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Design and Fabrication of a Suspension Rig

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DESIGN AND FABRICATION OF A SUSPENSION RIG

By

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A REPORT

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This report has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Mechanical Engineering.

Department of Mechanical Engineering – Engineering Mechanics

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Finally, I would like to thank my parents for supporting me with everything in my life. I thank God for being the light of my life.

Thank you

Abhijith Geo Philip

List of Abbreviations

3D	Three-Dimensional
CAD	Computer Aided Designing
CSV	Comma Separated Variables
DD	Double D
GM	General Motors
Hz	Hertz
IFS	Independent Front Suspension
IC	Instantaneous Center
I/O	Input/output

Abstract

Owing to its placement under the vehicle body, the suspension system is one of the parts of the vehicle which are difficult to comprehend completely, albeit being a vital component. For demonstrating the working of a suspension system, a physical model in which one can actually see the movement of all the components would be a great tool. A Mustang II independent front suspension system was purchased from Heidts Engineering Performance and a rig that can emulate some of the real world situations of vehicle suspension action was designed and fabricated. All the components are accessible and conditions like bounce, rebound and roll can be emulated manually using two jack screws. The rig was instrumented to measure the roll angle, the angle of the upper arm and the steering rotation. Motion simulation study of bounce, rebound and roll was done using NX 10 and the results were compared with the data obtained from the rig.

1. Introduction

1.1 Project Motivation

The suspension system is a vital part of the vehicle which is not completely visible. Even on a hoist, only part of the suspension system is visible. Unlike any other part of the vehicle, a suspension system has a lot of components. Some of the components are hidden inside the underbody. It is difficult to comprehend the assembly, geometry and functioning of each of these components unless there is a physical model which can demonstrate these. A complete independent front suspension that can emulate some of the real world situations of vehicle suspension action would be a great resource to demonstrate the functioning.

The parts of the suspension system must be easily accessible and there must be a mechanism to change the geometry of the system, while maintaining the stability of the whole system.

1.2 Suspension Systems

Suspension system connects the vehicle to the wheels. It has various components including the springs, shock absorbers and the linkages. The primary functions of the suspension system are to provide vertical compliance to the vehicle so that the wheels can follow the uneven road, isolate the chassis from the roughness of the road, maintain the wheels in the proper steer and camber, react to control the forces produced by the tires during the acceleration, brake, corner, resist roll of chassis and to keep tires in contact with road always. [1] The suspension allows relative motion between the wheels and the vehicle body.

1.3 Independent Suspensions

Independent suspensions allow each wheel to move vertically without affecting the other wheel. They are used in passenger cars and trucks, because they provide more room for the engine, and they have better resistance to steering vibrations. It also provides a higher roll stiffness relative to vertical spring rate. [1]

1.4 Sprung to Unsprung Weight Ratio

Unsprung components are the ones on the roadway side of the springs. They react with the uneven road with no damping except for the pneumatic resilience of the tires. The components on the vehicle side of the springs comprise the sprung weight. The unsprung mass can generate high vertical acceleration forces which degrade the ride quality when they react to the undulations on the road. The ideal combination of sprung to unsprung weight is to take build components in the unsprung mass which can take maximum ground pressure and minimal inertial forces; a high sprung-to-unsprung weight ratio will help this happen.

In the present system we have only the unsprung components. So, emulating the pitch condition would not be completely feasible, although the pitch geometry can be created to an extent. [2]

1.5 Ride Comfort

Body roll, pitch, vibrations and various other factors are detrimental to a comfortable ride quality. The suspension's response to bounce and rebound movements is critical for a comfortable ride. The shocks and the spring in the suspension help to cushion the ride by dampening the motion induced by the dynamic road conditions. Without shocks, the system oscillates in a cycle according to its natural frequency. The ride is comfortable if the natural frequency is in the range of 1 Hz to 1.5 Hz whereas, when the frequency approaches 2 Hz, the ride becomes harsh.

Vehicle handling is related to the way in which the inertial forces of the vehicle act against the cornering force of the tire. The inertial forces are established by the weight and balance of the vehicle. Also, the angular acceleration accounts for a force that acts in a direction away from the center of the turn. The combined action of the suspension and the tires determines the ability of the vehicle to overcome these forces and make a stable turn. [2]

1.6 Determination of Roll Centre

Roll center is the point about which the vehicle rolls while encountering a corner. Roll center is an important concept because all the forces acting on the center of gravity make the vehicle body roll about the point of the roll center. So, as the distance of the roll center from the center of gravity (Roll moment distance) increases, the vehicle roll increases. [3]

Roll center of the double wishbone system is derived from the concept that during the motion of the suspension system, the upper wishbone, the lower wishbone and the tie rod rotate about the same point called the Instantaneous Center (IC). The point where the line connecting the IC and the point of contact of the tire intersects with a line dropping down from the center of gravity is the Roll Center. [4]

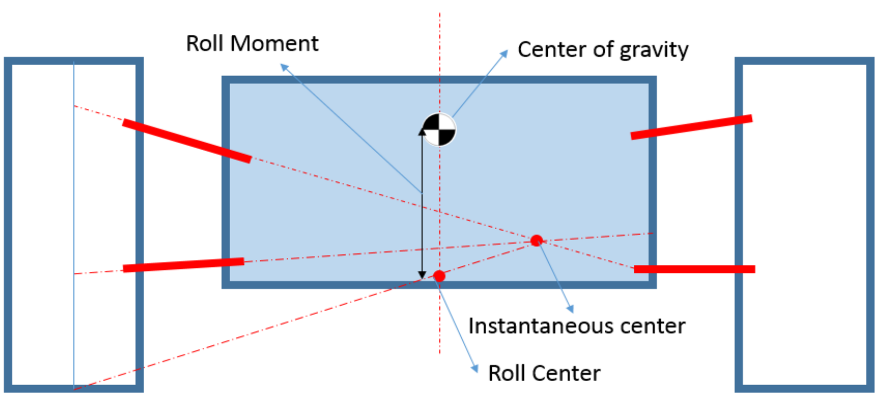

Figure 1.1: Roll center determination

1.7 Bounce, Rebound, Steering and Roll

The ride and handling of the vehicle center on how the wheels react to the disturbances and control inputs. This in turn depends on the springs, dampers and linkages which control the motion of the tires.

The bounce and steering movements of the wheels serve for a variety of purposes like providing steering input for direction change, compensating for body roll, improving handling and reacting to irregularities on the road. Since the wheels are connected to the body via suspension linkages, they are affected by rolling and pitching movements.

Droop is the total amount the chassis is able to rise above its natural ride height. When the car is lifted up on the car's chassis until the wheels just begin to leave the ground, the distance the suspension is able to extend downwards before the wheels leave the ground is the droop value. This occurs in a rebound situation.

In the present system, we are looking at emulating the Roll, Pitch, Bounce, Rebound and Steering motion of the vehicle [2].

2. Design

2.1 The Mustang 2 Independent front Suspension

The second-generation Ford Mustang is a car that was manufactured by Ford from 1973 until 1978. The car was not a commercial success due to the 1973 oil crisis, when buyers were turning towards lower-priced and fuel-efficient cars. Although the car was a failure, the Mustang II handled fairly well with its double wishbone suspension and rack and pinion steering. The front suspension of a Mustang 2 has been adopted by the car enthusiasts and tuners community for tuning performance cars.

For the project, the Mustang II Suspension kit was purchased from Heidts Engineered Performance. The project is aimed at making a system to emulate the conditions an actual suspension would be in, in a car.

2.2 Design Constraints

2.2.1 Cart size

The major requirement for the rig is that, it should be sized such that it can get into the door. The typical door dimension is 32'' x 81'', as shown in Figure 2.1.

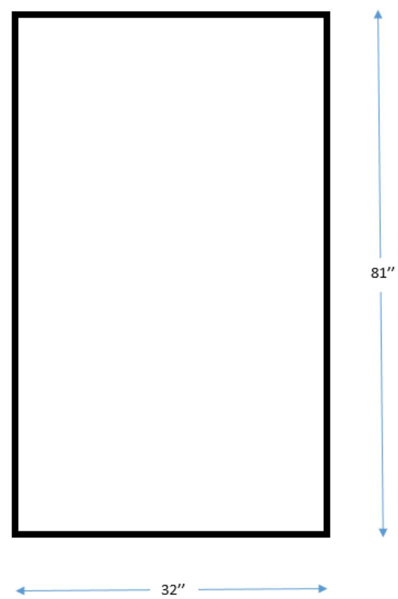

Figure 2.1: Design constraint for door

Considering that we had to make the system as close as we can get to the real vehicle with a typical wheel base of 114'', making the system within the 32'' constraint was a real challenge.

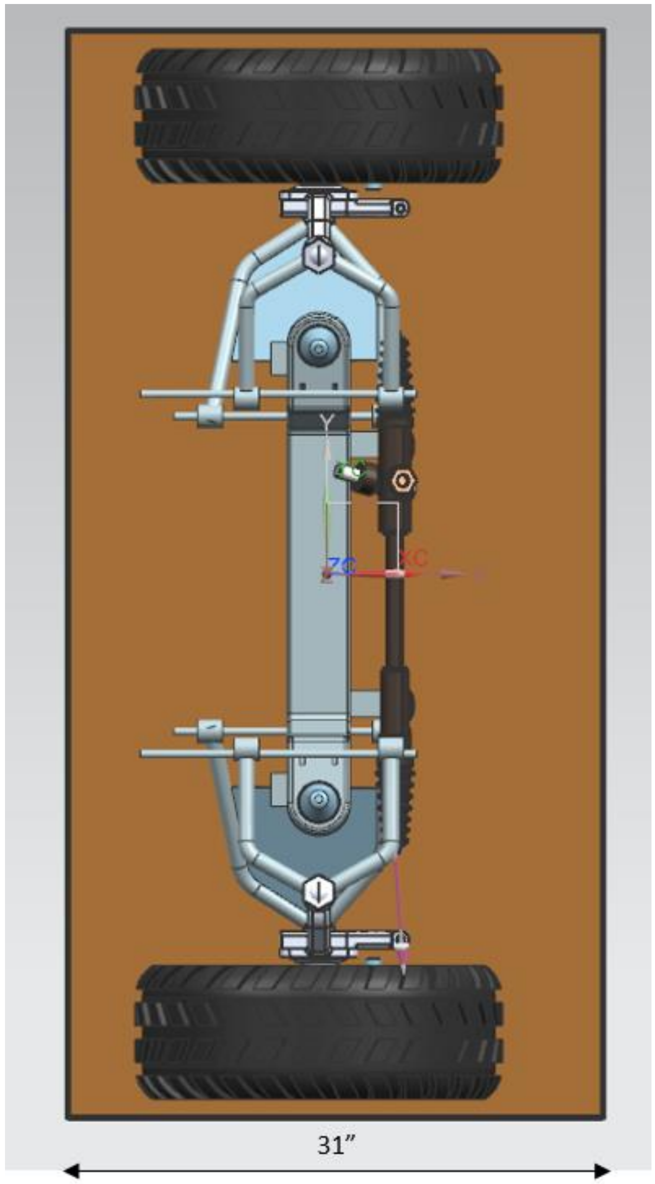

Figure 2.2: Design of the cart (Top view)

The width of the cart had to be less than 32''. To utilize maximum space on the cart, the width was chosen to be 31'', giving a 1'' clearance (Figure 2.2).

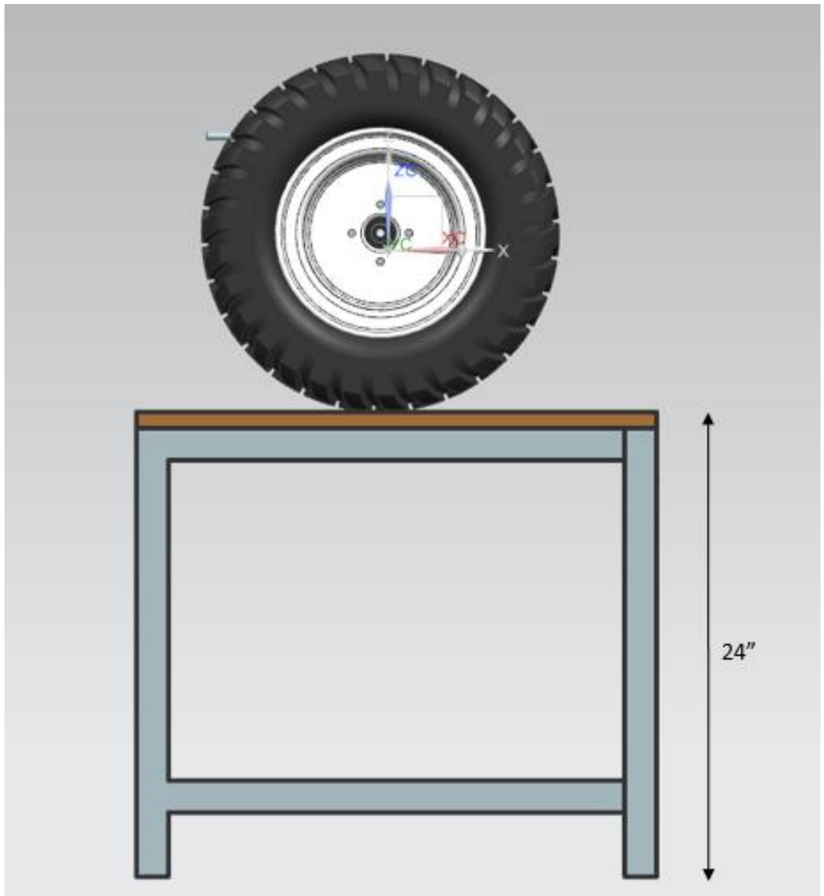

Figure 2.3: Design of the cart (Side view)

There was a cart available with similar width and a height of 24'' (Figure 2.3). So there was 81''-24'' = 57'' to fix the rest of the set up.

2.2.2 System stability

We had only the front suspension of the vehicle. Because of the size constraint it is impossible to have the whole frame with the rear wheels. We had to find a solution which can perform the following functions.

a) Emulate the heavy rear end of the vehicle
b) Prevent the wheels from rolling

We finalized on making two arms, one of which extends from the vehicle frame and the other from the cart, as shown in Figure 2.4.

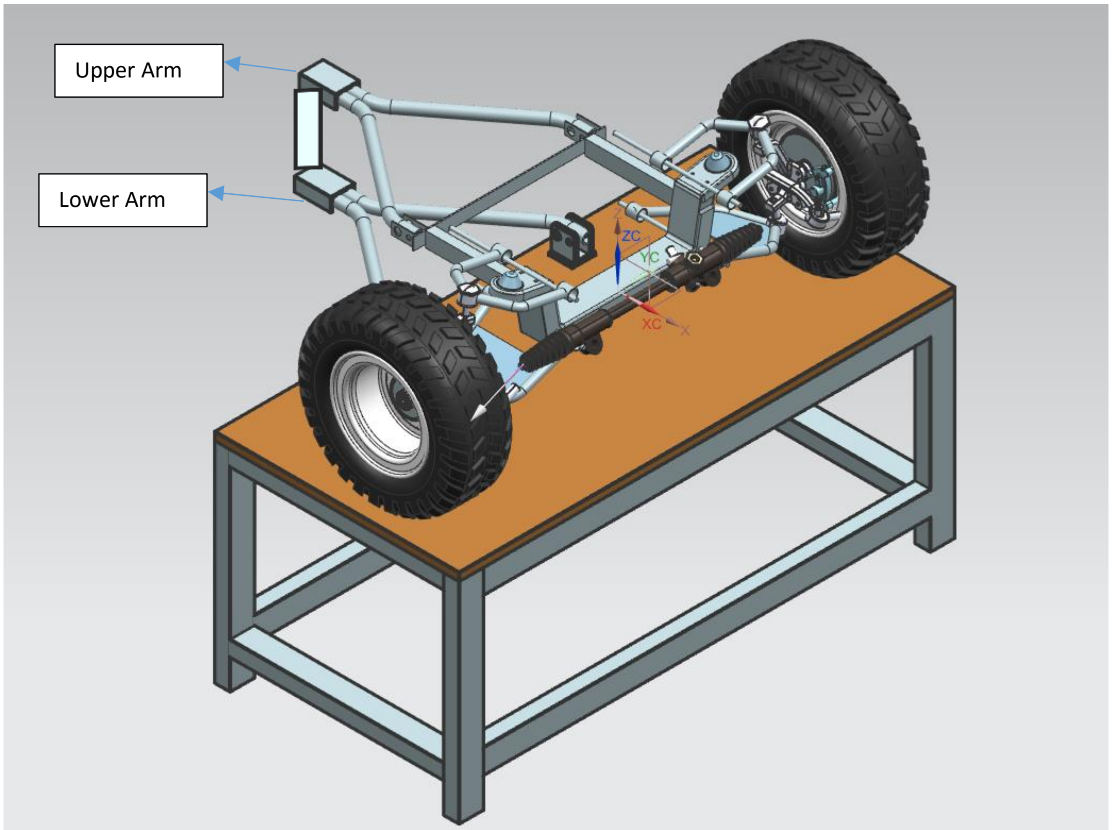

Figure 2.4: Flipping Arms

To make the system mobile, it was decided that the arms have to be made in such a way that they are foldable. It was decided to purchase Tow bars which can act as arms.

2.2.3 Controlling the movements

To bring the suspension system to action, movements on each side of the suspension system have to be controlled independently. To meet this criterion, it was decided to use two General Purpose Ratchet Jacks at both the ends of the cross member, so that each side of the suspension is independently adjustable.

2.2.4 Steering movement

In order to facilitate the steering motion, the tires have to rotate freely on the cart. Initially we thought of having a roller bearing and a plate to accomplish this. But this wouldn't work if the suspension height is jacked up, since the pivot point of the tire rotation is not constant. The scrub radius changes with change in height of the suspension. This is depicted in Figure 2.5.

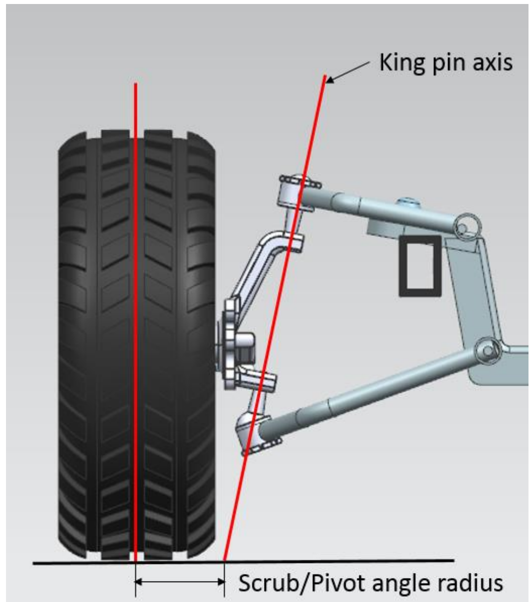

Figure 2.5: Turning Pivot point

So we decided to have a slip plate. A slip plate doesn't have a fixed axis of rotation. The top plate moves freely on the bottom plate.

2.3 CAD Modelling

A model of the complete IFS was designed in NX 10, including all components, as shown below. The measurements were taken from the Heidts system and this was used to build the CAD data as shown in Figure 2.6.

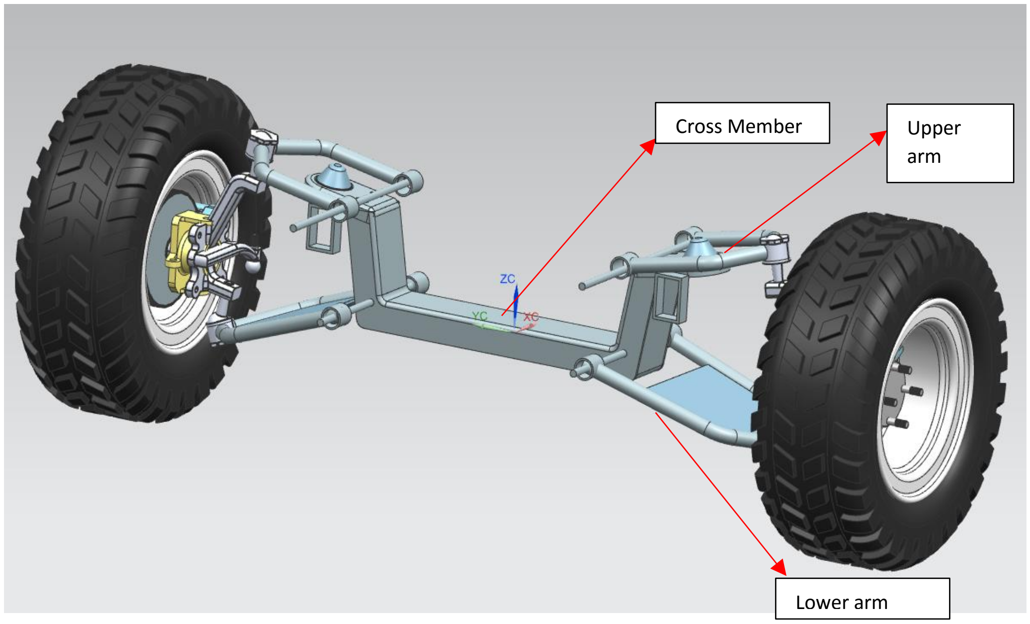

Figure 2.6: CAD model of the IFS

An extended body frame of 6’’ was designed on the cross member to be welded onto it so as to attach the upper arm.

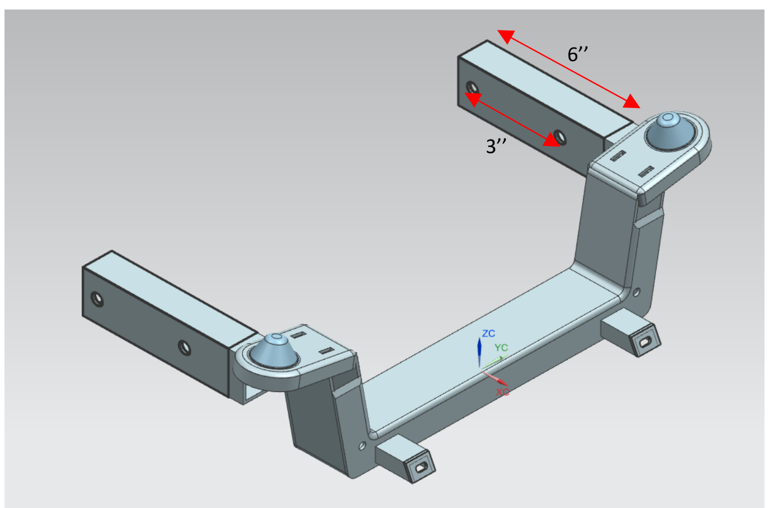

Figure 2.7 Extension of body frame from the cross member

Two brackets for attaching the lower arm were designed on the cart plate. The conceptualized design of the upper and lower flipping arms are as shown in Figure

2.8. The ends of the flipping arms are left free in the 3D model. A connecting linkage that connects the ends of the upper are lower arm was envisaged. The details of this is discussed later in the report.

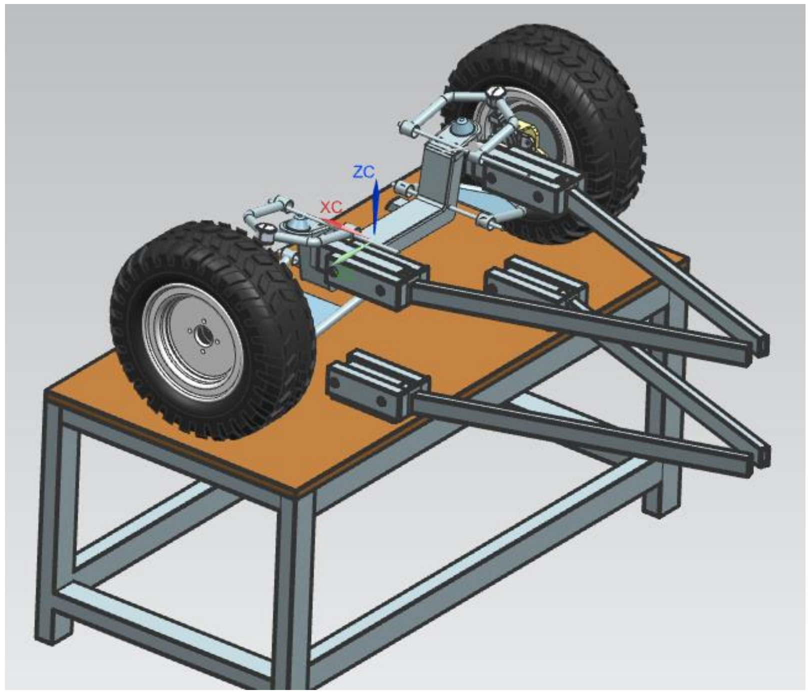

Figure 2.8: 3D model of the complete system with the flipping arms

2.4 Motion Simulation

A simple motion study was also done on the IFS. This motion simulation was done using NX 10 Motion Simulation. A 4-bar linkage mechanism was used to simulate the motion as shown in Figure 2.9.

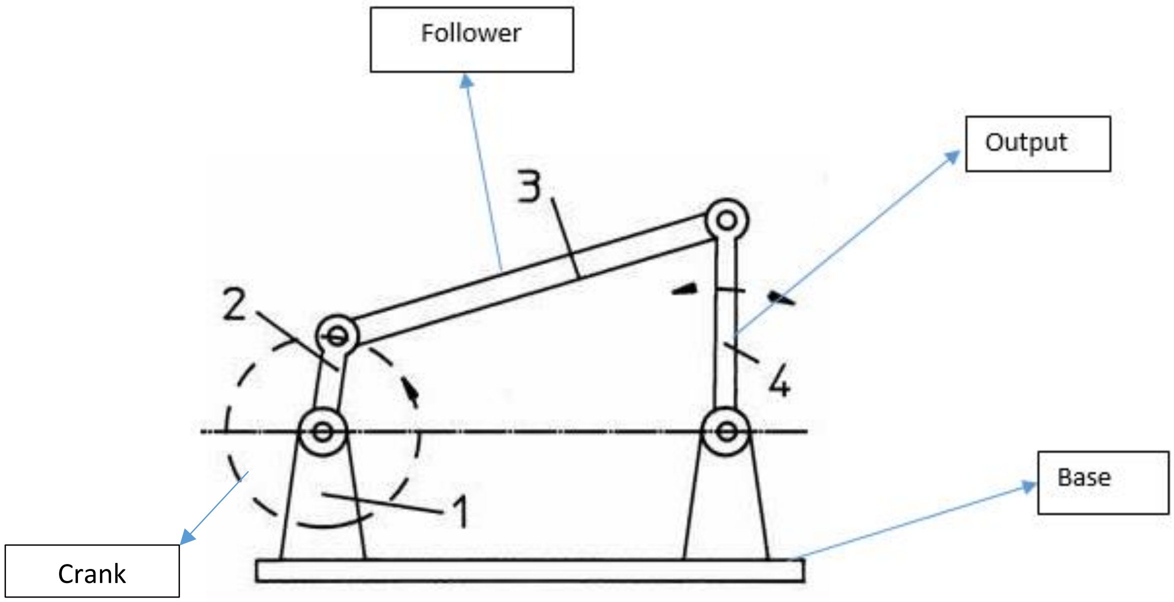

Figure 2.9: The typical 4 bar linkage

In the model, the frame/cross member is the base, the lower wishbone is the crank, the wheel and the spindle assembly is the follower and the upper wishbone is the output as shown in figure 2.10.

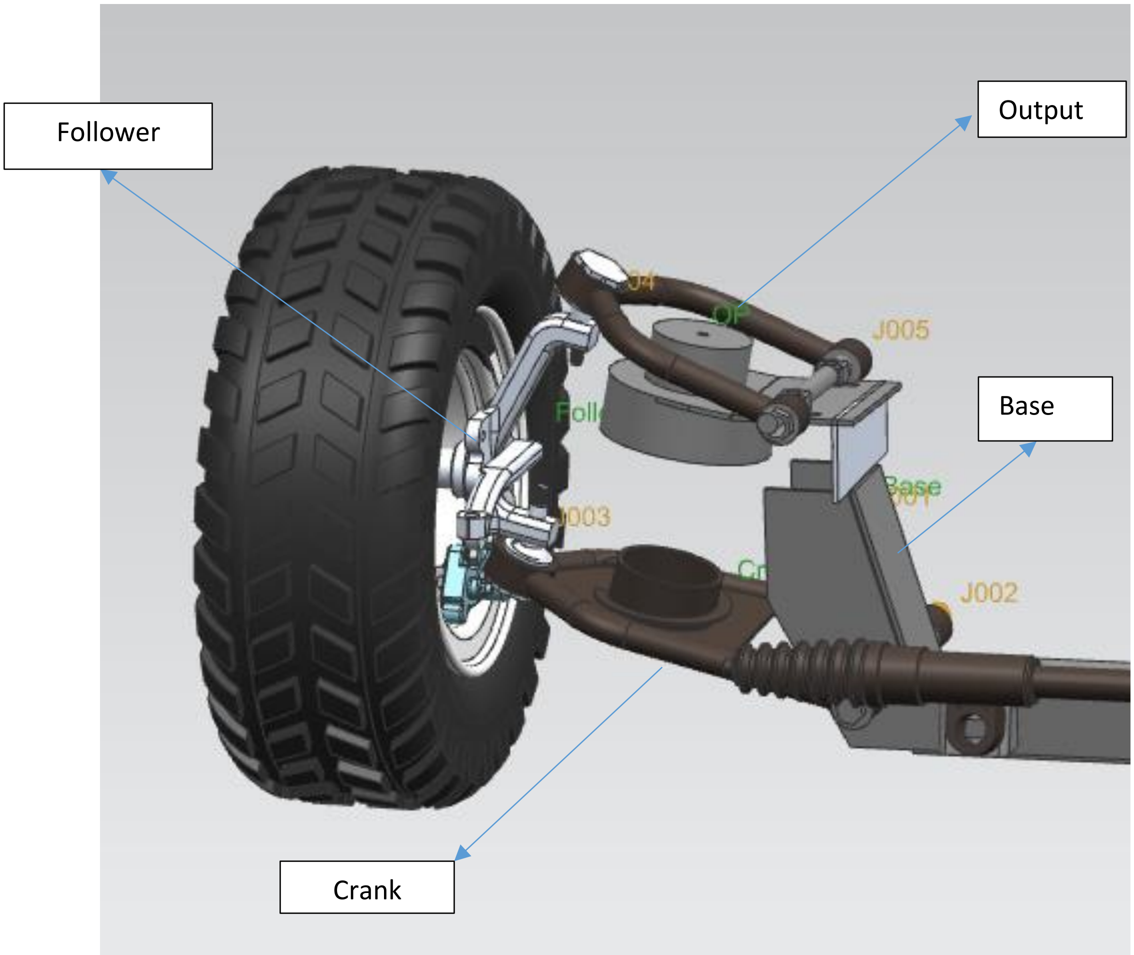

Figure 2.10: Motion simulation modelling

Two different scenarios of bounce and rebound are shown in Figures 2.11 and 2.12.

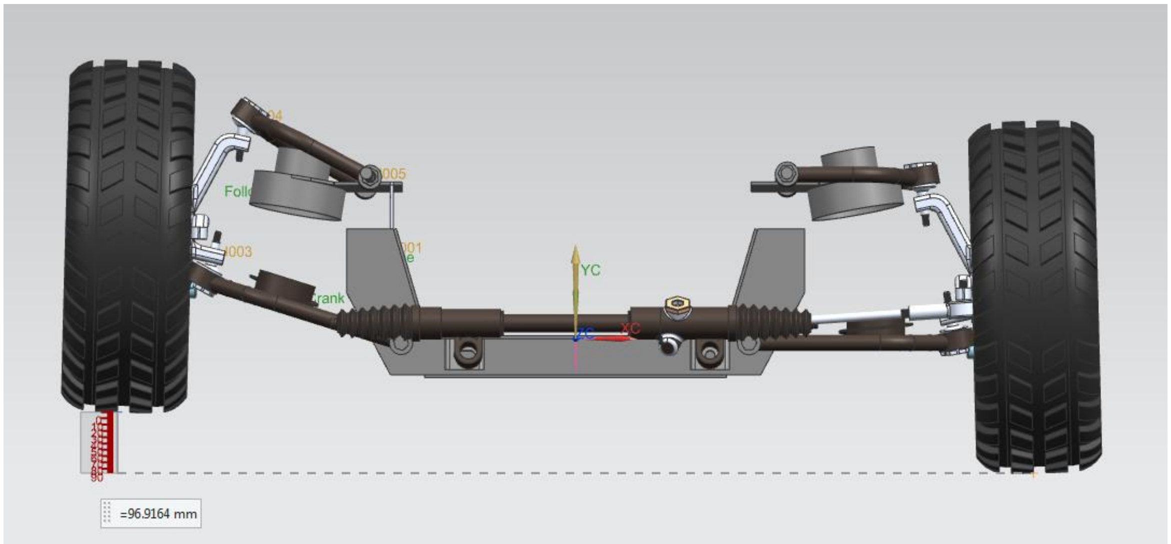

Figure 2.11: Simulating Bounce

Bounce is when the wheel is raised up from the surface.

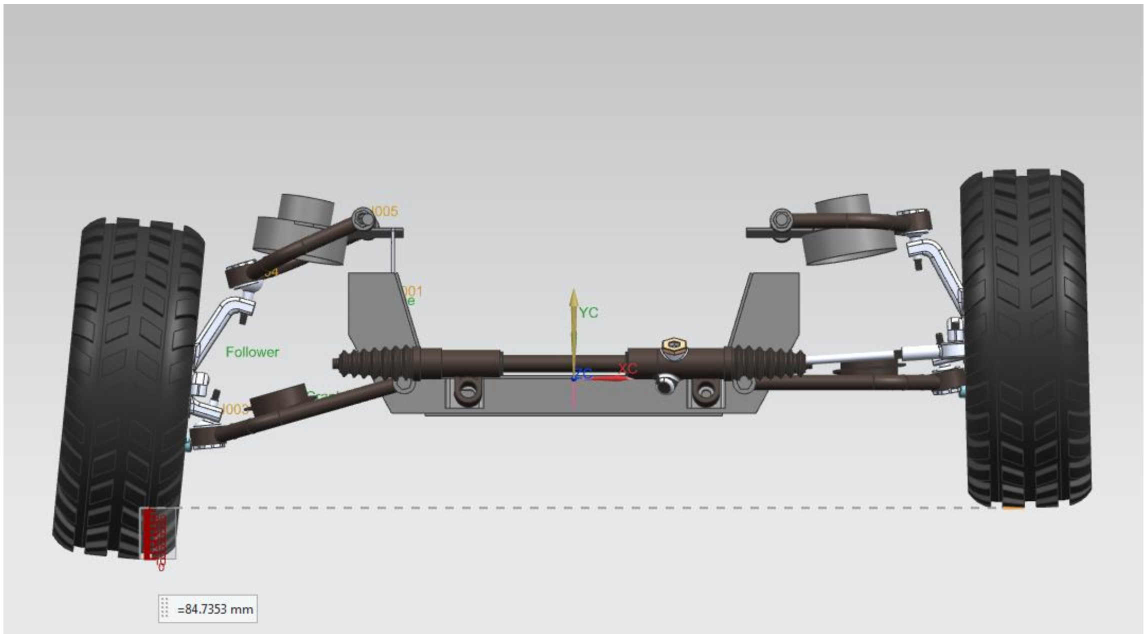

Figure 2.12: Simulating Rebound

Rebound is when the body of the vehicle is lifted up, and the wheel is lower than the surface level.

A motion simulation to emulate roll was also done (Figures 2.13 and 2.14). In this case, the chassis cross member acts as the crank. The vertical motion of the wheels was arrested in this case, assuming that the tires remain in contact with the road all the time. It was also assumed that the roll center is at the center of the cross member for doing this study.

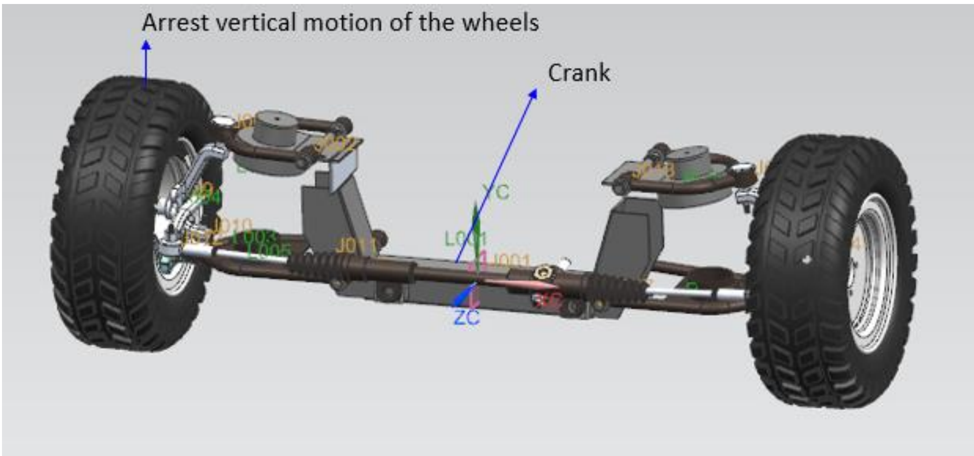

Figure 2.13: Roll modelling

The body rolls right in a left curve and it rolls left in a right curve.

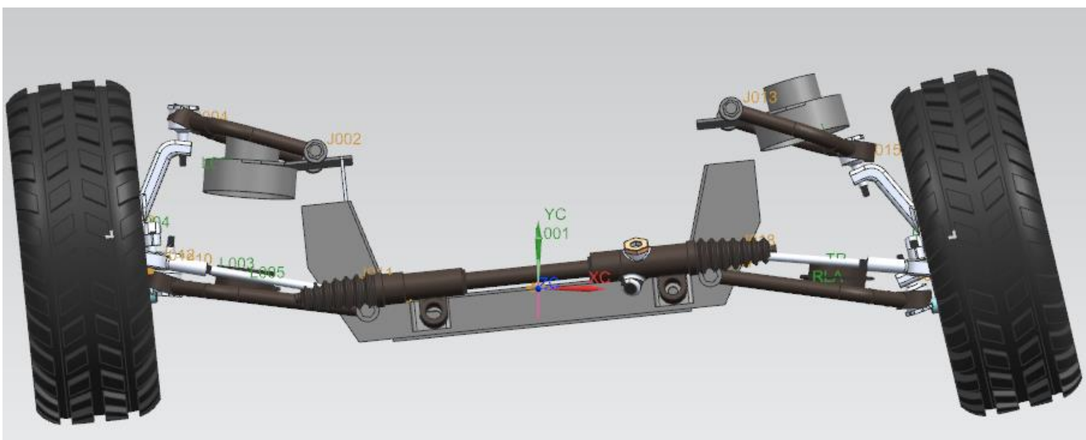

Figure 2.13: Simulating Roll

3. Fabrication

3.1 Purchase of Parts

The following parts were purchased.

	Component	Quantity
1	Mustang 2 IFS	1
2	Ratchet jacks	2
3	Tow bars	2
4	Adjustable height ball mount and ball	1
5	Slip plates	2
6	Rims and tires	2 each

3.1.1 Mustang II Independent Front Suspension Kit from Heidts Engineered Performance

Figure 3.1: The purchased Mustang II IFS from Heidts

Mustang II Suspension kits from Heidts come complete with a cross member, upper and lower control arms, 11” five lug rotors, bearings and seals, springs, shocks, stock spindles, GM calipers with brackets and pads, manual rack and pinion with tie rod ends and bushings, rubber spring cushions, spindle nuts, and mounting hardware (Figure 3.1). [5]

[5]

3.1.2 Two General Purpose Ratchet Jacks

The ratchet jacks have two screws which facilitate the rapid expansion and contraction of the jack in case of jacking up and lowering the suspension. (Figure 3.2)

Figure 3.2: The Ratchet Jack for adjusting height

3.1.3 Tow bars for the Upper and Lower Flipping arms of the system

Initially, two tow bars were purchased to be used as the two flipping arms, but only one of them were used, as the upper arm. The lower arm was later decided to be fabricated in the machine shop, for a more stable structure. (Figure 3.3)

Figure 3.3: Tow bar for the flipping arm

3.1.4 Adjustable height ball mount for connecting the Arms

The upper and lower arms were decided to be connected by the Adjustable height ball mount. A Reese ball mount and a trailer ball were purchased for this purpose. (Figure 3.4)

[6]**Figure 3.4: Adjustable height ball mount for connecting the arms**

3.1.5 Slip plates for steering motion of the tires

A pair of front Alignment Turn Plates (Figure 3.5) with 360 degrees uninhabited movement was purchased from Gill Smith Racing Foundation. This is a design with graphite lubricant in between the upper and lower plates. This is an all steel construction at just under ¾" tall. The plates measure 12" x 12" at the base, with a 12" wide top plate. The top plate can move 1 1/4" in any direction from the center point, in an uninhibited 360 degree. This motion allows to accommodate the scrub radius of 2" of the system. [6]

Figure 3.5: Slip plates for rotation of tires

3.1.6 Rims and tires

The Heidts system came with a hub assembly of 7'' diameter and a disc brake of 11'' diameter. We purchased a rim that fits the hub and disc assembly specifications, and a set of 195 R 15 65 tires. (Figure 3.6)

Figure 3.6: Rim and tire

3.2 Modular Grid

The location of the ratchets and any other measurement or supporting accessories should be flexible in order to accommodate slight movements of the tires and the rig on the cart. This was achieved by making a grid of threaded holes as shown in Figure 3.7. A grid of 5 x 14 number of 1/4'' 20 threaded holes was created on the cart. The holes were spaced at a 2'' distance.

At present, they are utilized for the Ratchet jacks and for mounting an encoder which is discussed later in the report.

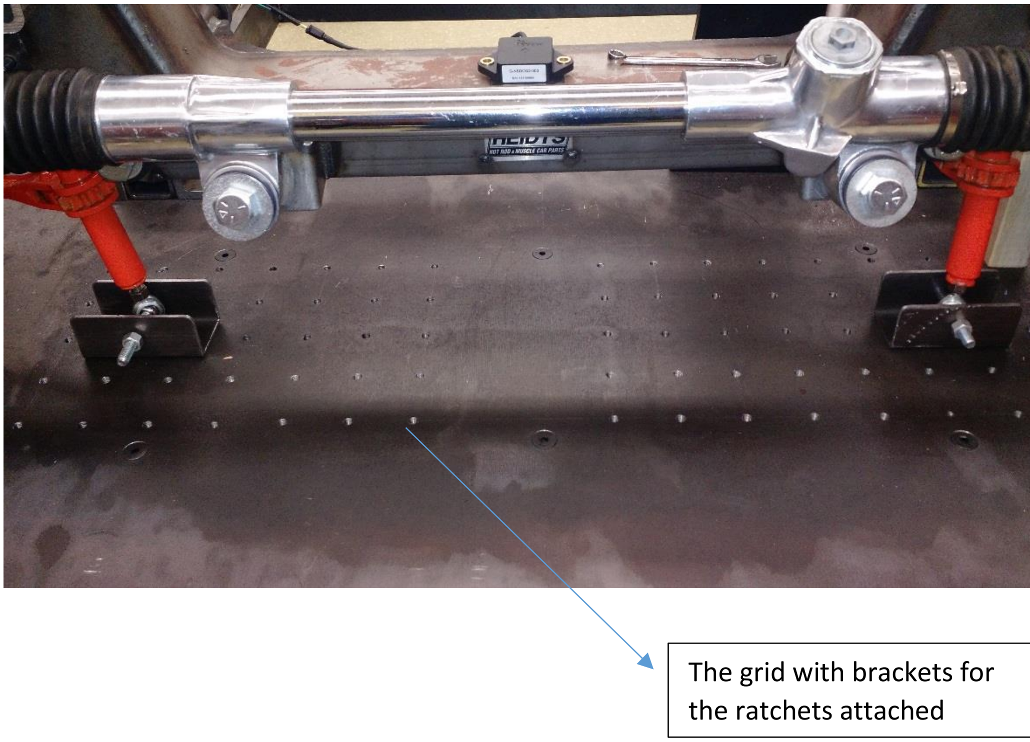

Figure 3.7: The Modular Grid

3.3 Fabrication of Flipping Arms

The upper flipping arm was made from the tow bar. The bolts for adjusting the angles of the tow bar were tightened so as to arrest the angle. The ends of the tow bar arms were cut and a ½" thick plate cross member was welded here for rigidity. On the cross member, two receiving brackets were welded, on each side to receive the body frame extension. The flipping arm is attached to the body frame using a two bolts on each side. A pivoting bolt and a locking bolt. The pivoting bolt is used for the flipping action. The arm can be locked of rotation by using the locking bolt. This holds the system stable. (Figures 3.8 and 3.9)

Figure 3.8: The Flipping Arms fabricated

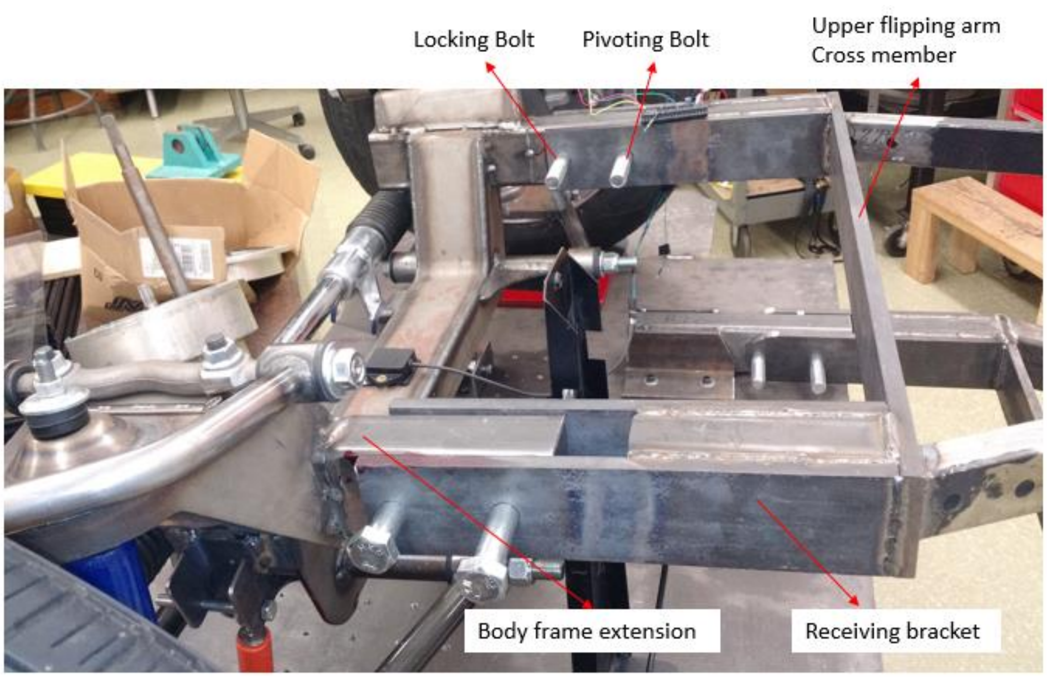

Figure 3.9: Locking pin and pivoting pin for the arms

During the fabrication process, the upper arm had to be heat treated and shaped to make a correct fit into the body frame extension, as there was a slight misalignment initially.

The lower flipping arm was made from a 3x2'' box beam. This was cut into a 'V' shape, resembling the Upper arm, but a scaled version of it. (Figure 3.8)

The ball mount should be attached to the lower arm to be hooked to the upper arm with the receiving end from the tow bar. A provision was made for this by welding on a vertical extension to the lower arm from the corner of the 'V'. The hitch (ball mount and the ball) is fit in such a way that it is adjustable vertically and horizontally.

To attach the lower arm onto the cart a bracket was fabricated and attached to the cart. The lower arm bracket was machined in such a way that the arm is slightly leaned back when flipped into upright position, as shown in Figure 3.10. This was done to make sure that the arm doesn't flip back on its own, which may lead to an accident. The lower arm also has a locking bolt to arrest the rotation of the arm as in the case of the upper arm.

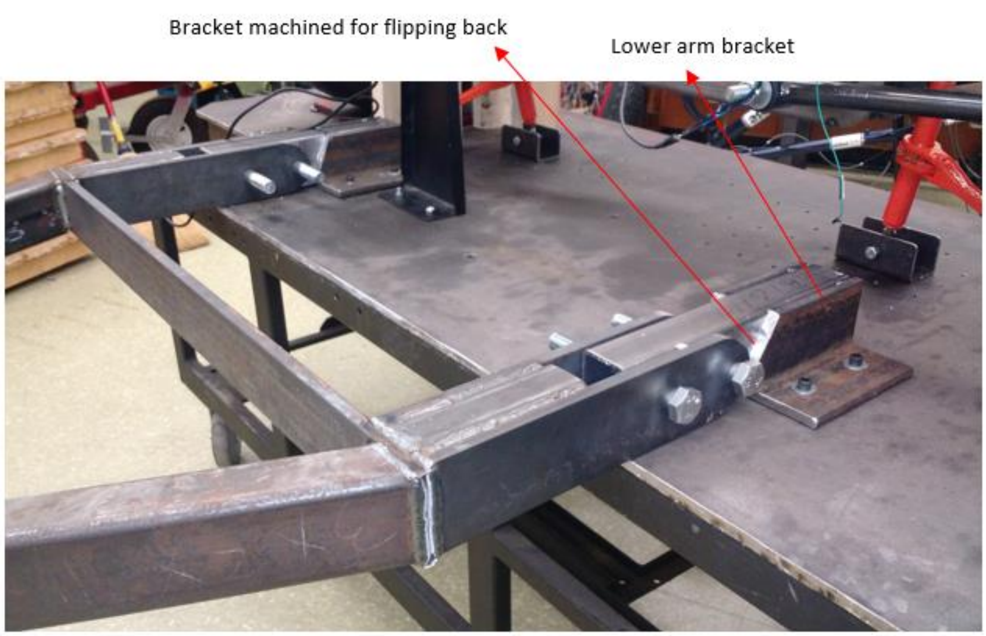

Figure 3.10: The lower arm holding bracket and the machined edges for flipping back safely

3.4 Placement to the Ratchet Jacks

3.4.1 Initial Model with the wooden block

The ratchet jack was initially placed on the flat area underneath the cross member.

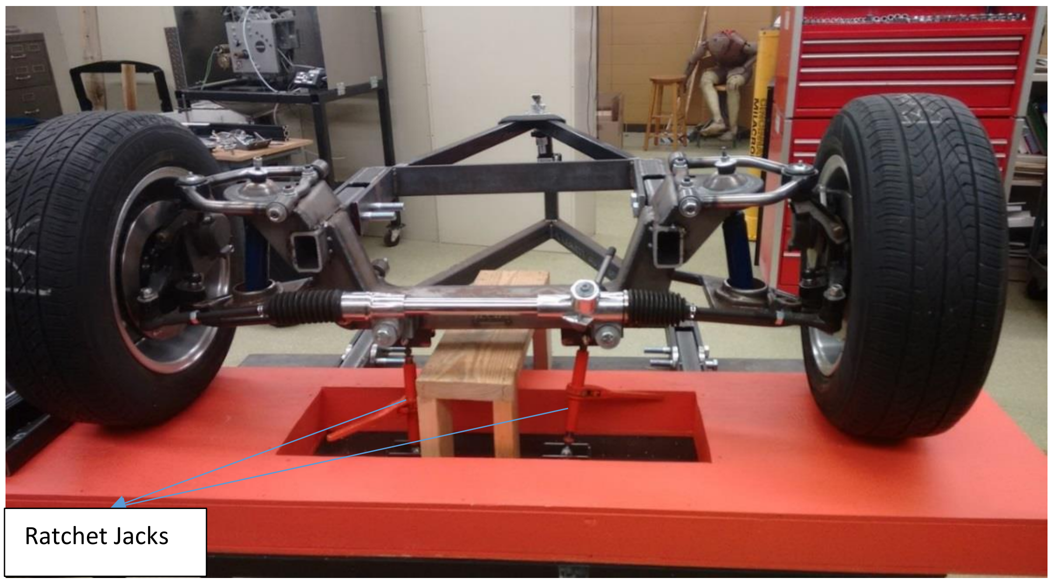

Figure 3.11: The initial placement of the ratchet jacks and the wooden block

The distance from the bottom of the flat surface of the cross member to the cart was 7”, whereas the minimum length of the ratchet jack was 9”. This called for the increase in height of the whole system, so that the ratchet jack remains upright without any compression.

Another issue which we faced was that the length of the cart was right about the size of the track width of the front wheels. So there was no clearance to accommodate any side movements.

Hence, a wooden block of 3’’ height was used initially with sides extending from the edges of the cart (Figure 3.11). This was used as a temporary arrangement to demonstrate the system in the class.

3.4.2 Moving the ratchets to the slant area of the cross member

To keep the ratchets in upright position, it was decided to move the point of attachment of the ratchet jacks on the cross member further up, to the sides of the cross member as shown. A small bracket was welded on the frame with a hole for the ratchet axis. (Figures 3.12 and 3.13)

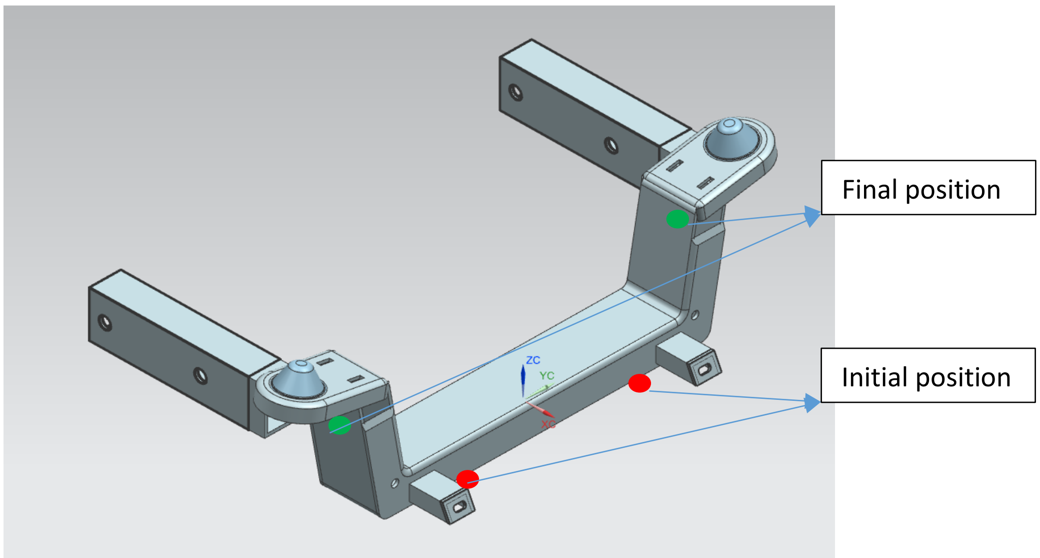

Figure 3.12: The final placement of the ratchet jacks (3D model)

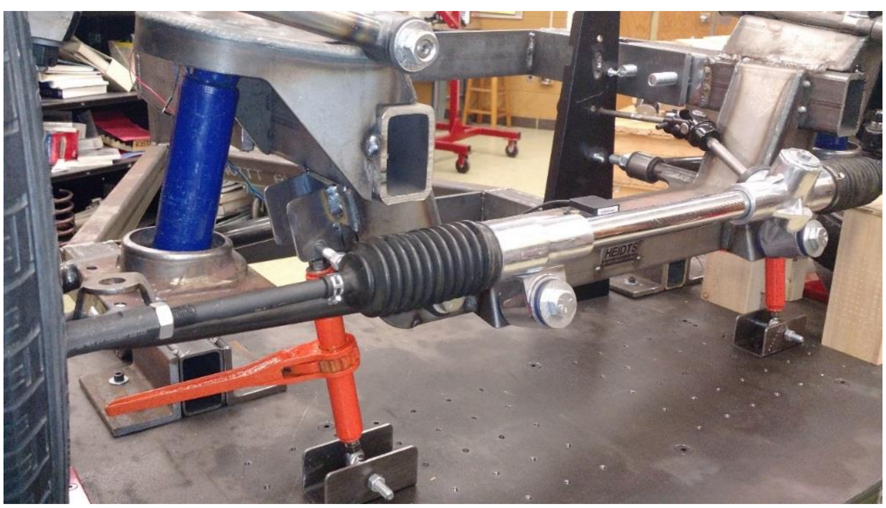

Figure 3.13: The final placement of the ratchet jacks (As fabricated)

3.5 Extension of the cart

As a permanent solution for the length of the cart being low, it was decided to extend the cart length by welding an add-on box beam frame to the sides of the existing frame and to fix a plate on top of the extension. Thus it was made sure that there is enough space allocated for the sideways movement of the wheels, if any. The extension was made as a cantilever with no support underneath since it was only 12'' longer on each side. This helps to maintain the aesthetics too. A CAD representation of the extension is shown in Figure 3.14 below.

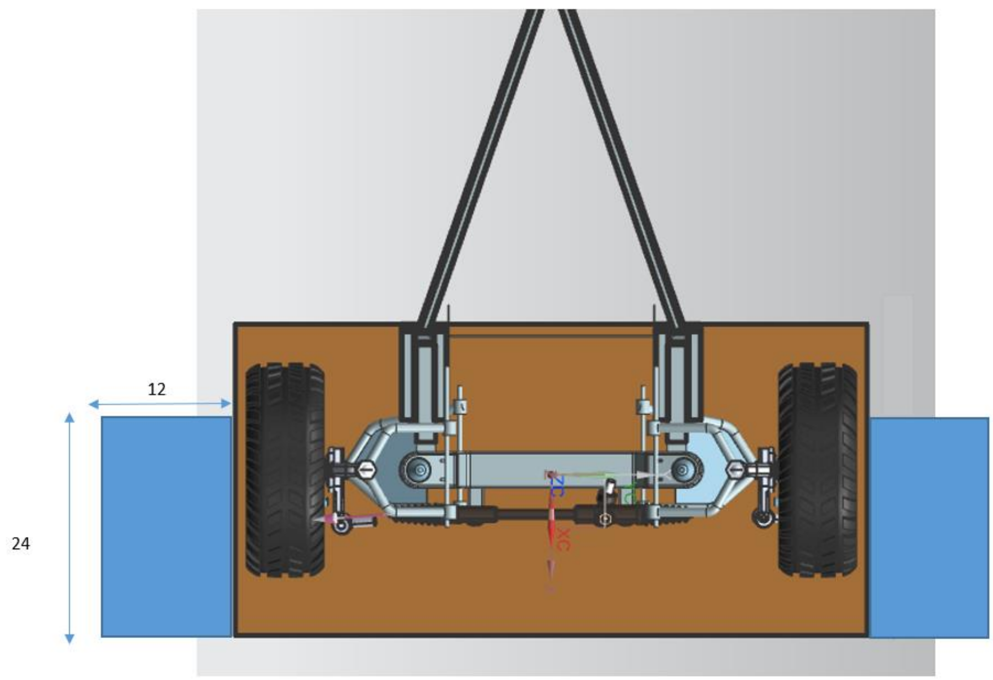

Figure 3.14: The extension of the cart

The extension plate was rounded off at the corners for safety.

3.6 The Assembly

The final assembly of all the components was done as shown in Figure 3.15. The components are heavy, but with the help of two wooden support blocks (these were made for the purpose of supporting the system when disassembled), this whole assembly can be handled by a single person. Set screw threads were machined on the lower arm and the hitch to give provision for screws that make the system sturdy and without any play.

Figure 3.15: The final assembly of the rig

4. Test Setup

4.1 Introduction

A simple test setup was made for demonstrating the behavior of the suspension arms when the wheels were subjected to uneven road conditions (case of bounce and rebound). The behavior of the arms during the case of roll also can be studied using this test setup. The road conditions were emulated by changing the height using the ratchet jacks. A provision for measuring the steering angle input on wheels was also made. This can be used for studying the change in camber and toe angles with steering input, which will be a subject for future study.

With the present system that we have, even though we are not able to create a bounce condition by lifting the wheels, the change in geometry of the arms during a bounce and rebound conditions can be emulated by lowering/jacking up the body frame instead of the wheels. The rig can also emulate the Roll and Pitch cases in a vehicle. Even though the range of motion is limited by the ratchet jacks, a good model of the actual action is obtained with the Rig.

4.2 Emulating Roll

Roll occurs during cornering and tires tend to tilt outside of the corner. We were able to emulate this effect in the rig by jacking up one of the ratchet jacks. During roll, the outer wheel will have a positive camber and the inner wheel will have a negative camber. The change in camber also affects the steering angle. However, a study of steering angle has not been done in this project.

Even though the emulation cannot give an accurate measurement of the angles as there are no sprung mass or springs used, it will give a fairly good idea of the change in geometry of the IFS in a roll situation. A demonstration of this is shown in Figure 4.2. The geometry is comparable to the simulation study done as shown in Figure 2.13. Slight variation in pitch angles can be emulated by jacking up both the ratchets simultaneously by equal amounts.

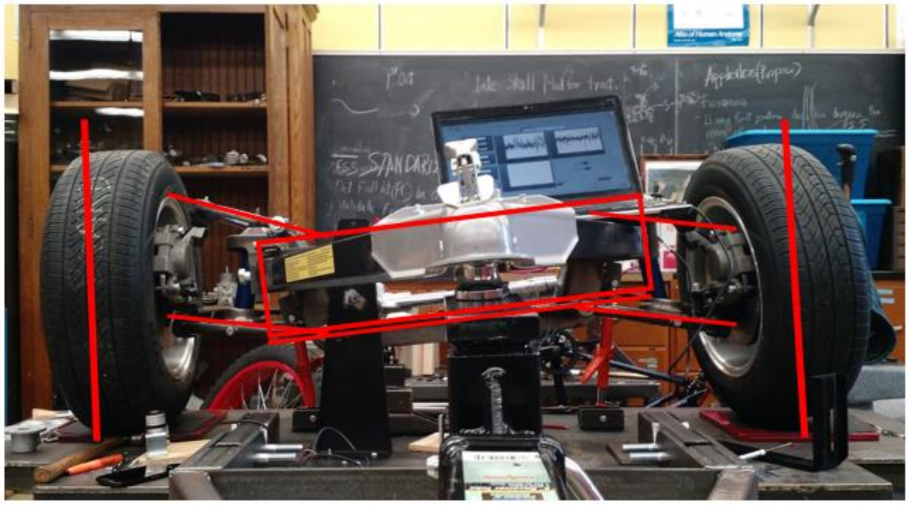

Figure 4.1: The emulated roll geometry in the system

4.3 Parameters being measured and sensors used

1. Roll angle wrt. ground
2. Pitch angle wrt. ground
3. Angle of Upper arm wrt. Ground
4. Steering angle

The following sensors are recommended while installing and performing the experiment

1. Inclinometer - G-NSDOG2-002 (For Roll and Pitch)
2. Accelerometer - ADXL 203 (For Upper Arm angle)
3. Incremental Rotary Encoder - LPD3806-360BM-05-24C

The NI MYDAQ is used for data acquisition. With 2 differential analog input channels and 3 PFI DMM inputs (for encoder timing acquisition), the data acquisition device has limited capability to log data from all the sensors simultaneously. However, the device is capable of acquiring data for the following exclusive scenarios:

1. Measuring the pitch and roll of front axle (Output has 2 Single ended channels – configurable with the 2 differential analog input channels of NI MYDAQ)

2. Measuring the tilt of suspension member (Output has 2 Single ended channels – configurable with the 2 differential analog input channels of NI MYDAQ)

4.4 Mounting of sensors

The 2-axis inclinometer measures both the roll and pitch. It measures the angle against the ground. This was mounted on the cross member at the center using a Velcro and a double-sided tape, as shown in Figure 4.2.

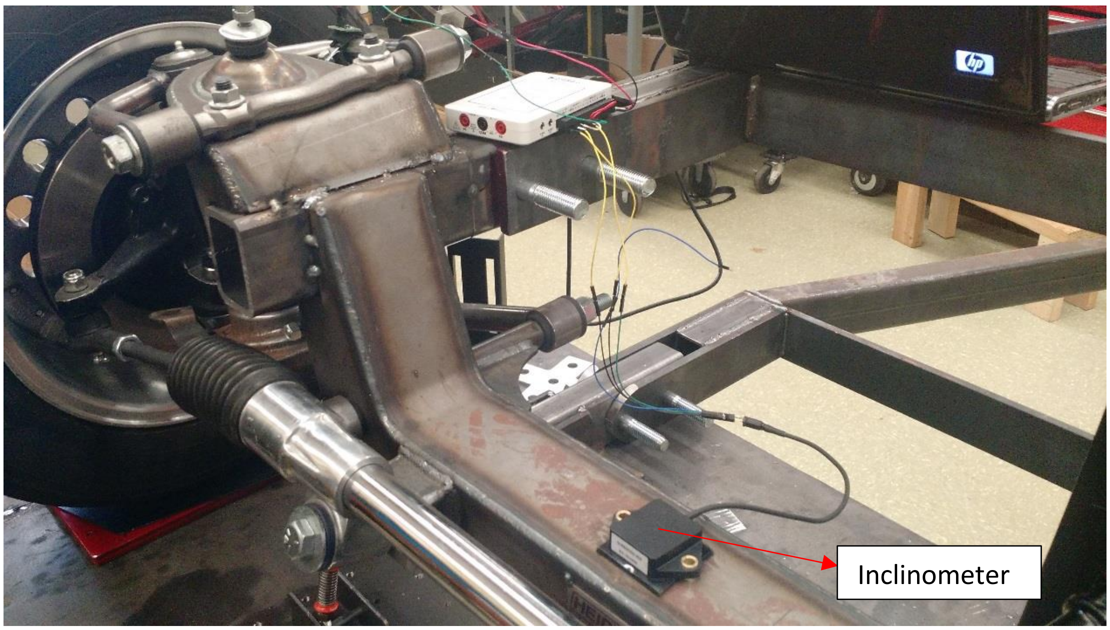

Figure 4.2: Mounting of inclinometer on the cross member

The accelerometer for measuring the Upper arm angle was attached to the upper arm using a Velcro ring as shown in Figure 4.3.

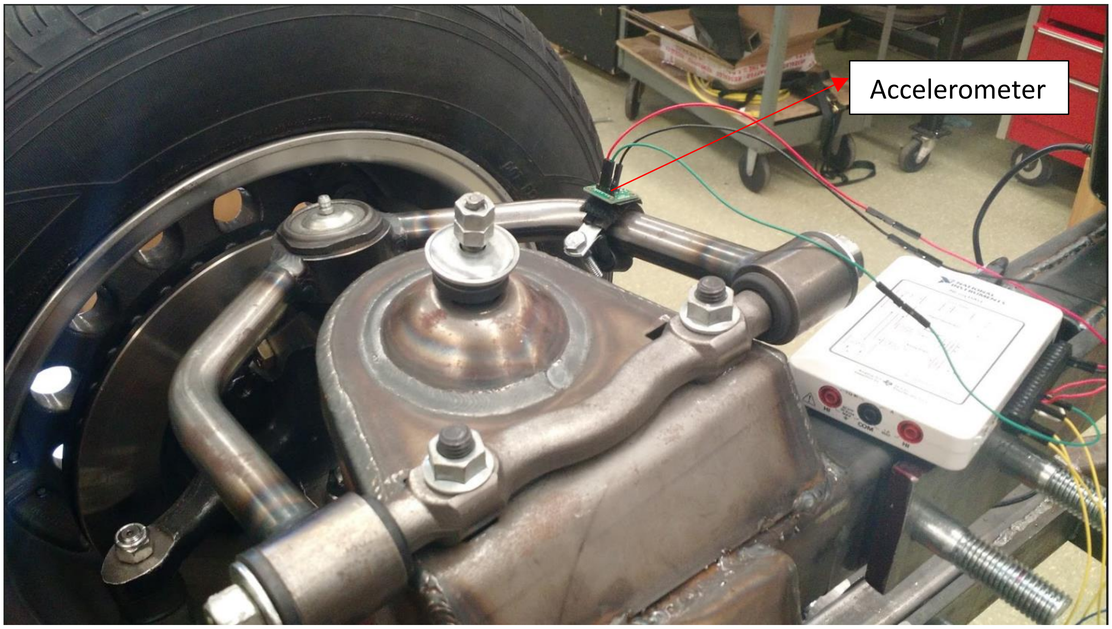

Figure 4.3: Mounting of inclinometer on the cross member

A bracket was made to mount the encoder for measuring steering angle. A Universal Steering U JOINT 9/16" - 26 Spline to 3/4" DD is used as an adaptor for the steering column. The rod connecting the Universal joint and the encoder has flats machined on it to make it rotate (for steering the wheels) with the help of a spanner. The encoder shaft (6 mm dia.) goes into the connecting rod and is tightened using a set screw. This setup is shown in Figure 4.4.

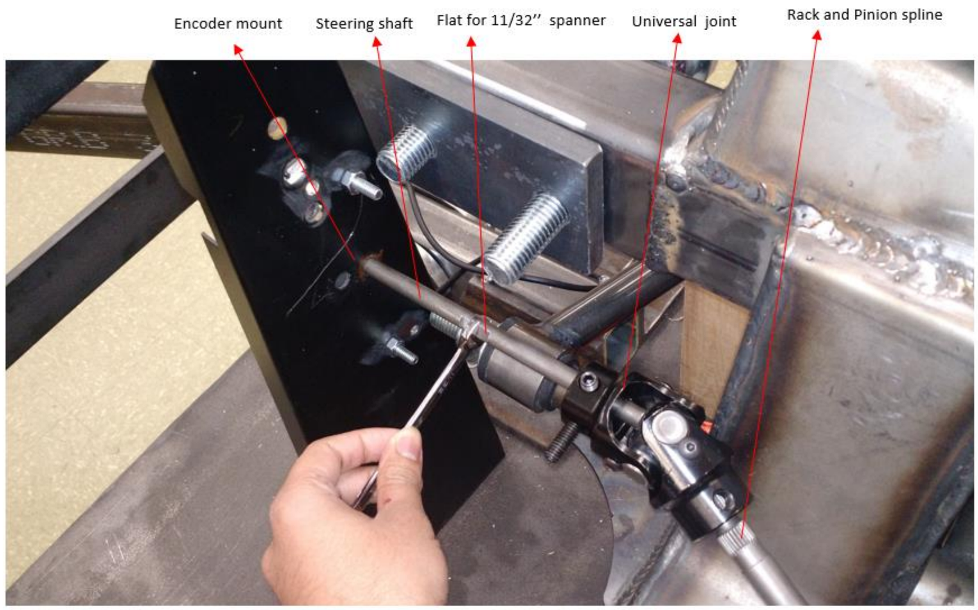

Figure 4.4: Mounting of the encoder and joints to the rack and pinion

4.5 Data acquisition

Data acquisition was done in NI Labview. A Labview Virtual interface was created for acquiring the data.(Figure 4.5)

The front panel allows the user to select program for each experiment and log the data into a separate file. The software enables the user to acquire data from the movement of front axle, upper wishbone member and steering angle, and displays corresponding XY charts and waveform graphs. The software also outputs the tabulated data in a CSV format file with the date, time and history of logging.

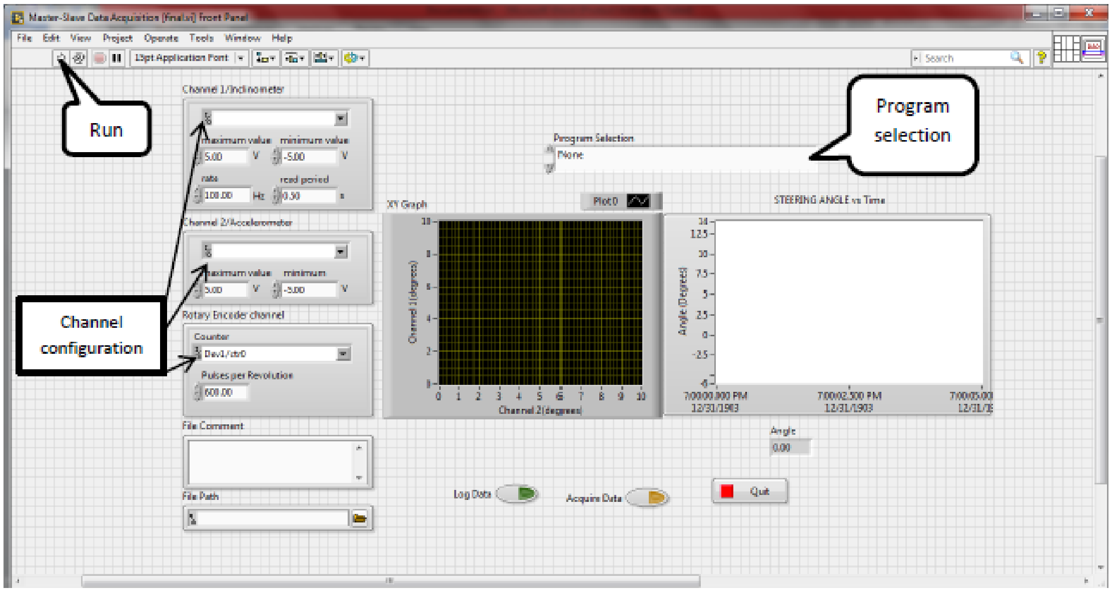

Figure 4.5: LabView User Interface

Channel configuration was done and the angle measurements from the accelerometer and inclinometer were done at a sampling rate of 100Hz. (Figure 4.6)

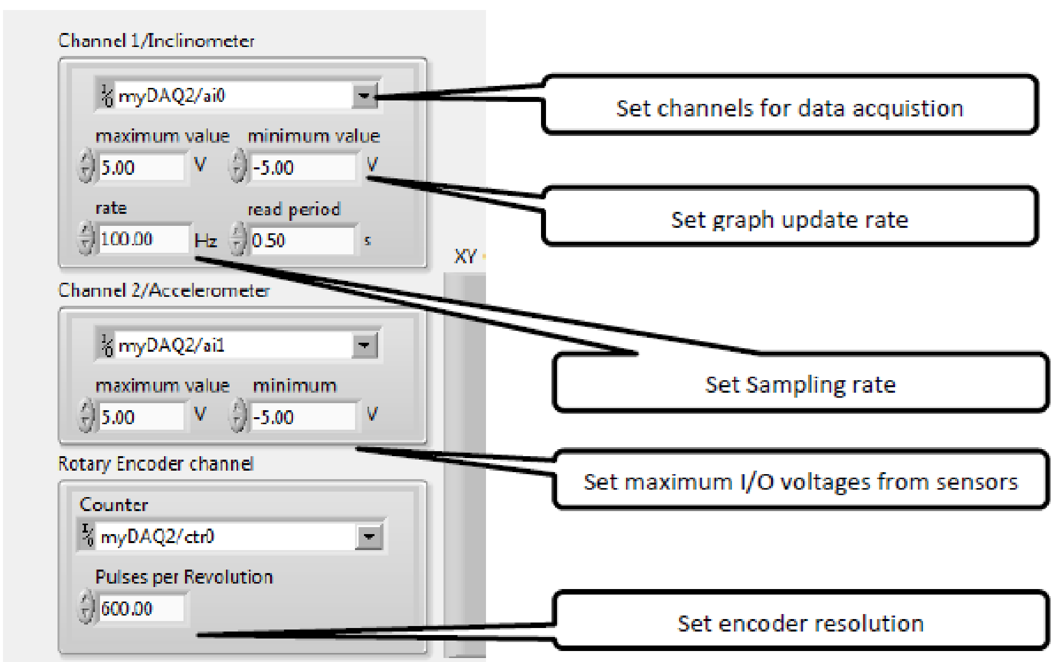

Figure 4.6: LabView Data Acquisition

Two Sets of data were taken and were averaged.

4.6 Post Processing

Since the environment was not noise free and the ratchet mechanism for jacking up the system was manual, the data measured had a lot of noise in it and it was jagged as shown in Figure 4.7. Also, there were slight movements of the whole system due to the movement of the wheels on the cart.

Therefore, a lot of post-processing had to be done to get a meaningful data. Because of the high sampling rate and the jaggedness of the manual control of the system input, it was decided to reduce the sampling rate in post-processing to 0.5 Hz. A moving average with a span of 10 was also used in Matlab to process the data. The final processed data looks as shown in Figure 4.8

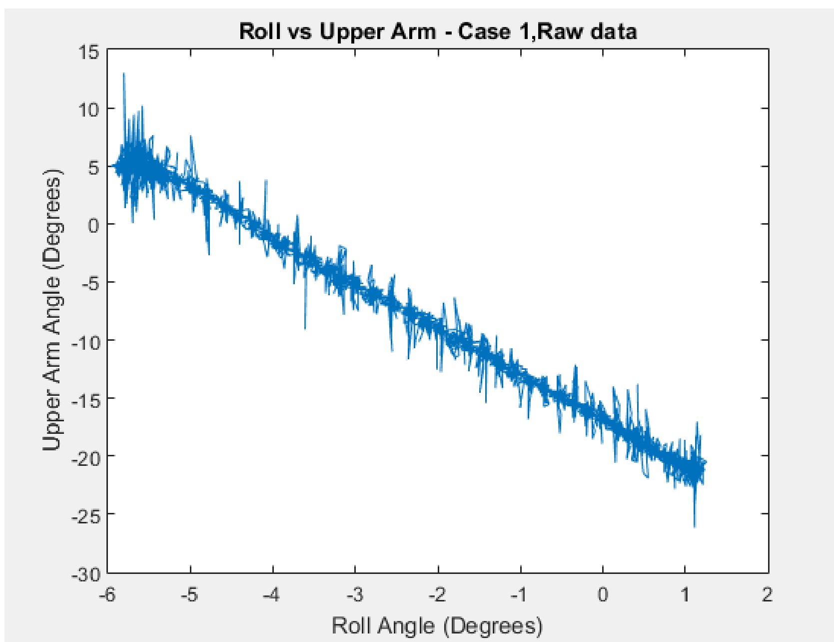

Figure 4.7: Upper arm angle vs Roll angle (Raw data)

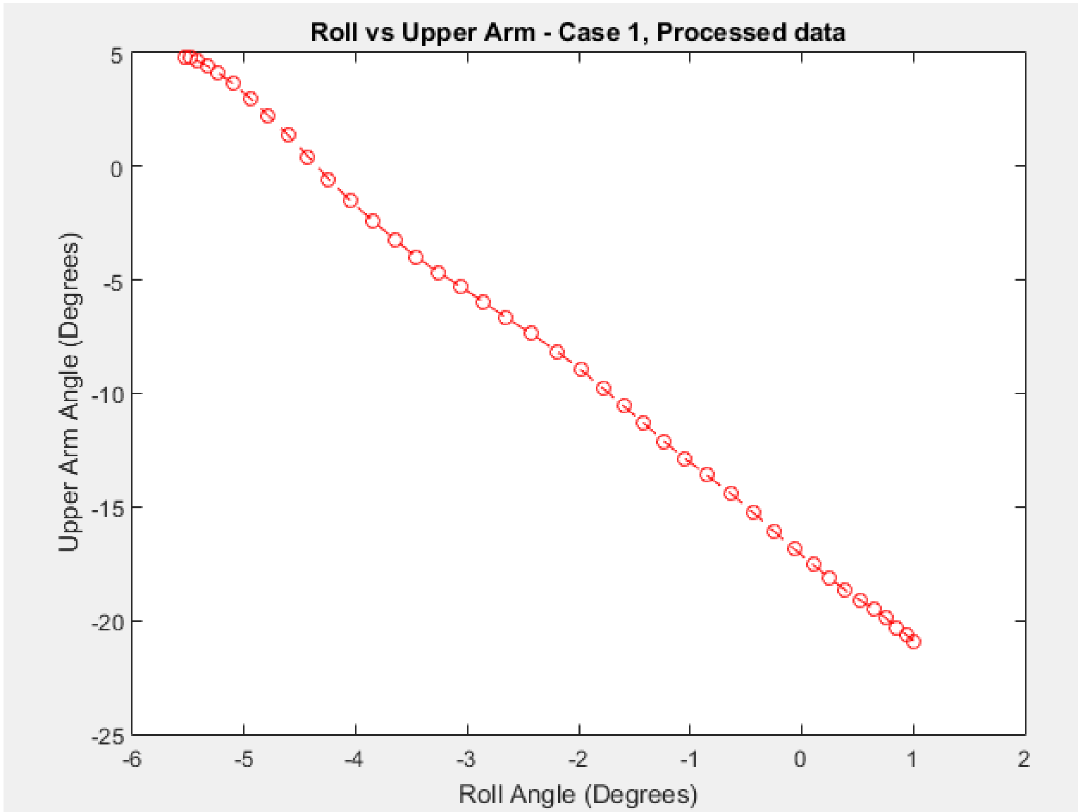

Figure 4.8: Upper arm angle vs Roll angle (Post processing)

5. Results

5.1 Emulating Roll:

Case 1: One side jacked up to the Maximum height of the Ratchet Jack

When the ratchet was jacked up from the minimum height to the maximum height, we were able to emulate a roll angle change from 0° to 6°.

A change in the arm angle from -20° to 5° is observed in this case. The change in arm angle w.r.t. the roll angle seems to be fairly linear in this case. (Figure 5.2)

A simple graphical representation of the wheels is shown in Figure 5.1 to understand the geometry.

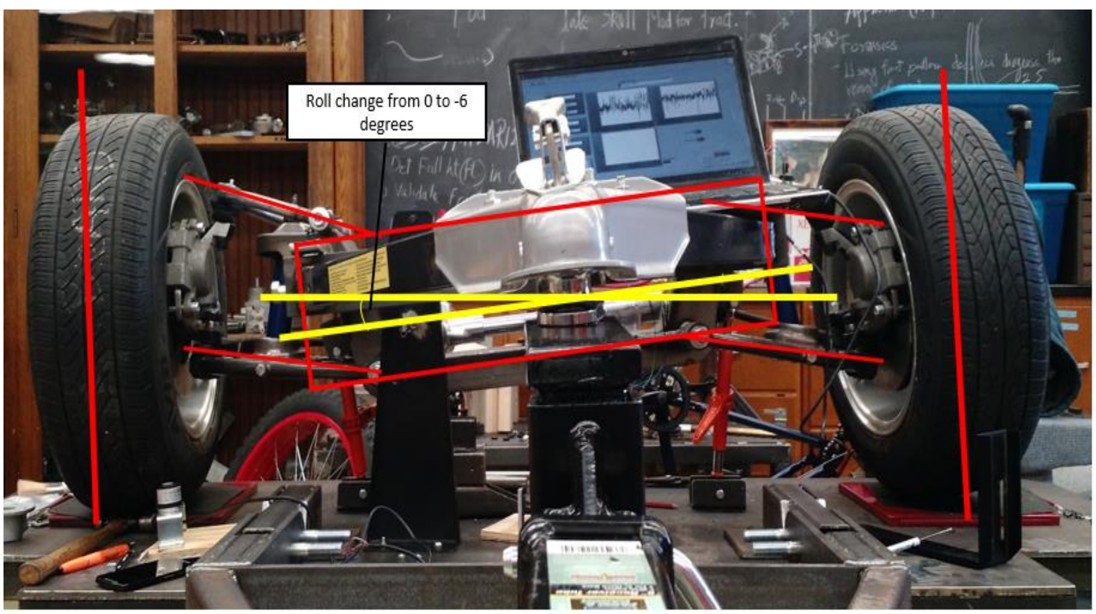

Figure 5.1: Emulating Roll in the system

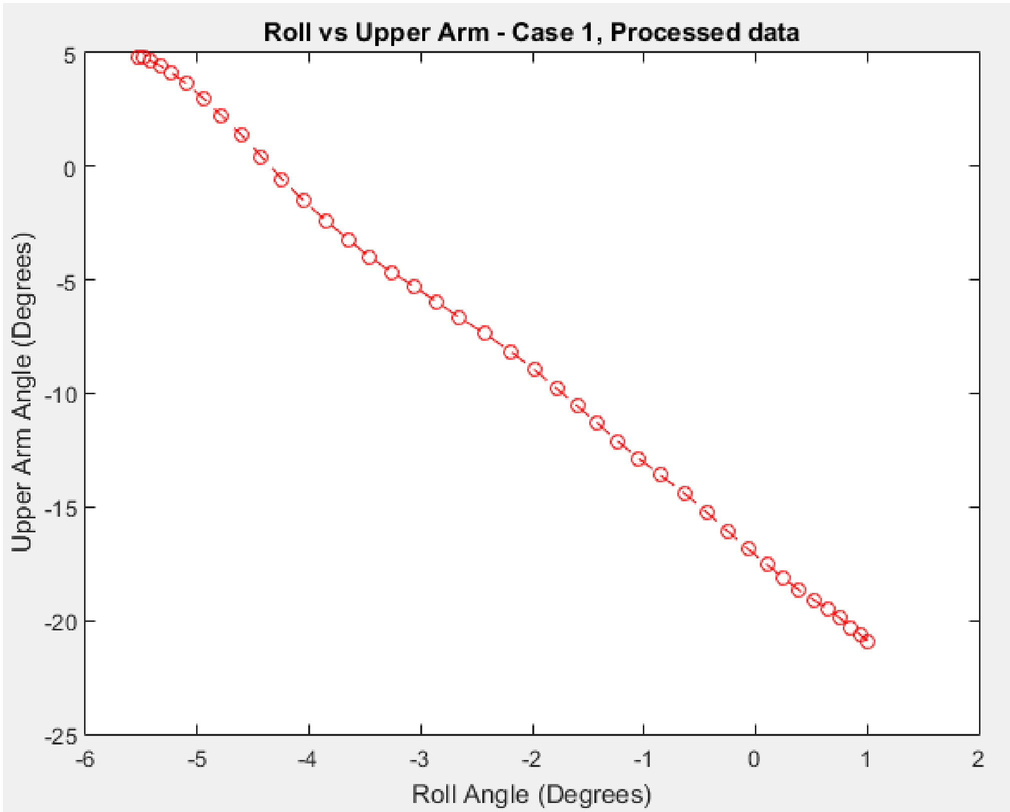

Figure 5.2: Upper arm angle vs Roll- Case 1

Case 2: Other side also jacked up to the Maximum height of the Ratchet Jack

While keeping the initial side at the same jacked up position, the other side was also jacked up. When the ratchet was jacked up from the minimum height to the maximum height, we were able to emulate a roll angle change from -6° back to 0°. Since this situation keeps both the sides at maximum height, it emulates a situation of droop.

A change in the arm angle from 4.5 to 1.75° is observed in this case. The change in arm angle w.r.t. the roll angle seems to be fairly linear in this case. (Figure 5.3) However it is to be noted that the change in arm angle is for the arm on which the initial measurement was done, since only one arm is instrumented with the accelerometer.

Therefore it can be concluded that when the other side is jacked up, the inclination of the arm reduces as the roll angle comes back to 0°.

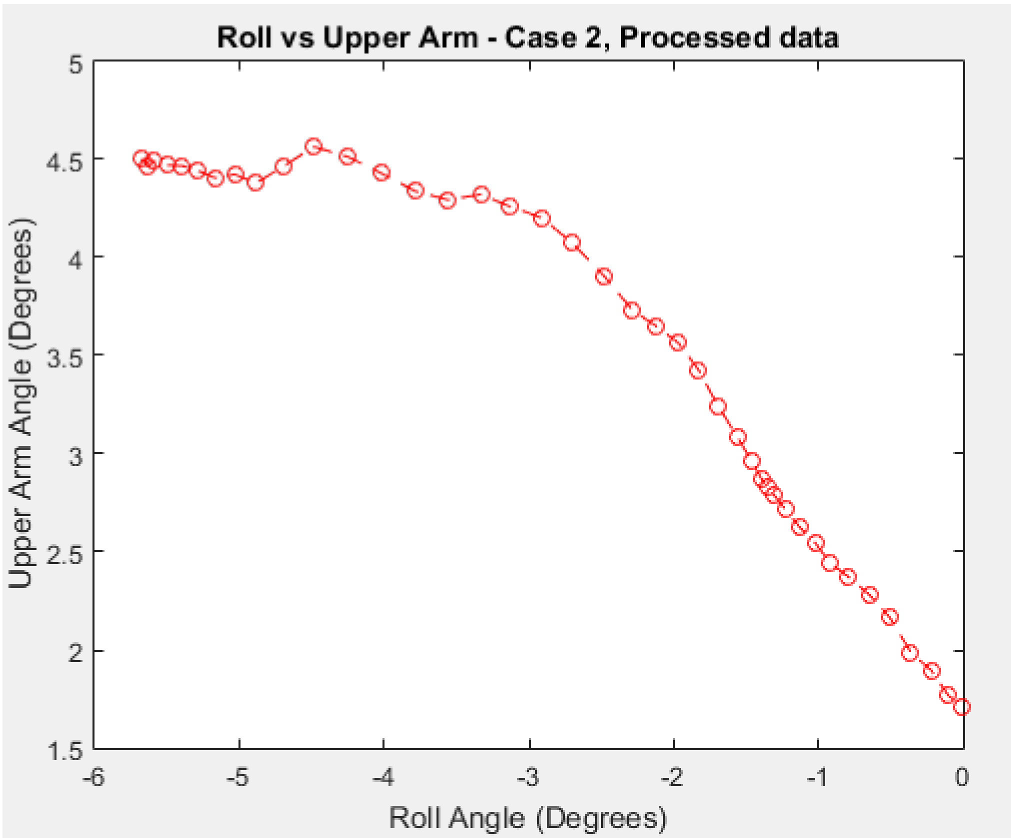

Figure 5.3: Upper arm angle vs Roll- Case 2

5.2 Emulating Pitch:

Emulating pitch angle was also tried by simultaneously increasing and lowering the height of the jacks. But there was no significant change in pitch angle as the system has no Sprung mass. This can be of future scope, adjusting the height of the hitch by a considerable amount.

7. Conclusion

The CAD model of the complete Independent Front Suspension (IFS) was created in NX along with a design for mounting it on the cart. A simple motion study was also done on the IFS. The motion simulation for bounce, rebound and roll were done using NX 10 Motion Simulation.

The suspension rig was fabricated in such a way that it passes through a typical classroom door, hence making it an effective tool for demonstration in class. The two flipping arms make this possible. They can be folded or taken off when it needs to be moved. The system has two ratchet jacks which can be adjusted to emulate different geometries in a real vehicle suspension system.

The rig was instrumented to measure Pitch and Roll, change in geometry of the arms and the steering angle.

The system was successfully able to emulate vehicle roll and geometry change of the arms due to roll. It was also able to emulate bounce and droop.

There is no significant change in Pitch angle with the current system. But this can be studied at a later stage with minor modifications in the system.

7. Future Work

1. The system is currently instrumented with an encoder to measure the steering angle. Instrumentation of the system for measuring the camber angle and toe angle should be done in future. This will be useful in studying the steering characteristics of the vehicle, during a Roll.
2. The current system's capability of emulating bounce/rebound and roll is limited by the range of the ratchet jacks. A ratchet with a wider range of adjustment can be used to get to the extreme conditions of these driving conditions. Also, adjusting the height of the ball mount can be done to emulate a significant change in pitch.
3. A study of the variation of tire pressure, foot print of tires and characteristics of tires in a roll situation can be studied using an ink/marker system.

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