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DESIGN, DEVELOPMENT, AND ASSEMBLY OF SPACE FLIGHT STRUCTURAL HEALTH MONITORING EXPERIMENT

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ABSTRACT

The paper presents the design, development, and assembly of Structural Health Monitoring (SHM) experiments intended to be launch in space on a sub-orbital rocket flight as well as a high altitude balloon flight. The experiments designed investigate the use of both piezoelectric sensing hardware in a wave propagation experiment and piezoelectric wafer active sensors (PWAS) in an electromechanical impedance experiment as active elements of spacecraft SHM systems. The list of PWAS experiments includes a bolted-joint test and an experiment to monitor PWAS condition during spaceflight. Electromechanical impedances of piezoelectric sensors will be recorded in-flight at varying input frequencies using an onboard data acquisition system. The wave propagation experiment will utilize the sensing hardware of the Metis Design MD7 Digital SHM system. The payload will employ a triggering system that will begin experiment data acquisition upon sufficient saturation of g-loading. The experiment designs must be able to withstand the harsh environment of space, intense vibrations from the rocket launch, and large shock loading upon re-entry. The paper discusses issues encountered during design, development, and assembly of the payload and aspects central to successful demonstration of the SHM system during both the sub-orbital space flight and balloon launch.

INTRODUCTION

On May 20, 2011, an undergraduate Space Launch Design Team from New Mexico Tech (NMT) launched its first experiment capsule with UP Aerospace. The goal for the launch was to determine the effects of the environment of space on piezoelectric active sensors used for structural health monitoring. A bolted beam, sensor adhesive, and sensor characterization test were integrated into the experiment capsule. The team recently was given the opportunity to fly its design canister aboard a suborbital rocket flight and high altitude balloon flight through the granting of a recent proposal to NASA. The expected dates of both launches are estimated to be in the fall of 2012. The team will repeat the same experiments from last year's launch with the addition of a wave propagation experiment which incorporates new, commercial structural health monitoring hardware. All of the data acquisition for the wave propagation test will be done with the HubTouch system provided by Metis Design Corporation.

Piezoelectric sensors have been used for many applications on earth. However, little research has been conducted about piezoelectric sensor behavior in space. Piezoelectric sensors have the potential to monitor tightened bolts on satellites before, during, and after orbit. In order to accomplish the goals of the project, the team partnered with a company that makes commercially available structural health monitoring (SHM) solutions. This company, Metis Design, sells solutions that are particularly appealing to the team due to the fact that they are already fitted with easy to use and easy to access data acquisition systems [1]. The Metis system consists of the piezoelectric sensors in an array coupled with a node for data collection. The data from each node is fed into a central data acquisition device where data is stored on an SD card for easy retrieval and post-experiment processing. Such a piezoelectric sensor array with accompanying node can be seen in Fig. 1.

Figure 1: Two connected Metis piezoelectric arrays attached to a data collection node

The team will be submitting a fully manufactured canister to UP Aerospace, a company that coordinates the sending of research, commercial merchandise, and business paraphernalia to space on a 15ft. rocket. The rocket launches seventy miles above the Earth's surface into space. The duration of the flight is roughly fifteen minutes and the rocket will reach speeds of about 4,000 miles per hour [2].

The canister design is separated into the following sections: Wave Propagation experiment, Electromechanical Impedance experiment, Sensor Box. A pictorial overview has been provided in the following figures.

Figure 2: Integrated canister design

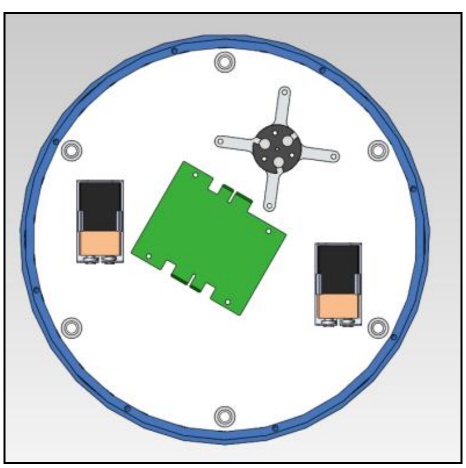

Figure 3: Top cap view showing EMI Experiment and Sensor Box

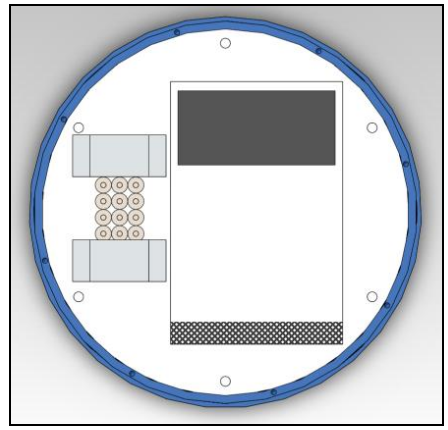

Figure 4: Bottom cap showing Metis HubTouch and battery pack

Experiments

Wave Propagation Experiment

The Space Launch Design Team selected circular aluminum plates to use for the SHM experiments to take advantage of Metis Design's directional piezoelectric sensors. These plates will be constrained by a series of bolts which will run through all of the plates. The plates will be separated to eliminate any interference by using standoffs. The standoffs will also be 6061-T6 aluminum, which will surround the bolts. This approach was selected because the standoffs will increase the rigidity of the fixtures and will allow for convenient assembly of all the plates. In order to reduce overall weight of the canister, the aluminum standoffs were removed for the bottom half of the canister. This change does not compromise the structural integrity of the structure and allocates for a higher weight budget elsewhere in the canister.

The team has designed a circular plate for the wave propagation test. The plate is constrained with bolts around the circumference of the plate. One of the bolts is torqued to a lesser value than the other bolts and monitored by the Metis Design hardware. There are five other pieces of Metis Design hardware on this circular plate. A piezoelectric actuator is placed in the center of the circular plate that provides an excitation signal that four other sensors on the plate monitor. Two sensors monitor the wave speed in the material, another sensor monitors the loose bolt, and the last sensor monitors a small crack in the plate. The crack in the circular plate helps test the capabilities of the Metis Design hardware and test if the system can detect flaws in the structural material. A visualization of this experiment set-up can be seen in the following figure.

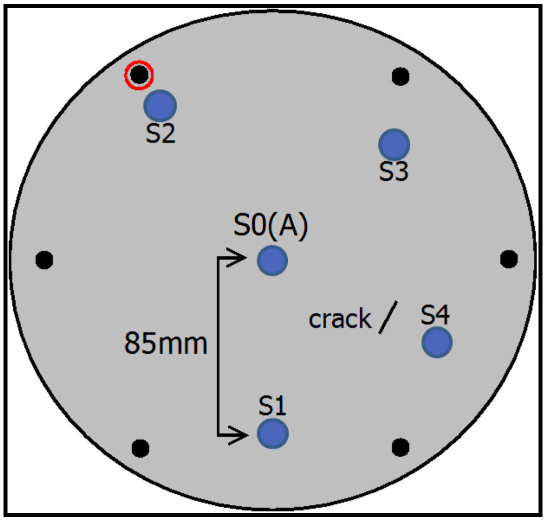

Figure 5: Wave propagation experiment plate

In this figure, the center piezoelectric sensor is the actuator which gives the excitation signal. S2 is the sensor that monitors the loose bolt on the perimeter of the circular plate. S4 is designated to monitor the propagation a small crack in the plate during the entire suborbital flight. S1 and S3 are placed on the plate to collect wave speed data of the aluminum plate. This wave speed data is important for the experiment because it provides a basis, or control, in which to compare the data from other sensors. A control wave speed test of the thin aluminum plate will be conducted in the lab, and the wave speed data from in-flight experiment will be compared to this control test to see if any changes have occurred during the flight. If the results are similar, the results are considered to be accurate.

In Fig. 5, the distance of S1 from S0(A) is specified to be 85mm. This specification is called out because it is the optimal distance in which to place this sensor for collecting wave speed data. In preliminary tests, a sensor was placed at ~100mm, and the sensor results showed a response that was heavy in reflection waves that were too close to the initial actuator pulse signal. As visualized in the following figure, the blue waveform is the signal generated from the actuator, and the green waveform is the response signal generated from a sensor that was placed 102mm away from the actuator. When placed at 85mm, the response signal shows a greater time difference between the initial pulse and reflection waves, which is ideal for data analysis in this wave speed experiment.

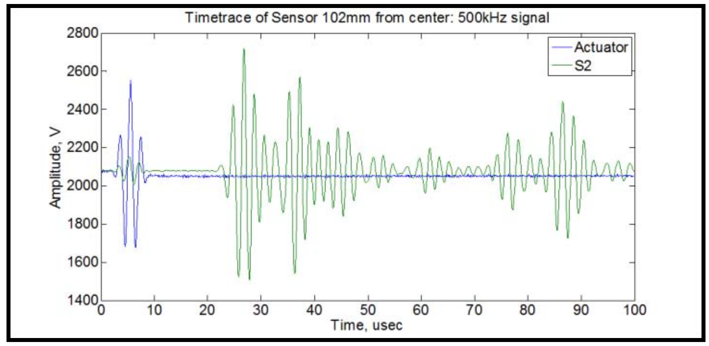

Figure 6: Wave Speed data from a preliminary test using Metis Design hardware

<u>Electromechanical Impedance (EMI) Experiment</u>

The electromechanical impedance (EMI) experiment will feature one aluminum circular plate that has threaded holes for the supporting columns. Bolts placed on the top and bottom of the plate will restrain it, and piezoelectric sensors will be placed at each bolt hole. These sensors will monitor the integrity of the bolt holes along with the rest of the plate. The sensors will be controlled by a microcontroller, or mother board, that has been designed by the NMT Electrical Engineering department. This mother board will also collect data for each sensor and will be placed on the top cap of our canister. All data will be stored on an SD card, thus allowing for easy access to the data. In order to simulate a discontinuity or failure a bolt will be loosened, therefore allowing the sensor to detect a change in impedance as compared to the sensors that are monitoring the tightened bolts. Fig. 7 depicts the layout of the EMI experiment.

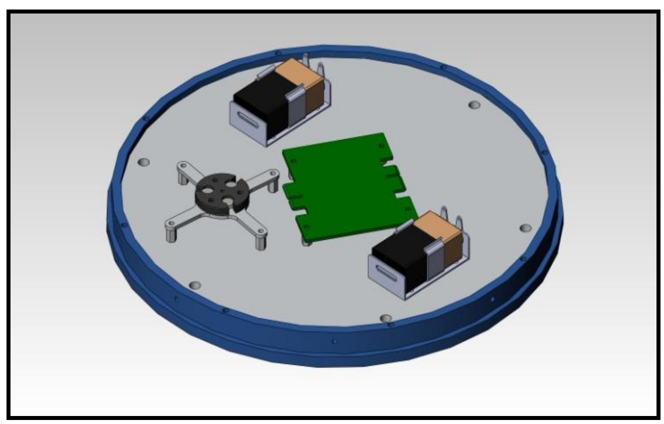

Figure 7: Top cap model for EMI experiment

<u>Sensor Box</u>

The sensor box designed by the team allows for six piezoelectric sensors to be mounted for maximum space exposure in the canister. Three sensors have a single electrode, and three sensors have two electrodes. Originally the design utilized silicone rubber to hold the sensors because of its outgassing property requirements. These outgassing properties required include a Total Mass Loss (TML) less than 1% and

Collected Volatile Condensable Material (CVCM) less than 0.1%. The rubber that the team planned to use turned out to be too expensive and both teams looked into new materials. A perfluoroelastomer material for an O-ring was found that had the proper outgassing requirements. As a result, the team needed to modify the current design. A design was made that held the clamped sensors between two O-rings, as seen in Fig. 8. Calculations are being completed for how much compression is required to keep the sensors in place.

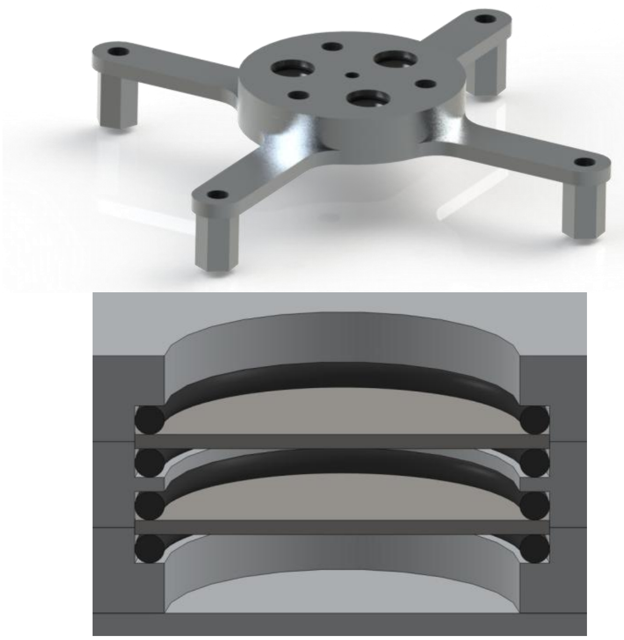

Figure 8: Detailed Design for Sensor Box

Triggering System

The experiments in the launch canister require a significant amount of power to actively run and collect data. With the launch weight requirements, the team chose a battery to power the experiments long enough for the duration of the flight. The team must use a triggering system to detect the initiation of the launch to then activate the experiments. If the system is triggered prematurely, from a drop or from being mounted in the rocket, the system will run out of power before or during the launch.

Previously, the team used a microcontroller to continually monitor an accelerometer. The experiment was then triggered after a period of sustained acceleration near 15 G's [3]. For the upcoming launches, the current team decided to use an RC circuit coupled with latching relays, as depicted by Fig. 9 and Fig. 10. The RC circuit acts to smooth out the acceleration signal so that there must be a sustained acceleration before the output of the RC circuit is large enough to trigger the relays. Once the relays are triggered, they will supply primary power to the EMI and Metis hardware, causing the hardware to turn on and start taking measurements.

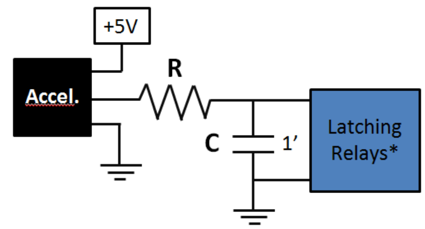

Figure 9: Rough schematic of the triggering circuit

The resistance of resistor **R** and the capacitance of capacitor **C** can be altered to adjust the required time of sustained acceleration until triggering. This aspect was appealing to the team because it requires no programming to adjust the parameters of the system. The triggering system is also simple and less prone to malfunction.

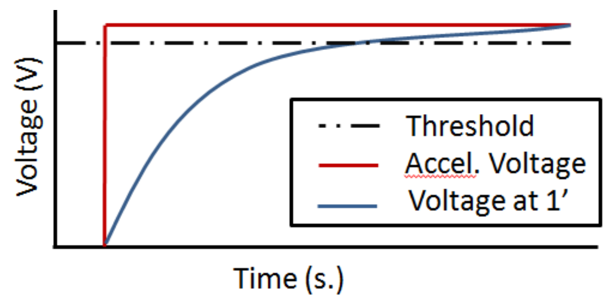

Figure 10: Response plot of the RC circuit (blue) with the expected output of the accelerometer during launch (red) and the threshold voltage for triggering (dotted line)

The team tested a similar setup in the lab and proved that it would work. There was a recent, minor change in the system architecture leading to the implementation of the latching relays, so the team will have to retest the new triggering system.

ACKNOWLEDGMENTS

The team would like to thank Matthew Landavaso from the Electrical Engineering Department of New Mexico Tech with his involvement with the triggering system.

NOMENCLATURE

Insert nomenclature list here (if applicable). Sort by upper and lower case English, then upper and lower case Greek, etc.

REFERENCES

[1] Metis Design, 2011, "Structural Health Monitoring." from http://www.metisdesign.com/structural-health-monitoring-company.html

[2] NMSGC, 2011, "Education Launch." from http://www.launchnm.com/

[3] UP Aerospace, 2010, "2009-2010 Launch Data." from http://www.launchnm.com/data.php