.

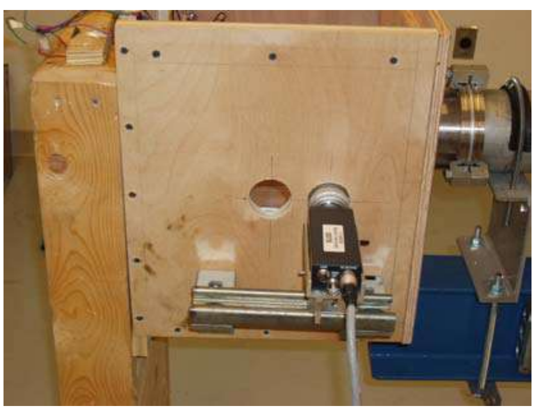

Figure 16: The video camera mounted outside the projectile chamber.

Paintshop Pro Animation Shop was used to make a movie from the tiff files stored on the computer from the camera. Files were examined during each projectile firing and only those that had captured an impact were saved. All saved files were animated and saved as both avi movie files and as animated gif files.

Figure 17: Image shows aluminum projectile captured as it struck the plate at 260 m/s.

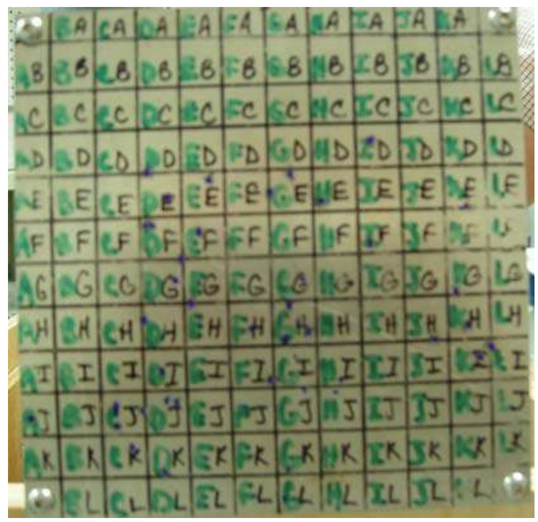

Figure 18: Blue dots show impacts on the aluminum plate. Small craters were formed by high velocity impacts.

Conclusion: A database of the frequencies and amplitudes of a 7075 aluminum plate has been created. The plate was mapped for PZT 1, 2, and 3. The mode of the frequencies and amplitudes was used to increase the accuracy of the maps. The amplitude maps will provide a standard of comparison with the maps of the LGG impacted plates when they are completed. Since the maps (Fig. 11 and 12) correspond with the bottom plate (where the PZTs are attached) a wave pattern can be seen coming from the rods. The areas of high amplitude represent constructive interference of waves, while the areas of lower amplitude represent destructive interference of waves. Higher amplitudes tend to occur in the region of PZTs. As far as the frequency maps, it is more difficult to come to some logical conclusion as to what is going on there. There is not an observable pattern. One can, however, see how the frequency is distributed on the plate. Future work will complete the mapping of impacted plates and then a comparison can be made to the control plates to see if amplitudes and frequencies are shifted. In this way dangerous impacts with space debris can be monitored, hopefully predicting potential problems.

REFERENCES

[1] European Space Agency. (2005, April). "What are hypervelocity impacts?" *Technical and Quality Management Portal*. Available: http://www.esa.int/techresources/ESTEC-Article-fullArticle_par-28_1112600510257.html

[2] G. Drolshagen. (2001). "Hypervelocity impact effects on spacecraft." Available: http://gate.etamax.de/NoCDebris/Publications/met_2001_GD.pdf

[3] C. A. Belk, J. H. Robinson, M. B. Alexander, W. J. Cooke, and S. D. Pavelitz. (1997, August). " Meteoroids and Orbital Debris: Effects on Spacecraft." *NASA Reference Publication 1408.* Available: http://www.knowledgenetwork.ca/space/articles/meteoroids.pdf

[4] W. E. Kinard. (2001, April). "Impact Damage of LDEF surfaces." NASA Langley Research Center, Long Duration Exposure Facility. Available: http://setas-www.larc.nasa.gov/LDEF/MET_DEB/md_impact.html

[5] J. Carmona-Reyes and *et al*. (2004). "Impact studies using a light gas gun." *Lunar and Planetary Sciences XXXV.* Available: http://www.lpi.usra.edu/meetings/lpsc2004/ pdf/1019.pdf

[6] J. Carmona-Reyes and *et al*. (2005). "Construction of a PZT sensor network for low and hypervelocity impact detection." *Lunar and Planetary Sciences XXXVI,* Available: http://www.lpi.usra.edu/meetings/lpsc2005/pdf/1127.pdf