INTERNATIONAL BACCALEAUREATE

PHYSICS EXTENDED ESSAY

“Investigation of the Effect of Two Different Suspension Systems (Dependent and Independent) on the Angle (Inclination) Formed by the Vehicle with the Ground When Passing Over Bumps of the Same Size, with 7 Different Spring Constant in Their Suspensions”

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Abstract

This test report examines how two distinct suspension systems dependent and independent affect the angle (inclination) that the vehicle forms with the ground using seven different spring constants, damping oscillations, and spring potential energy. Damping oscillation, which is the state in which an oscillator's damping enables it to quickly attain its equilibrium position without oscillating back and forth around it, means that the energy change in the damping cannot be shown to be constant. Slope angle and spring constant are therefore not correlated linearly.

This article determined the optimal constant for various suspension setups. Independent suspension has a spring constant of 257.8. The angle of inclination increases with the size of this constant. Suspension system performance might be affected by the outcomes. It was discovered that the slope angle increased quadratically as the constants increased. Therefore, improving suspension systems will improve passenger comfort while driving.

In order to employ the mathematical model for the optimal spring constant, this study examines five trials of seven different spring constants in two distinct suspension systems and slope angle.

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1. Introduction

Personal Engagement

With the increasing population around the world, transportation shortages have increased. However, most people wanted to facilitate transportation in expanding cities by purchasing personal vehicles. That's why, like everyone else, I have been encountering cars all over my life since my childhood. Not only in my daily life, but also in the remote-controlled toys I used to drive when I was a child, and in my favorite movie that was released when I was growing up, cars have an important place in my life. As a result, I became interested in racing sports during adolescence and became interested in Formula 1, where the greatest mechanical masterpieces are located. I became a fan of a team in this sport. After this team lost the championship due to mechanical problems, not aerodynamics, I started to think about the suspensions that caused the biggest difficulties during the season. It was more difficult to think about those complex machines. Instead, I thought about the suspensions in normal vehicles that are frequently used in daily life. I started thinking about how to solve the problem of the car being affected by the bad roads due to my house being in the village. However, as someone who cares about the driving experience, I wanted to investigate the effect of different suspension stiffnesses and types on the inclination of the car when passing over bumps and find the most efficient one for daily life. In addition to all these reasons, I also wanted to inform and improve myself by getting an introduction to automotive engineering or mechanics, which I want to be my profession in the future.

Background Information

Suspension

The system of tires, tire air, springs, shock absorbers, and connections that attaches a car to its wheels and permits relative motion between the two is known as suspension. Road holding, handling and ride quality are incompatible requirements for suspension systems. Finding the ideal constant is necessary for suspension adjustment. Because all ground or road forces operating on the vehicle pass through the tire contact patches, it is crucial for the suspension to maintain the road wheel's maximum level of contact with the road surface. The suspension shields the automobile from wear and tear, as well as any Cargo, luggage or human being. A car's front and rear suspensions could be made differently.

Purpose of Suspension

The purpose of car suspensions is to increase the amount of contact between the road and the tires. This contributes to more comfortable automobile rides and ensures the driver has stable steering and decent handling. Since there are many flaws and problems in roads of some LEDC countries, a suspension system must be built to overcome them while supporting the vehicle and human health by protecting spine. To keep the car's body and frame more stable, the suspension works to absorb energy from the tires. The ability of a car to move smoothly on a difficult road is called driving, and its handling allows it to accelerate, turn and stop safely. Understanding road characteristics, handling and cornering principles is very important for a driver, which is why the suspension system is so crucial.

Working Principles of Suspension

The concept of force distribution forms the basis of how an automobile suspension works. This foundation begins to take shape when determining the weight balance (center of mass) of the vehicle. Equal distribution changes the force ratios exerted on pedestrians. The suspension converts the force into heat, minimizing the impact on the car's body. The damping effect is produced by the use of parts of the suspension system such as springs, shock absorbers and struts.

Types of Suspension

There are basically 2 different types of suspension. These are: dependent and independent. However, 8 more suspension systems that are less used than the other two can be given as examples. These are: push-rod, pull-rod, air, multi-link, leaf spring, trailing arm, MacPherson strut and double-wishbone.

1. **Dependent Suspension**

A stiff axle connecting both wheels to a single axle defines dependent suspension systems. It is supported by a beam or solid axle, where the movement of one wheel immediately affects the movements of the other wheel. It is not practicle as independent suspenion.

Figure 1: Dependent suspension

2. **Independent Suspension**

Each wheel may move independently of the others thanks to independent suspension. By isolating wheel motions, it improves vehicle stability, handling, and ride comfort for driver. Double-wishbone, MacPherson strut, and multi-link are a few examples of different kinds.

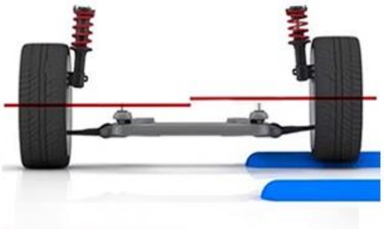


Figure 2: Independent suspension

Physics of Suspension Systems

As mentioned before, suspension systems work by converting energy into heat. This usually occurs when the springs are compressed, as will be tested in the experiment. That's why the physics of spring compression needs to be understood first. During the established experimental setup, one wheel of the vehicle will pass over the bump as if driving on a normal road. As in normal life, the suspension will compress a little while passing over this bump. In order to prevent the balance of the vehicle from being disrupted as a result of this compression, the spring that is compressed for a short time will be released again when descending from the bump. During this process, there will normally be heat loss, wear and other energy losses. Therefore the law of conservation of energy will be assumed. In order for the vehicle not to lose speed, a certain power and thus revolutions will be produced by the electric motor.

Conservation of Energy

In physics, the law of conservation of energy states that the total energy of an isolated system (mechanic energy in this experiment) remains constant; It is said to be preserved over time. In the case of a closed system (where the vehicle's engine provides energy, and the speed of the vehicle and surrounding friction are negligible), the principle states that the total amount of energy within the system can only be changed by energy entering or leaving the system. Therefore, after a vehicle moving horizontally at a constant speed (according to Newton's second law, it has no acceleration since no external force is applied; $F = m \times a$) encounters a bump, it will change the shape of the energy with the instantaneous force applied by the bump by the angled suspension because there is not any change in amount of energy. By lifting a tire up, it will convert some of the energy into spring and the other part into gravitational potential energy. For this, first the law of conservation of energy must be known and the formulas of energy types can then be used. According to the law of conservation of energy, its formula according to the types to be used in the experiment is as follows;

$$Potential\ Energy + Kinetic\ Energy = Mechanical\ Energy$$

Therefore;

$$|\Delta Potential\ Energy| = |\Delta Kinetic\ Energy|$$

Using this, it can show how kinetic energy and potential energy are calculated.

Kinetic Energy

During acceleration of the vehicle, the force produced by the engine is transferred to the ground. This force gives energy to the vehicle. The energy of a vehicle that has mass and moves at a constant speed is called kinetic energy. Kinetic energy, like other energies, can transition into different types of energy (ignoring that heat cannot be completely converted). The formula for kinetic energy can be obtained by deriving it from the work and kinematic equation. Assuming that the initial speed is zero and the work is done in the horizontal plane, the kinetic energy equation is obtained as follows;

$$W_{net} = \Delta Kinetic\ Energy$$

Therefore;

$$W = F \times d \times \cos\alpha$$

$$= m \times a \times d \times \cos 0$$

$$= m \times d \times 1 \times \frac{v_f^2 - v_i^2}{2d}$$

$$= \frac{1}{2} \times m \times v_f^2$$

As a result kinetic energy formula where mass is m and velocity is v shown as;

$$Kinetic\ Energy = \frac{1}{2}mv^2$$

Gravitational Potential Energy

The gravitational potential energy of an object can be found by deriving it from the law of gravity. According to the law of gravity, it is also defined as the work done to bring an object from an infinite distance to a place in space. Or, the work equation, which is directly shown in kinetic energy, can be found by lifting an object up against gravity. Assuming that the work done is against gravity and the plane is vertical, the following formula can be obtained;

$$W_{net} = \Delta Gravitational\ Potential\ Energy$$

Therefore;

$$W = F \times h \times \cos\alpha$$

$$= m \times a \times h \times \cos 0$$

$$= m \times g \times h$$

As a result gravitational potential energy formula where mass is m, gravitational accelartion is a and height is h shown as;

$$Gravitational\ Potential\ Energy = mgh$$

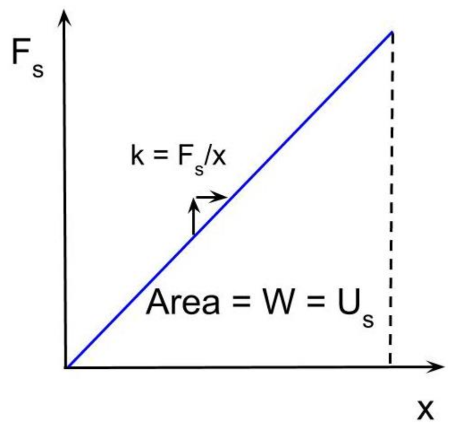
Spring Potential Energy

Springs, one of the most important parts of the experiment and vehicles, store energy in a slightly different way than others. According to Hooke's law, the force required to stretch or compress the metal spring is directly proportional to the distance of the spring from its natural state. Accordingly, the following formula can be obtained, where *x* in displacement *k* is the spring constant.

$$\vec{F_s} = k\vec{x}$$

One of the properties of the spring is that it undergoes an effect called recall force. This force tries to bring the spring to its initial state by applying force in the opposite direction of the spring being pulled or compressed. If the spring is released after being compressed in an environment where there is no energy loss, it will compress and extend periodically and perform simple harmonic motion. In the light of all this information, *k* can be left alone to find the value of the pedestrian constant and the resulting formula can be shown on a graph;

$$k = \frac{\overrightarrow{F_s}}{\vec{x}}$$



Graph 1:Force Against Displacement Graph For Spring

The graph shows that the k value is actually the slope. The area below the slope line showing *k* shows the work done. The work will be equal to the energy change, so it can be found by using the area of the triangle. The formula derived for this is as follows;

$$W_{net} = \Delta Spring\ Potential\ Energy$$

Therefore;

$$W = F_s \times x \times \frac{1}{2}$$

When the previously found Fs are substituted, the new formula is formed as follows;

$$W = k \times x \times x \times \frac{1}{2}$$

$$W = k \times x^2 \times \frac{1}{2}$$

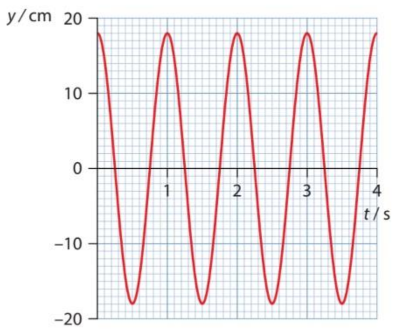
As a result spring potential energy formula where spring constant k and displacement is x shown as;

$$Spring\ Potential\ Energy = \frac{1}{2}kx^2$$

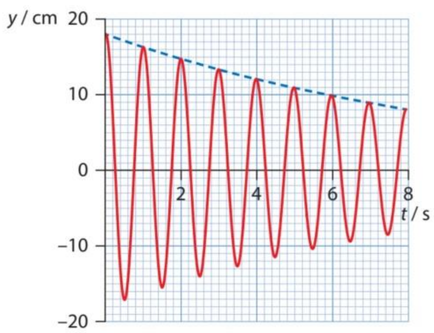
The suspension system of the car to be used in the experimental setup changes the bending amount of the car by converting the energy given. This change can be calculated using the formulas given above and will enable the experiment to be interpreted within the framework of meaningful values.

Oscillations and Damping

The suspension mechanism to be used in the experiment makes a simple harmonic movement due to the spring in an environment where there is no energy loss. However, conducting the experiment on Earth makes this impossible. Therefore, the spring will be damped at the same time as the oscillatory movement. In this case, critical damping, one of the 3 types of damping (critical damping, light dumping, overdamping), will occur.



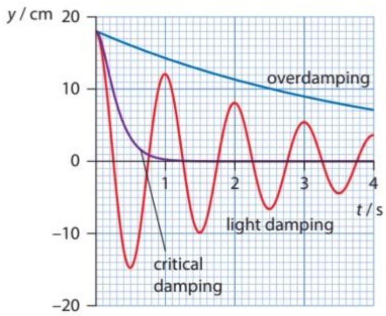
Graph 2:Energy Conserved (Undamped) Oscillations



Graph 3: Decreasing Energy (Damped) Oscillations

Critical Damping

Critical damping is when the system, which would normally start with a simple harmonic motion and slowly dampen by losing energy, reaches the equilibrium state as soon as possible without any oscillatory movement. The fact that the suspension reached its equilibrium position, that is, the vehicle in the experiment continued on its way straight, may explain the critical damping in the experiment.



Graph 4: Different Types Of Oscillations

2. Methodology

Hypothesis

As stated in the research question, two different experimental setups will be set up and two different experiments will be conducted. The first of these experiments is the effect of the single wheel of the independent suspension system on the inclination of the body at different suspension stiffnesses while passing over the bump. According to my hypothesis as a result of the experiment, I guess that the soft suspension, that is, the one with the lowest spring constant, will create a less angle for the vehicle, since the research will be carried out at a relatively slow speed due to the low energy produced by a small-sized electric motor.

In the experiment to be carried out with the second dependent suspension, according to my hypothesis, I think that the bending amount of the vehicle will be less in the one with the smallest spring coefficient. However, I predict that the angle measured with dependent suspension will be larger than with independent suspension with the same stiffness spring.

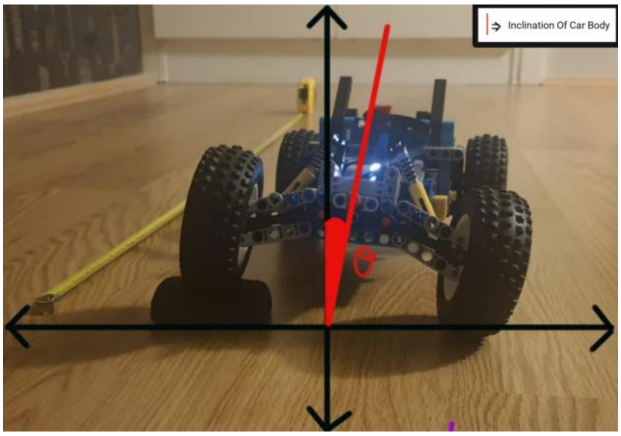


Image 1: Inclination Angle Of The Car Body

Variables

The first part of the variables to be written in the variables section will be used common for both experiments (suspension systems). Everything explained in the Methodology section is common to both experiments. The only difference between the experiments is the suspension system and does not affect any variables, materials or steps in the methodology section.

Independent Variables	**Dependent Variables**
Springs Used. All have different spring constants	The angle (inclination) formed by the vehicle with the ground

Table 1: Independent And Dependent Variables Of Experiment

Controlled Variables	Method of Control
Vehicle Properties	The speed, weight, shape and structure of the vehicle will be used the same so as not to affect the experiment.
Properties Of Bump	The experiment will be controlled by keeping the shape of the bump, its rigidity and the ability to pass over a single wheel the same.
Properties of Ground	The tested ground will be kept constant and any differences that may occur due to friction and slope will be controlled
Power Supply	The vehicle will be accelerated by using direct current from the same battery.

Table 2: Controlled Variables Of Experiment And Method Of Control

Materials

Toy car with interchangeable suspension parts designed for experimentation
3 sensors built into the vehicle and 1 engine that can be connected to the phone: speed sensor, horizontal and vertical tilt sensor and bluetooth
Springs that can be attached and removed to suspensions with 7 different hardness (spring constant) (384.6, 357.1, 333.3, 312.5, 294.1, 277.8, 263.2) (N/m)
Bump made of play dough (in the shape of a vertically divided cylinder)
A phone with Bluetooth (capable of instant screen recording)
Tape Ruler (3m ±0.01m)
Tape

Dynamometer (10 N) for measuring unknown spring constants
Pen

Table 3: Materials

Procedure

The first 5 stages are the preparation process of the experiment. The following stages, from 6 to 15, are the experiment itself.

1) Make a cylindrical bump with a radius of 0.02 m and a height of 0.05 m from play dough and wait for it to dry.
2) Cut the base of dough in half after it dries.
3) Fix the shaped bump to the ground with tape.
4) Measure 1 meter from the bump with a tape ruler and mark it with a pencil.
5) Calculate the spring constants used in the suspensions according to how many centimeters they are extended against a force of 10 N, by using the spring potential energy equation with the help of materials dynamometer and tape.
6) Set up the spring with the lowest spring constant to the suspension system.
7) Adjust the front wheel of the vehicle against the location you marked.
8) Turn on the vehicle's sensors and pair it with your application on phone.
9) Start your phone's screen recording to observe data after the experiment.
10) Run the vehicle towards the bump on flat ground. Energy will be provided from the engine in the vehicle.
11) Pass the wheel over the bump.
12) Get the inclination angle of the vehicle as the wheel passes from bump as data from your phone.
13) Repeat steps 7 to 12 five times and collect data.

14) Once five values have been obtained for a spring constant, replace the spring in step 6 and repeat steps 6 to 13 for all different spring constants.

15) Change the suspension system from independent to dependent and repeat steps 5 through 14.

Figure 3: Secreenshot Of Application (LEGO® TECHNIC™ CONTROL+) Used To Measure Inclination Angle (Mentioned In Step 8 And 9)

Safety, Ethical and Environmental Issues

There are no ethical problems in my experiment. The only thing that can be found is the electrical energy spent for the experiment, but this amount is too small to be taken into consideration. Spent battery can also be shown as an environmental problem. Failure to properly separate and dispose of it in the selected garbage after use may harm the nature. In terms of safety, the plastic structure of the vehicle protects it from possible electric shock. It is not likely to cause great harm due to its low reach and mass.

3. Modelling

The dependent and independent suspension shapes in which the designed prototype was performed are shown in the pictures below.

Image 2: Prototype With Independent Suspension

Image 3: Prototype With Dependent Suspension

The experimental setup in which the designed experiment was carried out, the image of the prototype with independent suspension passing over the bump during the experiment, and photographs of changeable suspensions with different stiffnesses (from top to bottom, from the one with the lowest spring constant to the one with the highest) are shown below.

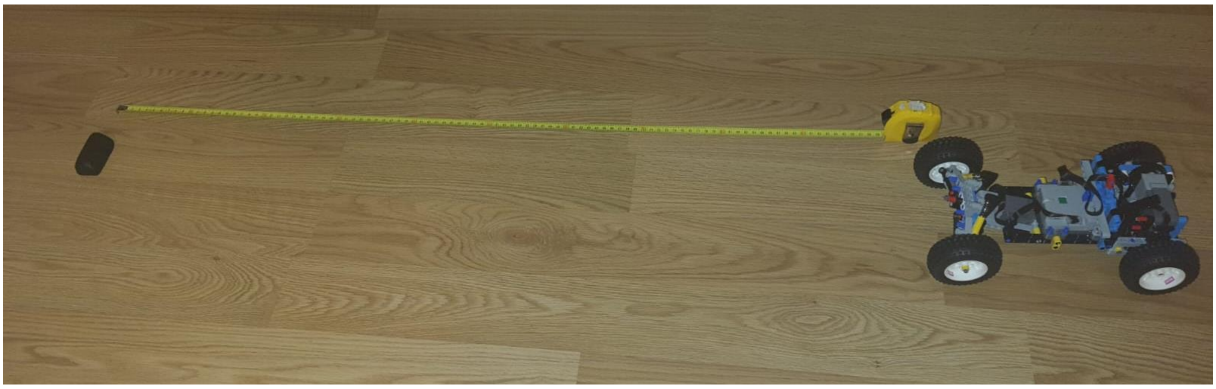


Image 4: Experimental Setup

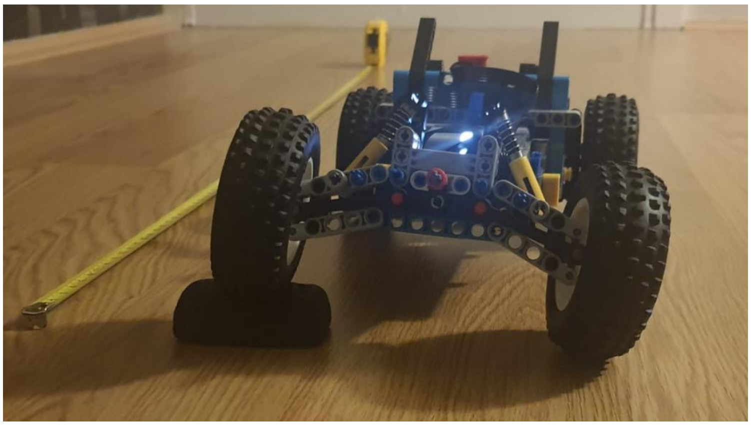


Image 5: Prototype Passing The Bump

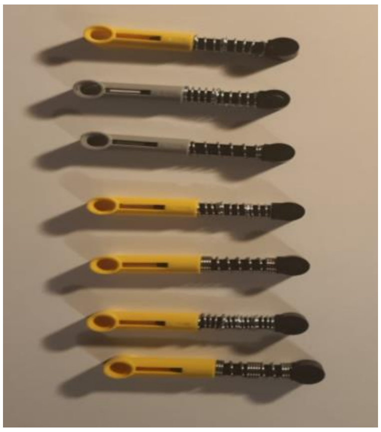


Image 6: Suspensions

All forces that occur during the experiment and affect it can be shown in 3 different images. Situation 1 shows the forces applied to the prototype while the vehicle is traveling straight at a constant velocity on a straight road. The second situation is when some of the force experienced when passing over a bump compresses the suspension, changing the speed of the vehicle and the direction of its tires by a negligible amount. The third situation occurs when the suspension gives the energy back to the tires when descending the bump and the opposite forces and results occur compared to the second situation. All are shown on independent suspension and similar situations occur in dependent. The lengths of the drawn vectors are not to scale.

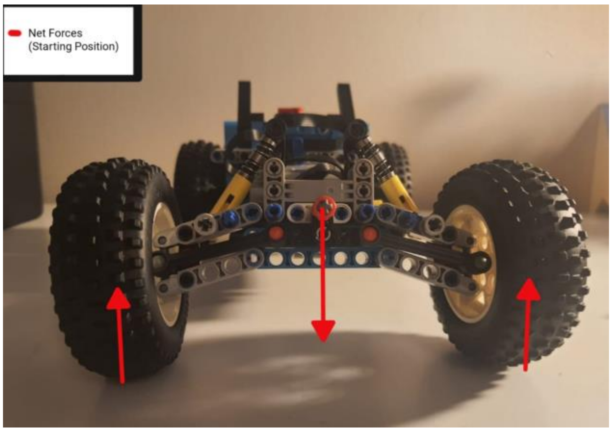


Image 7: Situation 1

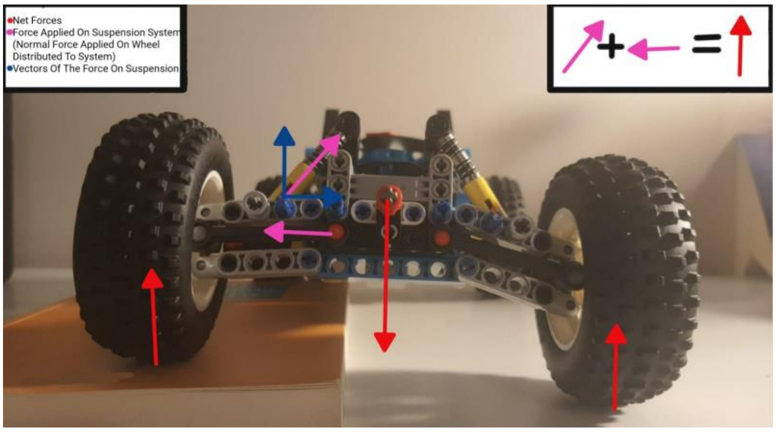


Image 8: Situation 2

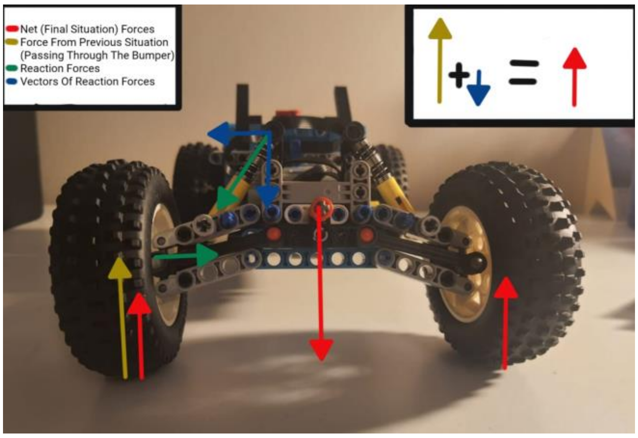


Image 9: Situation 3

4. Analysis

Qualitative Data

The vehicle, which has independent suspension at constant speed, has less inclination to the ground than suspensions with lower spring constant.
The vehicle, which has a dependent suspension that travels at constant speed, has less inclination to the ground than suspensions with a lower spring constant.
The prototype with independent suspension had less ground inclination in most measurements than the dependent.

Table 4: Qualitative Data

Quantitative Data

The margin of error of the spring coefficients was calculated using the equation k=F/x. Absolute uncertainty was found by dividing the uncertainty of the dynamometer (±0.1 N) by 10 Newtons, which is the constant applied force. After this, the uncertainty of the displacement was found using the values in the table. For fractional uncertainty, half of the smallest value range of the scale (±0.0005 m) is divided by 0.1 m, which is the amount of extension. Thus, the fractional uncertainties due to the division process were added up and a value of 1.5/100 was obtained. This calculated number was converted into a percentage by multiplying by 100 and the spring coefficients were recorded in the tables as (±1.5% N/m) uncertainty.

	Spring Constant (N/m) (±1.5%)						
	263.2	277.8	294.1	312.5	333.3	357.1	384.6
Inclination Angle (°) (±0.01) (Independent Suspension)	3.18	3.28	3.05	3.22	3.35	3.36	3.51
	3.25	3.20	3.23	3.31	3.38	3.35	3.49
	3.14	3.17	3.26	3.30	3.24	3.45	3.37
	3.19	3.05	3.08	3.10	3.31	3.40	3.48
	3.20	3.11	3.01	3.15	3.26	3.43	3.53

Table 5: Data Of Inclination Of The Prototype With Independent Suspension In Different Spring Constants

	Spring Constant (N/m) (±1.5%)						
	263.2	277.8	294.1	312.5	333.3	357.1	384.6
Inclination Angle (°) (±0.01) (Dependent Suspension)	5.30	5.27	5.40	5.50	5.42	5.53	5.80
	5.26	5.12	5.31	5.43	5.41	5.71	5.72
	5.20	5.21	5.26	5.46	5.57	5.68	5.69
	5.20	5.33	5.42	5.38	5.59	5.60	5.74
	5.28	5.18	5.37	5.32	5.52	5.63	5.75

Table 6: Data Of Inclination Of The Prototype With Dependent Suspension In Different Spring Constants

The average of all these values is taken to draw the graph. This average calculation is made by adding up all the values of the bending angle depending on the spring constant in a system and dividing by the number of trials. For the version of the independent suspension with a spring constant of 384.6, the value is calculated as follows.

$$(3.51 + 3.49 + 3.37 + 3.48 + 3.53) \div 5 = 3.476 \text{ N/m}$$

First of all, the uncertainity of the angle given in the measured data is given at the smallest decimal point due to the fact that the measurement is made with a digital device. Uncertainties for the average of the same values can be calculated in two stages. First, by adding up all uncertainties during the summation process. Then, the values must be converted into percentage uncertainties and summed for the division process. Since the resulting value will be given as a percentage, if it is taken as a percentage of the average, the actual number value will be found in third step. After all these, the resulting values will be brought to the number appropriate to the initial number of significant digits. For example, it can be done above the 384.6 value of the independent suspension.

1st Step

$$0.01 + 0.01 + 0.01 + 0.01 + 0.01 = 0.05°$$

Since all values were added at this stage, their uncertainties were also added.

2nd Step

$$(0.05 \div 17.68 \times 100) + (0 \div 5 \times 100) = 0.2828\ \%$$

Since the average calculation will be made, the uncertainty of the values was converted to percentage based on the total value (17.68). Since it will be divided by 5, which is the number of trials, it was added with the percentage uncertainty of that number.

3rd Step

$$3.476 \times 0.2828 \div 100 = 0.0098°$$

Finally, the percentage uncertainty was converted to absolute uncertainty for the average calculated value and a average value table can be created based on 3 significant digits.

Spring Constant (N/m) (±1.5%)	Average Of Inclination Angle (°) (±0.010) (Independent Suspension)
263.2	3.19
277.8	3.16
294.1	3.13
312.5	3.22
333.3	3.31
357.1	3.40
384.6	3.48

Table 7: Data Of Average Inclination Of The Prototype With Independent Suspension In Different Spring Constants

Spring Constant (N/m) (±1.5%)	Average Of Inclination Angle (°) (±0.010) (Dependent Suspension)
263.2	5.25
277.8	5.22
294.1	5.35
312.5	5.42
333.3	5.50
357.1	5.63
384.6	5.74

Table 8: Data Of Average Inclination Of The Prototype With Dependent Suspension In Different Spring Constants

This uncertainty found when looking at 3 significant figures is a very small value and is due to the measurement device. However, when the difference between the maximum and minimum values is taken and divided by 2, the difference caused by human error can be found and the following table can be created when calculated for each value.

Spring Constant (N/m) (±1.5%)	Average Of Inclination Angle (°) (Independent Suspension)	Absolute Uncertainty Caused By Human (°) (±)
263.2	3.19	0.055
277.8	3.16	0.115
294.1	3.13	0.125
312.5	3.22	0.105
333.3	3.31	0.070
357.1	3.40	0.050
384.6	3.48	0.080

Table 9: Data Of Average Inclination Of The Prototype With Independent Suspension In Different Spring Constants And Absolute Uncertainties

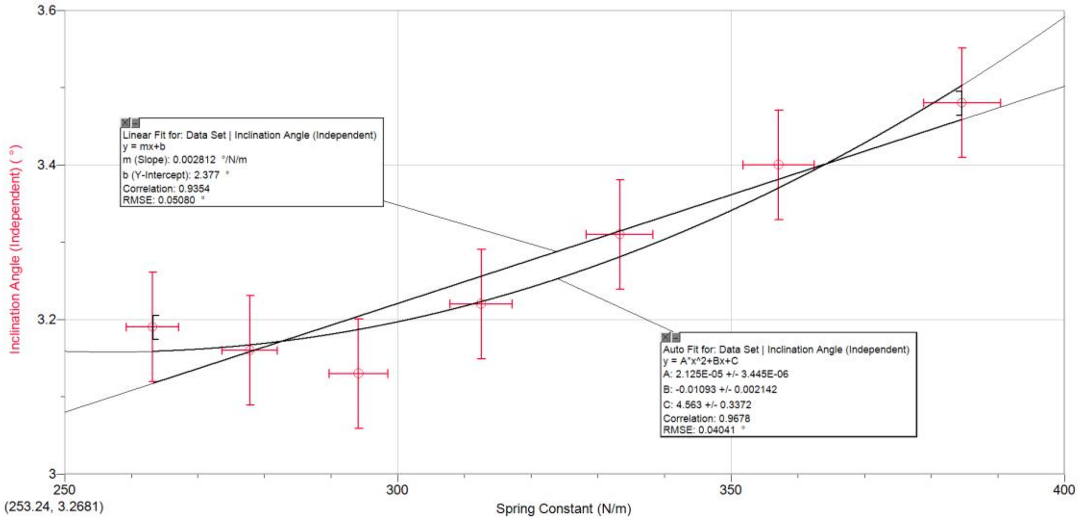
Spring Constant (N/m) (±1.5%)	Average Of Inclination Angle (°) (Dependent Suspension)	Absolute Uncertainty Caused By Human (°) (±)
263.2	5.25	0.050
277.8	5.22	0.105
294.1	5.35	0.080
312.5	5.42	0.090
333.3	5.50	0.085
357.1	5.63	0.090
384.6	5.74	0.105

Table 10: Data Of Average Inclination Of The Prototype With Dependent Suspension In Different Spring Constants And Absolute Uncertainties

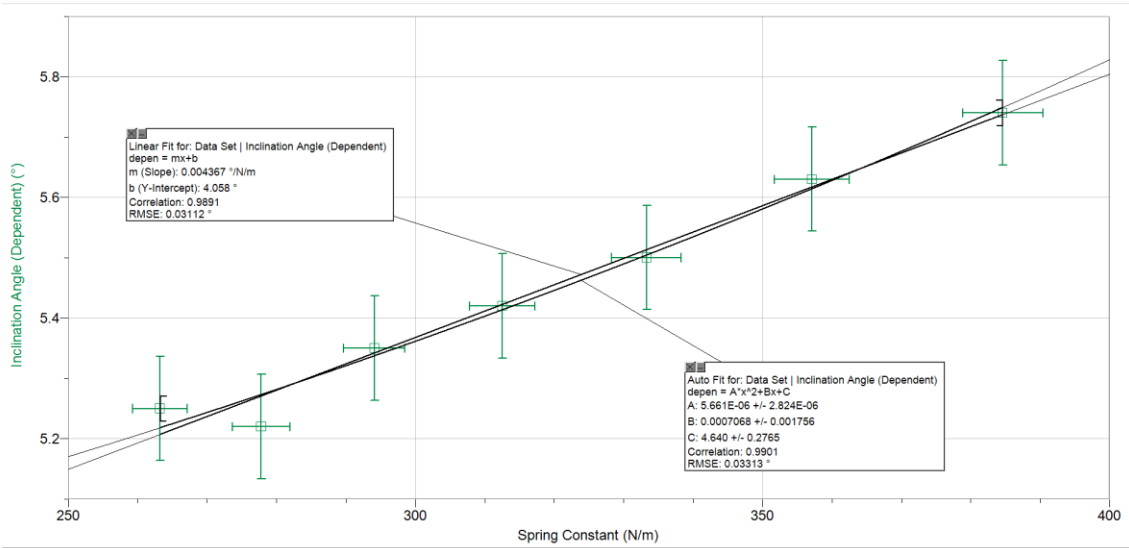
Since this numbers are higher than the calculated value, these values will be used in the graphs.

Graphs

Graphs can be created thanks to the obtained values. These graphs can be displayed to examine dependent and independent suspension differently.

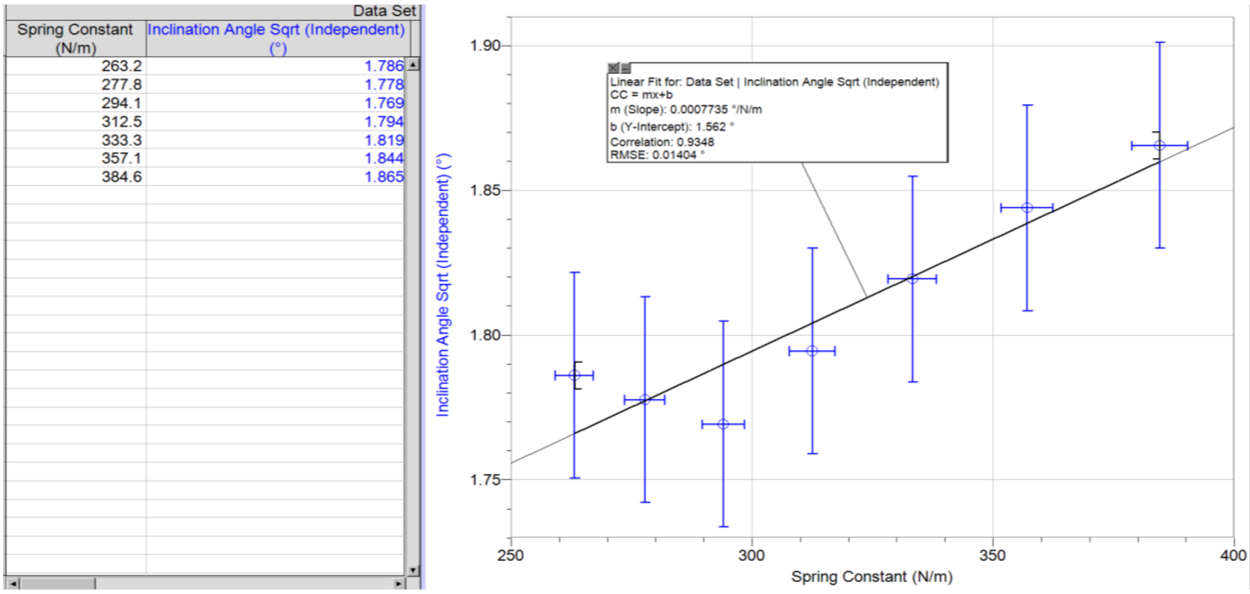


Graph 5: Spring Constant Against Inclination Angle Graph For Independent Suspension System

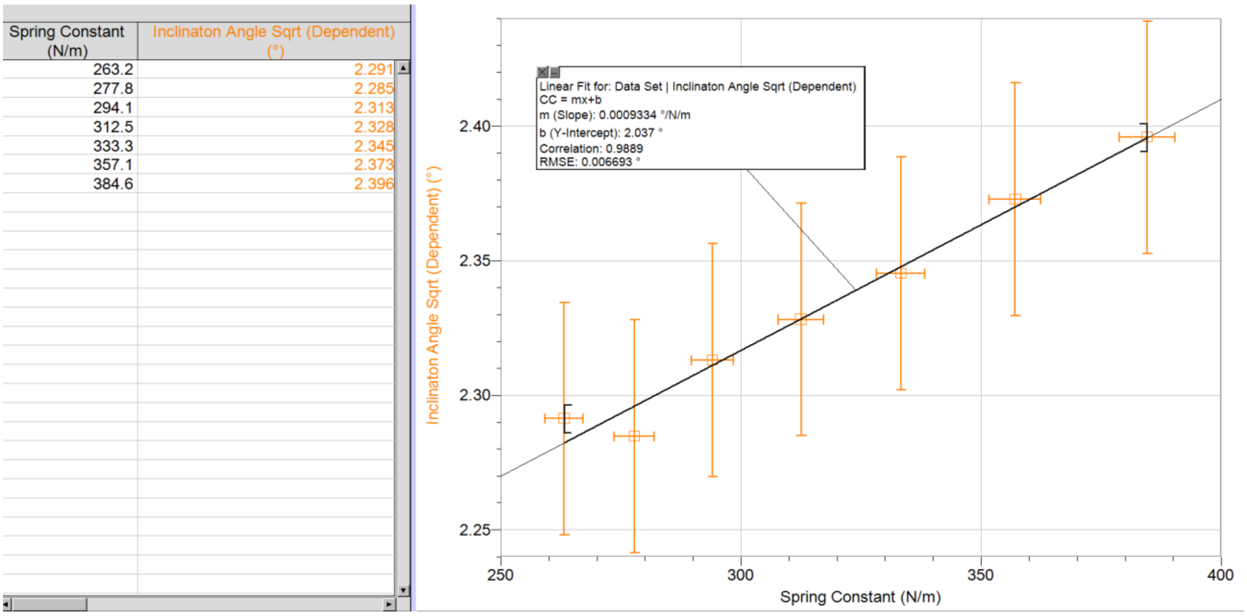


Graph 6: Spring Constant Against Inclination Angle Graph For Dependent Suspension System

As can be seen from the graphs above, in my experiment, the spring constant does not change the inclination angle to a large extent. Therefore, I examined both linear and parabolic fits for both systems to see which one fits better. As a result, I realized that the effect of the spring constant on the angle is more harmonious in a parabolic way. The reason for the higher parabolic fit is that the energy stored in the spring potential energy equation is directly proportional to the square of the spring's displacement amount. The ratio of the amount of displacement to the angle is due to the fact that the angles at small values are related to the compression amount of the sinuses. Therefore, another graph was drawn by squarerooting the angle values.



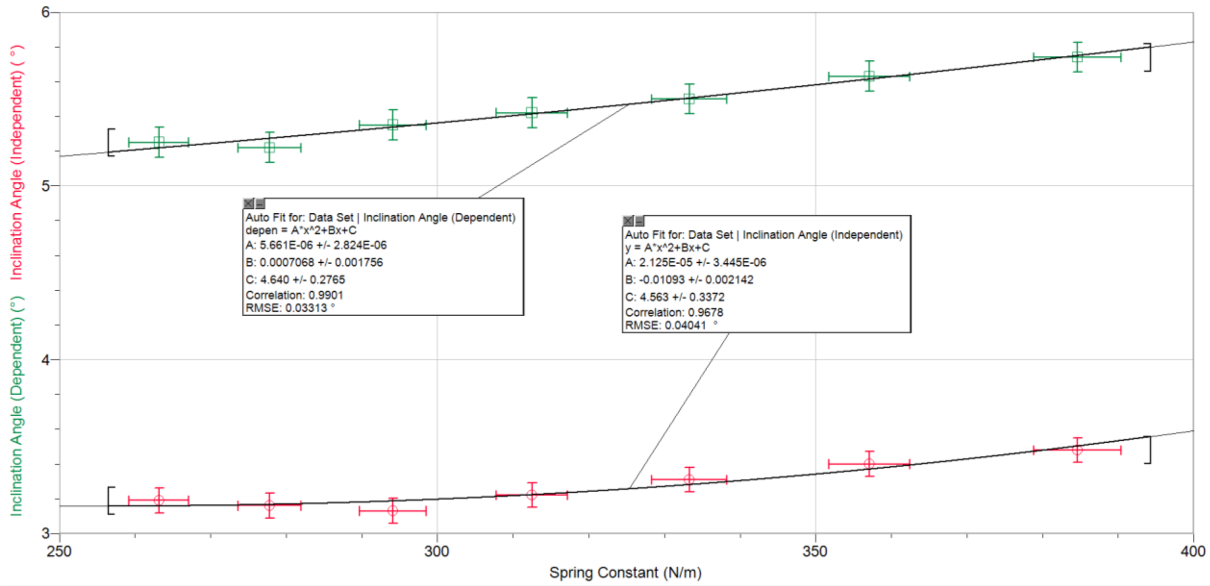
Graph 7: Spring Constant Against Squareroot Of Inclination Angle Graph For Independent Suspension System



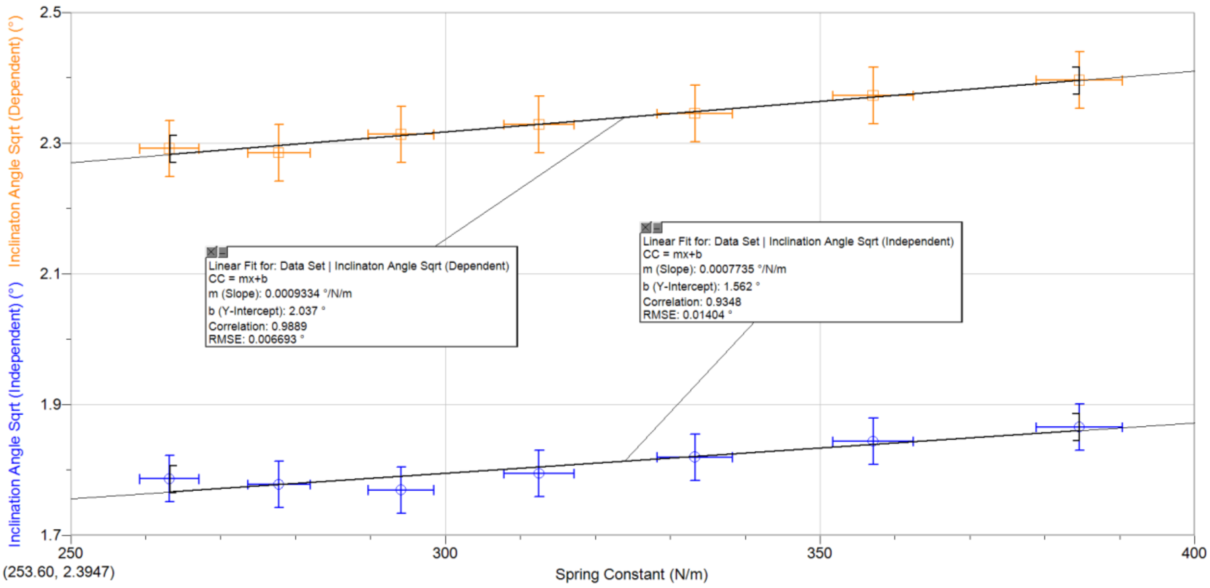
Graph 8: Spring Constant Against Squareroot Of Inclination Angle Graph For Dependent Suspension System

After squaring the angle values, a more linear line emerged in both graphs. Although these lines did not pass through all the points, they made it possible to create a smooth ratio.

Thanks to this, both systems were compared with both the normal angle value and the square root of the angle value.



Graph 9: Camparison Of Spring Constant Against Inclination Angle Graph For Both Suspension Systems



Graph 10: Comparison Of Spring Constant Against Squareroot Of Inclination Angle Graph For Both Suspension Systems

When the two systems are compared together, the 9th and 10th graph s appear. In these graphs, the data that are angularly higher and have a larger value are for the dependent suspension, while the data that are lower and have a smaller value are for the independent suspension.

5. Conclusion

Many conclusions can be reached by using all the data and graphs obtained in the experiment. If we need to classify these results, there are 3 different basic headings: Results, errors and limiting factors.

The data obtained as a result of the experiment shows that among two different suspension systems, the independent suspension is more comfortable when passing over a cylindrical bump divided in half and has a radius of a quarter of the diameter of the tire, which is known to travel at a speed of 1 meter/second. In addition, as the ideal spring constant in dependent suspension, which causes more inclination, decreases under these conditions, a more comfortable driving experience can be achieved. The minimum value of this angle can be found by the number at the peak of the x value. Since this number is a negative value, the smallest angle that the spring constant will take when it approaches zero from the positive direction is 4.64 degrees, according to the graph. In independent suspension, there is a slightly different trend and the peak has a positive value. However, if -B/(2A) is made with the values in the parabola equation of the 5th graph, the value at which the smallest angle will be reached and that spring constant can be found. The value of this spring constant is 257.8 N/m and the angle value can decrease to 3.16 degrees on the graph. This situation allows it to be concluded that independent suspension may be more comfortable for vehicles that will be used daily and on rough terrains, as seen in all comparative graphics obtained from the experiment.

There are many reasons why there is a change much higher than the error calculated in the denial graphs. There are many reasons such as the digital tool in which the measurement of the experiment is taken, an engine that provides energy continuously, negligibly small energy conversions during the descent and ascent of the bump, human line margin and finally the difference in the bump and ground friction. Despite this, the fact that the experiment was carried out in a way that confirmed the judgment put forward by the hypothesis as a result of the researched purpose is an indication that the experiment was progressed in the right direction, regardless of errors. To obtain more accurate results, many variables must be added and the experiment modified. In order to be adapted to real life, it must overcome many limitations.

Although there are no major factors limiting the experiment, there are many limitations in the inferences to be made from the experiment on the normal world. The reason why the experiment may not be applicable at normal angles is the difference in the amount of variables. Some of these variables are things like the momentum that normal vehicles gain thanks to the speeds they reach, the reactions caused by air-ground friction, the weight distribution of the vehicle, and the fact that the power produced by the engine cannot be constant at large rates. In addition, the fact that the vehicles' usage conditions differ (race, daily) and, lastly, the fact that the driver and environmental conditions affect and manipulate the conditions of the experiment very much show that this research will work more accurately on a small scale and will encounter restrictions when moving to a large scale.

6. Evaluation

The experiment on suspension systems and spring constants met the expectations of the research question. However, care was taken and a lot of effort was spent in all processes. Thanks to this, the methods used in the experiment (research skills) and the applications (LoggerPro, Excel, Word) and skills (suspension system design, calculus knowledge) used in the preparation and interpretation of the experiment have developed cumulatively in a way that is efficient and meets the predictions and expectations at the beginning of the experiment. As a result, it has become possible to estimate the ideal system and spring constant for the designed prototype vehicle.

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Resources of Images

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