Determining the Elastic Behavior of a Bungee Cord

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I. Introduction

This laboratory experiment is part one of a two part experiment series in preparation for the Bungee Challenge. The purpose of this experiment is to study and determine the elastic behavior of the bungee cord we will ultimately use for our jump. We assume that the bungee cord follows Hooke's Law, which states that the force that pulls or pushes a spring is equal to the negative of the spring constant multiplied by the distance that the spring is stretched or compressed:

$$\vec{F} = -k\vec{x} \qquad (1)$$

As Equation 1 relates to this experiment, F is the force that pulls on the elastic cord, k is the elastic constant of the bungee cord, and x is the distance that the elastic cord is stretched (displacement).

For the purposes of the Bungee Challenge, the bungee cord will be much longer than what can be easily tested in the lab room. Thus, we realized we needed to determine not only the elastic constant for one length of bungee cord, but also the *relationship* between elastic constant and cord length. Using the model we find for this relationship, we can determine how long our bungee cord needs to be when the time comes for the Bungee Challenge.

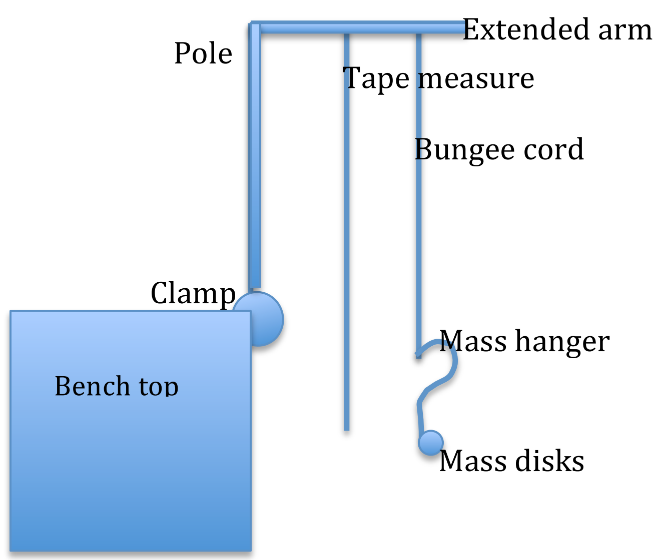
II. Methods

To determine the relationship between force and displacement, we varied the net force acting on the system and measured the displacement.

A. Set Up

Our system consisted of a pole that was vertically clamped to a bench top and had a horizontal arm extending from the top. This extended arm had holes with screws and bots that allowed us to attach the end of a tape measure at one screw and tie the end of the bungee at the other, which was right next to it. On a loop knotted at the end of the bungee was a mass hanger, to which we added mass disks once we began the experiment.

Figure 1. Set Up. How to set up our experiment, with equipment labeled.



B. Procedure

Once the system was prepared as described in the Set Up, we recorded the original length of the bungee without any weight added. This was our X_o value. Then we added the mass hanger of known value and recorded the new stretch of the bungee cord. This was our X value, the total stretch. In our data table, we multiplied the mass by the acceleration of gravity to find the weight, which was the force pulling on the bungee cord. We recorded the displacement of the bungee cord, $X_o - X$, also. The Displacement is the x value and the Force is the F value in Equation 1. After the mass hanger, we added mass disks, a total of 9, to the mass hanger, giving us a total of 10 data sets.

Then we began the process of finding the relationship between elastic constant and cord length. After the first ten data sets with the first length of bungee cord, we repeated the above procedure with 4 more lengths of bungee. We used the same piece of bungee cord throughout the entire experiment, so we had different lengths by tying knots at various positions along the cord. Thus, we had a total of 5 data tables, each with 10 data sets.

Then we had all of our data and were ready to graph. To find the elastic constants for each cord length, we plotted Displacement on the x-axis and Force on the y-axis. The slope of the graph was the elastic constant for that length of bungee cord. We repeated this process for the remaining 4 lengths of cord. Once we had all 5 elastic constants, we constructed a new graph with length on the x-axis and elastic constant (K-value) on the y-axis. This graph was not linear, so we used a power approximation that was close enough to -1 to be equal. Lastly, we made a final graph with 1/length on the x-axis and K-value on the y-axis. The trend line equation for this final graph gave us the relationship between elastic constant and bungee cord length.

III. Results

The data recorded for this experiment showed that as the force from the hanging mass increased, so did the displacement of the bungee cord. This trend occurred for all 5 of our cord lengths.

Figure 1: Cord Length of 0.264 m. This table shows how the displacement varied with the force of the stretch due to the hanging mass for a cord of length 0.264 m.

Xo = 0.264m (±0.003m)			
Hanging Mass	Force F	Total Stretch X	Displacement
kg	(N ± 0.01 N)	(m ± 0.003m)	(m ± 0.003m)
0.050	0.49	0.328	0.064
0.055	0.54	0.339	0.075
0.060	0.59	0.348	0.084
0.065	0.64	0.359	0.095
0.075	0.74	0.383	0.119
0.077	0.76	0.389	0.125
0.079	0.77	0.394	0.130
0.081	0.79	0.400	0.136

0.083	0.82	0.405	0.141
0.085	0.83	0.411	0.147

Figure 2: Cord Length of 0.499 m. This table shows how the displacement varied with the force of the stretch due to the hanging mass for a cord of length 0.499 m.

Xo = 0.499m (±0.003m)			
Hanging Mass	Force F	Total Stretch X	Displacement
kg	(N ± 0.01 N)	(m ± 0.003m)	(m ± 0.003m)
0.050	0.49	0.627	0.128
0.055	0.54	0.643	0.144
0.060	0.59	0.665	0.166
0.065	0.64	0.686	0.187
0.075	0.74	0.731	0.232
0.077	0.76	0.745	0.246
0.079	0.77	0.755	0.256
0.081	0.79	0.767	0.268
0.083	0.82	0.781	0.282
0.085	0.83	0.792	0.293

Figure 3: Cord Length of 0.740 m. This table shows how the displacement varied with the force of the stretch due to the hanging mass for a cord of length 0.740 m.

Xo = 0.740 (±0.003m)			
Hanging Mass	Force F	Total Stretch X	Displacement
kg	(N ± 0.01 N)	(m ± 0.003m)	(m ± 0.003m)
0.050	0.49	0.925	0.185
0.055	0.54	0.959	0.219
0.060	0.59	0.989	0.249
0.065	0.64	1.021	0.281
0.075	0.74	1.091	0.351
0.077	0.76	1.109	0.369
0.079	0.77	1.125	0.385
0.081	0.79	1.143	0.403
0.083	0.82	1.155	0.415
0.085	0.83	1.177	0.437

Figure 4: Cord Length of 0.919 m. This table shows how the displacement varied with the force of the stretch due to the hanging mass for a cord of length 0.919 m.

Xo = 0.919m (±0.003m)			
Hanging Mass	Force F	Total Stretch X	Displacement
kg	(N ± 0.01 N)	(m ± 0.003m)	(m ± 0.003m)
0.050	0.49	1.156	0.237
0.055	0.54	1.195	0.276
0.060	0.59	1.231	0.312
0.065	0.64	1.269	0.350
0.075	0.74	1.351	0.432
0.077	0.76	1.372	0.453
0.079	0.77	1.394	0.475
0.081	0.79	1.415	0.496
0.083	0.82	1.438	0.519
0.085	0.83	1.458	0.539

Figure 5: Cord Length of 1.302 m. This table shows how the displacement varied with the force of the stretch due to the hanging mass for a cord of length 1.302 m.

Xo = 1.302 (±0.003m)			
Hanging Mass	Force F	Total Stretch X	Displacement
kg	(N ± 0.01 N)	(m ± 0.003m)	(m ± 0.003m)
0.050	0.49	1.672	0.370
0.055	0.54	1.722	0.420
0.060	0.59	1.775	0.473
0.065	0.64	1.830	0.528
0.075	0.74	1.954	0.652
0.077	0.76	1.981	0.679
0.079	0.77	2.015	0.713
0.081	0.79	2.053	0.751
0.083	0.82	2.080	0.778
0.085	0.83	2.092	0.790

We plotted these data points on a graph with Displacement on the x-axis and Force on the y-axis. We chose the trend line that does not go through the origin because doing so gave a line that better fit the data points.

Figure 6: Force vs. Displacement. The slope of each set of data points is equal to the elastic constant (K-value) for the bungee cord at that length. The equations for the trend lines are displayed below the graphs in order or increasing cord length.

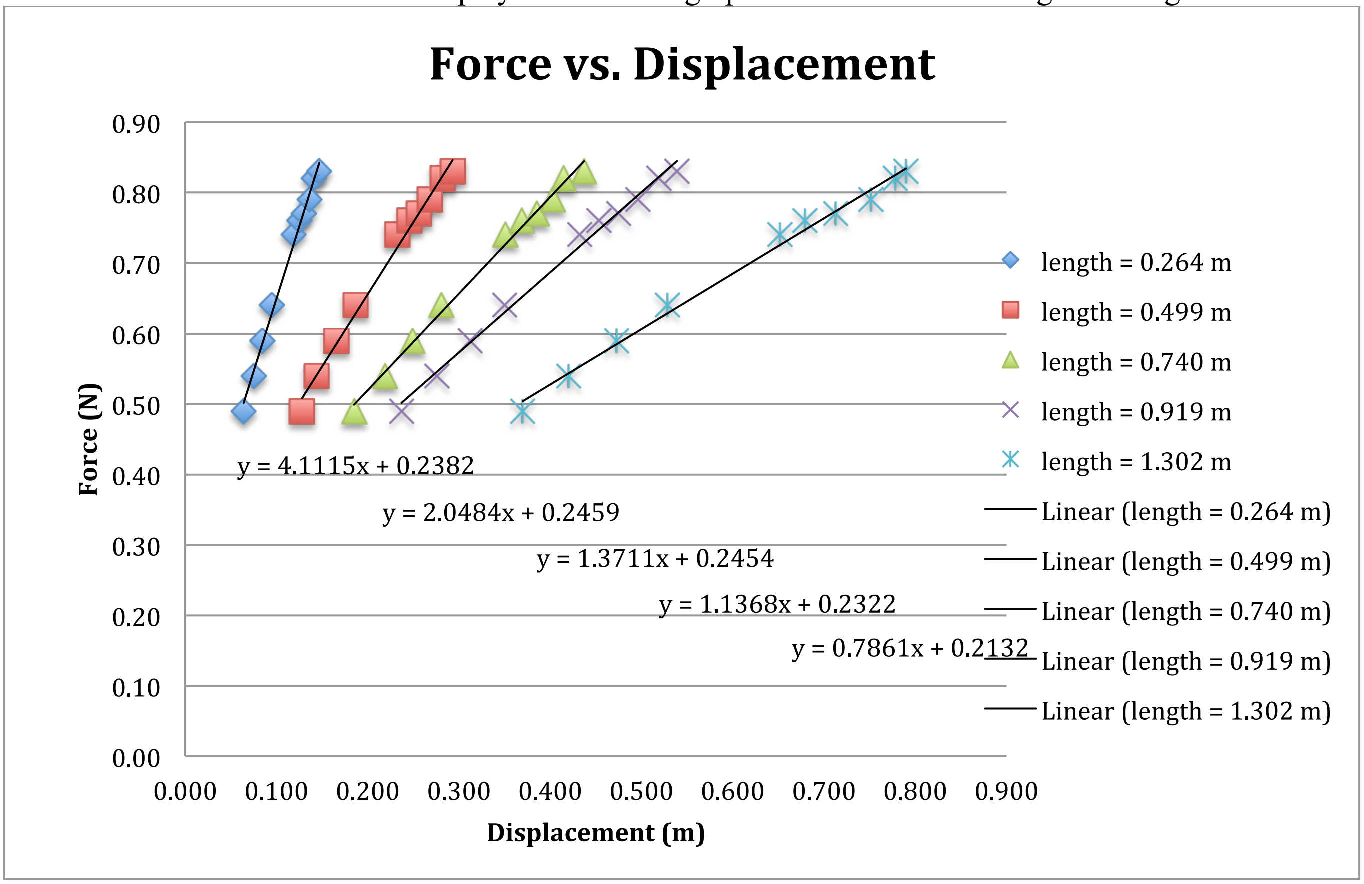


Figure 7: K-value vs. Length. This graph has a power close enough to -1 for that to be estimated as the relationship between our bungee cord's elastic constant and length.

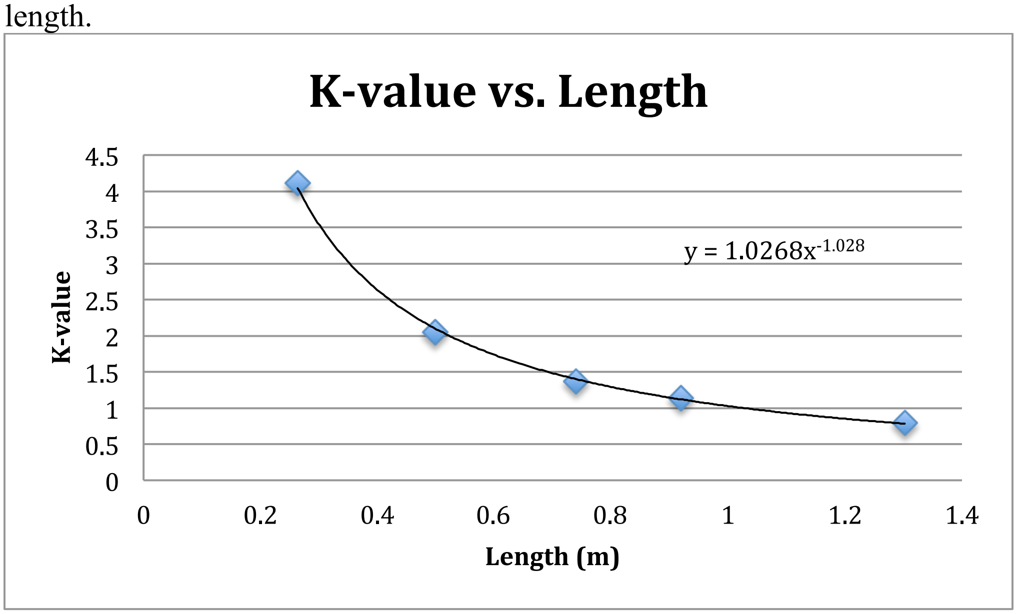
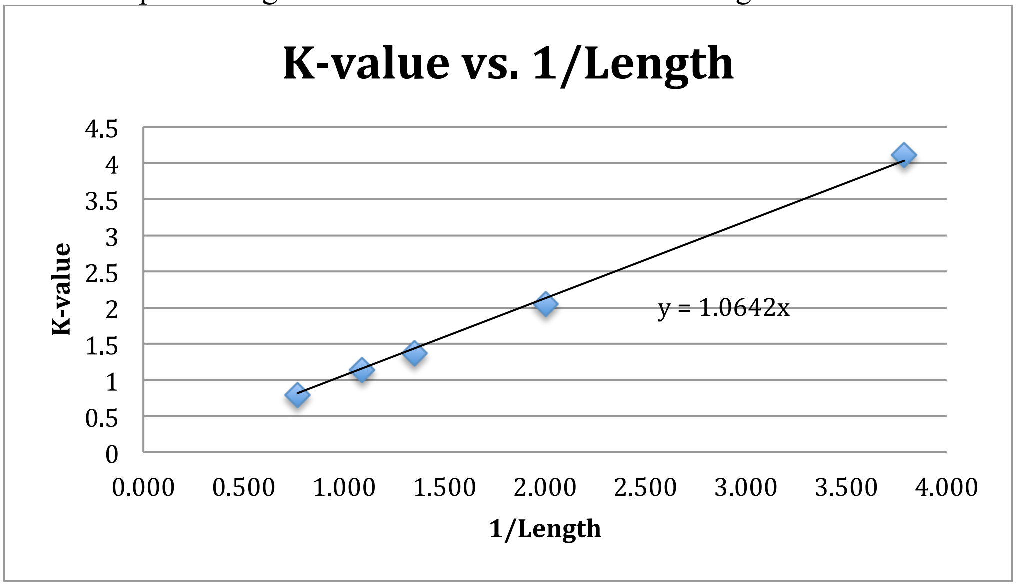


Figure 8: K-value vs. 1/Length. The equation for this graph gives the linear relationship our bungee cord's elastic constant and 1/Length.



The slope of our graph is equal to a value with units N times m. By replacing the "y" and "x" in the trend line equation, we get an equation that says the elastic constant for a given length of our bungee cord is equal to 1.06 divided by that length.

IV. Discussion

Figure 7 gave date points that had a power close enough to -1 for us to use -1 as the relationship between K-value and Length. This was important for us to linearize the data and create a final graph. This final graph of our experiment produced an equation that gives the relationship between our bungee cord's length and its elastic constant. This relationship is that the elastic constant equals 1.06 divided by the length (K = (1.06/Length). The standard error for this relationship is 0.02%.

Because this experiment's goal was to determine a relationship between bungee cord length and its elastic constant, there was no expected result to which we can compare our experimental results. Thus, there is no percent error between any values. The ultimate test for our model relationship between length and elastic constant will be the Bungee Challenge.

A. Phenomena we noticed.

In the execution of our experiment, we noticed that the bungee cord stretched a small amount (approximately <0.005 m) after we recorded the displacement. The weight of the hanging mass (plus mass disks if they had been added) fatigued the bungee cord beyond its original point. Throughout the experiment, we consistently only recorded the original stretch, not the displacement once the mass had been hanging for more than a few seconds.

B. Y-intercept of the graph.

In each of the graphs for Force vs. Displacement from which we determined the elastic constant for a given cord length, there was a small y-intercept (between 0.2132 and 0.2459). We consider these y-intercepts to be negligible for two reasons: 1) there was no consistent relationship between the y-intercept and cord length; and 2) the y-intercept values were close enough to the same value for each cord length that they could be attributed to some systematic error we made consistently, like some extra force not being considered because of the way the knot affected the bungee or some consistent error in cord length measurement.

V. Conclusion

The original purpose of this experiment was to determine the elastic behavior of the bungee cord we will later use for the Bungee Challenge. Our experiment produced a model equation from which we can determine what the elastic constant would be for bungee cord lengths longer than what is feasible to measure in the lab, meaning a length we likely will use for the Bungee Challenge. The behavior of our bungee cord is that the elastic constant equals 1.06 divided by the length.