Barbie Spring Model

Introduction

After creating a working spring model, we were instructed to make the spring into a bungee cord. This bungee cord would allow Barbie to go on a "great ride", by getting close to the ground without smashing into it. To make the bungee cord work, we used an IF THEN ELSE statement to turn off the spring force when Barbie was above the unweighted length. Barbie will be falling from a height of one meter, using 80 mm rubber bands, that has a spring constant of 88 N/m. The goals of this project are to compare the differences between the spring and bungee cord models and figure out how many rubber bands will be needed for jumpers at different weights of 60g, 70g, and 80g.

Model

Variable	Formula	Units
Acceleration	Total force/mass	m/s/s
Acceleration due to gravity	-9.81	m/s/s
Change in length	velocity	m/s
Change in velocity	Acceleration	m/s/s
Cross sectional area	0.0001	m*m
Drag	Drag constant*cross sectional area*velocity*ABS(velocity)	N
Drag constant	-0.65	kg*m*m*m
Length	1	m
mass	0.06, 0.07, 0.08	kg
Rubber bands	12.3	
Spring constant	88	N/m
Spring force	-Spring constant*(Length-unweighted length)*IF THEN ELSE(Length>1-unweighted length, 0, 1)	N/m
Total force	Weight+ spring force+ drag	N
Unweighted length	0.08*rubber bands	m
velocity	0	m/s
weight	Acceleration due to gravity*mass	kg*m/s/s

When we started to do this project, we had used the units that were given directly. This led to the spring effect not being captured appropriately due to the inconsistent units. In the explanation of the project, it said that the length of each rubber band was 80 mm. When we plugged it into our model however, the bounce went below –50 m. This was because our units were not consistent. So we converted it to 0.08 m to match the units, making the rubber bands smaller and not making the bounce super long. Another variable that had to be converted was mass. We were given three weights in grams, but this made the bounce very large due to not converting. We changed the weights from 60g, 70g, and 80g to 0.06 kg, 0.07 kg, and 0.08kg, which then made the bounce smaller.

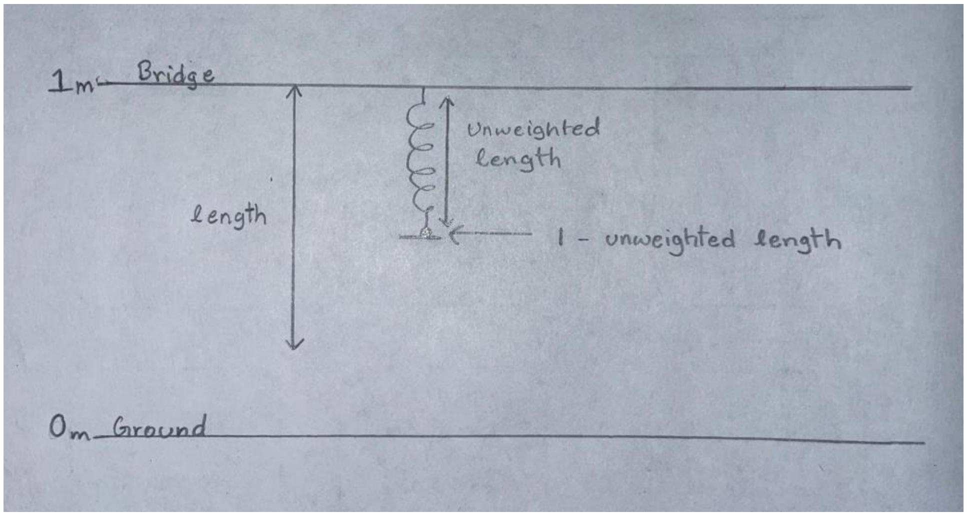
As you can see from the table above, we have taken our drag coefficient to be negative. This is because air resistance is acting against the falling body, hence slowing it down. Also, the cross-sectional area was not given in our instructions, so we assumed it to be 0.0001 m*m. This is a small number, which affects the drag force of the model. Drag force causes the height of the bounces in the model to get smaller. However, because our cross-sectional area is so small, it takes longer for the bounces to get smaller.

We see that when the Length goes to lesser than the unweighted length, the spring ceases acting like a spring and acts like a rope instead. This means that it goes slack and is in free fall. Thus, there is no spring force acting upon it at this point. That is why we use the IF THEN ELSE statement to apply a condition of the spring force going to zero whenever the Length is lesser than the unweighted length. We can cross-check whether this behavior has been captured correctly by graphing the acceleration. If we see the acceleration going to zero during this period of time, then it is a verification of the behavior being modelled correctly.

In our first trial of modelling this however, we had assumed that the Length and unweighted length could be compared directly irrespective of their signs. However, that wasn't the case. The unweighted length is positive while the Length is negative. Thus, we were unable to find the point when the length would be greater than the unweighted length as it would always remain smaller, being a negative value. That is why we thought that we should take the negative of the unweighted length in order to be able to compare both values, thus making the condition: IF THAN ELSE(Length>-unweighted length, 0, 1). However, even upon doing so, we noticed that the length wouldn't get more than zero. This was because in doing so, we had instructed the spring force to turn on only once the jumper had reached the ground. This would have just led to an accident.

Upon consultation and reexamination, we found the reason for this to be because we had considered our starting point at the top of the bridge to be 1 rather than zero. As indicated in the image below, this meant that we actually needed the spring force to turn on once the jumper had reached the point 1-unweighted length. Thus, we altered our condition to be as follows:

-Spring constant*(Length-unweighted length)*IF THEN ELSE(Length>1-unweighted length, 0, 1)

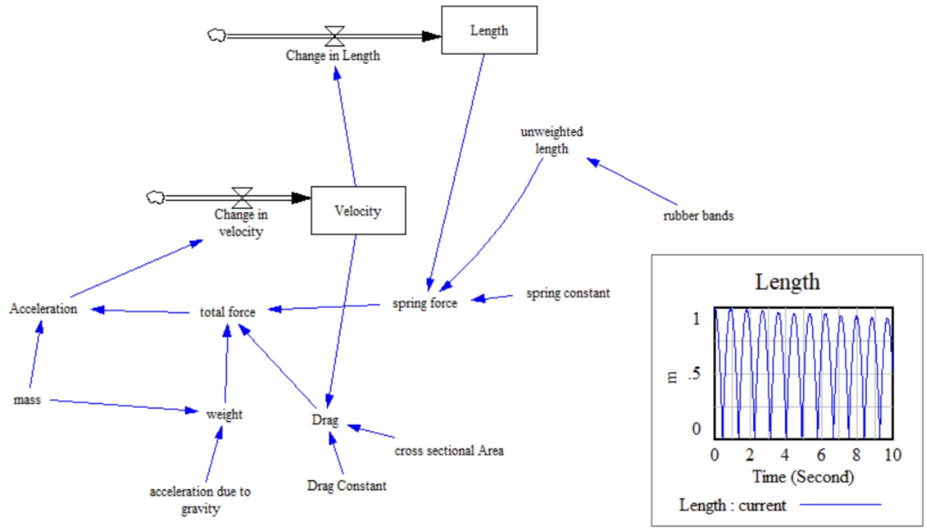


Upon making this alteration, we were finally able to capture the accurate behaviour in the graph with the bounces of the spring gradually decreasing. The resistance from the spring force too was applied at the right time, preventing the jumper from crashing to the ground. Depending on the number of rubber bands we used, we were then able to manipulate how close to the ground the jumper would get. We did so using a slider for the rubber bands.

Finally, another assumption we make is that rubber bands can be attached anywhere on the body. When using the slider to find the number of rubber bands required to make the length go to zero, we do not consider the additional length of the body itself. Suppose we were to tie the rubber band around the waist of the jumper, then when modeling the length to zero, it would be the waist that would be going to this zero i.e., the ground. This would lead to an accident from the lower half of the body crashing into the ground.

Model Results

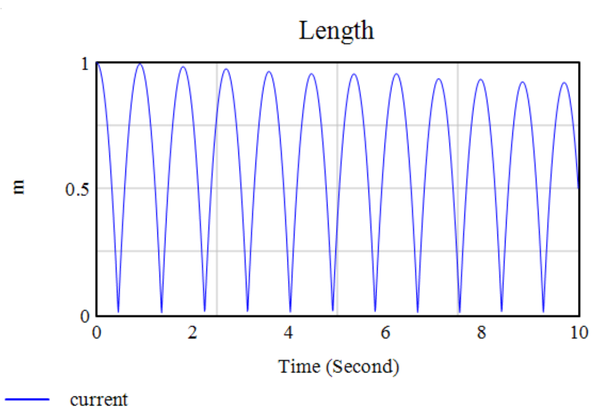
The first part of the assignment asked to figure out the differences between the spring and bungee models. Comparing the two models, we can see that the spring model uses initial displacement and weight displacement, whereas the bungee model does not. The bungee model, unlike the spring model, uses drag force due to air resistance, which helps to slow things down as they fall. Although we do not have a graph to show the difference between the two models, looking at a graph would be helpful to show drag force. Without drag, the spring will continue with constant velocity, while with drag, the falling object will slow down over time. The spring model also does not use an IF THAN ELSE statement, because the spring does not need to turn off.



This is a picture of the vensim diagram of our bungee cord model. It has many of the same variables as a spring model would have, however in addition, it also has drag, drag constant, cross-sectional area, and rubber bands. We also added a slider for the rubber bands using the IO Object tool so that we could change the number of rubber bands to see how close Barbie would get to the ground.

After creating our model and breaking it several times, we were finally able to create a model where the spring would shut off properly. After our spring force was fixed, we were able to start figuring out how many rubber bands were needed for each weight.

Below is our graph for the mass of 60g or 0.06 kg. It took 12.3 rubber bands to get the graph close to zero, without going below it. In the graph the effects of drag can also be seen, as the height of each bounce gets smaller. If the graph showed more time steps, the bounces would become smaller and smaller.



Although we put in different masses, 60g, 70g, and 80g, and changed the number of rubber bands for each one, we found that all three masses used 12.3 rubber bands to get close to zero, but not go below it. Although the number of rubber bands was the same, the drag force affected each mass differently. With 70g or 0.07 kg, the bounce became smaller faster. While the bounces for 80g or 0.08kg took longer than 60g to become smaller.

Conclusion

Graphs and data are important to see how close someone can get to the ground without dying. Using our model, we were able to find that the average number of rubber bands required to form the cord for 60 g, 70 g, and 80 g jumpers would be 12.3 rubber bands. This would enable them to reach very close to the ground without crashing. However, since we cannot have a fraction of a rubber band, we shall consider it to be 12 rubber bands in length, since it would be safer to round down than round up. From our model, we can tell that Barbie, regardless of weight, will use about 12 rubber bands for her jump.

Even though we have a working model, there are still several ways in which we could improve it. The first thing that we would change is the cross-sectional area. In this model, it is 0.0001 m*m, which is very small. We would experiment by making the value bigger, to see if it affected the number of rubber bands that we would need to use and to see how it affects the drag force. If we had more time, we would also take into account the position of where the bungee cord would be tied to the body of the jumper as that would affect the length. Finally, something else we could consider is the weather conditions. For example, had it been a windy day, then it would have affected the forces affecting the cord, requiring variations to the model.