Doubling Up: Effect of Multiple Bungee Strands on Acceleration of Hanging Mass

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ABSTRACT:

The purpose of this research was to examine how the number of bungee cords attached to a hanging mass would affect acceleration. Using a Capstone force detector to measure the force exerted by a constant hanging mass on a constant length of bungee, we determined the maximum acceleration experienced by the hanging mass using Newton's Second Law, $F = ma$. We graphed this acceleration versus the number of bungee cords that were attached to the mass, and produced a model for our system. We found that the maximum acceleration (in m/s^2) experienced by this system was defined by the linear equation: $a_m = 3.62n + 19.32$. This equation gives insight to how many strands of bungee can be attached to a hanging mass before the system experiences an acceleration of more than three times the acceleration due to gravity. In this case, the maximum number of cords that could act on the system before violating this rule was two.

INTRODUCTION:

Bungee jumps are designed so that the acceleration of the hanging mass is never more than three times the acceleration due to gravity to ensure a comfortable experience for bungee jump participants. The purpose of this experiment was to determine how the number of bungee strands of a constant length attached to a constant hanging mass would affect the maximum acceleration experienced by the hanging mass.

The following relevant equation was used in our calculations:

<u>Newton's Second Law:</u>

$$F = ma$$

Where:

- F=force experienced by a system (in Newtons)
- m=mass of the system (in kilograms)
- a=acceleration of the system (in m/s^2)

Using Newton's second law, the acceleration of the hanging mass can be found by calculating the force that it exerts onto the force detector. Given that the hanging mass is constant, and we can detect the force, Newton's Second Law can be arranged to:

$$a = \frac{F}{m}$$

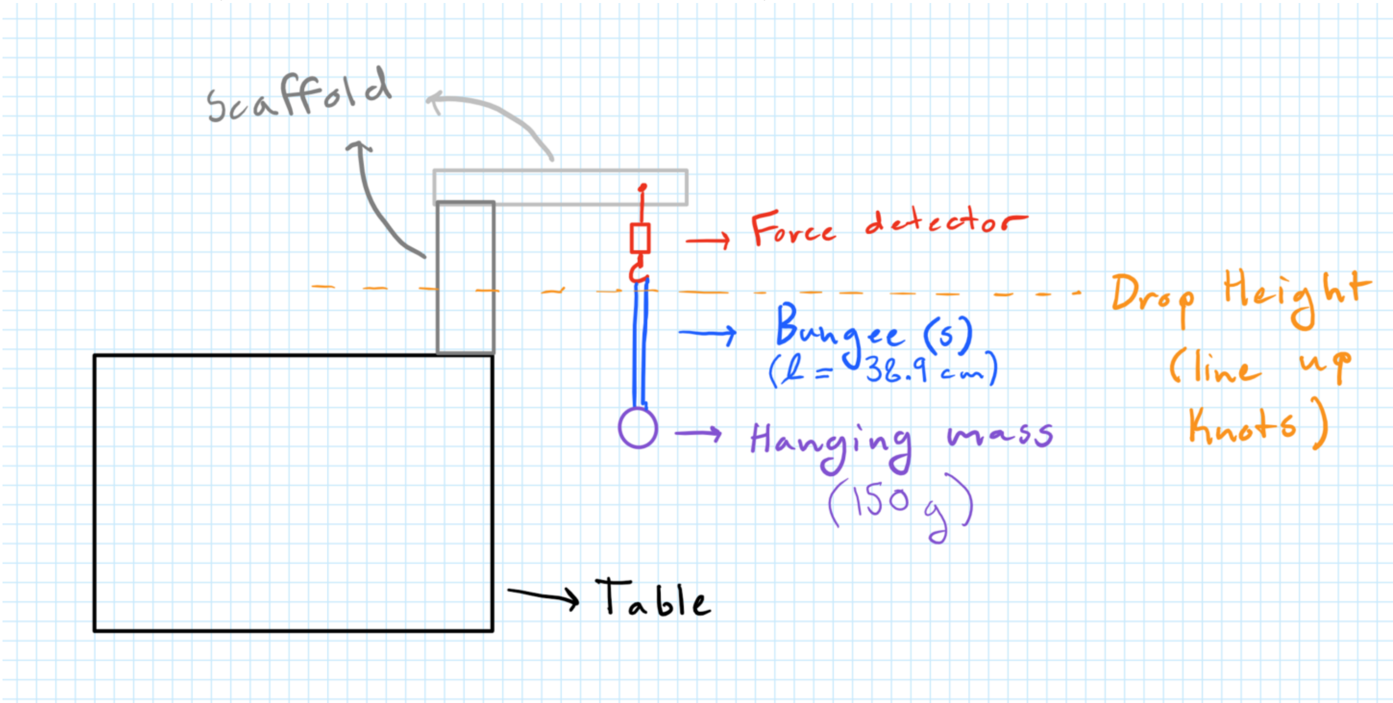
By collecting the maximum force data while varying numbers of bungee cords attached to the hanging mass, we can graph the maximum acceleration experienced by the system by the number of cords attached to the mass. This information will provide a model that will give us an idea of how many cords can be attached to the egg's harness before it experiences acceleration that is higher than $3g$.

We hypothesize that 4 cords and higher will provide a maximum acceleration higher than $3g$, and 3 cords or less will not exceed $3g$.

METHODS:

Our experimental set up involved hanging a Capstone force detector from a scaffold. The bungee was attached on one end to the force detector, and on the other to the hanging mass. The following picture (***Figure 1***) models the set up for our experiment.

***Figure 1*: Experimental Design Set Up:** This image roughly depicts how the experiment was set up. The Force Detector was a Capstone detector that was connected to a computer to read the force in Newtons.



Procedure:

- Attached the force detector to the scaffold and tare it without the cord attacted.
- Raised scaffold to appropriate level and tie two loops in the bungee, one to attach to the detector and one to the hanging mass.
- Used 150 g hanging mass. This was meant to roughly approximate the weight of the egg to be used in the Egg Drop.
- Length of bungee from knot to knot was 38.9 cm.
- Turned on force detector, tare the device without any cord on the device. Record the starting force before the drop (the force of the weight of the bungee cord) for each trial. This will be taken out later during a correction made in the data analysis.
- Dropped the hanging mass after lining up the knots of the two loops for a consistent drop height.
- Recorded the magnitude of the maximum force produced from the Capstone program.
- Repeated 3 trials for each number of bungee strands attached, up to 5 bungees attached.
- To increase the number of strands, one of the knots was untied, and the length was doubled. The cord was then wrapped in between the hanging mass and the force detector twice to provide two cords, and so on for subsequent iterations.

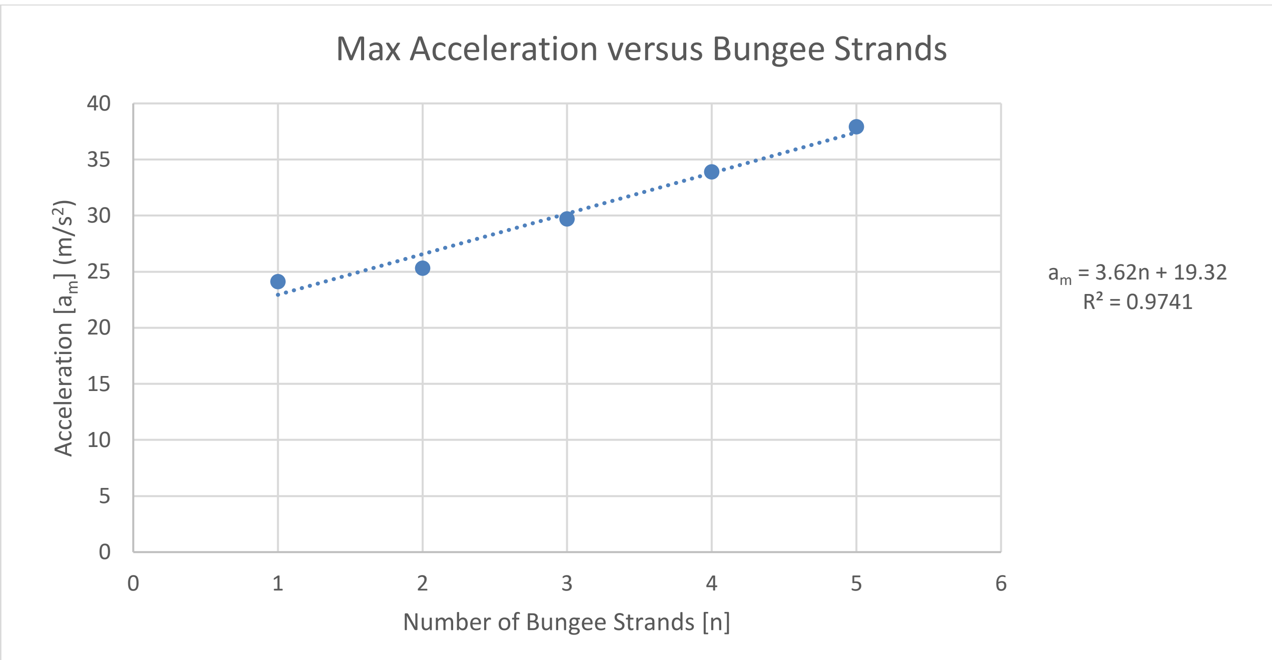
RESULTS:

The maximum force on the object for each drop was measured, and the instantaneous acceleration was calculated for that moment. This was graphed against the number of bungee strands attached to the hanging mass, allowing us to model the relationship between the two.

Figure 2: **Table of Averaged Maximum Force for Each Number of Bungees.** The average force had a correction applied to account for the baseline force detected from the weight of the bungee cord. The mass of the system was held constant at 150 g, as was the length of the bungee(s) attached at 38.9 cm. The uncertainty of the experiment comes from the standard deviation of the max acceleration.

# of bungee strands	Average Max Force (N)	Max Acceleration (m/s^2)	Standard Deviation (m/s^2)
1	3.61	24.11	0.03
2	3.79	25.29	0.01
3	4.45	29.69	0.01
4	5.08	33.89	0.05
5	5.69	37.91	0.08

Figure 3: **Maximum Acceleration Experienced by the Hanging Mass versus Number of Bungee Strands Attached to the Hanging Mass.** The linear fit model allows us to predict how the number of bungee strands will affect the acceleration of the system.



Equation produced from our model:

$$a_m = 3.62n + 19.32$$

Where:

- a_m equals the maximum acceleration of the hanging mass
- n equals the number of bungees attached to the hanging mass
- Length of the bungee cords, hanging mass, and height of fall are all held constant.

Uncertainties (obtained with an Excel Linear Regression Analysis):

uncertainty for slope=	±.34	% uncert= 9%
uncertainty for y-intercept=	±1.13	% uncert= 6%

Our value of interest is the slope of the linear line of best fit through the data. This coefficient will tell us the relationship between the increase in acceleration that comes along with increasing the bands attached to the hanging mass. We can also use the model to determine when the hanging mass experiences an acceleration of greater than $3g$.

value obtained = 3.62

uncertainty of experimental value(s) = ±.34 % uncert= 9%

We found that the acceleration of the bungee cord appears to increase linearly with increasing the number of bungee strands attached to the hanging mass. The equation $a_m = 3.62n + 19.32$ models how we expect the increasing number of bungee strands attached to the hanging mass to act on this system.

DISCUSSION:

There is no value for us to compare our model to, but we can use our model to predict how many bungee cords would create an acceleration of more than $3g$. More than 2 cords will produce an acceleration of more than $3g$ for this system, which we observed during our experiments. Our model is very limited in that it cannot account for a variable mass or a varying length of bungee cord, but time constraints and a lack of extra bungee cord prevented a more vigorous analysis of these additional factors.

Uncertainty was added to our experiment from the fact that we could only measure up to 5 bungees being attached to the hanging mass, given the limited amount of bungee cord that we had to work with. Having a larger range would bring our uncertainty down, and this was likely the largest source of uncertainty in our experiment. We also were limited in how long our bungee cord could be, given that we had to be able to wrap the bungee back to add additional strands. A longer bungee cord would be an easier system to measure, and might help to lower our uncertainty to a degree. In addition to these systematic influences, it is possible that the bungee cord experienced some degree of degradation over the course of the experiment. There was also likely a small variability in the exact height from where we dropped the hanging mass, but this random error was likely very small given the small standard deviations of the maximum acceleration.

Our main results did not support our hypothesis. We were expecting 4 cords to create an acceleration of more than $3g$, but our data suggests that this point is reached with 3 cords.

CONCLUSION:

Our experiment suggests that attaching three or more bungee cords to a hanging mass of 150 g will create an acceleration of more than $3g$, giving us insight to the maximum number of bungee cords that we can attach to our egg harness the day of the egg drop. Further experimentation could consider if the length of the bungee cord influences this relationship, and how a variable mass changes the behavior of the system across different numbers of bungee cords.

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

Pledged: Michael Sullivan