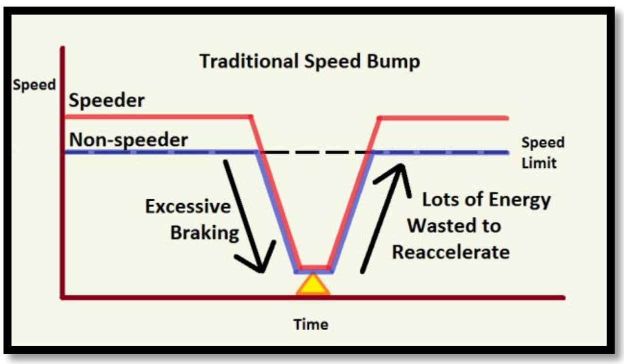
Final Report on Jerkling
An Energy-saving Speed Bump
21W.732

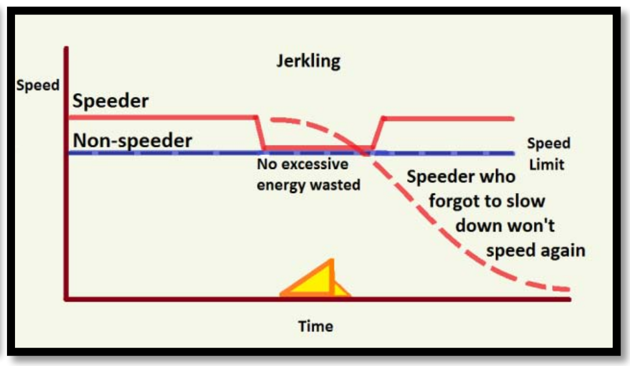
Abstract:
The standard speed bump wastes energy in that vehicles have to slow down to speeds considerably less than the speed limit in order to avoid discomfort. Much energy would be saved if vehicles traveling the speed limit could easily pass over the speed bump and only speeding vehicles would experience a significant discomfort. Jerkling, a new design for a speed bump, is designed to only cause discomfort at higher speeds. Jerkling utilizes a dashpot, which mechanically increases resistive force relative to the compression velocity. From testing the actual effect of speed bumps and the properties of a constructed dashpot, Jerkling appears to be a feasible alternative to the traditional speed bump.

Introduction

This report discusses how traditional speed bumps waste energy, offers a new speed bump design (labeled “Jerkling”), argues why the new design should work better than alternatives, and evaluates relevant testing.

Motivation- Energy Wasted on Regular Speed Bumps:
As cars accelerate, they burn more fuel than if they were to simply travel at a constant speed. This is because extra energy is needed to increase the speed of the car.[1] Hence, continual acceleration and deceleration of a car causes a great amount of energy loss. This makes speed bumps a major concern from an ecological point of view. It is very common to observe cars slow down abruptly for speed bumps and then quickly speed back up again. Jerkling will help save energy by allowing drivers to traverse the speed bump while traveling within the safe and preset maximum speed. Figures 1 and 2 show respectively how energy is wasted on regular speed bumps and how Jerkling can fix this problem.





Figures 1 and 2: The left figure is a graph that depicts the speed of two vehicles traveling over a traditional speed bump. The right figure is a graph that depicts the speed of two vehicles traveling over Jerkling.

In Figure 1, both the speeder and the non-speeder have to do excessive braking to travel over the traditional speed bump. Then much energy is wasted when the vehicles reaccelerate to their previous speeds. The speeder may resume speeding again.

In Figure 2, the non-speeder can continue at the speed limit without braking. In this scenario, Jerkling eliminates reacceleration, thereby saving energy. The speeder may simply brake and then reaccelerate. The reacceleration is lessoned relative to the traditional speed bump. Lessoning acceleration saves energy.

However, the purpose of a speed bump (to control the speed of the vehicle) appears defeated. One might argue that drivers would speed more with Jerkling because there is less excessive braking and reacceleration. The counterargument to this is that Jerkling’s motivation to slow down is not excessive brake. Instead, Jerkling’s motivation to slow down is that Jerkling should cause significant discomfort and put strain on the vehicle if the speeder forgot to brake sufficiently. This increased discomfort and strain/harm (much more than in the case for the traditional speed bump) will help to motivate speeders to not speed in areas with Jerkling.

Design Overview:

The design consists of a curved ramp that compresses when a vehicle passes over it. The compression is limited by a dashpot. A dashpot, by definition, is a piston inside a cylinder that is closed except for a tiny air hole. This air hole in the dashpot allows the air pressure's resistance to be proportional to the velocity of the compression.[2] This means that when the ramp is compressed quickly, a great resistive force prevents the ramp from lowering, but when the ramp is compressed slowly, the ramp easily lowers. A basic model for Jerkling is shown in Figure 3.

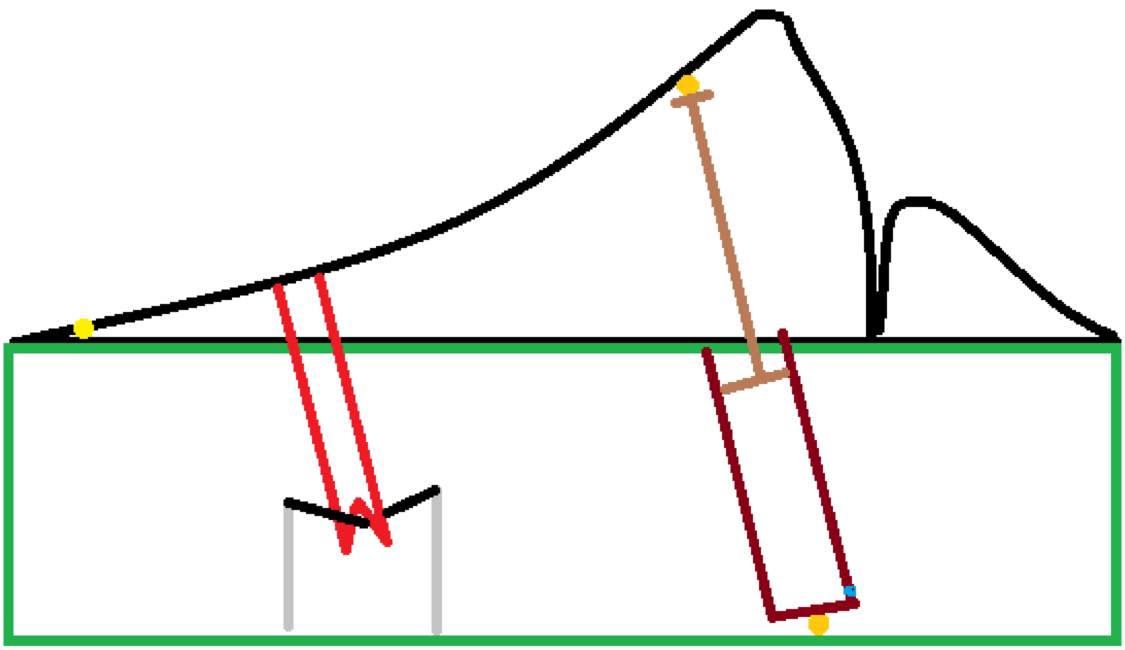


Figure 3: Jerkling uses a dashpot (shown in brown) to be compressed, but only so quickly. Hinges (shown as yellow dots) allow the ramp to compress and the dashpot to be compressed without bending. Jerkling will rise back up using an elastic force provided by the band shown in black. The ramp will always have a little bump (as it will never fully compress). This is to ensure there will always be some degree of a speed bump for extraordinarily heavy vehicles. Note that everything in the green box lies beneath the surface of the road.

Background

Many considerations went into this project and the contrasting results between the simplified model and the experimental results of driving over speed bumps contribute to a much better final design.

Existing Solutions

There currently exist a few different speed bump models, all of which have unique features. The most common of these is the conventional speed bump. Conventional speed bumps generally range from 3 to 4 inches in height and aim to slow cars down to a speed between 5 and 10 mph.[3] Speed humps are similar in that they are generally the same height, but they tend to exert less force on vehicles. They are built wider, to span the width of the road, and are only meant to slow down vehicles to speeds of 10-20 mph.[4] Speed tables are an elongated version of speed humps that plateau for a section in the middle. They aim to slow down vehicles to speeds of 20-30 mph.[5] Speed cushions are the most modern form of speed bumps. They are built wide enough so that cars have to traverse them, but narrow enough so that emergency vehicles, which have longer axle lengths, can pass over them without being slowed.[6] The most common mediums that speed bumps are made of, no matter which type, are asphalt, concrete, and rubber.[7]

Speed Bump Model

The average force on a vehicle when passing over a speed bump was calculated using the physics principle that Force F = the change in momentum over time $\Delta p/\Delta t$. The model assumed constant speed as if the speed bump only redirects the vehicle's motion to be a given number of degrees above the horizontal. One calculation showed that a 1.5 foot ramp, angled at 15˚, could be driven over at 15 MPH, producing a g-force of about 3.6 g's. This means that the average force applied to the vehicle, over the .07 seconds traveling over the ramp, would be about 3.6 times as great as the force generally applied by gravity.

The "average force" was assumed to be a meaningful value because the suspension should distribute the force on the car over time.

A full example with calculations and a drawing, as well as graphs of the model's results, are given in Appendix 1.

The model highlights that the force applied, not accounting for gravity, is proportional to the speed squared, increasing the g-force more and more.

Initial Speed Bump Testing

A set of speed bumps were driven over at various speeds and an accelerometer recorded the cars vertical acceleration. The data from the accelerometer show that the car's suspension absorbs much of the discomfort potentially caused by the speed bumps. In one case, driving 32 MPH over a standard 1.5

foot long/roughly 4 inch high speed bump produced a maximum g-force of about 2.2 (gravity included). (Measurements were taken from inside the vehicle). This is far less than the model that predicts an average g-force of about 24.6 (assuming the final velocity is 30˚ above the horizontal).

Model vs. Speed Bump Testing Part 1: G-forces

The reason for the large discrepancy between the model and speed bump testing is that the model did not take into account that vehicle's suspension (and tires) would lessen the effect of the speed bump by preventing the final velocity from being 30˚ above the horizontal. The model assumed that the suspension would help spread the force over the time it takes to clear the ramp, but the model did not consider that the length of the speed bump is so short that there is not ample time for the compressed suspension to do ample work on the car.

Working backward from the data's average g-force of 1.7 (gravity included), the model estimates that the actual angle of the final velocity of the vehicle was about .7˚. This is coherent with the observation of the passengers who noticed that the car was not significantly air borne.

With using the model, the data can produce a similar estimate for the final angle. Summing the area of vertical acceleration (integrating in a Riemann sum fashion) gives a total acceleration of about .233 m/s upward. The arcsine of vertical speed/total speed is roughly the arcsine of (.233/32) which equals .42˚. This value is not too far from .7˚, especially when using so few data points and ignoring any reduction in total speed from a decrease in kinetic energy. See the results section for other final angle calculations.

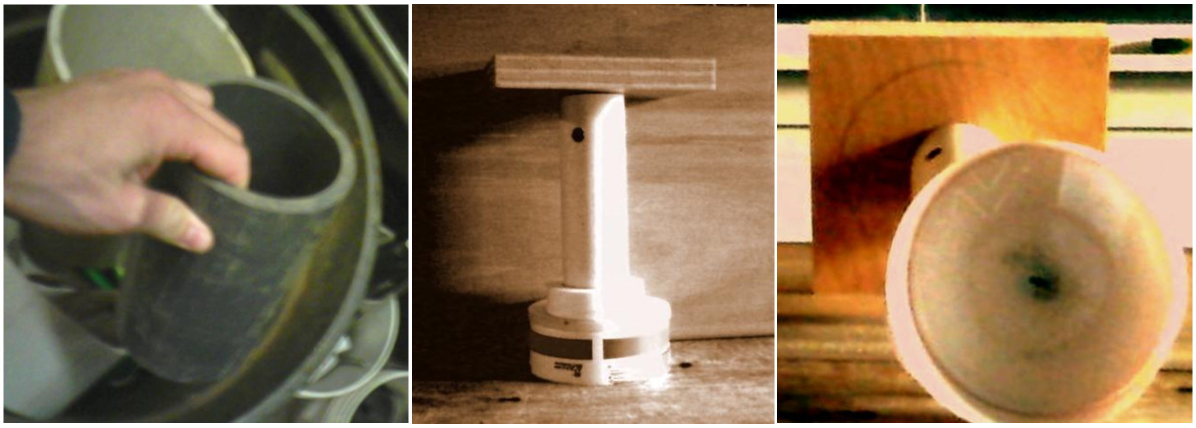
The low final angle calculations mean that the suspension greatly decreases the effect of the speed bump, and the model, if adjusted for the actual angle of terminal velocity, is moderately believable.

Methods

The Prototype

Building the prototype proved to be a challenge. It was decided to attempt to build the dashpot rather than purchase one online. The hope was that building a dashpot would save money while offering a deeper understanding of the fundamentals of a dashpot.

The task of building a dashpot was hampered by low quality materials, unfortunately presumed to be of a higher quality. The main setback was that the cylinder in which the piston moved was not perfectly circular. A countermeasure was taken to use a flexible piston made from a plastic yogurt container. While the yogurt container provides some resistance from compressed air (at least 10 pounds based on testing), the yogurt container is an inadequate substitute for tight-fitting metal dashpots. Due to this setback, testing was primarily focused on the effect of speed bumps and the physics of a dashpot.
The dashpot is shown in Figures 4-6.



Figures 4-6: The left photo is a picture of the cylinder that the piston is supposed to slide in. The cylinder was not perfectly circular, which presented many difficulties during building. The middle photo is a picture of the piston. The top is a plywood board. This is connected to a PVC shaft which is attached to a plastic ring. This is resting on the piston (middle and right picture) which consists of the plastic, flexible yogurt container supported by the plastic slabs on the inside and outside. The plastic slabs provide more support to the flexible yogurt container.

The dashpot was the only component of the design that was built given the time available to complete the project. As a result, the testing for Jerkling had to be run differently than originally planned. The dashpot was evaluated for its effectiveness and its ability to hold to the claim that resistive force is proportional to compression velocity.

Results/Discussion

Speed Bump Testing

The speed bump testing took place on November 15th at MIT along “Dorm Row” (Memorial Drive) and along Vassar Street. The goal was to understand the actual effect of speed bumps already used today. Dave Custer’s car was driven over standard size speed bumps around MIT at various speeds and an accelerometer was used to evaluate the vertical acceleration applied by the speed bumps.

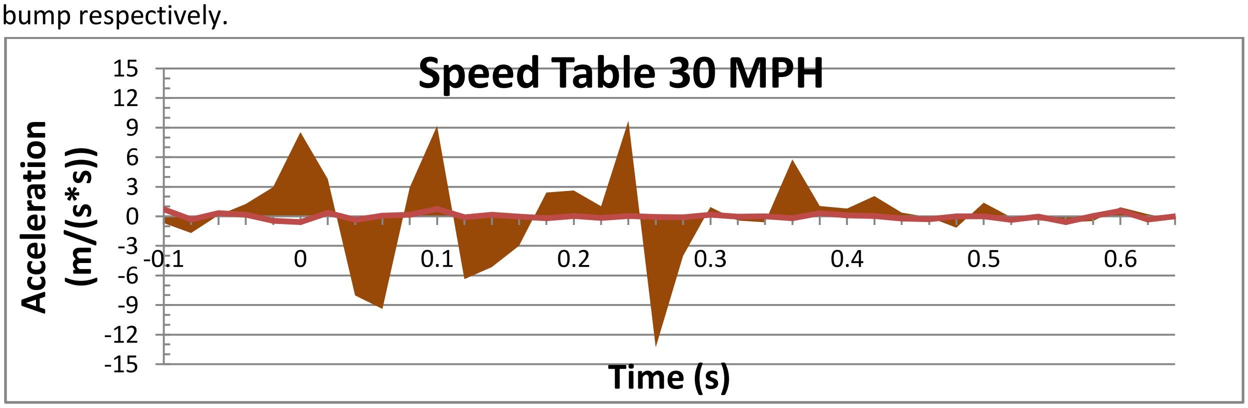
The accelerometer was placed in the front, middle console of the car, as shown in Figure 7. Since the accelerometer is in the front, the accelerometer’s measurements best reflect the acceleration of the front of the car. It should be noted that the, the accelerator was zeroed. For the data, zero m/s^2 means the car is not accelerating. A positive 9.8 m/s^2 is equivalent to a g-force of 1 without gravity and a g-force of 2 with gravity. A negative 9.8 m/s^2 means the car is in free fall.

Figure 7: The accelerator was place in the front, middle console of the car.

The data shown in figure 6 highlights that the car's suspension absorbs much of the discomfort potentially caused by the speed bumps. In one case, driving 25 MPH (see Figure ***) over a standard 1.5 foot long/roughly 4 inch high speed bump produced a maximum g-force of about 1. To find the g-force, divide the acceleration by 9.8 m/s^2. Measurements were taken from inside the vehicle. This is far less than our model for an ideal speed bump (final angle left unaffected by suspension) which predicts a g-force of about 8.

As the model contrasts greatly from the empirical results, it is clear that the car's suspension (and the tires) dramatically reduced the effect of the speed bump on the car and on the passengers inside. The effect of the suspension and tires is also evident from the data. As shown best in the 15 and 25 MPH graphs, the initial jerk upward increases over time. This means that the suspension, like a spring, gets compressed more and more, and thus starts accelerating the car more and more while the front wheel first travels over the speed bump. If there were no suspension, the data would show an acceleration that abruptly starts at its maximum.

Another type of speed bump was evaluated: a speed table. Speed tables are elongated and much more gradual. The fact they are elongated helps the suspension to act on the car (increasing the impulse), but the fact they are elongated decreases the force at any given moment (decreasing the acceleration). At 30 MPH, this produced a maximum upwards g-force of about .99 (without gravity), which is about the same g-force of .98 from a standard speed bump at only 25 MPH. Thus speed tables allow cars to pass at high speeds without additional discomfort. See Figure 6 for the 30 MPH speed table and 25 MPH speed bump respectively.



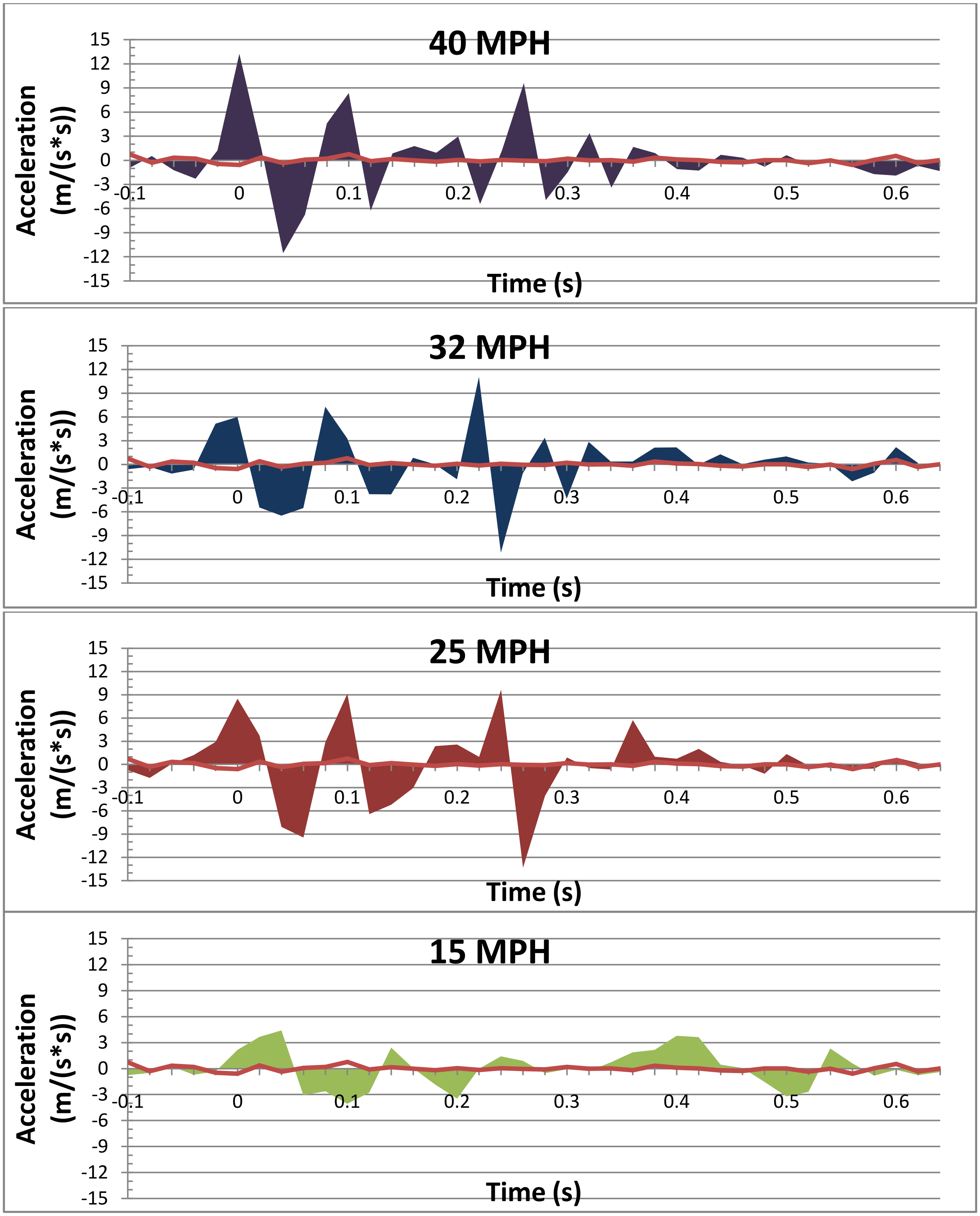


Figure 8-12: The acceleration from a speed table or speed bumps at different speeds. The red line is normal vibrations of the car without a speed bump. Notice the differences in magnitude of the accelerations and their duration.

Final Angles	How It's calculated:	**15**	**25**	**32**	**40**
Average Acceleration	Add points and divide	3.402	5.689	7.272	13.240
Time to clear ramp	From model (x MPH & 1.5 ft)	0.068	0.041	0.032	0.026
Total acceleration	Avg acc. * time to clear ramp	0.231	0.233	0.233	0.344
Average G-force from data	avg acc./9.8 + 1	1.347	1.580	1.742	2.351
Final Angle from data	arcsin(vertical speed/MPH)	**0.88**	**0.53**	**0.42**	**0.49**
Final Angle from Model	Use G-force, MPH, and 1.5 ft	**2.0**	**1.2**	**0.7**	**0.6**

Table 1: The angles of the final velocity of the velocity just as it first clears the speed bump. The top bold numbers are the speeds in MPH. The bottom bold numbers are the calculated final angle.

In Table 1, Notice how the final angle is always small, and grows smaller and smaller as the speed increases. This shows how the suspension and compression of the tires are most effective at compensating for the speed bump when traveling faster; at higher speeds there is not ample time for the suspension and tires to do much work on the car. This is strong evidence that the suspension and compression of the tires help to lessen the effect of the speed bump.

Model vs. Speed Bump Testing Part 2: Final Angles

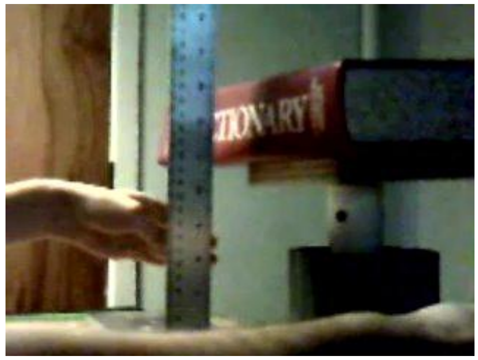
It is important to realize that the average acceleration is very much approximated using the small sample of data points, which make the derived final angle calculations data less reliable.

Furthermore, the data alone predicts a lower final angle than the model. This discrepancy is because the calculations using just the data assume the speed of the car (and the kinetic energy) remains constant over the speed bump. Some kinetic energy is converted into potential energy of the compressed suspension and tires. Additionally, some energy is lost due to sound energy and friction. Therefore, the speed of the car should decrease after hitting the speed bump, causing the actual final angle to be slightly higher than what was found in the data.

This reasoning is supported by the fact that the final angle from the data deviates less from the model when the vehicle is traveling faster. At higher speeds, the lost kinetic energy is proportionally less as the car’s total kinetic energy is greater.

In summary, a fair estimate of the true final angle is reasonably between the final angle from the data and the final angle from the model.

Dashpot Testing

Figures 13-14: These are two pictures of the testing setup for the dashpot. Weights (books) were added to the dashpot and the rate of compression was measured using a video recorder on a laptop. The ruler measured the distance dropped and the video footage measured the time elapsed. The terminal velocity of the dashpot was measured in this way. Shown in the left picture is the scale that was used to measure the weight of the books.

On 11/23/10, the dashpot (shown in Figures 13 and 14) was tested to see how the forced applied related with the velocity of compression. This was carried out using a small weight scale, a long ruler, a number of books, a smooth base board, the dashpot, and a video recording device (laptop).

Different weights were placed on the dashpot. As they fell, they quickly reached a terminal velocity. The terminal velocity is the velocity of the falling object when the force of gravity is equal in magnitude to the resistive force pushing up.

The terminal velocity was measured using the video recording device and the ruler. The velocity was measured by how much the object fell in a given amount of time. This was converted into in/s.

The compression force was simply the weight of the objects. The scale was used for these calculations.

The data shown below in Figure 15 are compiled into one display to make the general trend easier to see.

As Figure15 shows, there is a definite association between velocity and resistive force. The question then becomes is the resistive force directly proportional to the velocity of compression. This is more difficult to conclude. The graph shows a linear trend line, which accounts for 81.99% of the variation in the resistive forces. However, the data is clearly curved, and so a much better model is the power trend line. This power trend line accounts for 95.65% of the variation in the resistive forces.
The data does not perfectly reflect the hypothesis that the resistive force is proportional to the velocity of compression. However, a little intuition helps to explain why there is a curved shape to the data, and

it makes it reasonable to believe that the resistive force may be proportional to the velocity for an ideal dashpot.

The nonlinear trend shape is reasonably from friction present in the dashpot. This frictional force makes the resistive force slightly larger than it normally would be given a particular velocity. Since the kinetic friction force is essentially constant regardless of velocity, the effect of the frictional force is most significant at low velocities. A better manufactured dashpot that would have an accurate circular shape could be made with less frictional resistance.

Additionally, some objects (if not heavy enough) tended to wobble as they fell. This wobbling decreases velocity and increases the friction. As the piston wobbles, the force between the inner piston and the cylinder increase, increasing friction. A better manufactured dashpot would not wobble.

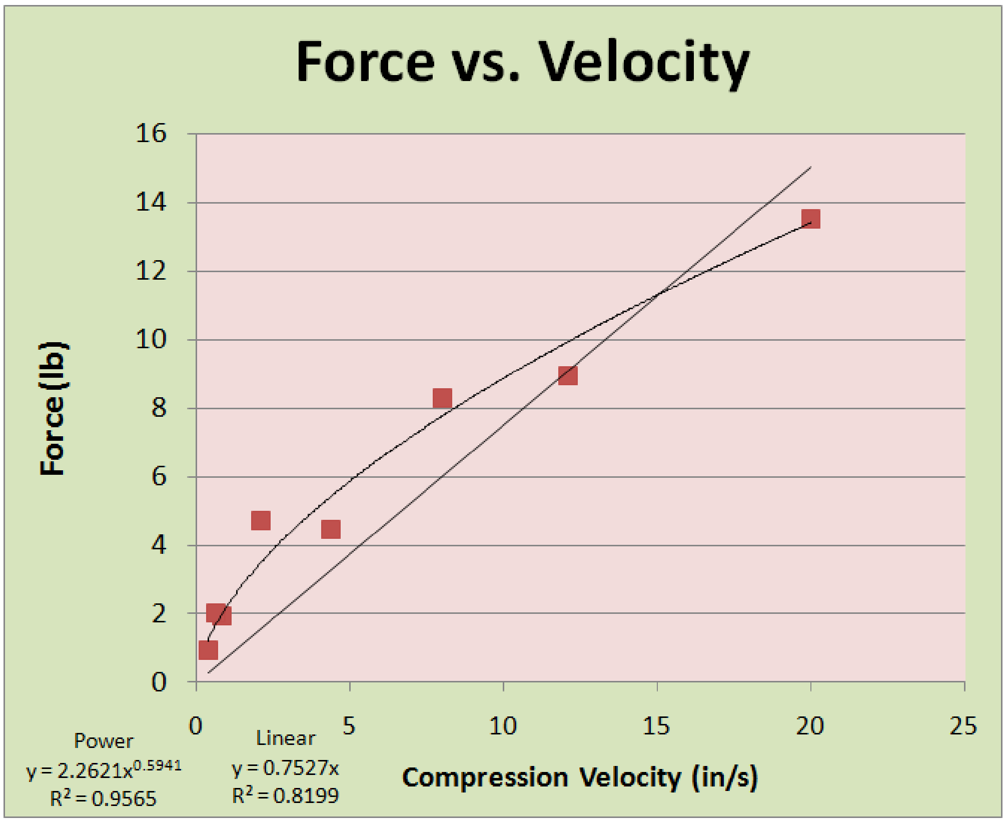


Figure 15: A graph showing the relationship between the compression velocity and the resistive force.

It is important to note that for testing, compression velocity was a dependent variable of the force applied, but the inverse that force is dependent upon compression velocity is more applicable to Jerkling.

Another important consideration of this data is how the dashpot might actually function if vehicle were being ridden over it. If the ramp takes about .2 seconds to cover (7MPH and a 2ft ramp) and the expected compression is a total of about 4", the average compression velocity is 20"/s. The dashpot constructed will exert a force of about 13 lb. This will not support the weight of the vehicle. The sheer force of gravity would fully compress the dashpot in this scenario. Given the weak ability of the dashpot built, the dashpot used in reality must be larger and more effective (less air gaps/leakages).

Conclusion

The data from empirical speed bump testing and the predictions from the speed bump model show that far too much of the impact of a speed bump is absorbed by the suspension of the vehicle to make Jerkling's original design feasible and effective as a speed bump. However, the empirical data also show that the force upon landing is just as great as the force when initially hitting the speed bump. With a slight revision in Jerkling's design, the overall concept of a mechanical speed bump could be feasible. An improved design for Jerkling would be an elongated design as shown in Figure 16.

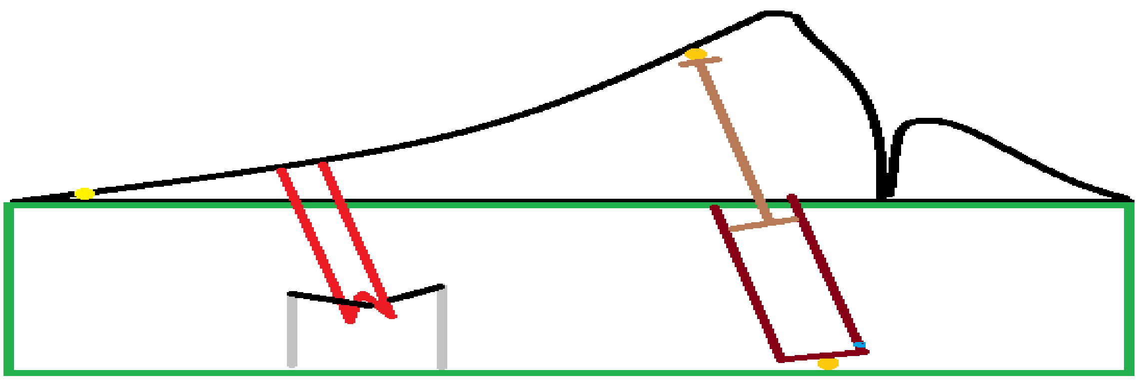


Figure 16: An elongated design for Jerkling.

An elongated design would primarily increase the time that a force is applied on the vehicle while decreasing the force applied while going up the ramp. This would limit the effectiveness of the suspension, increasing the final angle, and thus increasing the corresponding force applied upon landing.

An elongated design would also provide a greater physiological advantage.

The dashpot would be required to apply less overall force and it could compress more slowly. A much more substantial dashpot or another resisting device would be needed to complete the design.

Appendixes

Appendix 1: Sample Calculation Using Speed Bump Model.

To model the "discomfort" of a speed bump, it is necessary to determine the force needed to cause discomfort. This can be accomplished by generalizing that discomfort occurs when there is a sudden large acceleration. The model gives the force necessary to cause acceleration in the brief time that the vehicle goes over the speed bump and changes direction. The vehicle is assumed to have constant speed, and the force calculated is the average force applied to the vehicle. See Figure 17.

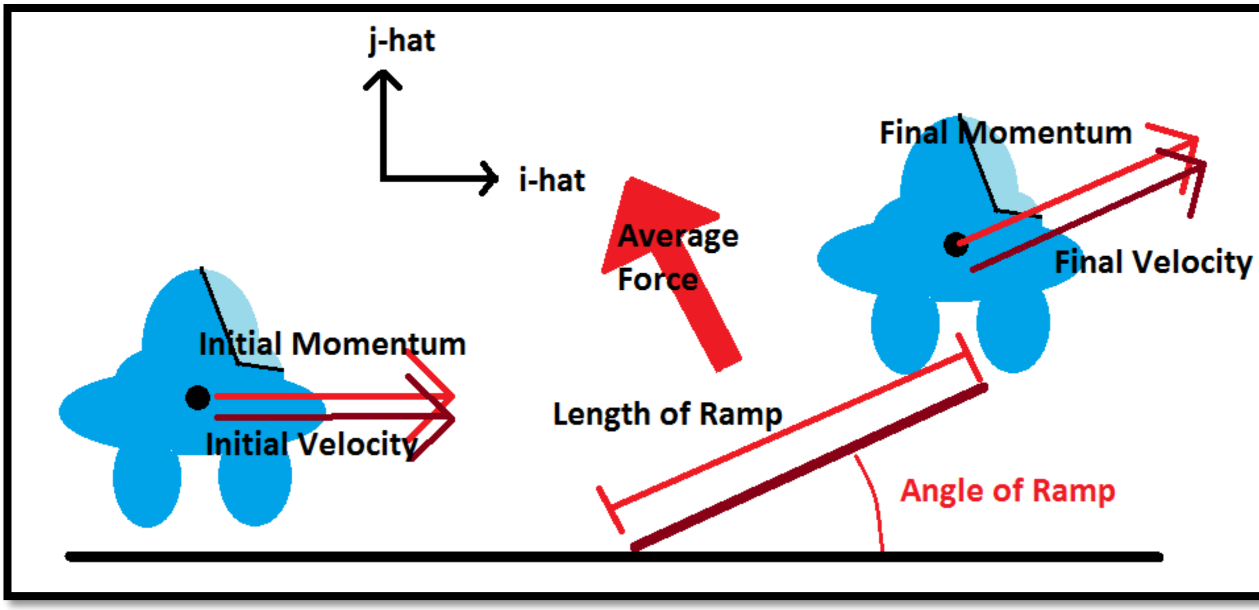


Figure 17: This is a simple sketch on which the model is based. Note the time to clear the ramp is simply the length of the ramp divided by the initial speed.

For this example, the vehicle will be accelerated such that the final velocity will be 30 degrees above the horizontal. This would make a discomfort both when accelerated upward and when landing.

The force necessary to cause discomfort can be estimated by finding the change in momentum. F = change in momentum/change in time. (**F** = d**P**/dt). Momentum is a vector defined as mass * velocity, where velocity is a vector. The mass of the vehicle can be say 2000 lb.

The momentum can be defined using unit vectors (i-hat = positive horizontal direction, j-hat = positive/upward vertical direction)

The speed of the vehicle is contingent upon the speed limit. We start our model with 10 miles per hour, even though this is very slow.

The initial momentum (before hitting the speed bump) is mass * velocity = 2000 lb / (32 ft/s^2) * 200 MPH * (1.46667 ft/s /1MPH) = 911.8 lb*s. Note: we divided the weight by 32 ft/s^2, the acceleration to due gravity. This derives that actual mass from weight.

The initial momentum is thus 911.8 lb * s forward.

We assume the final momentum has the same speed, just in a different direction. We can assume this because the air pressure in tire (of either a bike or a car) will make this collision more elastic. Moreover, if we assume that little to no height has been reached when the bike and biker are redirected by the speed bump, then the speed is the same. No kinetic energy has been converted to gravitational potential energy.

So the final momentum is thus 911.8 * (cos 30 i-hat + sin 30 j-hat) lb * s = (789.7 i-hat + 455.9 j-hat) lb*s

To get the change in momentum, we subtract the initial momentum from the final momentum.

Change in momentum = ((789.7 – 911.8) i-hat + 455.9 j-hat) lb*s = (-122.1 i-hat + 455.9 j-hat) lb*s

Recall F = change in momentum/ time.

The time of this collision is the distance of the speed bump / rate.

So t = 1.5 feet / 10 MPH * 1 MPH / (1.46667 ft/s) = .102 seconds

So **F** (a vector) = (-122.1 i-hat + 455.9 j-hat)/.102 lb.

The magnitude of the force = $\sqrt{}((122.1)^2 +(455.9)^2)$/.102 lb =lb = 4627. lb

The angle giving the direction of the force, (where the horizontal forward direction equals 0 degrees), is arcos (-122.1/472.) = 105.0 degrees. Note: the 472 is the total change in momentum given by $\sqrt{}((122.1)^2+(455.9)^2)$.

The force in the vertical direction is then the sin (105) * 4627 lb = 4469.0 lb.
Adding 2000 lb for gravity yields 6460 lb in the vertical direction.

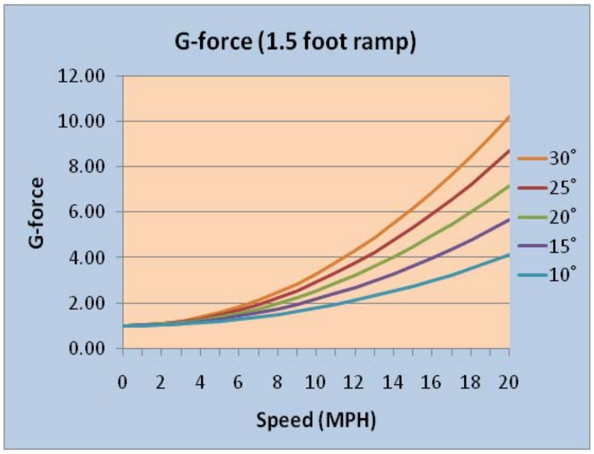
The horizontal force is cos(105) *4627 = -1198 lb.

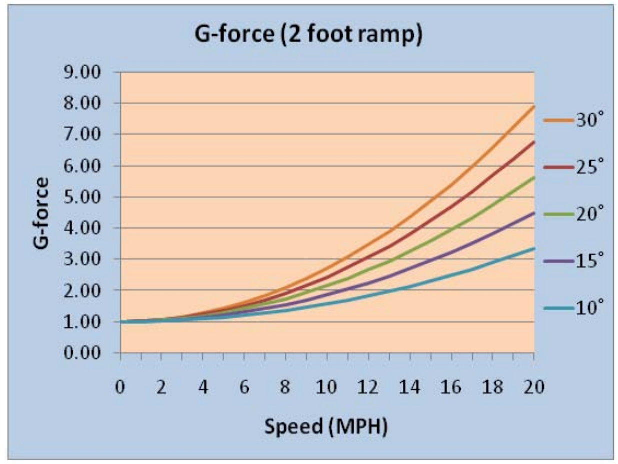
The total force is then = $\sqrt{}((1198)^2 +(6469)^2)$ which equals 6579 lb.

This means during the .102 seconds of the collision, an average force of 6579 lb will be applied to the vehicle.

The g-force that corresponds to that is 6579/2000 = 3.28

These calculations can be repeated and varied for different angles and lengths of the ramp, speeds, and masses. Note that the masses cancel out when calculating the g-force. Using the model the following graphs (Figures 18 and 19) were generated for 1.5 and 2 foot ramps.





Figures 18 and 19: Graphs of the average g-forces applied to a vehicle riding over 1.5 and 2 foot angled ramps. Notice the changes in scale that reflect change in the magnitude of the average acceleration.

A few key features are noticeable from this model. Primarily, the shorter ramps are shown to make much greater g-forces. Seconds, as the speed increases, the g-force increases more and more. Also worth mentioning is that the mass (aka weight) of the vehicle cancels out so that the g-force for any mass is the same holding all other variables constant. This is important to consider because vehicles of different masses will go over Jerkling.

Part of the reason why the g-force increases more and more (and the reason why it starts at 1 and not zero) is because gravity was taken into account as part of the contact force that acts on the object. As the vehicle's speed over the ramp increases, the contact force from the ramp is concerned more with changing the vehicle's momentum than with accounting for gravity.

Ignoring gravity, the g-force is proportional to the speed squared. The change in momentum is greater, and the time to cover the ramp is less.

Appendix 2: Resources and Contributors

Qualifications of primary investigators

The students are two MIT undergraduates of the class of 2014. Both are currently enrolled in 21W.732, Writing Through Digital Media.

Overview of Consulted Oracles

Our research can from a wide variety of sources. We consulted online databases and firms as well as experts in the fields of metal construction.

Acknowledgements
The students would both like to thank Peter Dourmashkin for help with the speed bump model.

The students would both like to thank Barbara Hughey who heads MIT's 2.671 lab. Barbara lent the accelerometer that was used in the speed bump testing.

The students would both like to thank their professor Dave Custer for so graciously offering his car for speed bump testing. This experience totally made this project (despite illness and setbacks in construction) worth it. The empirical research from riding over speed bumps at high speeds was instrumental in correctly analyzing the effect of speed bumps.

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[1] Vehicle Acceleration & Gas Mileage | eHow.com, http://www.ehow.com/facts_5873964_vehicle-acceleration-gas-mileage.html#ixzz14czMprc0.
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[5] Speed table - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Speed_table.
[6] Speed cushion - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Speed_cushion.
[7] Speed bump - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Speed_bump.

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