



# Sandia National Laboratories

Operated for the U.S. Department of Energy by  
**Sandia Corporation**

Albuquerque, New Mexico 87185

## **Sandia National Laboratory Project:**

### **Final Report of NMSBA Project for Z-Coil (Database # 3985)**

#### **Introduction**

In FY01 a New Mexico Small Business Assistance (NMSBA) Program was set up with Mr. Al Gallegos, President of Z-Coil Footwear. Mr. Gallegos and Z-Coil Footwear have developed and patented shoes that are different from traditional shoes in that they have a steel coil spring located in the heel for cushioning. The support requested for this project was for mechanical testing of the spring, orthotic plate, and fore foot cushioning, and to make a prototype of a lightweight toe guard, which mounts on the outside of their boots. This memo is intended to document the work that was done for this project.

#### **Description of Work**

Three coil spring sizes (large, medium, and small) are used in the various Z-Coil shoes depending on the shoe size. The following mechanical tests were performed to evaluate these springs used in Z-Coil Shoes:

- The force vs. displacement (spring constant)
- The force vs. displacement at different locations (off-axis) on the springs
- Distance required to "bottom out" springs

In addition, tests were run to measure the cushioning in the heel and toe box of a pair of his shoes and then compared to a name brand cushioning shoe. A test to evaluate the stresses on an orthotic plate built into his shoe was setup, but due to time and funding, was never run. A lightweight prototype toe guard, made for the outside of a Z-Coil boot, was made for Mr. Gallegos to present at a safety meeting.

#### **Mechanical Test Results**

Testing of the springs to determine their spring constant was performed with an Instron Mechanical Tester, which records the force and displacement of the spring as it is being compressed to a set displacement. The plot in Figure 1 shows the results of two tests run on a spring of each size (large, medium, and small). From this data, it is apparent that the three sizes of springs, which were supposed to give three different levels of stiffness, are not very different, and in the case of the large

springs, somewhat variable. If the springs are compressed any further beyond 0.8" or 0.9" the load increases at a much higher rate due to the springs being fully compressed or "bottomed out".

### Z-Coil Spring Tests

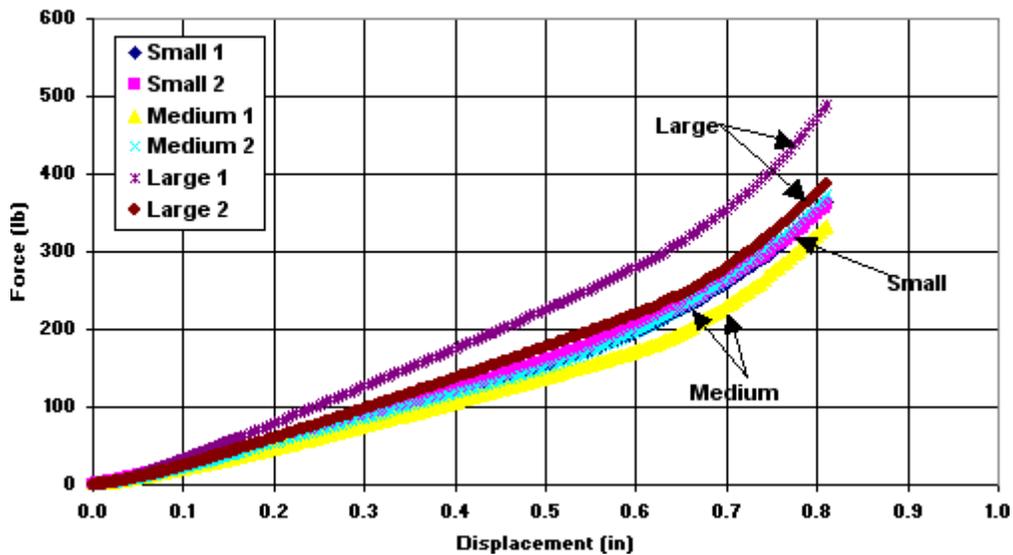


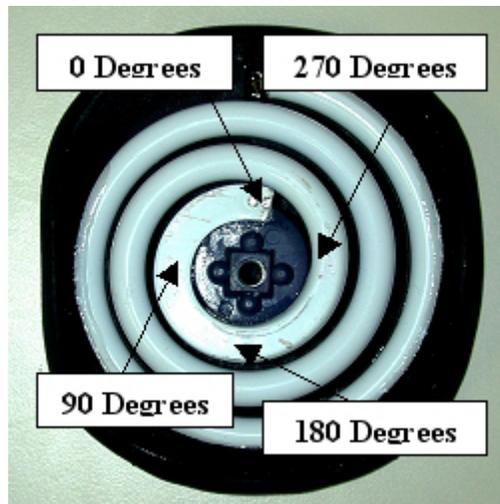
Figure 1

An off the center axis compression test, pushing at a distance from the center axis, was run on the two small and large springs to show differences in spring stiffness vary with location of loading. This can be advantageous to help a runner who pronates or supinates excessively. The test location angle is defined as the 0 degrees being the end of the spring and different angles are taken by following the spring from there (see Figure 2). As the data in Table 1 shows, the springs are stiffest in the 0o to 270o location and least stiff, almost 20% less, at the opposite end (90o to 180o location).

**Table 1. Off-Axis spring test results.**

Sample ID	Spring Size (Small/Medium/Large)	Off-Axis Test Location (Degrees)*	Normalized Spring Constant (no units)
Large 1	Large	0	0.93
		90	0.78
		180	0.86
		270	1.00
Large 2	Large	0	0.95
		90	0.84
		180	0.88
		270	1.00
Small 1	Small	0	0.99
		90	0.88
		180	0.88
		270	1.00
Small 2	Small	0	1.00
		45	0.93
		90	0.86
		135	0.82
		180	0.85
		225	0.95
		270	0.98
		315	0.98

\* Force off-axis location was defined as location starting at end of spring outside and moving along spring toward middle.



**Figure 2**

A cushioning (displacement for a given force) comparison test of a Z-Coil shoe to a popular name brand cushioned shoe was done by pushing on the toe box and heel of the shoes and measuring force and displacement. Figure 3 shows the data from these tests. The results show an increase in cushioning, at various forces, of over 100% in the toe box and 50% in the heel of a Z Coil shoe when compared to the name brand cushioned shoe.

### Z-Coil and Popular Name Brand Cushioned Shoe Cushioning Test Comparison

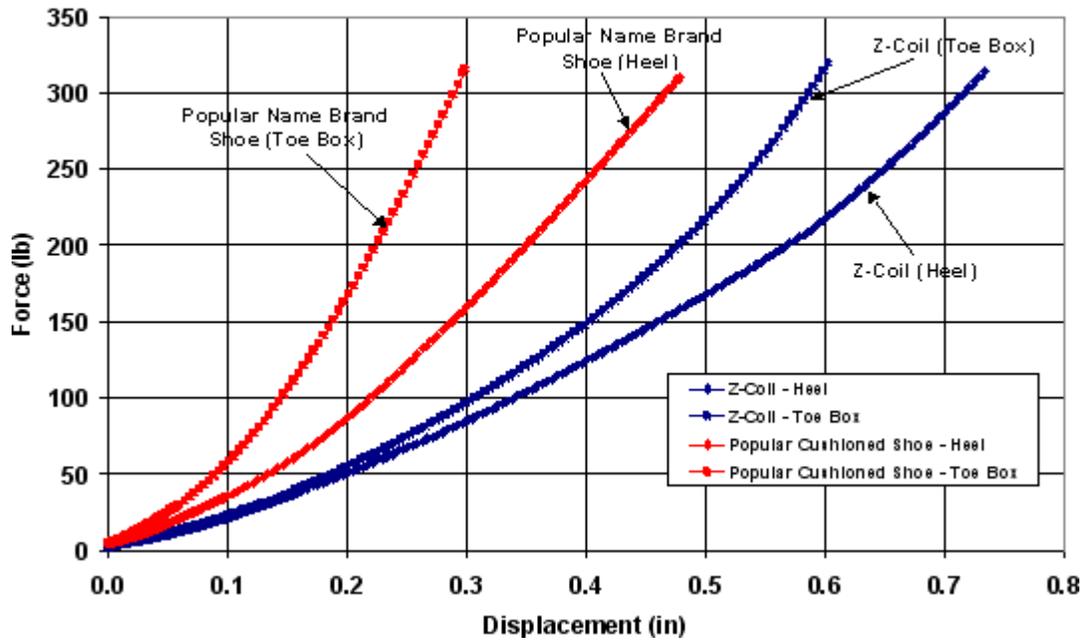


Figure 3

A test to measure the relative stresses on the orthotic plate was part of the initial test plan, however, due to insufficient funding and time, this was not completed. An image of the test setup is shown in Figure 4.



Figure 4

### Fabrication of Prototype Toe Guard

The customer requested the fabrication of a lightweight toe guard that is mounted to the outside of a

boot. An ABS plastic material was chosen for the toe guard due to availability, processing ease, and low cost. The fabrication process involved using a boot to make an RTV mold master, making another mold from the master, thermoforming the ABS material over the mold, and then trimming the part to size (Figures 5-8).



Figure 5



Figure 6

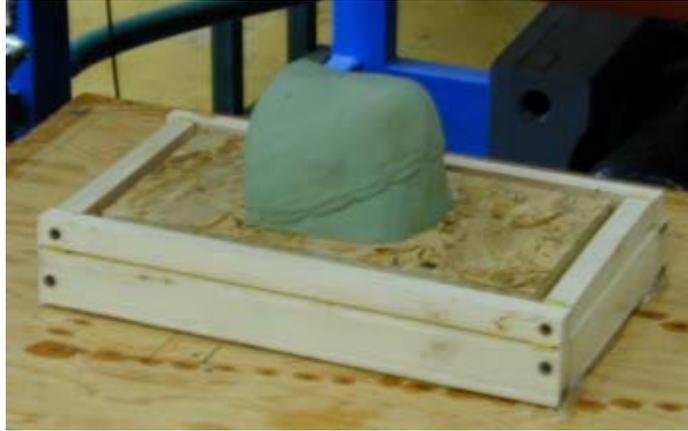


Figure 7



Figure 8

## Conclusions

As part of the New Mexico Small Business Assistance (NMSBA) Program several mechanical tests were run to characterize the cushioning and support of a pair of Z-Coil shoes. These tests showed some variability in the stiffness of the springs used in the heel of these shoes and not much difference between the three spring sizes. The tests also showed a large increase in cushioning with the Z-coil shoe when compared with a popular name brand cushioned shoe. A lightweight toe guard that mounts on the outside of a boot was also manufactured.