Determining the Ratio of Unstretched Cord Length to Total Length of Simulated Bungee Jump Distance

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Introduction:
Bungee jumping is an exhilarating experience where daredevils jump off a structure (usually a bridge) tied to an elastic cord which allows them to freefall before slowing them down and bouncing them back up. Usually this cord is long enough to allow you to get very close to the surface beneath you (whether it is ground or water) but short enough that you don’t make contact with the ground. It has enough elasticity to stretch longer than its resting length, but not so much that it deforms or breaks. The cord has enough tension to stop your acceleration without causing any physical harm to the diver.

Using an egg, we want to replicate a bungee jump. For this, we will use an elastic cord, an egg in a harness, and the Great Hall in the W&L science center. We want to design a bungee for an egg for the ~9m fall from the 4th floor bannister to the bottom of the Great Hall. We want to prevent the egg from splatting on the ground, but give it an exciting ride.

In order to create a successful bungee, we need to determine the amount of elastic cord we want to use and if we want to use a single cord or add more to it. We want to test the cord for its elasticity (using Hooke’s Law, Equation 1), and the force it has on the mass using Newton’s Second Law (Equation 2).

$$ F = -kx \hat{i} \quad \text{Equation 1} $$

$$ F = ma \quad \text{Equation 2} $$

To test the elasticity of the cord, we are going to test the total distance the cord stretches when simulating a bungee, and compare that in a ratio to the length of cord used.

Methods:
Using the elastic cord given to us, we empirically tested to cord for its stretched length. We did this using a single strand, double strand, triple strand, and quadruple strand. We used the balloon-knot tying method to tie our cords together. We determined that the single strand cord was too stretchy for our experiment and the quadrupled cord was not stretchy enough. We arbitrarily chose to triple the cord. We folded the cord three times and tied a knot where it could hang from on one end and a knot where the mass could hang from the other end. Any excess cord was left to hang or was wrapped around the “jumping point” to be kept out of the way. A measuring tape was set up next to the cord so all measurements could be taken at a moment’s notice. This setup is shown below in Figure 1. A measuring tape was hung next to the cord in order for reliable measurements to be taken by iPad camera.
The cord was then measured for its resting length. We tested 4 lengths of the cord at 0.95 m, 0.80 m, 0.66 m, and 0.53 m. Each length was measured before adding weight to the cord. The mass used on the cord was 150 g (within the range 100-170g of estimated mass for the egg in its harness). This mass was chosen arbitrarily. By pulling the mass up to the 0 m mark, where the cord was hanging from, we were able to let the length of the cord dangle loosely, simulating a bungee jump where the cord is dangling below you before you jump off the bridge. We dropped the mass from height 0 m and recorded the farthest length stretched by the cord. This setup is shown below in Figure 2.
Results:

We created Table 1 by measuring the resting length of the cord (m), the length of the drop in both trials of our simulated bungee (m), the average of our two trials (m), and finally the ratio of extended length of the cord and resting length of the cord.

Table 1. The resting length of the cord (column 1) in comparison with the extended length of the cord in bungee trials (columns 1 and 2, average shown in column 3) as a ratio (column 4). This ratio represents how far the cord stretches in comparison to the resting length of the cord.

<table>
<thead>
<tr>
<th>Length of cord (m) ±0.02</th>
<th>Total Length 1 (m) ±0.02</th>
<th>Total Length 2 (m) ±0.02</th>
<th>Average Total Length (m) ±0.01</th>
<th>Resting:Total Length ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95</td>
<td>1.63</td>
<td>1.63</td>
<td>1.63</td>
<td>1.71</td>
</tr>
<tr>
<td>0.80</td>
<td>1.38</td>
<td>1.40</td>
<td>1.39</td>
<td>1.74</td>
</tr>
<tr>
<td>0.66</td>
<td>1.10</td>
<td>1.04</td>
<td>1.07</td>
<td>1.62</td>
</tr>
<tr>
<td>0.53</td>
<td>0.84</td>
<td>0.85</td>
<td>0.84</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Using Table 1, we created two figures. The first, Figure 3, shows resting length of cord (x-axis) vs average total length of cord (y-axis) where the slope of the trendline represents the
resting:total cord length ratio. We calculated uncertainties based on regression analysis of the trendline.

**Figure 3.** This figure shows the resting cord length versus average total length. The equation represents the trendline shown in blue. This trendline has an uncertainty of ±0.10 in the slope and an uncertainty of ±0.08 in the y-intercept.

We also used Table 1 to create Figure 4, which shows the resting length of the cord (x-axis) versus the average total length of cord (y-axis), under the assumption that the y-intercept is equal to zero, as when the cord is 0 meters long it will stretch 0 meters. We calculated uncertainties using regression analysis on the trendline.

**Figure 4.** This figure shows the resting cord length versus average total length. The equation represents the trendline shown in blue. This trendline has an uncertainty of ±0.03 in slope.
Discussion:

We expected the resting:total cord length ratio to remain constant when we varied the length of the cord. Based on Table 1, that is not the case. The resting:total cord length ratio changed for each different cord length we tried. This implies that there is not a linear relationship between unstretched length of cord and stretched length of cord. In Figures 3 & 4, the slope of the trendlines represents this resting:total cord length ratio. Figure 3 shows data with a slope representing a ratio of 1.90±0.10 m. The calculated ratios in Table 1 are outside of this value. Figure 4 shows data with a slope representing a ratio of 1.68±0.03 m. These uncertainties were calculated from regression analysis of the data in Table 1. Some calculated values in Table 1 are within the experimental uncertainty of the slope from Figure 4, and Figure 4 was created under the assumption that the y-intercept must be zero, therefore we believe Figure 4 is a better fit to our data.

We used a cord that was tripled-up, meaning that we hung our mass on a loop made out of two folds of the cord. We measured the resting length of the cord from the shortest length that the cord was at. This tripling effect was not always even, so the length of the cord was limited to the length of the shortest of the three parts of the cord. This could be part of the error that caused the y-intercept in Figure 3 to not be zero. It could also be attributed to changes in the resting:total cord length ratio.

Time limits caused us to choose two trials per length, so further refinements to the experiment may warrant more trials per length of cord, and more careful cord folding to reduce error in cord length. Also our data point at length 0.66 is outside of our raw experimental uncertainty. This error could have been caused by the way we dropped the mass (e.g. not straight down), which could have affected the total distance dropped to be outside uncertainty. Having more trials would allow us to minimize this type of error.

Conclusion and Future Work:

We found that a cord, tripled up, has a resting:total cord length ratio of roughly 1.68±0.03 m when a simulated bungee with 150 g of mass was used. We expected that ratio to remain constant, and will further refine this data by designing a more thorough experiment. In this refined experiment, we will use more than two trials per cord length and additionally we will measure force of the cord on the mass to determine how large the force is and whether we need to do trials using a doubled up cord, as opposed to a tripled up cord.