Extensible Column Compliance System

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Extensible Column Compliance System

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This research investigates a possible solution to lower the stiffness of the Extensible Columns, which provide support to the Mobile Launcher. Material_X was determined to be the material best suited to lower the stiffness while still supporting the load. The only vendor to supply sufficient data that could prove their product would work was Vendor_A. The data they provided on the Product_Y General Bumper was analyzed and a compliance system using the bumper was designed. A test plan was developed and bumpers were ordered for testing. Testing is currently in progress to determine if the Product_Y is truly a solution.

I. Introduction

A. Background

The purpose of the given system (SYS) is to provide additional support to the Mobile Launcher during the launch of the Space Launch System (SLS). The structures will be connected to the flame deflectors and will provide vertical support around the flame hole of the Mobile Launcher. It is essential that the SLS not be damaged during launch, so to ensure this, the structures are required to have a stiffness within a certain range. Based on an integrated structural analysis the overall stiffness of the structure needed to be lowered to reduce risk of over-stressing the vehicle. To achieve this, a compliance system needs to be added to the SYS to lower the overall stiffness. The compliance system consists of a high performance Material_X that was determined to be the material best suited to obtain the necessary stiffness, being able to handle high compression loads and provide damping.

B. Requirements

Based on analysis, a structure stiffness of value_q lbf/in would not damage the vehicle as it lifts off of the Mobile Launcher. The current stiffness of the SYS steel structure is greater than value_q, so, to lower the total stiffness down to the required value, a compliance system must be added to the top of the structures and it must have a stiffness of value_r lbf/in at the load of the fully fueled vehicle. Allowing for ten percent difference results in the range of value_r1 to value_r2 lbf/in. Before the launch, each structure will be preloaded to a certain load and will then experience an additional load from the fully fueled vehicle. The maximum load the structure must support is value_s lbs. Therefore, the compliance system must have a stiffness within the necessary range under the load of the fully fueled vehicle, and also be able to support the maximum load.

II. Product Summary

A. Product_Y General Bumper, Vendor_A

One material that fits these requirements is the Product_Y General Bumper, from Vendor_A. These bumpers are made of hardness_x durometer Material_X that has been processed in a way to make it stronger and to increase its load bearing capacity. Vendor_A provided height vs force data and, using this and the fueled load, a required number of bumpers was calculated to achieve the necessary stiffness. They also provided temperature data for a similar product composed of the same material, which shows that at higher temperatures, the material becomes less stiff, bringing the total stiffness down further into the required range. Currently, this is the most cost effective and data supported solution, and is the main focus of this report.

B. Hardness_x/Hardness_xb Durometer Material_X Pad, Vendor_B

This is a standard Material_X sold by Vendor_B, both the hardness_x and hardness_xb durometers were purchased and tests will be run on them to obtain stiffness and load capacity data. Vendor_B was unable to provide meaningful compression data, but the pads have a similar durometer to that of the Product_Y bumpers. This is a secondary option

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to the Product_Y bumpers and the results of the tests run on this material will give a baseline to judge the effectiveness of the bumpers.

C. Other Materials

Several other materials were considered, but no company was capable of providing data that could confirm that their material could support the load while having the necessary stiffness. If testing reveals that the Product_Y bumpers do not fit the application, other materials can be obtained and tested, but at a much higher price with much lower confidence. Other vendors have been contacted, and upon receiving data and pricing information, more materials can be ordered and tested.

III. Calculation

The Product_Y is shaped like a large bar of soap with two mounting holes and is more than capable of withstanding the necessary force. The minimum and maximum number of bumpers possible is determined by the minimum number required to support the load and the maximum number that can fit on the top surface of the structure. Calculations had to be done to determine what number of bumpers between these two values would have a stiffness within the necessary range at the fully fueled vehicle load. First, a number of bumpers per side was chosen within the range of maximum and minimum, this number being based on the results of the last calculation, making this an iterative process. Then, the force per bumper was calculated by dividing the fueled vehicle load by the number of bumpers. Using this number and the data given by Mineral Elastomer, the slope at that point, and therefore the stiffness per bumper, was found by calculating the slope of data points around the force per bumper. Fig. 1 shows the graph of the data points surrounding the force per bumper value, as well as the equation of that line, and Fig. 2 shows the entirety of the data points, demonstrating that the stiffness is not linear. The slope that line gives the stiffness per bumper, which was then multiplied by the number of bumpers per side to give the stiffness. Although one layer of bumpers could adequately handle the load, the stiffness was too high, resulting in an unacceptable overall stiffness value. To lower the stiffness further, a second layer of bumpers were added in series to the first. All of these values are reported in Table 1.

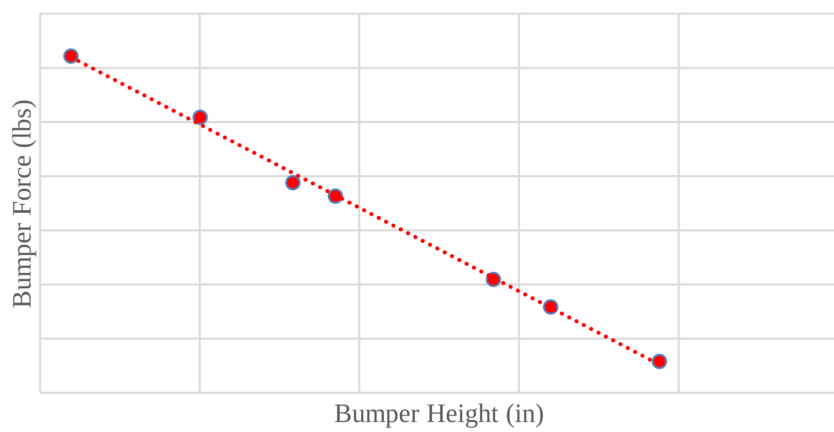

Figure 1. Height vs force of the Product_Y General Bumper at 1.7 million pounds. *This curve shows the points used to calculate the slope of line at a given load.*

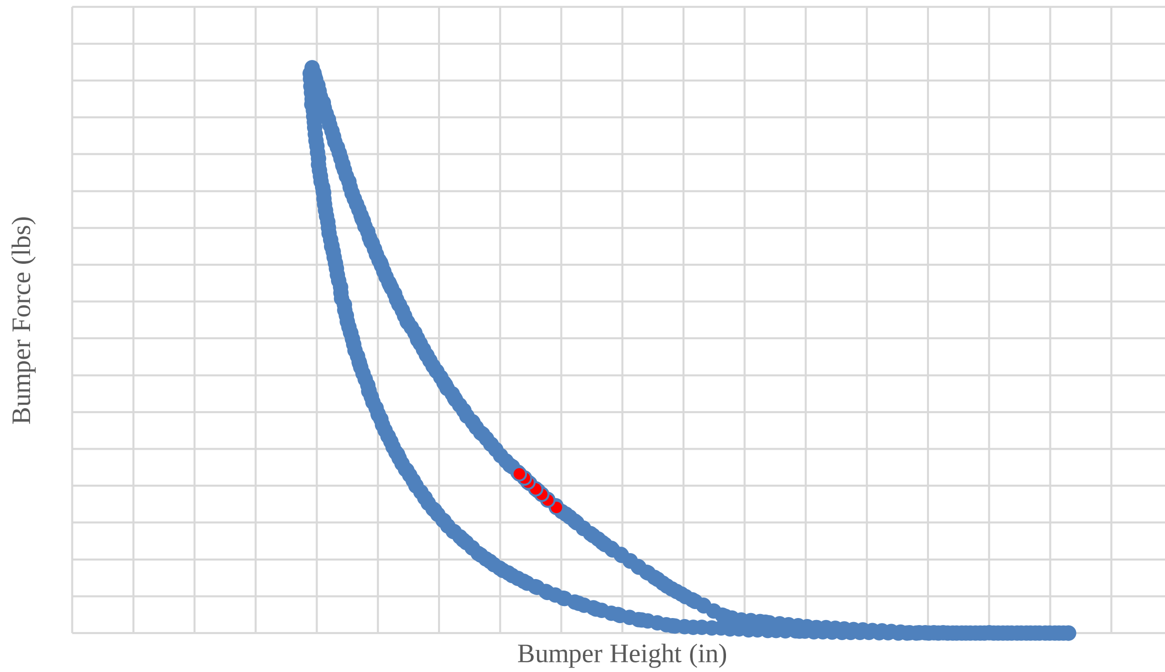

Figure 2. Height vs force of the Product_Y General Bumper with all data points plotted.

Number of bumpers per side	Total load (lbf)	Stiffness per bumper (lbf/in)
42	Fueled Load	Stiffness
Force per bumper (lbf)	**Stiffness of one side (million lbf/in)**	**Total stiffness (million lbf/in)**
(Fueled Load)/42	Stiffness*42	(1/(Stiffness*42)*2)^(-1)

Table 1. Results of Calculations. *The actual values have been removed, but the formulas are shown in their place.*

IV. Temperature Effects and Closure Explanation

A. Temperature Effects

The temperature data that was provided is not specific to the Product_Y bumpers, but is of a similar product made of the same material. This was the best data Miner Elastomer could provide, but the materials in Fig. 2 react similarly to the Procuct_Y bumpers to increases and decreases in temperature. Fig. 2 shows a trend of decreasing stiffness as temperature increases, and vice versa.

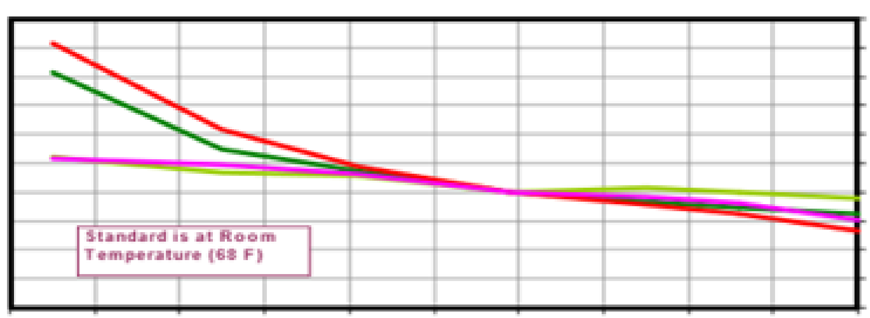

Figure 3. Temperature effects on general products. *These curves show the general trend of stiffness increasing at lower temperatures and decreasing at higher temperatures.*

B. Closures

The Product_Y bumpers experience "closures" as they are loaded to different points. Fig. 3 shows the path that the Product_Y bumpers will follow throughout the loading process. During the preload, the deflection will follow the first closure curve, but, because the bumpers will be left at that load for up to 72 hours, the material will deform, dropping down and to the right on the graph to the second closure curve, which it will follow up to about the fully fueled vehicle load each individual bumper will experience. Table 2 shows the loading from the first closure data and Table 3 shows the loading to a greater load, from the second closure curve. The bumpers may be preloaded up to 72 hours and, as shown on the graph, will either decrease in height or load over that time, dropping from closure one to closure two. Vendor_A was unable to provide specific data on this process because it varies based on multiple factors, so tests will be conducted using the correct parameters to determine how the bumpers change during the preload. If necessary, the preload can be increased so that, by the time the vehicle is ready to be fueled, the load is back to the original preload. Once the test results are obtained on how the bumpers will react to the 72 hour preload, it can be determined if that load needs to be increased or if the bumpers maintain the load applied to them.

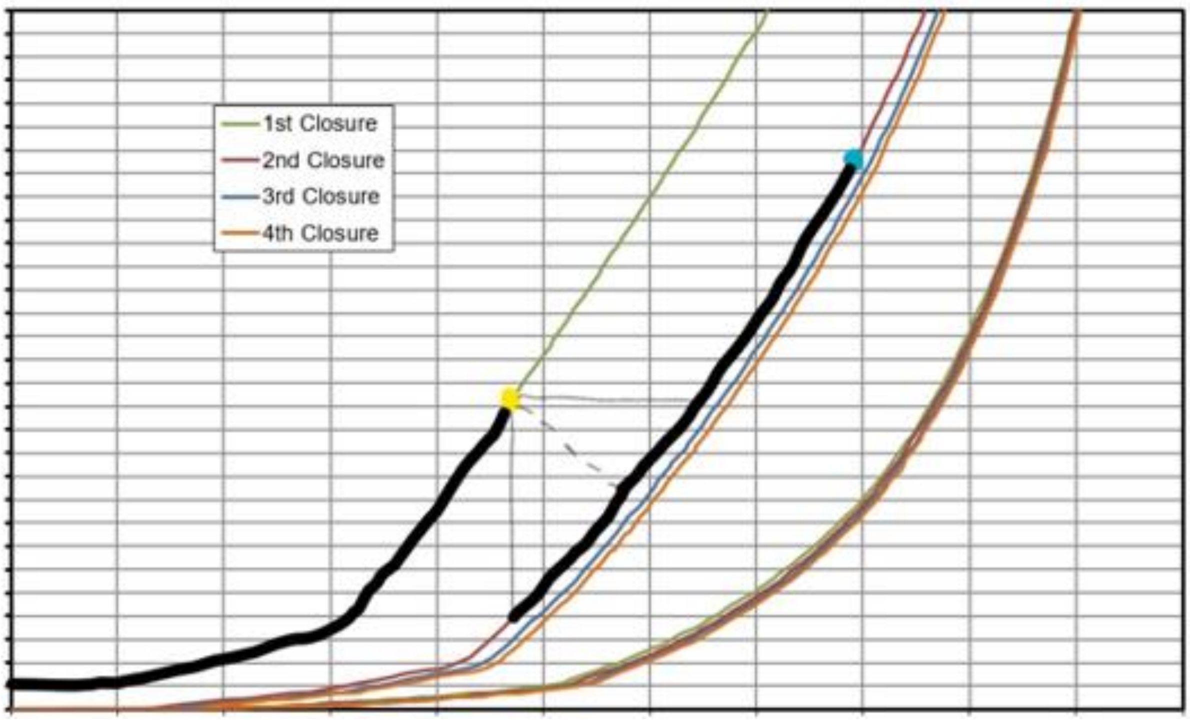

Figure 4. Product_Y closure curves. *This Fig. shows the path the bumpers will follow during the preload and fully fueled vehicle load.*

Force per Bumper (lbf)	Total Force (lbf)	Total Stiffness
2380	100000	Low
4762	200000	Low
7143	300000	Low
9524	400000	Low
11905	500000	Low
14286	600000	Low
16667	700000	Low
19048	800000	Low
21429	900000	In Range
23810	1000000	In Range
26190	1100000	In Range

Table 2. Stiffness data for loading to 1.1 million lbs. *The Stiffness numbers have been removed, and are instead represented by whether or not they are in the necessary range.*

Force per bumper (lbf)	Total Force (lbf)	Total stiffness
8000	336000	Low
10000	420000	Low
15000	630000	Low
20000	840000	Low
25000	1050000	Low
30000	1260000	Low
35000	1470000	In Range
40000	1680000	In Range
45000	1890000	In Range
47619	2000000	In Range

Table 3. Stiffness data for loading 2 million pounds. *The Stiffness numbers have been removed, and are instead represented by whether or not they are in the necessary range.*

V. Configuration

The bumpers must be arranged in a way that does not over stress the steel plate supporting them. The largest concern is bending stress, so to eliminate this the bumpers are aligned over one another. The current configuration is a plate with the bumpers aligned directly over each other and secured using socket nuts and screws. This method of stacking the bumpers minimizes the bending stresses in the plate and allows for a thinner plate. Fig. 5 is a screenshot of the bumper Creo model without the side plates. The side plates, which can be seen on the model on the cover page, will provide protection to the bumpers, as well as hold the entire system in place on top of the extensible structures. As Fig. 6 shows, the majority of the stress is in the bumpers, which are capable of withstanding those loads, and the steel plate is free of bending stress and has low compressive stress as well.

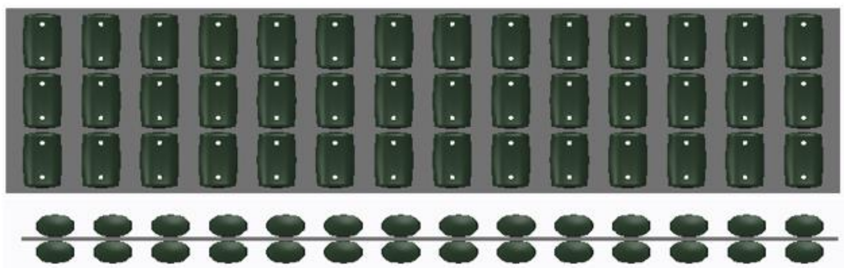

Figure 5. Product_Y configuration. *The bumpers are aligned directly over each other, with 42 on each side.*

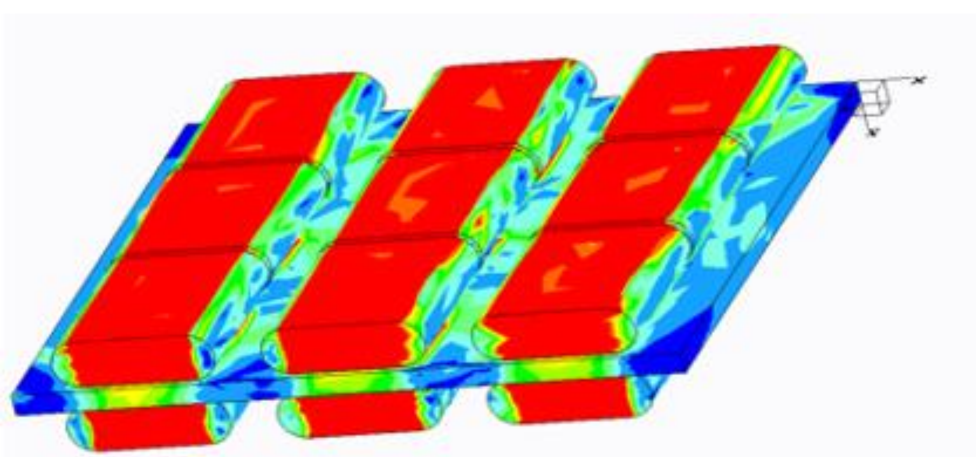

Figure 6. FEA model of a section of the damping system. *This model shows that load travels through the bumpers and that there is little to no bending stress in the steel plate.*

VI. Testing

A. Original Test Procedures

Materials have been ordered to begin testing the bumpers to see how they behave under the loads that they will experience. For the first test an individual bumper will be compressed to value_c lbs, the load on a single bumper at value_d lbs, and its displacement will be measured, so as to determine the stiffness. The second test will consist of a bumper being compressed to value_e lbs, the load each bumper will experience at the preload, the load will be fixed, and the bumper will be left to sit for seven hours, to observe how the stiffness changes over time. After seven hours, the load will be increased to value_f lbs, representative of the fueled vehicle load, and fixed there for an hour, and then finally the bumper will be loaded up to value_c lbs, the maximum load. In the third test, four bumpers will be configured as shown in Fig. 7, in the same configuration as they will be in for the actual system. This testing fixture will be loaded to simulate different load cases, including the preload and maximum load cases. Once again, the displacement will be measured throughout the test, and the system's load will remain fixed at the preload to see how it will react. Finally, the bumper and test system will be tested for a 72 hour launch scrub after the vehicle is fueled. This will be a similar test to the preload test, except the load cases will change from the preload case, to the greater than preload case, and then back to preload, to see how the bumpers deform. The Material_X pads from Vendor_B will also be tested using the same method as with the single Product_Y bumper, to see how the bumpers compare to plain pads of Material_X. Once all of these test results are obtained, it can be determined if the Product_Y bumpers are the correct material for the application.

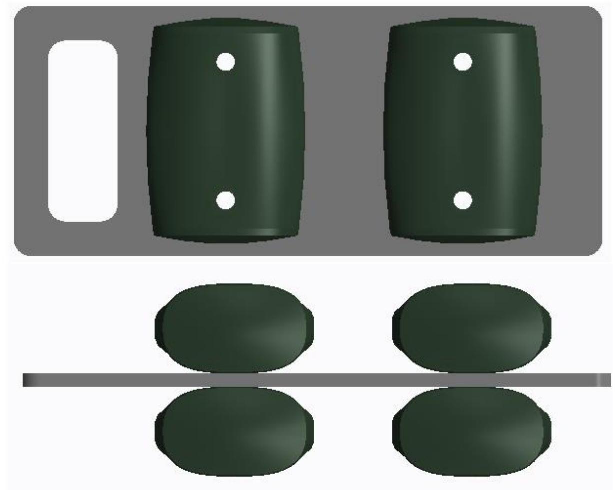

Figure 7. Test plate configuration. *This is the test plate that will be used for the compression test of the Product_Y bumper.*

B. Test Changes

Two tests have been completed so far and their results are shown below in Fig.s 8 and 9. Fig. 8 shows the result of the first test, the simple load up to value_c lbs with the Product_Y and both Material_Xs. This data only represents the first closure of the bumpers and this test was only done to try to match the data obtained from Vendor_A. Fig. 9 shows the results from the second load test, and demonstrates unexpected behavior in the bumpers. The critical stiffness point occurs immediately after the fueled vehicle load is applied for an hour and, as the graph shows, this is the steepest point on the curve, therefore having the largest stiffness. This stiffness is almost 150% higher than the required value, meaning that in the current configuration, the system would be too stiff. The slope immediately after the value_e lb preload was calculated to be almost the same as the slope after the fueled load, showing a promising trend of equal slopes after a load is held, no matter the value of

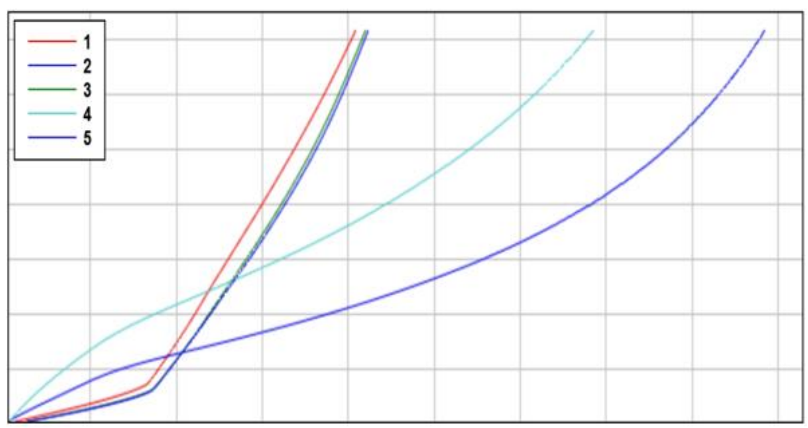

Figure 8. Results from test procedure 1. *The results are as follows: the three bumper tests are lines 1, 3, and 5, the shore 90A urethane is line 2 and the shore 95A urethane is line 4. The bumper results closely match the data obtained from Miner Elastomer.*

the load. Our next test will be to increase the preload value to value_g lbs and the fueled load to value_h lbs, which would be the values of a 21 per side bumper system, and see if the slope after holding is still the same. If it is, the stiffness will be back within the required range.

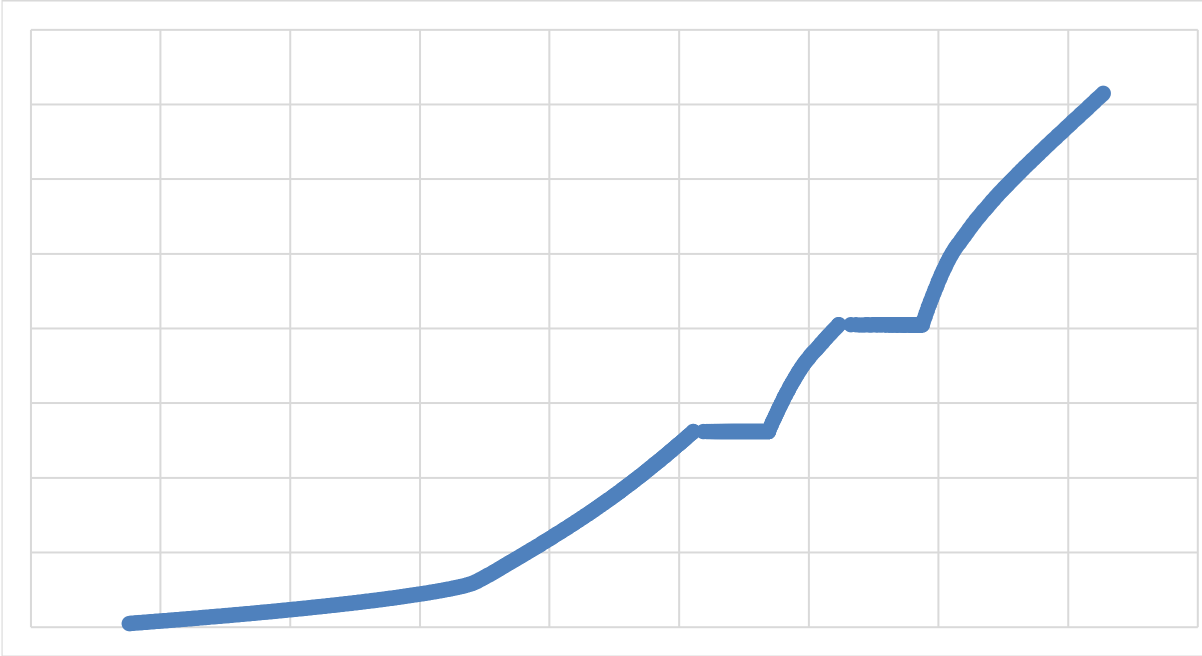

Figure 9. Results from test procedure 2. *This graph represents the data obtained from the second test procedure and is the reason for the change in testing.*

C. Final Results

After data was obtained from the final test procedure, it was determined that the bumper was still too stiff at the critical point. As Fig 10 shows, the stiffness per bumper increased by the same factor that the number of bumpers was decreased by, rendering the change in procedure useless.

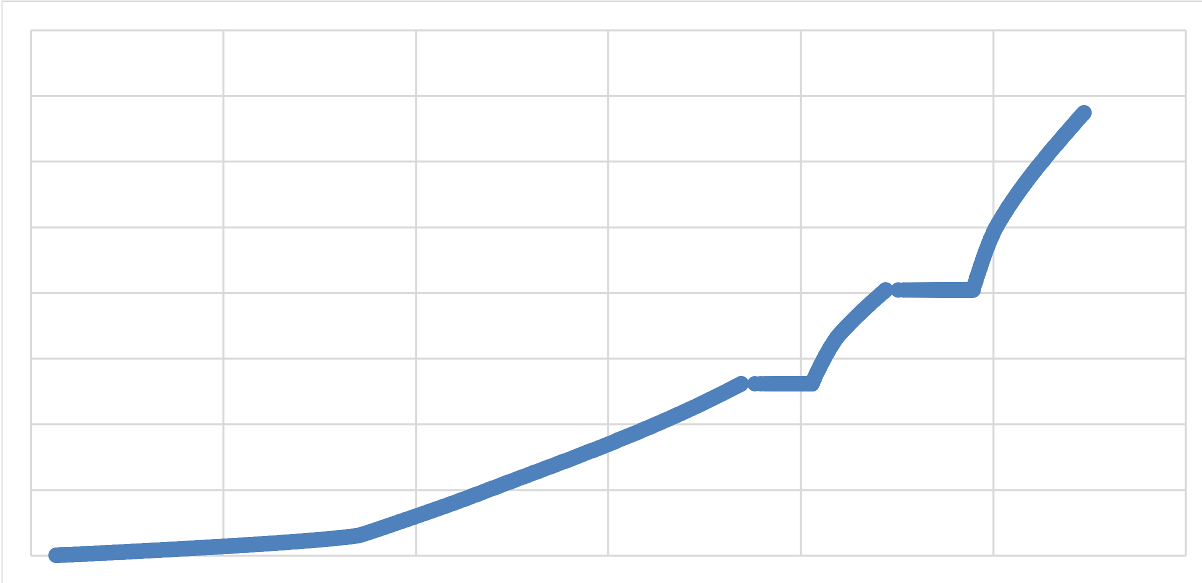

Figure 10. Results of final test. *Although the number of bumpers was decreased by a factor of two, the stiffness per bumper increased by the same factor, rendering the change useless.*

VII. Conclusion

Based on the available data, the Product_Y General Bumpers are the best solution to the stiffness problem, but other configuration options must be explored. The investigation is ongoing, and the current solution that is being tested is the possibility of adding more layers of bumpers in series. The bumpers are a cost effective and simple solution to the problem, and if testing confirms their abilities, the compliance system can be constructed easily and quickly. If testing reveals that the bumpers cannot meet the requirements, other materials will be ordered and tested, and other solutions will be pursued.

Acknowledgments

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References

All data was either provided by Vendor_A or obtained from testing of their products. Only the curves of the test results are shown in this report, all numerical data was provided by the vendor.