

Determining the Relationship Between Elastic String Length and Maximum Acceleration

ABSTRACT

An experiment was carried out in order to assess the relationship between the length of elastic string and the maximum acceleration of the bungee system. It was hypothesized that increasing the elastic string length would decrease the maximum acceleration. Using Newton's Second Law of Motion, the maximum acceleration was computed from a known maximum total force and mass. After dropping a 150 g mass attached to the string, total force over time was recorded using a force sensor hooked up to the Capstone program. The elastic string length was varied across five different values, and two trials were performed and averaged for each string length. The acceleration vs. length data was fitted to a linear curve, which gave a slope of -2.23. However, the uncertainty for this slope was 96.4%, so the data was fitted to another linear trendline with the intercept set at the average acceleration across all string lengths. The slope of this curve was -0.285, which was so close to zero that we concluded that changing the elastic string length has no effect on the maximum acceleration. We expected the variations in maximum force values to be due to differences in how the mass was dropped. The average maximum acceleration was well below 3g, so we can conclude that if we use a bungee cord composed of only elastic string, then the maximum acceleration of the egg will remain safely below this limit.

INTRODUCTION

The purpose of this experiment was to determine the relationship between maximum acceleration of a bungee system and the length of elastic string. In our first set of bungee experiments, we determined the relationship between resting elastic string length and maximum stretch at different weights, and were thus able to build a model that predicted the maximum stretch from the weight of the mass and the resting elastic string length. However, we had no way of determining the acceleration from this model, so we decided to next examine the relationship between acceleration and elastic string length in order to ensure that that the maximum acceleration will not exceed 3g during the final bungee jump.

Newton's Second Law of Motion:

$$F_{\text{TOT}} = ma$$

Newton's Second Law of Motion states that the acceleration of an object depends upon its mass and the total force acting upon it. Thus, we could divide F_{TOT} (measured with a force sensor) by the mass to compute acceleration.

It was hypothesized that increasing the elastic string length would decrease the maximum acceleration.

METHODS

We used a force sensor and the Capstone program to measure the total force on the bungee system as a constant 150 g mass was dropped from the starting position for 5 different elastic string lengths. We then divided the maximum force by the mass to compute the maximum acceleration for each length.

Experimental Setup

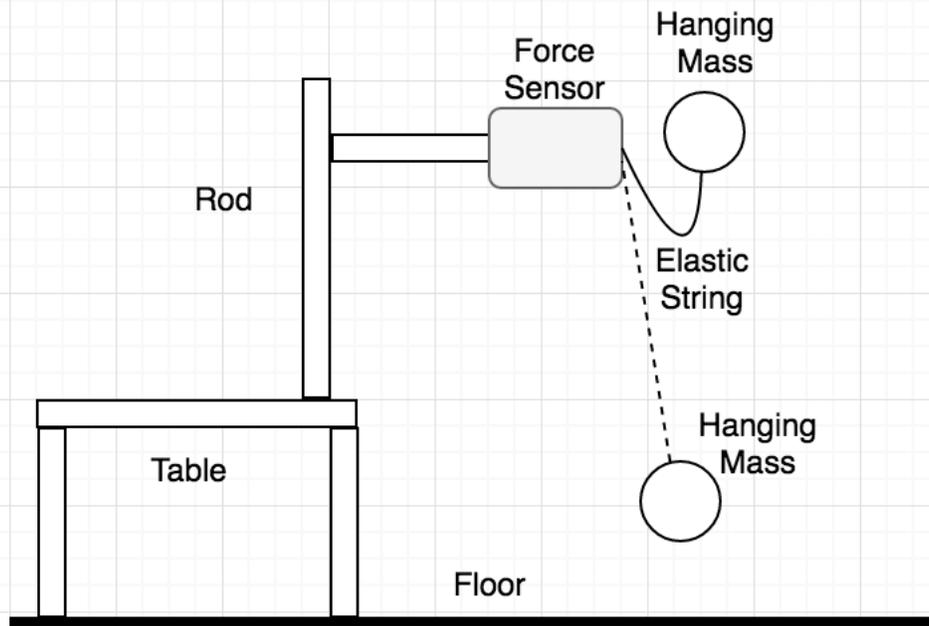


Fig 1: Diagram of Experimental Setup.

Setup

- One end of elastic string attached to force sensor hooked up to Capstone program
- Other end attached to 150 g hanging mass

Procedure

- Hanging mass was kept constant at 150 g
- The mass was dropped vertically from the height of the knot on the force sensor for each trial
- 2 trials for each elastic string length were run and averaged
- The elastic string length was varied across 5 values
- The force sensor was tared with just the elastic string attached
- The maximum force was pinpointed using the Capstone program
- Maximum force was then divided by the mass to compute maximum acceleration

RESULTS

A force sensor hooked up to the Capstone program was used to measure the total force on a bungee system after a mass was dropped from the height of the force sensor. The maximum acceleration at each elastic string length was computed by dividing the maximum total force by the hanging mass.

Hanging Mass ($g \pm 0.01 g$)	Length of Elastic String X_L ($m \pm 0.01 m$)	Max Total Force F_{max} ($N \pm 0.02 N$)	Max Acceleration A_{max} ($m/s^2 \pm 0.02 m/s^2$)
150	0.22	-3.42	-22.8
	0.30	-3.54	-23.6
	0.43	-3.50	-23.3
	0.13	-3.34	-22.4
	0.35	-3.37	-22.5

Fig. 2: Maximum Force and Acceleration at Different Elastic String Lengths. 2 trials were performed for each of the 5 elastic string lengths. Raw uncertainty for hanging mass and length estimated.

Uncertainty for max total force was derived from the average standard deviation of the force measurements. Uncertainty for max acceleration was assumed to be the same as for max total force using the weakest link shortcut.

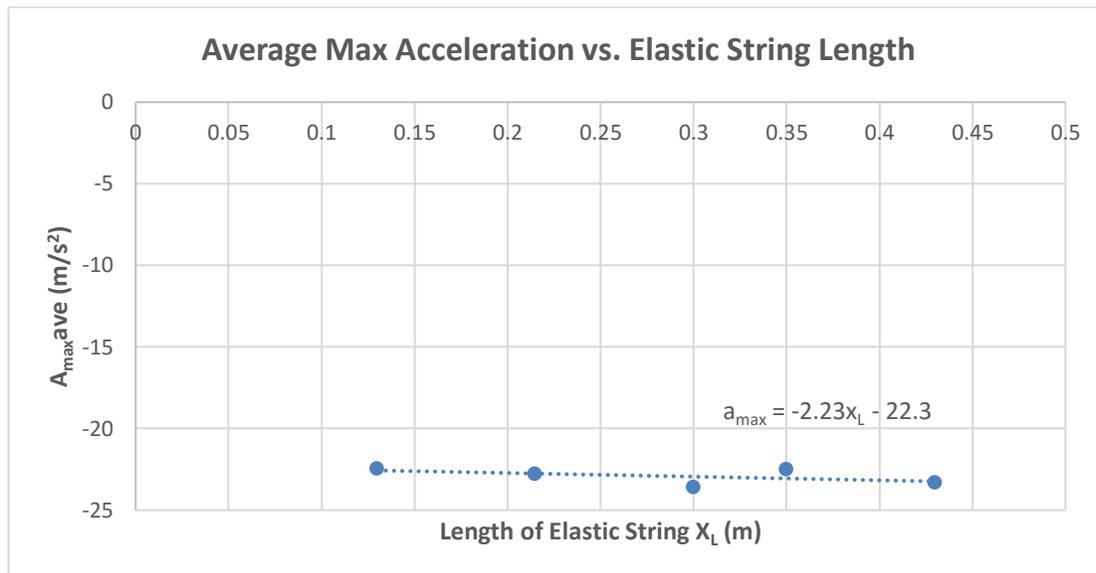


Fig. 3: Average Max Acceleration vs. Elastic String Length. The data was fitted to a linear curve to create the trendline.

$$a_{max} = -2.23x_L - 22.3$$

uncertainty for slope = 2.15

% uncert = 96.4%

uncertainty for y-intercept = 0.653

% uncert = 2.93%

Because this linear fit had such a high uncertainty, and because we suspected that the trendline should theoretically have a slope of zero, we fitted another trendline to the data, setting the intercept to the average maximum acceleration across all five elastic string lengths.

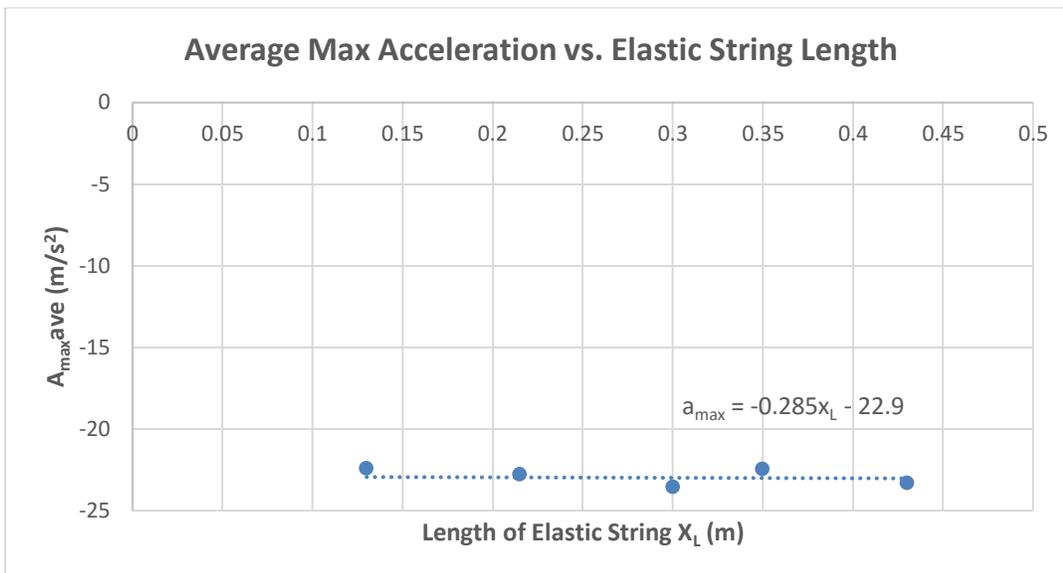


Fig. 4: Average Max Acceleration vs. Elastic String Length. The data was fitted to a linear curve with an intercept set to the average max acceleration across all elastic string lengths to create the trendline.

$$a_{max} = -0.285x_L - 22.9$$

Note: Due to the limitations of the data analysis feature on *Excel*, we were unable to perform a regression analysis on this new trendline.

The first experimental value of interest is the slope of the first max acceleration vs. elastic string length curve because it describes the relationship between the two variables.

value obtained = -2.23

uncertainty of experimental value(s) = 2.15

% uncert = 96.4%

The uncertainty was obtained from *Excel* regression analysis.

The second experimental value of interest is the slope of the second max acceleration vs. elastic string length curve because it describes the relationship between the two variables.

value obtained = -0.285

uncertainty of experimental value(s) = n/a

% uncert = n/a

Analysis of our data revealed that the slope of the max acceleration vs. elastic string length curve (-0.285) was close to zero within the limits of uncertainty. Therefore, it is reasonable to expect that changing the length of elastic string has little to no effect on the acceleration of the bungee system.

DISCUSSION

Because the uncertainty of the slope of the first linear trendline was so high, it is reasonable to conclude that the actual slope is closer to the slope of the second linear trendline. In fact, we suspect that the actual slope would've been zero if it hadn't been for uncertainty in the measurements and procedure.

One major source of uncertainty was variation in the way that the mass was dropped. If any external force caused the mass to sway during its motion, then the total force and therefore acceleration would've been altered. This is likely what caused the small differences in total force for the different trials rather than the length of the elastic string itself.

Our hypothesis that increasing the elastic string length would decrease the maximum acceleration was not supported. Rather, it is suspected that changing the elastic string length has no effect on the maximum acceleration. The high uncertainty in our results is slightly bothersome for this conclusion, however, looking at the maximum acceleration values themselves, it is apparent that they are all very similar and likely only differed as a result of procedural uncertainty.

CONCLUSION

We can reasonably conclude that changing the length of the elastic string has no effect on the maximum acceleration of the bungee system.

It is also important to note that the average maximum acceleration value across all elastic string lengths was about - 23 m/s², which is a good amount less than 3g. Therefore we can conclude that it is safe to use the model we developed (that only uses elastic string) in that the acceleration of the egg shouldn't exceed the limit.

On my honor, I have neither given nor received any unacknowledged aid on this assignment.

Pledged: Scott V. Philips