Maximum Net Force in Relation to Bungee Cord Strand Number

Introduction:
The purpose of our work last week was to create an experimental environment that could identify a relationship between the maximum net force experienced by a bungee jumper and the number of strands comprising the bungee cord, if such a relationship existed. Like our experiment from the first bungee lab, a variation of the Hooke’s Law equation is employed to aid in verifying the existence of this relationship, as seen below:

\[ F_{\text{net}} = \frac{1}{s}kx \]  

(Equation 1)

In equation 1, ‘\( F_{\text{net}} \)’ is the net force exerted on the egg bungee jumper when deceleration is at its greatest, which is also when the net force is maximized. Similar to Hooke’s Law, the ‘\( k \)’ variable is the spring constant of the bungee cord, which is equal to the force, in Newtons, required to stretch the bungee cord one meter, while ‘\( x \)’ is the displacement in meters caused by this force. Where our experiment deviates from Hooke’s equation is the introduction of \( \frac{1}{s} \) where the ‘\( s \)’ variable indicates the number of strands used in the bungee cord. As equation 1 indicates above, we believed that the net force was inversely proportional to the maximum net force experienced by the bungee jumper. We made this assumption because one would believe that adding strands to the bungee cord will increase the net force experienced by the egg.

Methods:
In our experimental model, we attempted to illustrate this relationship by measuring the maximum net force experienced by a falling mass at varying lengths with either one or two strands present in the bungee cord. In doing this, one would hope to see this relationship maintain itself as the length of the bungee cord changed.

⇒ Set-up: Below is an illustration of our experimental set-up

![Bungee cord setup diagram]

Figure #1: Bungee Jump Week Two Experimental Set-up. The hanging mass representing the bungee jumper is hung from the bungee cord with either one or two strands.
Figure 1 shows our experimental environment for our work. The hanging mass is hung from the bungee cord, which must then be hung from a hook on a device that is able to measure the force of the falling mass. As the mass is allowed to fall from the top of the bungee cord, the device measures the net force experienced by the mass.

Procedure: In order to measure the maximum net force experienced by our bungee jumping mass, we utilized a device that measures the force of the falling mass. One end of the bungee cord was looped around the protruding hook of this device, while the other end held the hanging mass, which was kept at a constant 0.100 kilograms for each trial. Once this was set-up, we allowed the hanging mass to fall freely from the top end of the bungee cord (the top of the experimental apparatus), and the device measured and displayed the force experienced by the hanging mass on a computer using the capstone software. We repeated this exercise with five different lengths of bungee cords with either one or two strands. The five trials with a one-stranded bungee cord measured the maximum net force at lengths of 0.26m, 0.495m, 0.21m, 0.65m, and 0.34m. The next five trials, performed with two strands making up the bungee cord, measured maximum net force at lengths of 0.26m, 0.50m, 0.22m, 0.56m, and 0.34m. For each of the trials mentioned above, we recorded the maximum net force experienced by the hanging mass before moving on to the next trial.

Results:
The maximum net force experienced by the hanging mass increased by a factor of approximately 1.3 when strand number was increased from one to two. For the five trials with one and two strands in the bungee cord, the maximum net force was essentially constant at each length respectively.

<table>
<thead>
<tr>
<th>Bungee Cord Length (m +/- 0.1m)</th>
<th># of Strands in Bungee Cord</th>
<th>Maximum Net Force (N +/- 0.01N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.21</td>
<td>1</td>
<td>2.35</td>
</tr>
<tr>
<td>0.26</td>
<td>1</td>
<td>2.49</td>
</tr>
<tr>
<td>0.34</td>
<td>1</td>
<td>2.29</td>
</tr>
<tr>
<td>0.495</td>
<td>1</td>
<td>2.40</td>
</tr>
<tr>
<td>0.65</td>
<td>1</td>
<td>2.35</td>
</tr>
<tr>
<td>0.22</td>
<td>2</td>
<td>3.10</td>
</tr>
<tr>
<td>0.265</td>
<td>2</td>
<td>3.26</td>
</tr>
<tr>
<td>0.34</td>
<td>2</td>
<td>3.14</td>
</tr>
<tr>
<td>0.50</td>
<td>2</td>
<td>3.28</td>
</tr>
<tr>
<td>0.56</td>
<td>2</td>
<td>3.11</td>
</tr>
</tbody>
</table>

Figure #2: Data of Bungee Cord length, Number of Strands, and Maximum Net Force. The data table above gives the maximum net force recorded by the device at each bungee cord length.
Figure 2 gives the data collected from the ten trials performed. For each of the lengths tested with either one or two strands, the device utilizing the capstone software gave the maximum net force experienced by the hanging mass. The lengths of the cord were determined with a tape measure as they hung from the force device. This data is relevant because it can aid in determining the relationship between maximum net force and the number of strings present in the bungee cord. As mentioned before, all of these trials were performed with a hanging object whose mass was held at 0.1 kilograms.

Figure #3: Maximum Net Force in Relation to Unstretched Length of the Bungee Cord. The graph above relates maximum net force to the length of the bungee cord for one- and two-stranded bungee cords.

Figure 3 plots the ten trials performed on a graph relating maximum net force to the length of the bungee cord with both one and two strands. The maximum net force was determined with the help of the force device from which the bungee cord hung, while unstretched lengths of the bungee cord were found with a tape measure as the bungee cord hung from the force device. The lines of best fit for both types of bungee cord possess small slope values (1-stranded = -0.078 & 2-stranded = 0.109) The graph is pertinent to our experiment because it gives an illustration of any relationship that may exist between maximum net force and the number of strands used in the bungee cord.
Figure #4: Standard Error for the One Strand and Two Strand Bungee Cord Trials. 
Standard error for the two different types of bungee cords.

Figure 4 gives the standard error values for the five trials performed with one- and two-stranded bungee cords. The coefficients for the one and two loop systems indicate the maximum net force experienced by the falling mass. This data is relevant, as it will determine whether the original hypothesis can be accepted or rejected in relation to the observed values.

With the data presented above, the proportional effect of bungee cord strand number in relation to maximum net force can be found.

\[
\frac{F_2}{F_1} = S \quad \text{(Equation #2)}
\]

\[
\frac{3.13}{2.41} = 1.30
\]

Discussion:

The results from our experiment indicate that bungee cord strand number is not inversely proportional to maximum net force experienced by the hanging mass. With our original hypothesis, one would have expected the maximum net force to double when the strand number was doubled from one to two. As the observed increase in force was only by a magnitude of 1.3, the percent error of our data is 35% \(\left(\frac{2.41 - 2.0}{2.0} \times 100\right)\). Because this percent error is greater than the standard error values for the one-stranded (9.9%) and two-stranded (14.4%) trials, one is compelled to reject the original hypothesis in light of the observed data. Such a large percent error indicates that additional variables to those mentioned in equation 1 are likely at play when trying to determine a relationship to maximum net force; however, the increase in maximum net force does show that the force increases as the number of strands in the bungee cord increases. The reason for this is that the two strands are able to decelerate the falling mass more quickly than one strand. This quicker deceleration causes the falling mass to experience a larger net force as
its trajectory downward is stopped. With this large deviation from expected results, it is clear that significant sources of uncertainty existed in this experiment. One of these potential sources was likely the additional bungee cord present in the double knots of the two-stranded cords. Because the singular cord needed to be looped back into itself in order to create a double strand, the additional cord present in these knots may have altered the effect of increasing from one strand to two. Related to this, it is possible that the difference in mass between the two types of cords, which was not originally accounted for, may play a more significant role in determining net force than originally expected. Finally, a third potential source of uncertainty may be inconsistencies in the angle at which the hanging mass was dropped when measuring the maximum net force. If the hanging mass was dropped at slightly different angles (i.e. not directly vertical), it may affect the net force reading by the device used in the experiment. One way to reduce the uncertainty experienced would be to use two separate strands rather than loop one strand back onto itself in order to create the two-stranded bungee cord. In addition, this would reduce the length of cord in the knots, which possibly created the uncertainty observed.

**Conclusion:** Though we did not observe an inverse proportionality between strand number and maximum net force, it is clear that the number of strands did have some sort of proportional effect on the net force. In terms of our original experiment, ways to improve our methods may include using multiple cords, rather than looping a singular cord back on itself, and determining if other variables are present that may affect our expected inverse proportionality. Because a general increase was observed when strand number was increased, we can keep this general trend in mind as we prepare for our live bungee jump challenge.