DEVELOPMENT, EVALUATION AND IMPLEMENTATION OF A SURFACE-MOUNT, HIGH-G ACCELEROMETER

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ABSTRACT

The Endevco model 7270A high-g accelerometer has been used successfully in numerous flight tests at the U.S. Army Research Laboratory. The accelerometer is available in ranges as low as 6,000 g's up to 200,000 g's so they can be used in a variety of situations to measure setback, set forward and balloting in artillery rounds, mortars and tank projectiles to name a few. However, one of the disadvantages of the model 7270A is its physical size, in the era of die level and surface mount components, the 7270A is relatively large. The sensing element is packaged inside a metal case with screw holes for mounting to a rigid surface. In addition, there are wires protruding from the case for electrical connections. In the area of munitions, small cavities don't always afford the room for a large gauge. It was desirable to repackage the die in a smaller container and make it a surface mount component for a printed circuit board. A contract was developed for Endevco to repackage the die and to develop a tri-axial version with the repackaged die. The newly developed accelerometers were tested and evaluated by the U.S. Army Research Laboratory.

KEYWORDS

Accelerometer, High-G, Triaxial, Endevco Model 7270A, Repackaged, Smaller Size

INTRODUCTION

The Endevco model 7270A high-g accelerometer has been used successfully in numerous flight tests at the U.S. Army Research Laboratory. The accelerometer is available in ranges as low as 6,000 g's up to 200,000 g's so they can be used in a variety of situations to measure setback, set forward and balloting in artillery rounds, mortars and tank projectiles to name a few. However, one of the disadvantages of the model 7270A is its physical size, in the era of die level and surface mount components, the 7270A is relatively large. The sensing element is packaged inside a metal case with two clearance holes for #2 screws to mount the gauge to a rugged surface. From this metal case wires are protruding to make the electrical connections. A photo of the gage can be seen in figure 1.

Figure 1: Endevco Model 7270A Accelerometer

With the small cavities to work with in the area of munitions a gauge of this size will often consume a lot of valuable real estate and in some situations will not fit at all. The desire of the community was to repackage the gauge into a surface mount component that could be mounted directly to a printed circuit board. It was desirable to use the existing die, or one with similar electrical characteristics, and replace the metal housing and mounting scheme with a much smaller package that would consume considerably less space. Endevco was contacted and it was determined that repackaging the die in a smaller surface mount package was a doable effort. Through the Hardened Subminiature Telemetry and Sensor System (HSTSS) program a contract was awarded to Endevco for this effort with testing and evaluation to be performed at the U.S. Army Research Laboratory.

SINGLE AXIS ACCELEROMETER

The die from the existing 7270A accelerometer was repackaged into a small plastic carrier and a surface mount, high-g accelerometer was developed by Endevco and given the designation model 70. The 7270A is approximately 0.565" x 0.275" x 0.110" whereas the model 70 accelerometer is approximately 0.250" x 0.125" x 0.075". Since the model 70 is a surface mount component there are no wires extending from it. A photo of the two gauges side by side is shown in figure 2. The model 70 gauge was made in three different g levels, 6,000, 20,000 and 60,000 g's.

Figure 2: 7270A Accelerometer vs. Model 70 Accelerometer

Independent of this contract Endevco was redesigning the die used in the 7270A gauges. Leveraging that effort, the die used in the model 70 60,000 g accelerometer was a new design whereas the initial 6,000 g and 20,000 g accelerometer used the preexisting die. The new die was designed to be transparent to the user in the sense that it had the same or similar electrical and mechanical properties as the original. The main difference was that it is easier and less time consuming to assemble.

SINGLE AXIS ACCELEROMETER SHOCK TESTS

Shock table tests were performed on the gauges to determine if they performed according to the specifications in the contract. An MTS Shock Table, shown in figure 3, at the U.S. Army Research Laboratory was used to perform the tests. The shock table has a range of loads it is capable of imparting from very small shock with a relatively long duration to shock as high as 30,000 g's and a short (μs) duration. As the shock load increases the maximum duration obtainable decreases.

To operate the shock table the device tested is rigidly mounted on a table and the table and device, as a unit, is raised to a given height and held in place via a set of brakes. A bungie cord, attached to the table, applies a force in the direction of the base. The higher the table is raised the more the bungie cord stretches and the load is increased. To impart the shock the brakes are released and the table slams down on a solid base. A buffer material, such as felt, is placed on the solid base to program the level of shock. The duration and level of shock is determined by the height of the table and the thickness and makeup of the buffer material. To increase the shock duration a thicker and/or softer buffer material is used, however, this reduces the maximum shock load for a given height. To obtain a given shock load with a thicker material the table height has to be increased. There is a trade off between shock duration and shock pulse and these are controlled by table height and buffer material.

Figure 3: MTS Shock Table

Figure 4: Accelerometer Test Board

In order to compare the 7270A gauge and the model 70 gauge it was desirable to test them at the same time on the shock table and observe the response of each one. A circuit board was designed and developed, shown in figure 4, that would hold both accelerometers and provide the power regulation and signal conditioning for both the gauges. Note that one side of the 7270A gauge was cut off in order to make it fit on the circuit board. This procedure is used frequently to fit the gauge into small locations. Instead of mounting it with screws, it was glued to the board with five minute epoxy and the entire board was bolted to an aluminum plate that would be mounted to the shock table as shown in figure 5. With this setup the two gauges are as close together as possible which would allow for a good comparison on the shock table.

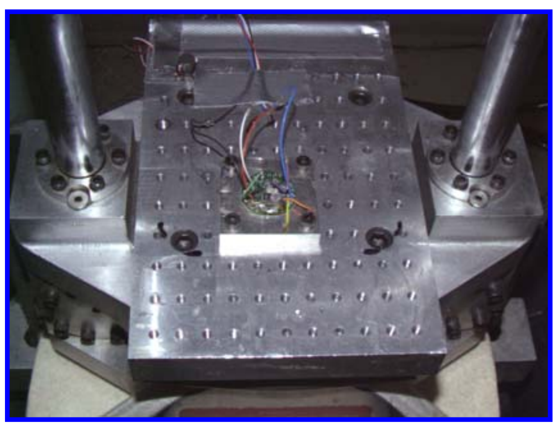

Figure 5: Accelerometer Test Fixture Mounted to Shock Table

Multiple drop tests were performed and the output of each sensor was measured, recorded and converted to acceleration using the scale factors supplied with the gauges by Endevco. It can be seen from the graphs in figures 6 and 7 that the response of the model 70 gauge is very similar to the response of the 7270A gauge. The minor variations in the shock pulse from one gauge to the other were expected. Even though the gauges were mounted as close together as possible there are still variations that can occur on the shock table and it is possible that the printed circuit board could have some minor deflections contributing to variations in the measured shock pulse. Overall, these results are very promising and show that the two different versions of accelerometers are indeed functioning as expected.

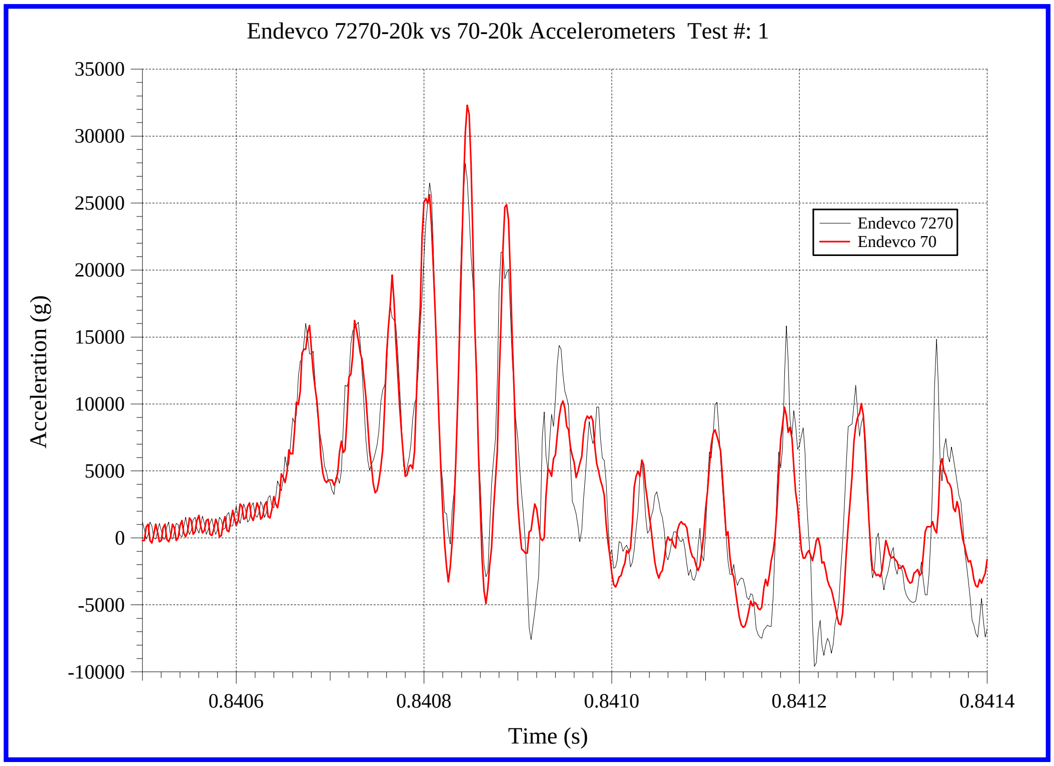

Figure 6: Comparison of the 7270 and 70 Accelerometer Outputs for Drop Test #1

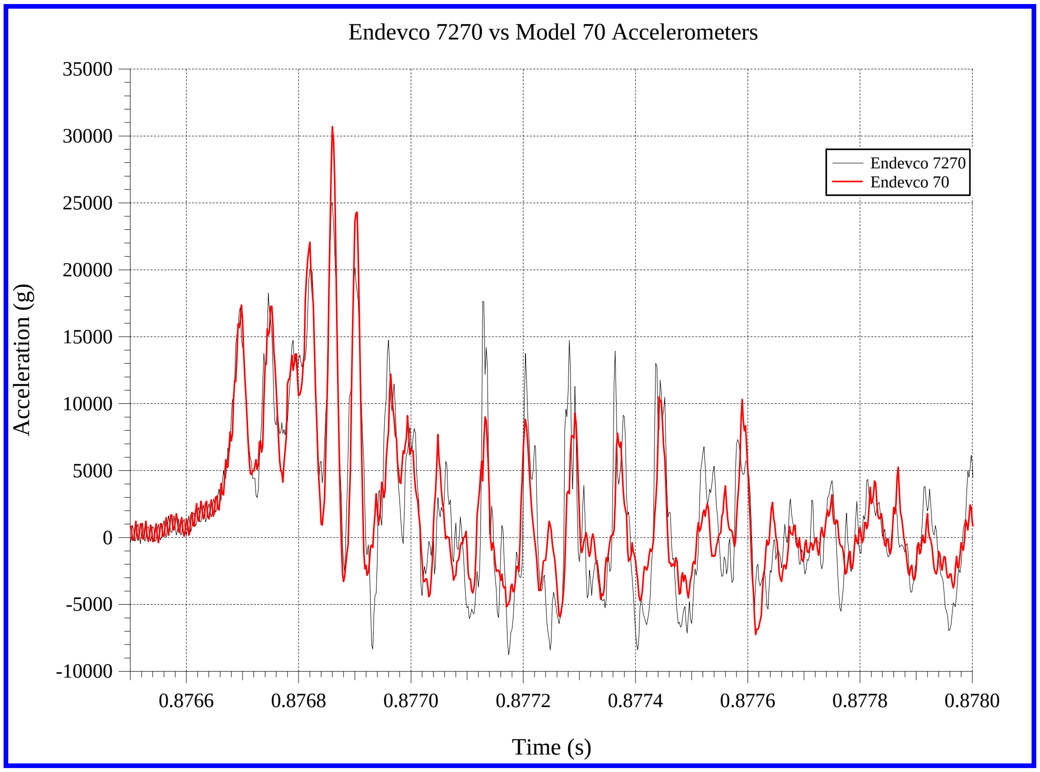

Figure 7: Comparison of the 7270 and 70 Accelerometer Outputs for Drop Test #2

TRI-AXIAL ACCELEROMETER

In addition to repackaging the die it was also determined that it would be beneficial to have a surface mount, high-g, tri-axial accelerometer. The concept was to mount three model 70 gauges on a cube that would allow for the measurement of acceleration in all three axes. A cube was developed with electrical traces and three accelerometers were mounted on it as shown in figure 8. On the bottom of the cube were solder pads so conductive epoxy could be used to mount it to a printed circuit board. In addition to the pads on the bottom of the board, there were also pads on top for wires in case that was the desired connection point. The accelerometer on the top of the cube was a 60,000 g accelerometer and the two on the sides were 6,000 g accelerometers. However, any of the three ranges (6k, 20k, or 60k) can be mounted on the cube giving it a great degree of flexibility depending on the required measurement ranges. This particular configuration was chosen for a typical gun launch where the top gauge would measure setback acceleration and the side gauges would measure balloting.

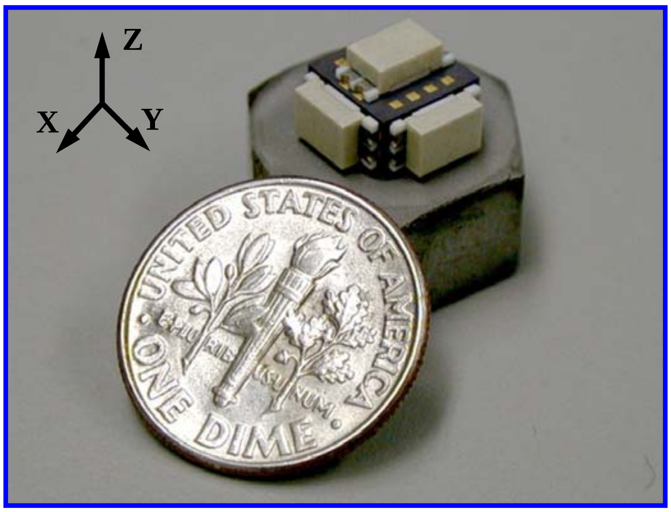

Figure 8: Model 73 Tri-Axial Accelerometer

TRI-AXIAL ACCELEROMETER SHOCK TESTS

A printed circuit board (PCB), shown in figure 9, was developed to test the tri-axial accelerometer. The PCB provides power for the accelerometer cube as well as signal conditioning for all three of the accelerometers on the cube. The accelerometer cube was initially attached to the PCB via conductive epoxy only, but an additional nonconductive epoxy was later added, as shown in figure 10, after if was concluded that the conductive epoxy alone was not strong enough to hold the cube to the board.

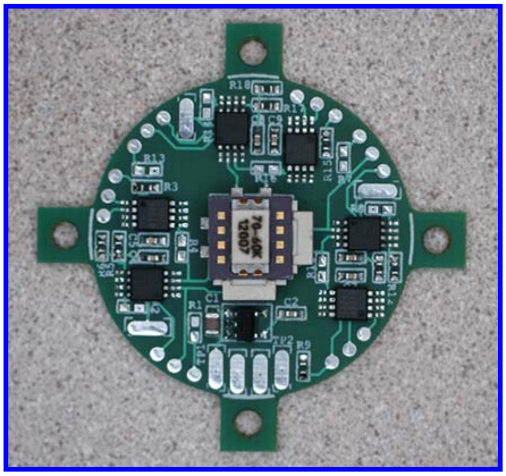

Figure 9: Tri-axial Accelerometer and PCB

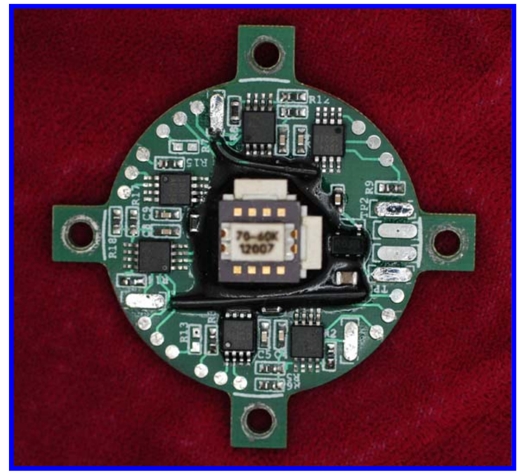

Figure 10: PCB with additional epoxy

Similar to the model 70 accelerometer tests, one 7270A was mounted near the model 73 accelerometer cube as a reference. However, it was not mounted on the PCB due to space limitations. The 7270A was instead mounted next to the PCB as shown in figure 11.

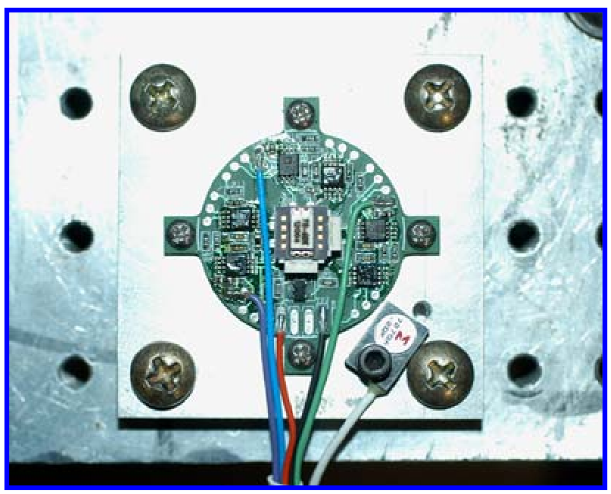

Figure 11: Accelerometers mounted to the shock table

Results for these tests are shown in figures 12 thru 14. In each case, the z-axis is the axis in the direction of movement of the shock table whereas the x and y axes are perpendicular to the axis of movement. Ideally, the response from the z-axis gauge on the model 73 should be as close as possible to that of the 7270A accelerometer. The results from each of the following tests show that the output response of the model 73 z-axis accelerometer is very similar to the response of the 7270A accelerometer. As seen with the earlier model 70 tests, there are some differences between the outputs of the two accelerometers. However, this was expected since the sensors are located at different points of the shock table and it is typical for multiple sensors to often have small differences in output response. Overall, the results of these tests show that the model 73 accelerometer is working as expected and providing good measurements.

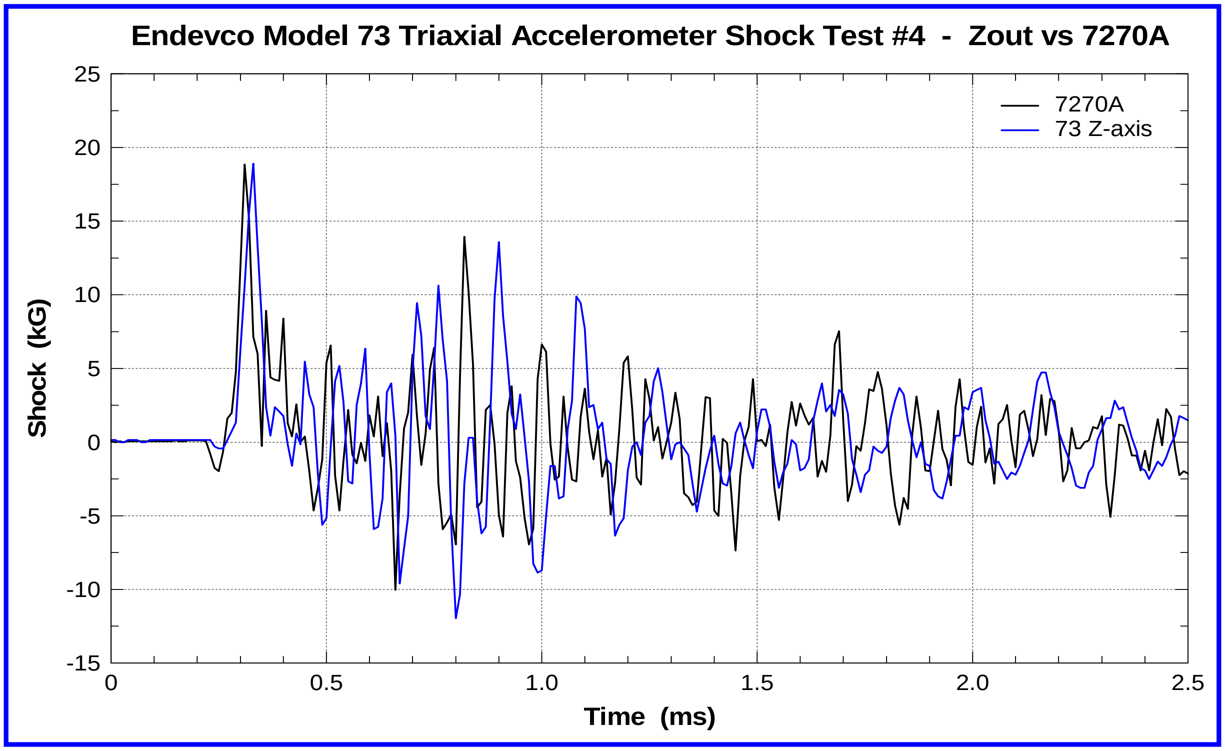

Figure 12: Comparison of the 7270A and 73 Z-axis Accelerometer Outputs for Drop Test #4

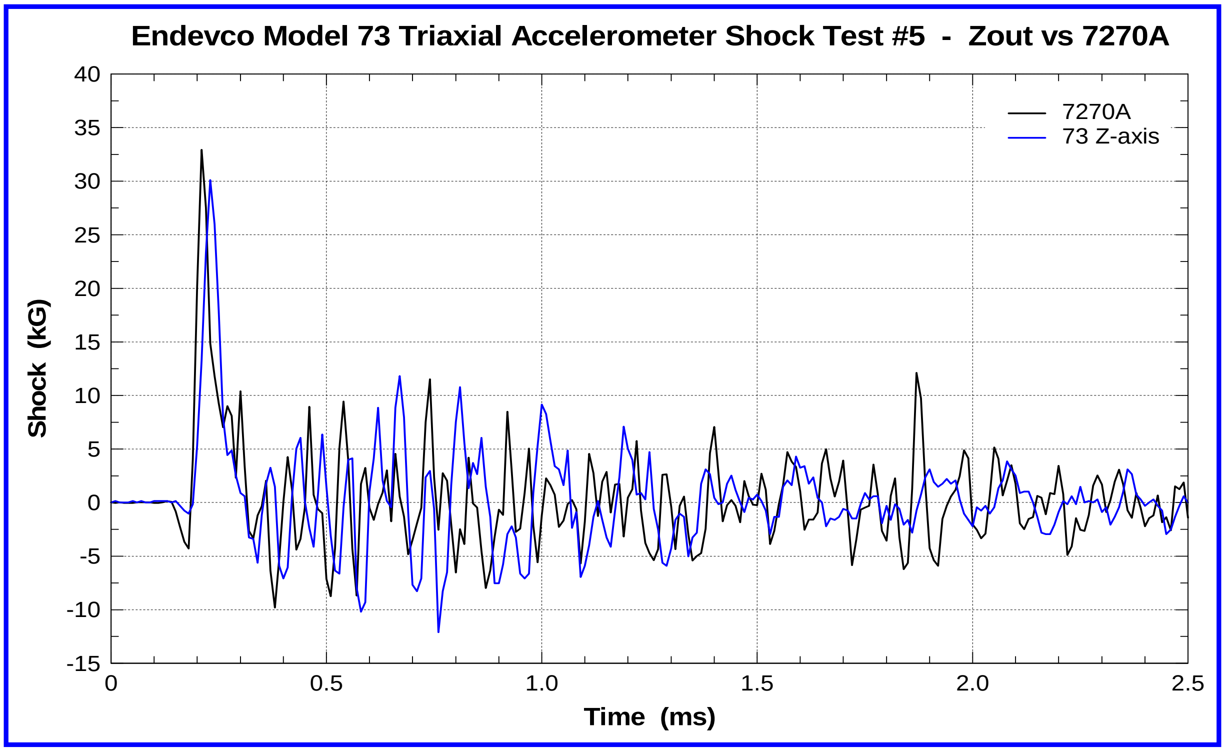

Figure 13: Comparison of the 7270A and 73 Z-axis Accelerometer Outputs for Drop Test #5

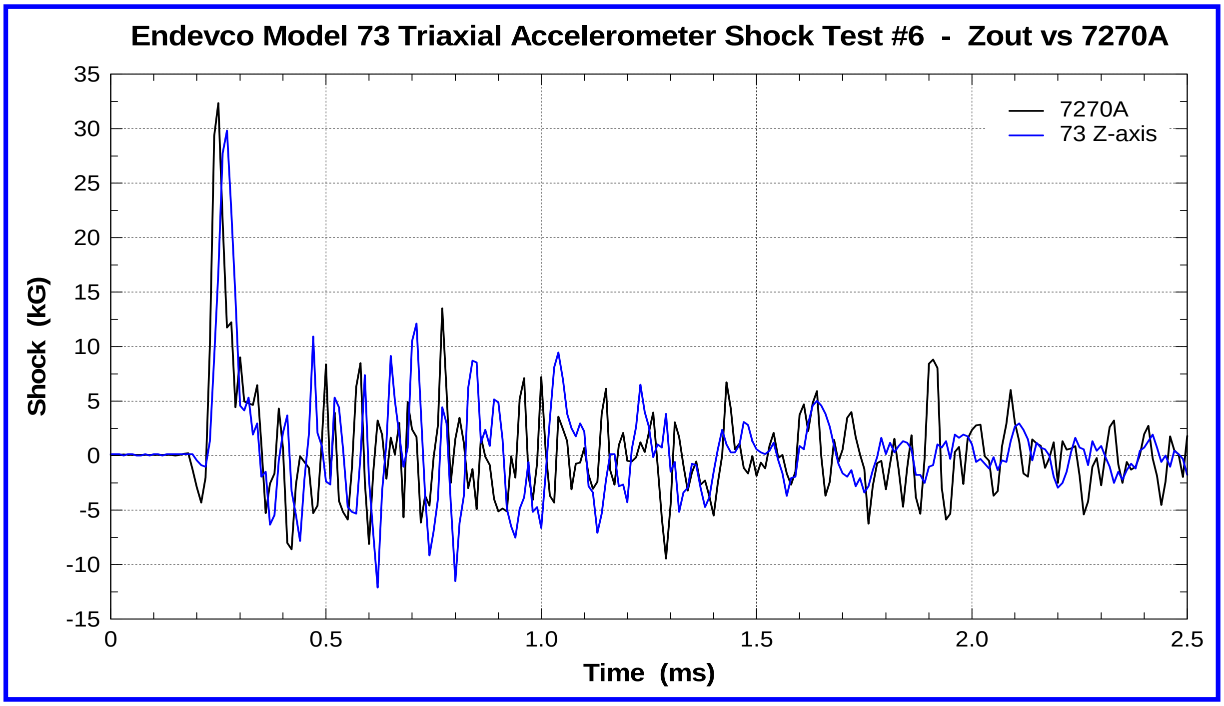

Figure 14: Comparison of the 7270A and 73 Z-axis Accelerometer Outputs for Drop Test #6

In addition to the z-axis measurements, the response of the x and y axis gauges were also recorded for each test. An example is shown in figure 15. Each of these gauges also measured small amounts of acceleration during the tests. This was expected because the shock table is a very harsh environment and it does not always produce a unidirectional shock. Although not planned, there is lateral movement which is measured by the x and y accelerometers.

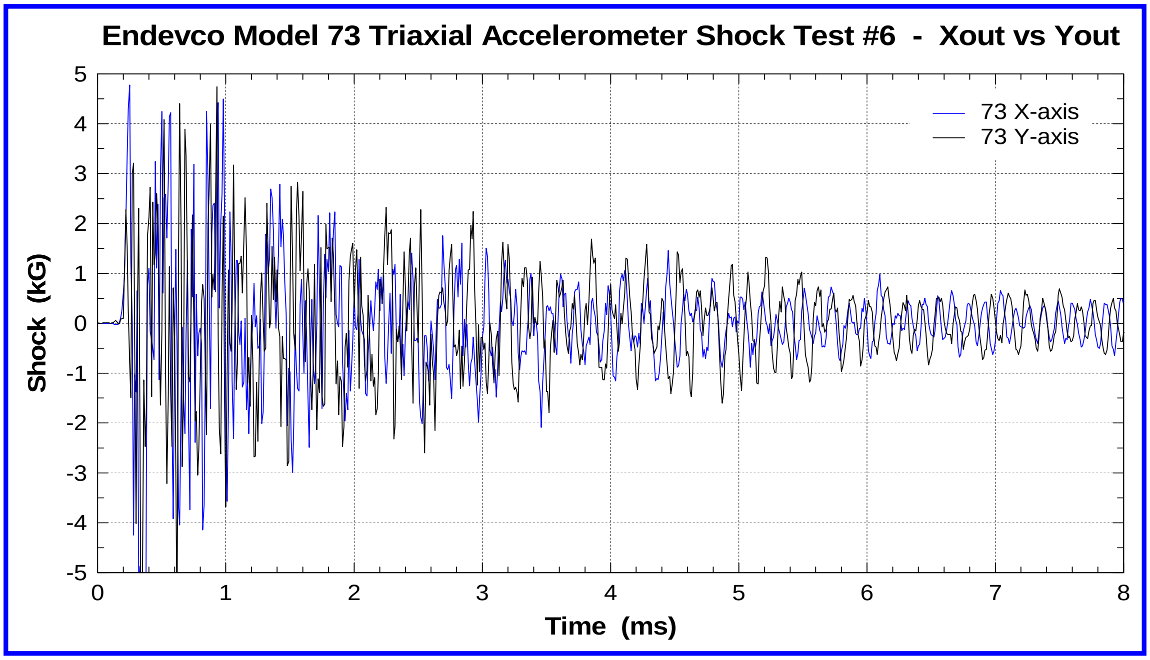

Figure 15: Comparison of the Model 73 Tri-axial Accelerometer X and Y axes

FLIGHT TEST DATA

Once evaluation of the model 73 accelerometer cube was completed, it was used on a variety of flight tests. In one case, onboard sensor data, which included the model 73 and several pressure sensors, was provided via an onboard telemetry system. The model 73 and pressure sensor data was used to measure set-back acceleration. A comparison of all three data sets, shown in figure 16, provided the test engineers with an accurate assessment of set-back acceleration.

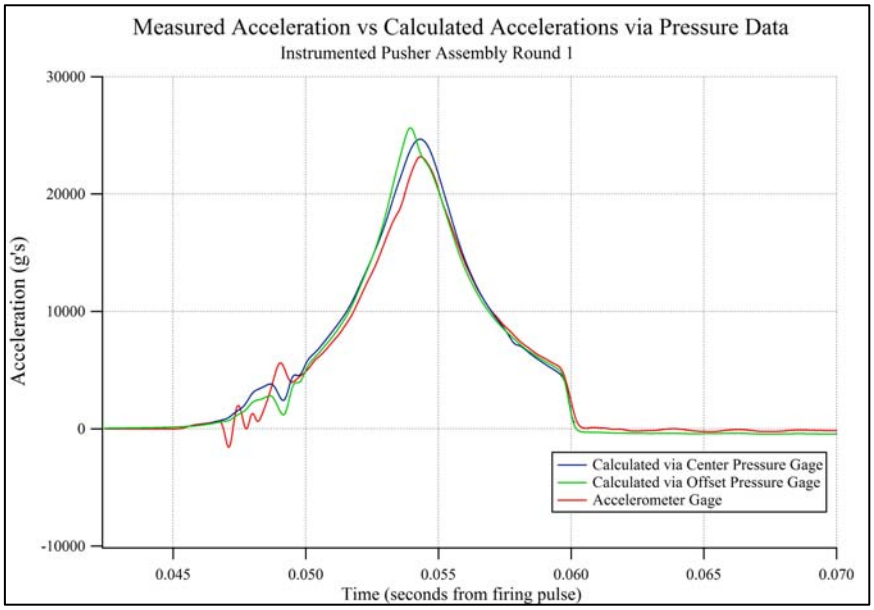

Figure 16: Flight Test Data Provided by the Model 73 Accelerometer Cube

CONCLUSION

Through a contract with Endevco, a new surface mount accelerometer, the model 70, was developed which reduced the size of the 7270A high-g accelerometer significantly. The model 70 was also packaged onto a small cube to form a surface mount tri-axial accelerometer, the model 73. Both of these new accelerometers were shock tested numerous times up to 35,000 g's and the response of each one was found to be very similar to the standard 7270A gauge. These new accelerometers free up valuable real estate in the small cavities where instrumentation and sensors are often placed and provide greater design flexibility over the original 7270A gauge.

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