NUST COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

Design and Fabrication of Six-Wheeled ATV

A Project Report

DEGREE- 40

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ACKNOWLEDGEMENTS

All honor and credit be to Allah Almighty, who facilitated us to accomplish something in our efforts. We are grateful to our project supervisor, Dr. Raja Amer Azim, for his unwavering support and being available all the time whenever we needed it the most. We are also grateful to our parents for their unwavering support and prayers.

Mission Statement

The purpose of designing and fabrication of this ATV was targeted primarily for military applications. Integration of ATVs such as UGVs into infantry role can greatly assist military personnel on ground. In addition to that, making these vehicles autonomous can save lots of lives. Six wheeled ATV has the advantage of performing in every kind of environment or terrain. Using multiple attachments such as a grenade launcher, a mini gun, a small radar as well as mine detection equipment can allow the user or the soldier to survey sensitive areas. These types of vehicles can also be used for transporting ammunition to soldier that are deployed in areas where it is difficult for normal vehicles or trucks to approach. Traversing multiple kind of terrains with ATVs can also provide our military with the chance of surveying areas and deploying soldiers with adequate ammunition where it was not possible previously by foot or trucks. Militaries all over the world have deployed ATVs to support their infantry and we believe our country where the land army is the biggest countering threats from all sides can greatly be assisted by this kind of vehicles.

ABSTRACT

An **All-Terrain Vehicle (ATV)**, also known as a **light utility vehicle (LUV)**, is a vehicle that travels on low-pressure tires, it is designed to handle a variety of terrain than most other vehicles. By the current **ANSI** definition, ATVs are intended for use by a single operator who can operate the vehicle on board as well as remotely. ATVs are used in numerous industries for their maneuverability and off-roading capability. These include border patrol, construction, emergency medical services, land management, law enforcement, mineral and oil exploration, pipeline transport, search and rescue, small-scale forestry, surveying, wild land fire control, and applications in military. ATVs are also used in several sports competitions as well. These machines can be modified for multiple racing disciplines such as motocross, woods racing, desert racing, hill climbing, ice racing, speedway, flat track, drag racing and others. In Pakistan, ATVs are mostly used in the form of Quad bikes or in 4x4 configuration. Whereas in USA and Europe, there has been a lot of development in the field of 6 wheeled and 8 wheeled ATVs. These multi axle ATVs provide the added benefit of better traction, weight distribution, more contact patches, better cornering, stability, and improved maneuverability. Not only this, but ATVs have also been modified for unmanned application in both space and military applications. As they are built to tackle any type of terrain, this is very much helpful in utilizing them in unmanned situations as well as autonomous applications.

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Chapter 1: Introduction

1.1 Background

An ATV is defined as a motorized off-highway/off-road vehicle designed to travel on four low-pressure or non-pneumatic tires. ATVs are subdivided into two types as designated by the manufacturer. Type I ATVs are intended by the manufacturer for use by a single operator and no passenger. Type II ATVs are intended by the manufacturer for use by an operator and a passenger and are equipped with a designated seating position behind the operator.

All-Terrain vehicles (ATVs) have some of the following more common characteristics; they travel on tires with low pressure, an operator sits on the seat and controls the movement of the vehicle with the handlebars/sticks provided for steering. According to the American National Standards Institute (ANSI), ATVs are fabricated for use by a single operator. They can, however, be modified. ATVs are intended to be used for many purposes. In the field of agriculture, they are used for surveying, forestry, pest control, extraction and plantation. Similarly, they are used for various other purposes such as medical service, fire control, search and surveying and exploration. Perhaps the greatest application ATVs have found are, in space exploration and the military.

Another rising concept is of the ‘Six-Wheeled ATV’. Six-wheeled ATV offers numerous advantages over the conventional 4-wheel ATV or Quadbike. It is equipped with additional Axle for the 2 extra wheels which can offer space for passengers or trunk compartment for luggage or goods. It provides improved maneuverability in off-road tracks and better load bearing abilities as the load is divided on 6 wheels instead of 4.

Figure 1: Amphicat; six wheeled ATV

For a vehicle to travel off road, it is generally required to have large tires with deep open tread, a flexible suspension and low ground pressure so that it may not sink in soft ground, good ground clearance, better traction and large load bearing capacity. Wheeled vehicles accomplish this by having a suitable balance of large or additional tires combined with tall and flexible suspension. Tracked vehicles accomplish this by having wide tracks and a flexible suspension on the road wheels.

Tires play a significant role for any off-road vehicle equipped with wheels, as they ensure optimal traction required to keep it moving. The off-road tire tread types vary depending on the terrain type. The most common types of off-road tires are A/T (stands for "All Terrain") and M/T (stands for "Mud Terrain"). While the A/T tires perform excellently on the sand, they are barely usable in the mud. There are also unique Sand Blaster and Mud bogging tires used for the most challenging terrains such as dirt, sand and even water to maintain traction at extreme angles and high speeds.

This is due to their biggest advantage that a 6x6 ATV can also be fitted with tracks like that of a tank to operate in a variety of terrain and conditions with ease. ATVs then can be fitted with a variety of attachments. All these qualities have enabled the ATVs to be used in Aerospace and military.

1.2 Multi-wheeled ATVs

The term ATV at first defined, six wheeled amphibious vehicles such as The Jiger, Amphicat and the Terra Tiger. These all were produced during the 1960s and the 70s. The first ATV as we know it emerged as a 3-wheeler. The Sperry-Rand Tricart was designed in 1967 and manufactured in 1968. However, it was the Honda ATC that made 3-wheelers a household name and set the path for today's ATV. During this time, farmers realized the value of using an ATC for work and the 3-wheel market tapped into a new demographic.

In 1984, Yamaha debuted their first four-wheeled ATV, the YFM200, in the United States. Other contributions include the Grizzly 600, a 4x4 ATV with automatic transmission in 1998 and in 2000 the Buckmaster Edition Big Bear 400 4x4, the first ATV with camouflage bodywork. Suzuki actually sold the first 4-wheeler in 1982 called the Quad Runner LT125. Three years later, the company offered the first high-performance 4-wheeler, the LT250R Quad Racer, which featured a liquid-cooled two-stroke, and a five-speed manual transmission.

1.2 Six Wheeled ATVs

Some of the widely available 6 wheeled ATVs are discussed below as shown in figure

Figure 2: A Six Wheeled ATV

1.2.1 Amphicat

The 'Amphicat' is an amphibious, skid-steer, six-wheel-drive, all-terrain vehicle designed and produced in the early 1960s through the late 1970s by Mobility Unlimited Inc. of Auburn Hills, Michigan. The manufacture line was purchased by Magna American (a sub-unit of Magna Corporation) which manufactured the vehicle in Raymond, Mississippi for many years. The product was also produced in Canada by Behoo Industries and was slightly different from its American counterpart, mostly on transom.

1.2.2 Unmanned Ground Combat Vehicles: Spinner

The Spinner is six-wheeled, combat, hybrid, ground vehicle. It has the capability to endure rollover crashes and carry on with the operations to complete the objective. The Spinner's suspension, hull and wheels have been designed for extreme forward impacts from accidently colliding with a rock, tree or any unseen obstacle at high speed. The Spinner's high maneuverability on rough terrain is possible due to its large tire diameter together with independent suspension, high ground clearance, and low center of gravity. Low obstacles equal to the diameter of the tire is relatively smooth because of the six-wheel, high-torque, motor-in-hub design.

1.2.3 Howitzers

A howitzer is typically a long-ranged weapon between an artillery gun (also known as the cannon outside of the United States) – that has smaller, high-velocity shells launched at flatter trajectories – and a mortar – which launches at higher angles of ascent and descent.

The G6 is a self-propelled, mine-protected howitzer. It was designed as a self-propelled, turreted variant of the G5 howitzer series, attaching the gun to a six-wheeled armoured chassis. The permanent six-wheel drive has transverse and longitudinal differential locks. The suspension system is made of fully independent torsion bars with shock absorbers and hydro-pneumatic bump stops.

1.2.4 Crushers

The Crusher, developed by DARPA, has a new hull made from titanium nodes and high-strength aluminum tubes. The Crusher's suspension system support 30 in. of travel with variable stiffness and adjustable ride height. The Crusher was a major design point. It can easily carry over 8000 lbs. of payload and armor. It offers more reliability, mobility, flexibility and maintainability than Spinner, at relatively 29 percent less weight. The six-wheel base increases ground traction and pressure to allow it in overcoming tough obstacles. We have designed our ATV with a six wheeled base for this reason.

Chapter 2: Motivation

Our motivation to select this project is that Six-Wheeled vehicles are a stream that is the center of attention for a lot of researchers all over the world and is emerging as a potential market for automotive industry in the future. It has a lot of application in different fields e.g., Agriculture, Medical, Military and Surveillance.

There has been a lot of research in the field of 4 Wheeled ATVs but surprisingly there has not been as much research in this field as it potentially offers. This offers an opportunity to put in our efforts in this field so that this concept can be introduced and can be competed on international level. Our automotive industry is not producing these types of ATVs regardless of the applications they can be used for. This project is an effort to initiate this aspect of the industry which has the potential to be a milestone in the research and development of automotive industry.

Similarly, these ATVs are being used by Military in the US, UK, and Israel. These have proven very successful in transportation, reconnaissance, survey, and unmanned ground roles. These have been successful in approaching areas which were not possible due to difficult offroad terrains. There is a huge potential of ATVs in Pakistan Army as it has been operating in difficult terrains all over the country.

Why do we want to work on this project?

1. It is better than off-road vehicles with tracks
2. It can be modified into a track vehicle
3. It has major applications in Agriculture and Medical Sectors
4. It has major applications in military for transportation and surveillance
5. Further possibilities of modifications can be explored e.g., Amphibious, and unmanned role etc.

Chapter 3: Chassis

3.1 Vehicle Dynamical Terminologies

Chassis can be presumed as the center of the vehicle dynamics. In chassis models, we discuss the equations of motions revolving around accelerations; both translational and rotational. Forces being applied on tires are also discussed.

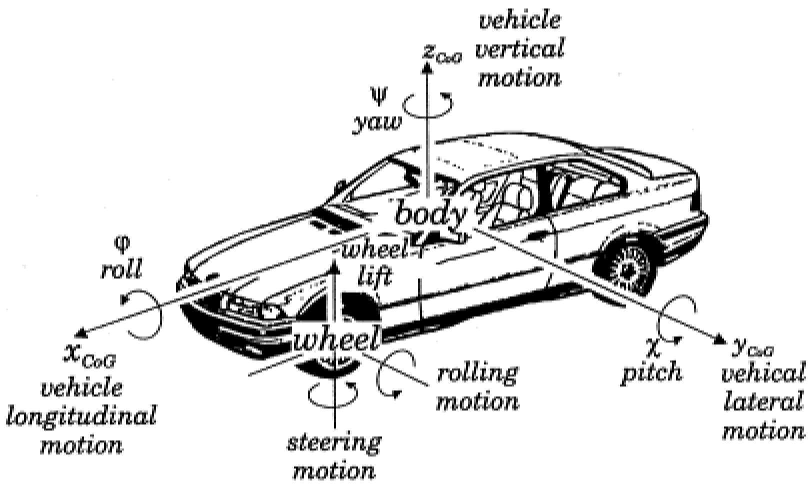

Figure 3: Vehicle fixed SAE Coordinate System

In a general Six Degree of Freedom System, following dynamics are present:

- **Longitudinal Motion (X- Axis)**

Motion which takes place in the direction of vehicle travel is this motion. In longitudinal motion, following forces are generated:

1. Tire forces
2. Rolling Resistance
3. Drag Force
4. External Push

These forces sum up to give longitudinal acceleration given by the following equation.

$$\Sigma Fxi + \Sigma FRollingRes + \Sigma FDrag + \Sigma Fext,x = max$$

- **Lateral Motion (Y- Axis)**

Lateral motion is imparted during turning and cornering. It is induced because of

1. Tire forces rising form steering angles imparted during turning
2. External push

Mathematically,

$$\Sigma Fyi + \Sigma Fext,y = may$$

- **Vertical Motion (Z- Axis)**

Vertical Motion is a measure of passenger's comfort. How much shocks are absorbed by shock absorbers and dampers. These are vertical forces imparted on springs.

$$\Sigma Fsprings + \Sigma Fdampers + mg = maz$$

- **Roll Rotation (Moment about X- Axis)**

This moment is induced due to forces imparted on vehicles during high-speed cornering which can cause the vehicle to topple to one side.

$$\Sigma M\ susp,x - m*ay*droll = Ix*\alpha x$$

- **Pitch Rotation (Moment about Y- Axis)**

This moment exists during acceleration and deceleration. It causes the weight of the vehicle to be shifted forward or backward depending upon acceleration or deceleration.

$$\Sigma Msusp, y + m*ay*dpitch = Iy*\alpha y$$

- **Yaw Rotation (Moment about Z- Axis)**

Spin of the vehicle about its own axis is called yaw rotation. Mathematically,

$$\Sigma Mtire,Fx + \Sigma Mtire,Fy = Iz\alpha z$$

Complete nomenclature of the variables is defined below

ΣMsusp,y	Suspension moment about y
ΣMtire,x	Tire moment about x
ΣMtire,y	Tire moment about y
dpitch	Distance of pitch axis from CoG
Ix	Moment of Inertia about x
Iy	Moment of Inertia about y
Iz	Moment of Inertia about z
ΣMsusp,x	Suspension moment about x
m	Sprung mass

ΣFxi	Tire forces in x
ΣFyi	Tire forces in y
ΣFsprings	Spring forces
ΣFdampers	Damper forced
ΣFDrag	Drag forces
ΣFRollingRes	Rolling Resistance
ax	Acceleration in x
ay	Acceleration in y
az	Acceleration in z
αx	Rotation acceleration about x
αy	Rotational acceleration about y
αz	Rotational acceleration about z

Table 1: Nomenclature of Dynamics

The chassis is the actual load bearing frame of any object or structure supporting its functionality [1]. In the case of vehicles, the chassis acts as support for mounting the frame, the engine, transmission, and various other components.

3.2 Frames

Frames are constructed using channel shaped beams welded or fastened together. Various type of frames is used in the automotive industry some of them described below. [2]

3.2.1 Ladder Frame

As the name suggests, the ladder frame is of the shape of a ladder in which two long beams are welded with in between lateral members. Mostly trucks are made of this type.

Figure 4: A Ladder Frame

3.2.2 Perimeter frame

In perimeter frame, frame members are welded or riveted around the entire body. These are good for providing support to suspension and its components.

Figure 5: A Perimeter Frame

3.2.3 Stub Type Frame

Stub type frames are usually used on unit body vehicles to support power train mainly.

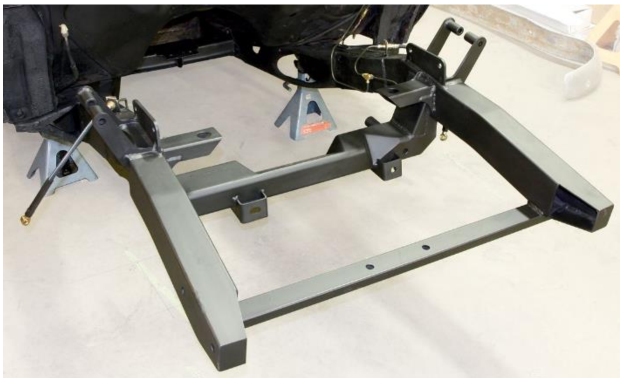

Figure 6: A Stub Frame Section

3.2.4 Unit Body Construction

This design combines the body with the frame of the vehicle to create a shaped structure. It supports the engine and driveline in addition to suspension and steering components.

Figure 7: An example of a unit body Construction Frame

3.2.5 Space frame Construction

It consists of formed steel sheets used to construct the framework for the vehicle.

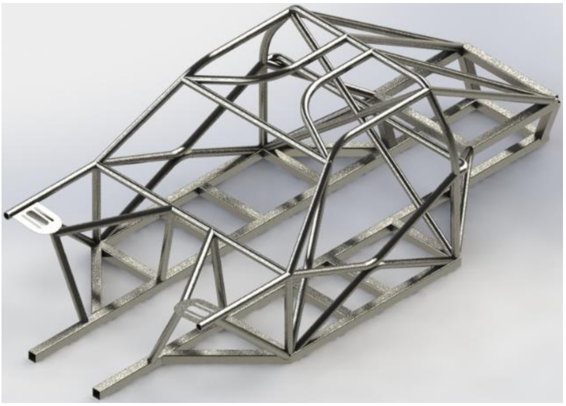

Figure 8: A CAD Model of a Space Frame Construction

Chapter 4: Steering Systems

Steering system is a crucial part of any vehicle. Its function is to make sure that the vehicle is driving as per the requirement of the driver. It has a direct concern with manipulative stability in a car. It is a vital factor take under consideration to reduce traffic accidents and protect driver's safety. It also helps in improving the driver’s working condition. Steering is the collection of components, linkages, etc. which allows any vehicle (car, motorcycle, bicycle) to follow the desired course.

4.1 Basic Steering Components

Almost all the world's car steering systems are made up of the same three or four components. The steering wheel, which connects to the steering system, which connects to the track rod attached to the tie rods, which are connect to the steering arms. all the steering system designs essentially move the track rod left-to-right across the car. The tie rods connect to the ends of the track rod with ball and socket joints, and then to the ends of the steering arms, also with ball and socket joints. The purpose of the tie rods is to allow suspension movement as well as an element of adjustability in the steering geometry. The tie rod lengths can normally be changed to achieve these different geometries.

4.2 Types of Steering Systems

A proper steering system is necessary to effectively control the vehicle with safety during its entire speed range without much effort. It should also be able to tackle wide variations of road surfaces, bumps and bounces to the vehicle. It is the basic feature of a vehicle to be steered straight and maintain it at that position, or turn at the driver’s will without putting much efforts to do so. It is also necessary that the moving vehicle is under driver’s perfect control in order to avoid any accident.

4.2.1 Conventional Steering

The most conventional steering arrangement is to turn the front wheels using a hand operated steering wheel, which is positioned in front of the driver via a steering column. As the steering wheel is turned, the steering shaft rotates the pinion gear. The teeth of the pinion gear and the steering rack interlock as the pinion rotates. This rotation will push the rack when the rack moves the attached rods, and steering knuckles act as pivot points and turn the front tires. [3]

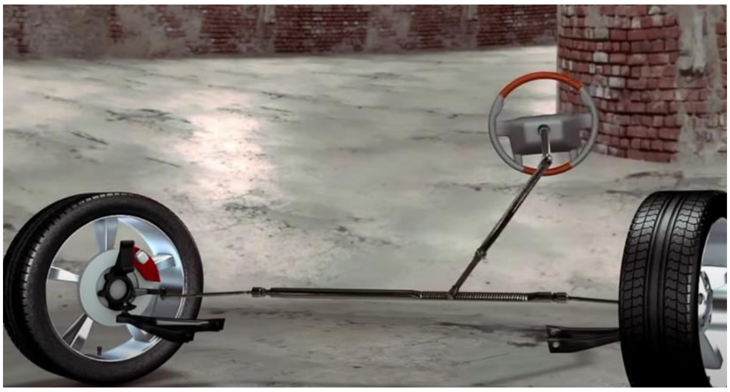

Figure 9: Conventional Steering

4.2.2 Four Bar Steering

The four-bar steering mechanism consists of a fixed link that is connected by two short pivot links and a tie rod. When the car turns, only the tie rod moves. If you steer the vehicle to the left, the tie rod moves to the right and if you steer the vehicle to the right, the tie rod moves to the left. In this mechanism, the slip angle will be the same.

When the four wheels rotate on the axis of the center point, it is known as the true rolling condition. The true rolling condition occurs when the front wheels are rotated with a minimum slip to turn the car. In this situation, the outer wheel of the car has to travel more than the inner wheel of the car. For this reason, we have to rotate both the wheels at different angles.

4.2.3 Ackermann Steering

In Ackermann steering, the tie rod length will be reduced as compared to four bar steering. As a result, both the operative small link will be inclined in a way that its axis will be connected to the rear axle center. When you turn the vehicle, the wheels will be turning at different slip angles. When you release the steering, the vehicle's straightening force helps to bring back steering to its initial position. In this mechanism, the wheel turns at different slip angles the four-wheel center axis will meet at the instantaneous center point at both sides which helps to turn the vehicle with its true rolling conditions.

4.2.4 Power Steering

The power steering is a system that reduces the effort required of the driver to turn the steering wheel. Without power assist, the steering of most vehicles would be extremely heavy particularly during low-speed maneuvers such as pulling into a parking spot, turning a 90-degree corner in the city or driving in a crowded gas station

There are three types of power steering system. They are hydraulic power steering, electric or motor driven power steering, or electro-hydraulic power steering. [4]

4.2.5 Skid Steering

Skid-steering is an unintuitive method from lateral sliding that must take place for a skid steer vehicle to turn steering due to the multiple forces. It maneuvers a vehicle by simply incurring a velocity difference between its two lateral sides. In such vehicles, the wheels or tracks on each side can be driven at various speeds in forward and reverse. Skid steering is more commonly used on tracked vehicles in addition it is also employed with six and eight wheeled vehicles. What happens is that each side can be driven at different speeds although the tires on one particular side all have same speed. This causes the wheels or tracks to slip or skid on the ground hence allowing vehicle maneuverability. To move the vehicle forward, both the Left-Hand Side (LHS) and Right-Hand Side (RHS) tires are moved or rotated at the same speed.

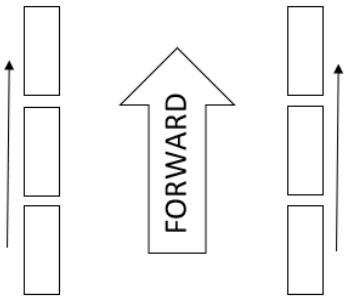

Figure 10: Skid Steering Forward Maneuver

Similarly, to move the vehicle in reverse both LHS and RHS are rotated at the same speed but in reverse direction.

To turn the vehicle, the wheels in the turning direction are rotated at a slower speed than compared to the wheels in the opposite direction allowing the vehicle to “skid” in the direction of wheels that are being rotated slowly.

Similarly, the vehicle can also be rotated 360- degrees about its own axis.

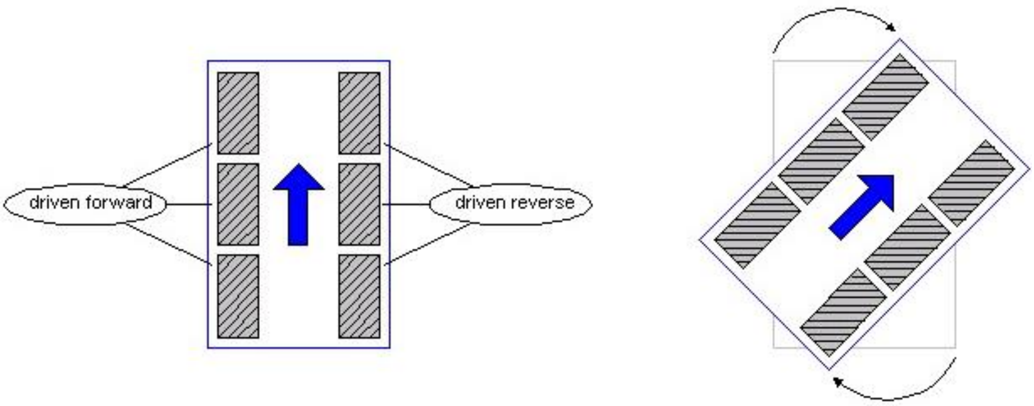

Figure 11: Skid Steering Turning Process

As seen in the above figure, the left set of tires are being driven forward while the right side are being driven in reverse. The result is a clockwise rotation of the vehicle which can be controlled to give it maneuverability. [5]

4.3 Multi-axle Steering Systems

Multi Axle Steering Systems are those systems in which the steering wheel is used to control more than one axle. Most of the commercially available vehicles use the single axle steering system in which only one axle is controlled by the steering wheel.

Multi Axle vehicles have the following advantages over single axle vehicles:

- The vehicle cornering behavior becomes more stable and controllable at high speed as well as on wet slippery road surfaces.
- The vehicle response to steering input becomes quicker and more precise throughout the vehicle enter speed range.
- The vehicles straight–line stability at high speed is improved. Negative effects of road irregularities and crosswinds on the vehicle’s stability are minimized.
- By steering the rear wheels in the direction opposite the front wheels at low speed, the vehicle’s turning circle is greatly reduced. Therefore, vehicle maneuvering on narrow roads and during parking become easier.

Multi Axle vehicles also have a few disadvantages:

- The 4ws, due to construction of many new components, the system becomes more expensive.

- The system includes as many components as possible (especially electronic) there is always a chance for any par to fail, thus the system become in operative.
- More components mean more weight of the vehicle.

Chapter 5: Driveline

There are 3 types of drive systems which are commonly used in vehicles

1. FWD
2. RWD
3. AWD

With all three terms, it refers to where the power of the car is distributed from. In other words, when you put your foot down on the pedal, which wheels do the engines turn. In front wheel and rear wheel drive, only one pair of wheels is powered. The others will obviously move, but only through the motion of the vehicle, rather than the engine powering them.

In simple terms. Front wheel drive is where the power is sent to the front two wheels. Rear wheel drive sends power to the back two wheels. And all-wheel drive distributes the power evenly between each wheel.

5.1 Advantages and Disadvantages:

- Forward-wheel drive can mean you spend less money on petrol. Because the engine and the drivetrain are both at the front of the vehicle, then you will get better traction than you might have when power has to be sent to the back of the car. You might also find that front-wheel drive cars have bigger boot space, as they don’t need the powerful drivetrain to take up space in the back of the car.

- The biggest advantage of rear-wheel drive vehicles is that you have better handling. In a front-wheel drive vehicle, the front wheels must power the car and steer the vehicle. This can have a negative affect when you take a corner, especially when you are going faster.

- An all-wheel drive vehicle is ideal for going off-road. Because power is sent to all four wheels, if one loses traction, then the other wheels should be able to compensate. But all-wheel drive cars tend to be heavier, as the drivetrain takes up more space, meaning you will burn more fuel.

5.2 Six Wheeled Drive (AWD)

Theoretically, there are three possible ways in which Six Wheel drive can be achieved.

5.2.1 Chain Sprocket Mechanism

This is employed by Argo industries to achieve a much smoother turn. A spring element is added between the handlebars and brake systems to achieve a progressive, dual rate steering system.

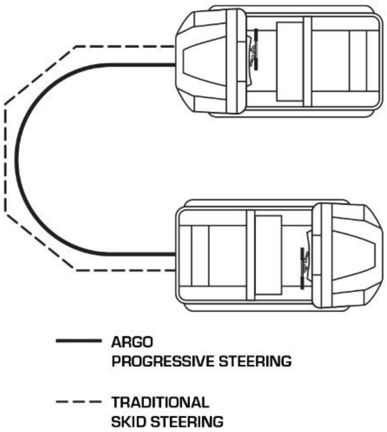

Figure 12: Skid Steering Comparison

As shown by the comparison above, in traditional skid steering, the vehicle has to be turned every few degrees after a certain short travel distance to achieve a complete 180-degree rotation.

A much more detailed mechanism is shown below

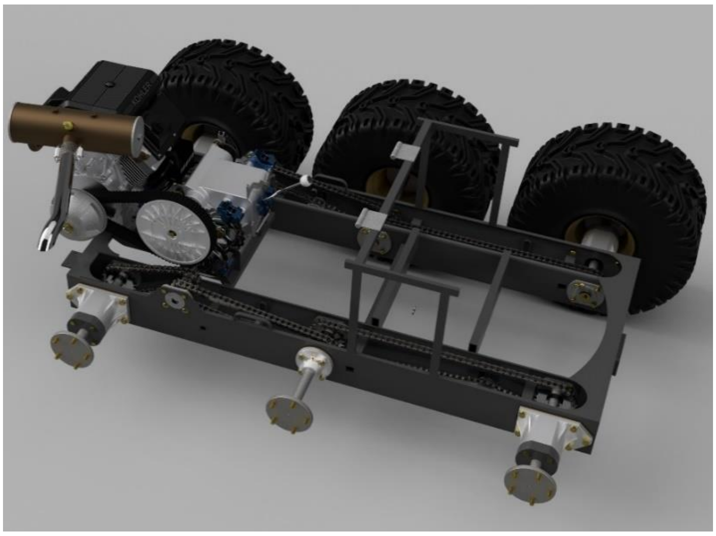

Figure 13: Argo Driveline

It can be seen that the vehicle has a dual output shaft engine where the vehicle can be controlled with handlebars in addition to skid steering. Both sides of the output shaft are connected to the rear two axled via a chain- sprocket assembly allowing all three axles to be "live axles". A live axle means that all the wheels or the axles are being driven directly off the engine power. [6]

A closer view is shown below in figure 14,

Figure 14: Chain Sprocket Mechanism of Argo

A similar type of design has been used in our ATV to achieve 6- wheel drive. It can be seen in the figure below that main drive is linked from the engine to the first axle through two sprockets located on top of each other. This is then linked to the center and last axles through a similar chain and sprocket.

Figure 15: Chain Sprocket Mechanism

5.2.2 Using Multiple Differential Locks

The primary type of differentials used in this type of are the Locked Differentials. This type of differential is primarily designed for off-road vehicles. It is essentially an open differential with the added benefit of getting locked in place essentially creating a fixed axle. These types of differentials allow much greater traction than conventional differentials. This is because the torque is not split equally between the left and right wheels and hence more torque can be channeled to the wheel that has better traction. [7]

A considerable disadvantage of locking differential is called "binding". It is caused when excessive torque builds up and needs to be released. This is done by wheels leaving the ground to achieve a "reset position" or by simply releasing the locks once they are not needed.

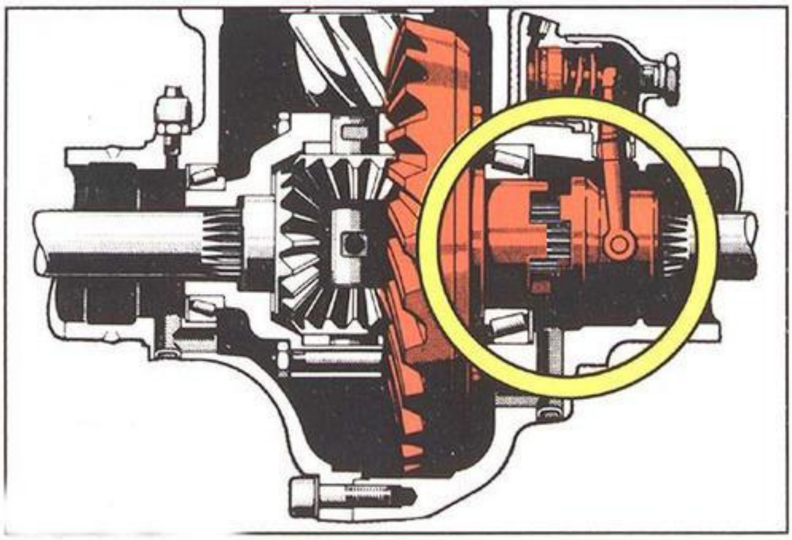

Figure 16: A manual locking differential

In differential type steering, the engine power is transmitted through a single output shaft and then to the wheels through the use of differentials (locking type usually). An intermediate shaft is also present between the second and third axle which transmits power to the third axle and then to the respective wheels through their own differential.

5.2.3 Planetary Gear Steering System

In planetary gear system, the input from the engine is transmitted to the shaft through a bevel gearing. The tracks are connected to the shaft by the planetary gears. The vehicle is steered by disengaging the clutch and then the brakes are applied to the ring gear. However much more power is required to turn a vehicle in this type of system than the other two. [8]

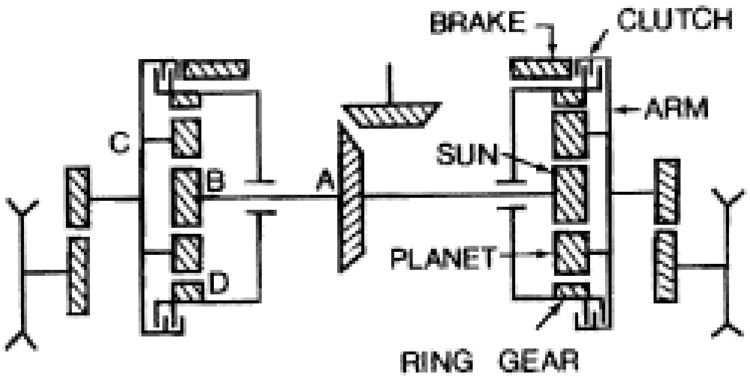

Figure 17: Planetary Gear Steering System

Chapter 6: Terrain

A part/piece of ground having specific characteristics is called terrain. These characteristics may include roughness, smooth path, soft surface, rocky path or steeply surface, icy path, etc. These characteristics affect the vehicle's motion its suspension, and traction of the wheels. The details of these effects and different types of terrains are discussed below.

6.1 Rough Terrain

An uneven surface is called rough terrain. You need large traction in order to move the vehicle and for the stability of the vehicle as well. It is very difficult to keep the car stable on rough terrain.


,

Figure 18: Rough Terrain [9]

Effects are discussed in detail below.

6.2 Effects of rough terrain

This terrain not only affects the motion of a vehicle but also causes damage to the internal and external parts of the vehicle such as the suspension and alignment.

6.2.1 Suspension

The main role of the suspension in the vehicle is to keep the vehicle balanced and support the body. When a vehicle moves on rough terrain wear occurs in the suspension system. It can affect the shock absorbers which will result in an uncomfortable ride. Rough terrains affect the suspension in such a way that the vehicle will start bouncing more and will be hard to steer even at low speed.

6.2.2 Alignment

The bad/rough road does not affect only the suspension but also the alignment of the vehicle. when the vehicle will be having bad alignment, it will be very hard to steer the vehicle, handling is compromised, and brakes may not work right which increases the risk of an accident

6.2.3 Tyres

When a vehicle moves on rough terrain tyres are the first thing to get affected because they are in direct contact with the rough surface which increases the wear of the tyres and decreases the lifespan of the tyres. There is a possibility of one tyre getting more wear than the other which increases the chances of a flat tyre or a blowout. [10]

6.3 Soft Terrain

soft terrain includes the muddy or watery terrain on which the vehicle tires get stuck or slip while moving.

Figure 19: Soft Terrain [11]

6.3.1 Effects of soft terrain

These soft terrains make it very difficult for the vehicle to move. Tyres get stuck in the surface, and it becomes very hard to steer, tyres slip off the road. The grip of the wheels decreases which causes the slipping. The vehicle can end up covered with mud that dries out and cakes on vehicles paint, they can rut, or washout can also occur. Large traction is needed in order to move the vehicle on soft terrain. Vehicle skidding is the biggest problem in driving the vehicle through muddy areas. In modern vehicles, there is automatic traction control. So when passing through such an area engaging that may help prevent the vehicle to skid.

6.4 Icy Terrain

Skidding is the biggest problem on the icy terrain. When the vehicle moves on the slippery icy surface, it losses its traction very quickly and the vehicle start skidding and increasing the risk of accidents. Also, when a vehicle moves on such terrain it becomes very hard to steer the vehicle. Manoeuvring becomes very hard while driving on such terrain. Tyres with good treads help a lot in the traction of the wheels which creates more grip on the icy terrains and helps the vehicle to move easily and without skidding and without causing steering problems.

Icy terrains may include roads totally covered with ice.

Figure 20: Icy Terrain [12]

The wet roads after ice melts also create a lot of problems in steering the vehicle. Same problems occur same as the icy surface with a little more of skidding and slipping of the vehicle. Again. traction decreases on the icy surface which creates problem with the wheels.

Figure 21: Wet Icy Terrain [13]

6.5 Rocky Terrain

Rocky terrain is a terrain covered with rocks and has nothing growing on it. It is extremely rough terrain and has a lot of negative effects on the vehicle. It effects the wheels causing wear in the tyre, tyre tread and decreases the lifespan of the tyres. These types of terrain also create problems like vehicle alignment. Vehicle alignment further creates problem in steering the vehicle. Suspension of the vehicle is affected a lot. Rocky terrains affect the leaf springs and shock absorbers which causes very uncomfortable ride. In order to move on rocky terrain traction of wheels, and better suspension is needed. Rough terrains affect the suspension in such a way that the vehicle will start bouncing more and will be hard to steer even at low speed.

Figure 22: Rocky Terrain [14]

All-terrain vehicle is an offroad vehicle which can move on any terrain mentioned above with very minimum effects of the terrains on the suspension, tyres and other vehicle parts. Since wheels used in an ATV are large traction wheels and better suspension with power delivered to every trye makes the vehicle move more smoothly than any other vehicle on these terrains.

Chapter 7: Tracks vs Tires

In deciding whether to use tires or tracks, we must keep in mind the following factors because the greatest use of a six wheeled ATV is its ability to incorporate tracks.

7.1 Mobility

Mobility is the ability to move quickly and freely on a terrain of to perform different objectives. It is also defined as the freedom of a system to move. We have to consider the mobility factor in our design. The two important factors that affects the mobility are

- Weight of ATV
- Area of the tread

A quantity called Vehicle Core Index VCI is determined by the soil strength and the vehicles ground pressure. Lower VCI means better soft soil mobility, better performance on slopes and sandy terrains. Tracks and wheels have their own pros and cons. Since track vehicles have large contact area with ground so they provide better mobility over diverse terrains. On the other hand, wheels provide faster road speeds and better mobility when terrain is not rough.

7.2 Survivability

while solving the wheel-track dilemma survivability is one of the Key factors to be discussed. Since tracked vehicles are more compact than wheeled vehicles and the main reason of this compactness is reduced clearance in the suspension which makes the tracked vehicle to survive in the combat ground. Whereas in wheeled vehicles wheels gets vulnerable to small arms fire, grenades, artillery shell fragments and the land mines. While wheeled platform vehicles are less noisy and can be used to carry out secret missions or for surveillance purposes or to spy on enemies in combat fields. But the tracked vehicles are noisy.

7.3 Fuel economy

Tracks are heavy weight because of the metallic components they are made of which increases the mass of the vehicle. So, to drive a heavy vehicle more power is needed and hence more fuel is required. Whereas wheel platform vehicles consume less fuel because of less weight and hence are economical.

7.4 Operating cost and support

Track vehicles are heavy, so their operating cost is more. Where wheeled vehicles are gives better operating cost and support. So wheeled vehicle is better option.

7.5 Payload

Since tracked vehicles have high surface area which makes tracked vehicles to bear high payload.

7.6 Weight growth potential

Tracked vehicles have benefits because of its high surface area to the ground. We can also achieve good mobility if the tiers of the ATV are increased so instead of four tiers if six tiers are used. This will also increase the payload factor. Increasing the number of tires will also improve the movement of the ATV on softer terrains.

Chapter 8: Roll- Cage

Roll cage is actually a frame constructed over head of the driver's compartment in order to prevent the driver and passenger from injuries in case of accident. It is a single bar behind the driver that to provide rollover protection. There are two purposes of the roll cage one is protecting the drive-in case of rolling of the vehicle and the other use is that it decreases the weight of the vehicle since it is adding more support to the car more of the interior can be removed. Roll cages stiffens the chassis and provide more strength to the vehicle body.

Figure 23: At typical Roll Cage fitted inside a vehicle

A roll cage keeps the driver's cockpit intact in the event of a wreck. Roll cages are either bolt in or welded in. Bolt in roll cages is easier to fit and cheaper but welded in roll cages are stronger than bolt in roll cages. Roll cage is made from high tensile steel, and it is flexible enough to dissipate the impact energy away from the driver and rigid enough to withstand the impact. In off-road vehicles roll bars are very important as the terrains are rough and slippery so there is a high risk of vehicle rolling over. Off-road racing vehicles have to have roll cages because vehicles taking sharp turn at high speed also have a large risk to roll over so roll cage must be there for the protection and safety of the driver in a car wreck. Roll cage saves the driver and passengers from crushing during an accident.

Chapter 9: Tires

Tires are a major component in the vehicle that governs the behaviour of the vehicle. They offer a connect ion between the chassis of the vehicle and the road or the terrain on which the vehicle is moving. The tires transmit several forces on the terrain that are majorly referred as vertical, lateral and longitudinal forces. For the prediction of the vehicle behaviour, it is important to study the characteristics and features of tires and their effect on driving and terrain. In order to study the behaviour of tires with respect to the behaviour, it is important to study the tire models as it is not feasible to build physical models or prototypes as it is costly and requires a lot of time and energy.

A tire model is a kind of multibody Simulation used to simulate and predict the working pattern of a tire. There are numerous tire models which are used to study according to the required working conditions. Tire models can be categorized based on their accuracy and complexity. These models range from Empirical modes e.g Paceika's Magic Formula to physically based models like brush models.

It is important to gain a knowledge of the basic nomenclature of the tire axis system. The tire axis system shows the forces and moments acting on the tires as a result of movement.

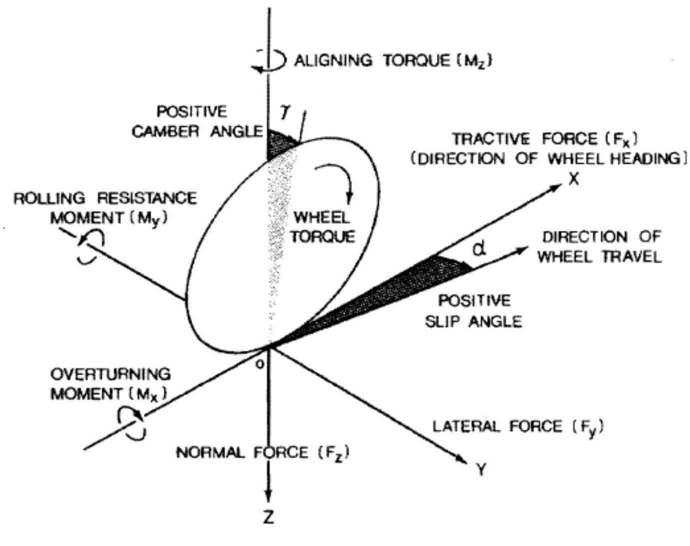

Figure 24: Tire Axis system

Normal force acts in a direction vertical to the tire whereas the longitudinal force acts in the direction of motion. Lateral force acts in the y direction, perpendicular to the tire.

Rolling resistance moment acts on the tire by the road in the road plane and normal to the intersection of road plane and wheel plane whereas Overturning moment is acted upon by the road in the plane of the road and parallel to the intersection of road plane and wheel plane.

It is to be noted that all the forces on the tire are not applied to a point but are resulted due to the normal and shear stresses in the contact patch. The pressure distribution is also not constant in the contact patch; It is higher in the forward region of the contact patch. Other than these forces, the acceleration and braking cause a slip between the tires and the road.

Slip is given by the formula:

$$Slip\ (\%) = \left(1 - \frac{r\omega}{V}\right) 100 \text{ CITATION Sch11 \\l 2057 } [2]$$

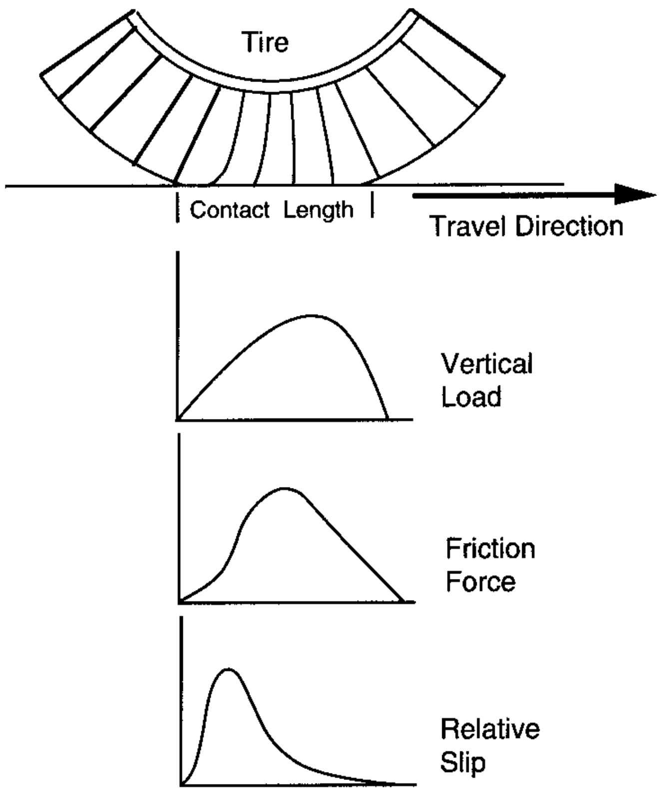

Figure 25: Tire Deformation [15]

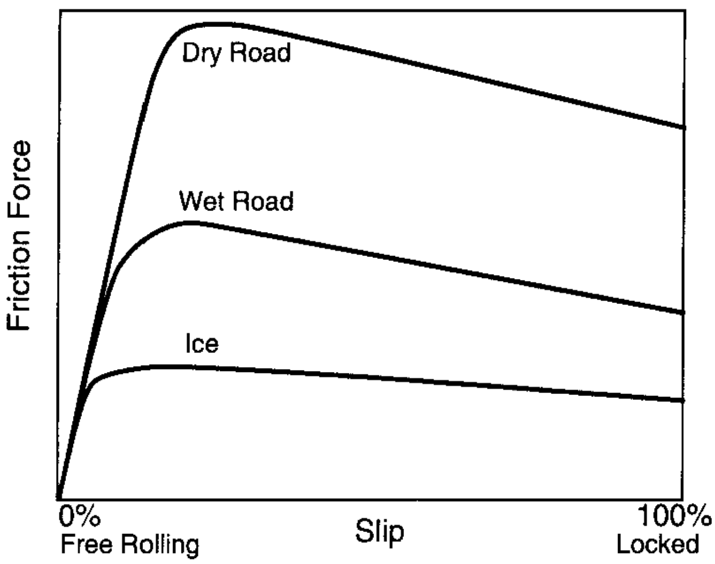

Figure 26: Friction force vs Slip [15]

The tires that we have selected keeping in view the above parameters are, 135 X 10 Radial Tires. These are commonly referred to as 10 inches tyres. Additional tires means that there will be additional slip between the tires and the road. These slip angles are to be taken in account while steering design. Steering is discussed in this paper that how to tackle this challenge to provide a steer to the 6 wheeled vehicle.

9.1 Tire Forces and Torque

The most elaborative tire forces and torques according to the coordinated frames and sign conventions are studied or obtained from Pacejka [16]

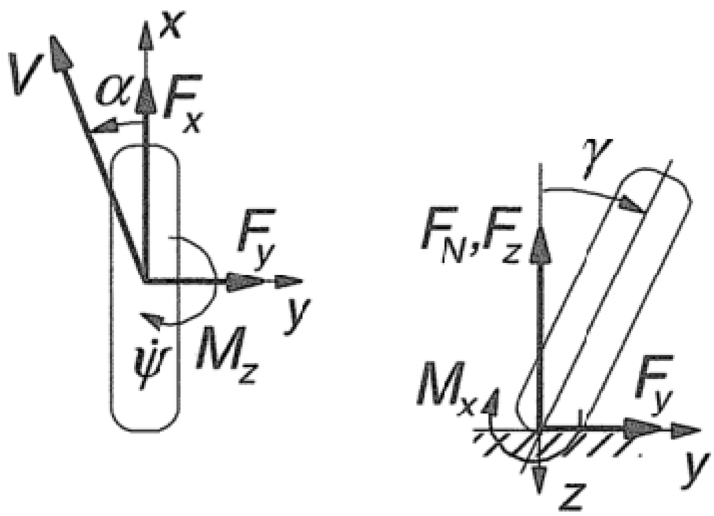

Figure 27: Reference frame

The Symbols used in this figure are as follows [16],

V	Speed of travel of wheel centre
α	Side slip angle
Υ	Camber Angle
Ψ	Yaw rate
F_x	Longitudinal force
F_y	Lateral force
F_z	Normal Force
M_z	Self-aligning torque

Table 2: Vehicle Nomenclature

All these forces are to be taken in account when studying the behaviour and manoeuvrability of the vehicle. All these forces act differently on different terrains at different speeds. We have seen that as soon as the vehicle starts to turn, the tangential velocity and the direction of vehicle changes. This gives the changes in slip angles. To study their behaviours different tire models are used.

9.2 Types of Tires based on construction

There are numerous types of tires that are used in different vehicles according to their usage. They can be differentiated based on their construction or usage. Selecting the right type of tire is important. There are many standards and rating of tires that help the OEM to decide the best suitable tire for the vehicle. [17]

9.2.1 Radial Tires

Radial tires are made up of a series of steel cords, that extend from the beads, across the treads such that the cords are at right angles to the centre line of tread and are parallel to each other. This type of construction gives strength and shape to the tires. As the tire is made up of all steel radial construction, it gives it more flexibility which results in less rolling resistance, lower fuel consumption and greater grip and ride comfort.

The Disadvantages of radial tires are that they provide hard ride at low speeds on a rough terrain while off-roading.

Figure 28: Radial Tires

9.2.2 Bias Tires

The construction of bias tires includes layers of rubber-coated, plies of fabric, nylon in most cases, placed at angles varying from 30-40 degrees with opposite plies in opposing angles in a crisscross configuration. This type of tire provides better drive on rough surfaces and can sustain higher loads

The drawbacks are that these have lower grip at high speeds and are subject to overheating which causes wear and increases the fuel consumption.

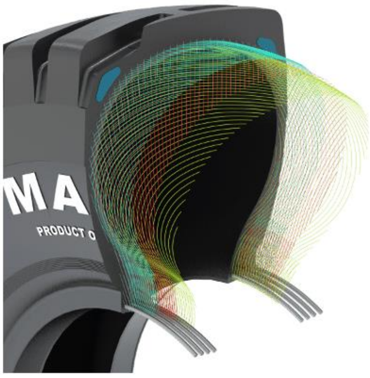

Figure 29: Bias Tires

9.2.3 Solid Tires

Solids tyres are non-pneumatic which means that they are not filled with air. These types of tires do not have a hollow core. They are used for heavy duty vehicles such as trucks, folk lifters and numerous industrial vehicles as well. These tires are very much resistant to punctures and can provide a very stable drive. They can sustain higher weight load without any threat of blowouts or bursts. They are designed for slow moving vehicles that are required to lift heavy loads. They are not very common in conventional daily transport vehicles.

Figure 30: Solid tire

9.3 Types of tires based on Usage and Performance

9.3.1 All Season Tires

All-season tires are known for their soft and flexible material. As the name suggests, these tires are designed to work in all type of weather.

9.3.2 All Terrain Tires

These tires can be used on and off the road. They are not used for comfort and offer a hard ride so that they can be used in diverse types of terrain

9.3.3 Mud Terrain Tires

Mud tires are used specifically for muddy terrains as normal tires cannot provide the required traction and keep on slipping in muddy areas.

9.3.4 High Performance Tires

These are intended for high performance race cars. They provide better grip and road handling.

9.3.5 Winter Tires

These tires are built for snow and icy terrains and are used in extreme winter conditions.

Chapter 10: Brakes

Brakes are an energy-absorbing mechanism that converts vehicle movement into heat while stopping the rotation of the wheels. Brakes are designed to reduce the speed and stop a moving vehicle and to keep it from moving if the vehicle is stationary. Equal forces must be applied to both the left and right sides of the vehicle to assure straight stops. There are different types of braking systems which include automatic braking system.

10.1 Types of brakes

There are different types of brakes which include drum brakes and disc brakes.

10.1.1 Drum brakes

When drum brakes are applied, brake shoes are moved outward against a rotating brake drum. The wheel studs for the wheels are attached to the drum. When the drum slows and stops, the wheels also slow and stop. Drum brakes are usually used on the rear of many vehicles.

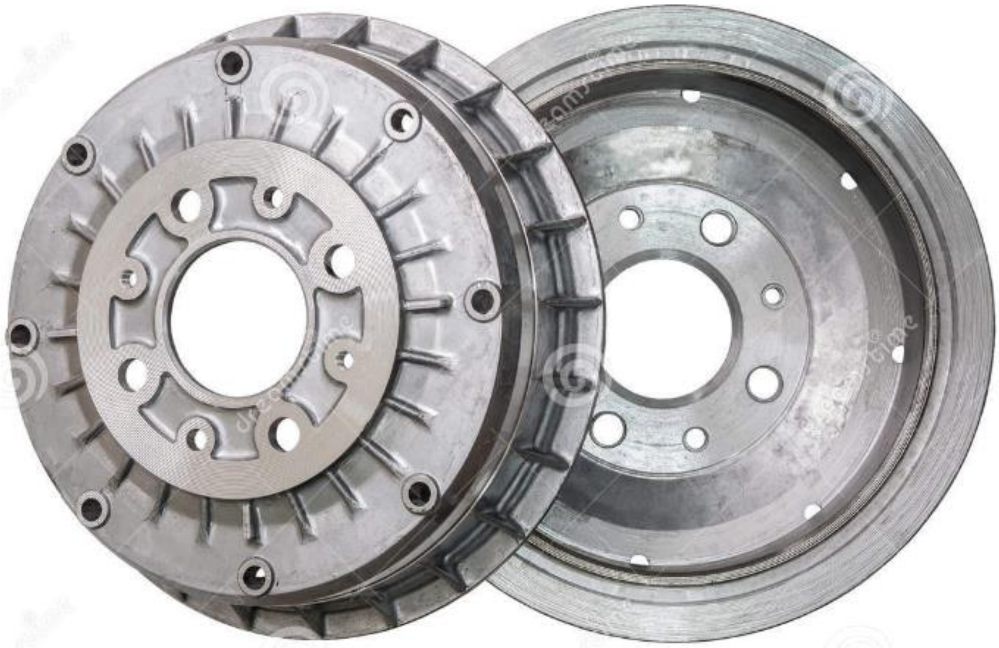

Figure 31: Drum Brakes[18]

One advantage of drum brakes is that they make excellent parking brakes. A simple linkage fitted to the brake assembly allows relatively low effort from the driver to hold a heavy vehicle in place when parked. Drum brakes can apply more stopping power for a given amount of force applied to the brake pedal than can disc brakes. This is possible because the drum brake design offers a self-energizing action that helps force the brake linings tightly against the drum. Some drum brake designs use servo action that enables one brake shoe to help apply the other for increased stopping power.

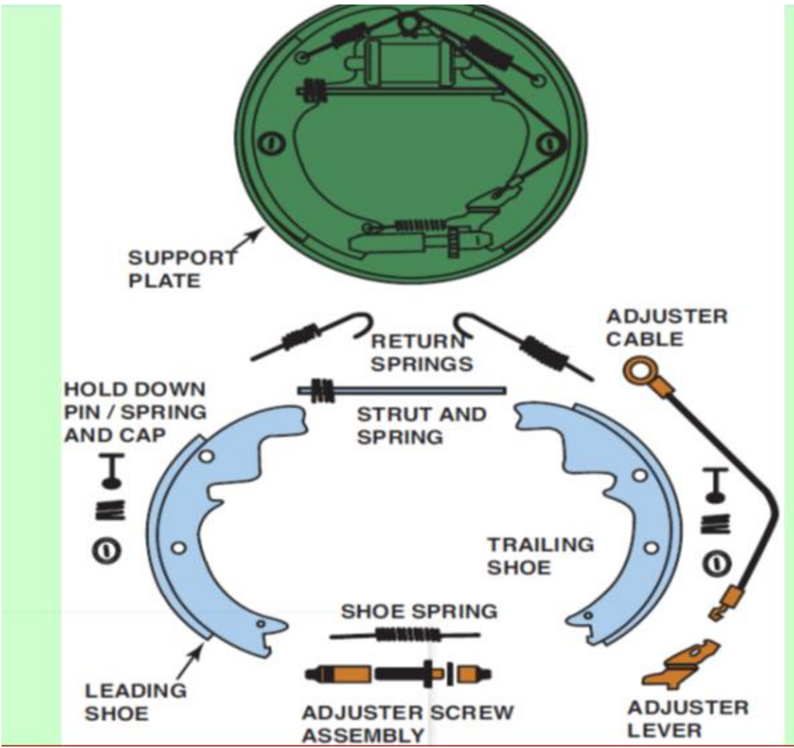

Figure 32: Components of drum brakes

10.1.2 Disc Brakes

Disc brake operates by squeezing brake pads on both sides of a rotor or disc that is attached to the wheel.it uses calipers to squeeze pads against a disc to create friction which slows the rotation of a shaft to reduce the rotational speed of the wheel.

Figure 33: Disk Brakes[19]

10.1.3 Antilock braking system

Antilock braking systems (ABS) help prevent the wheels from locking during sudden braking, especially on slippery surfaces. This helps the driver to maintain control. It increases safety because they eliminate lockup and minimize the danger of skidding, allowing the vehicle to stop in a straight line. It also allows the driver to maintain steering control during heavy braking so the vehicle can be steered to avoid an obstacle or another vehicle. It can improve braking when road conditions are less than ideal, as when making a sudden panic stop or when braking on a wet or slick road. ABS does this by monitoring the relative speed of the wheels to one another. It uses this information to modulate brake pressure as needed to control slippage and maintain traction when the brakes are applied.

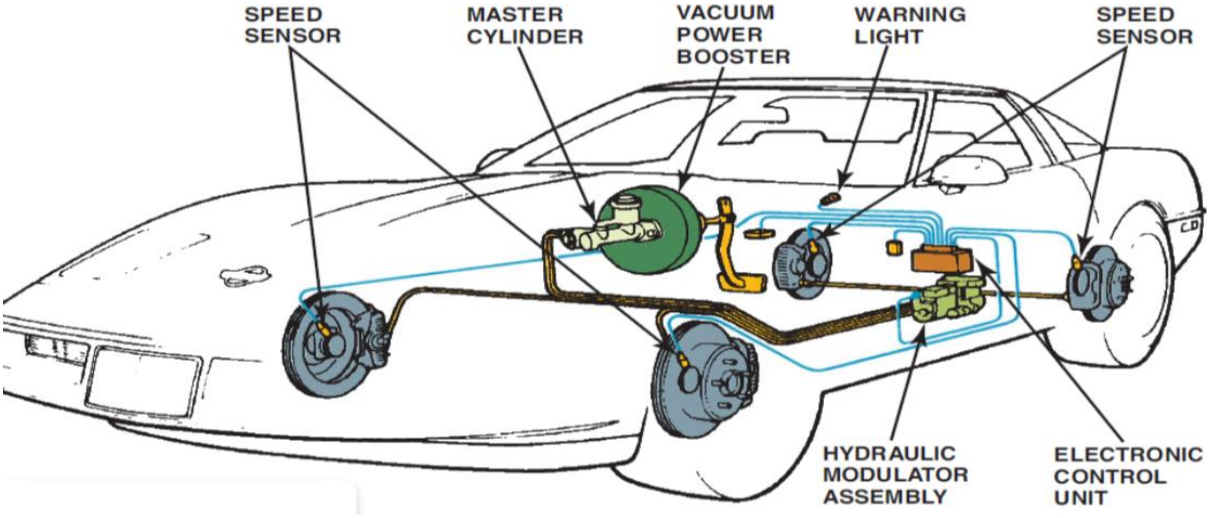

Figure 34: Brake System of a Vehicle

Chapter 11: Fabrication and Achievements

Six-Wheeled ATV basically serves for the purpose of off-road accessibility. In order to design and fabricate a Six-wheeled ATV, we would require a detailed research and study of different models as mentioned above. The first and foremost task is to develop a template of the ATV so that it can be used to test our assumptions and any modifications required.

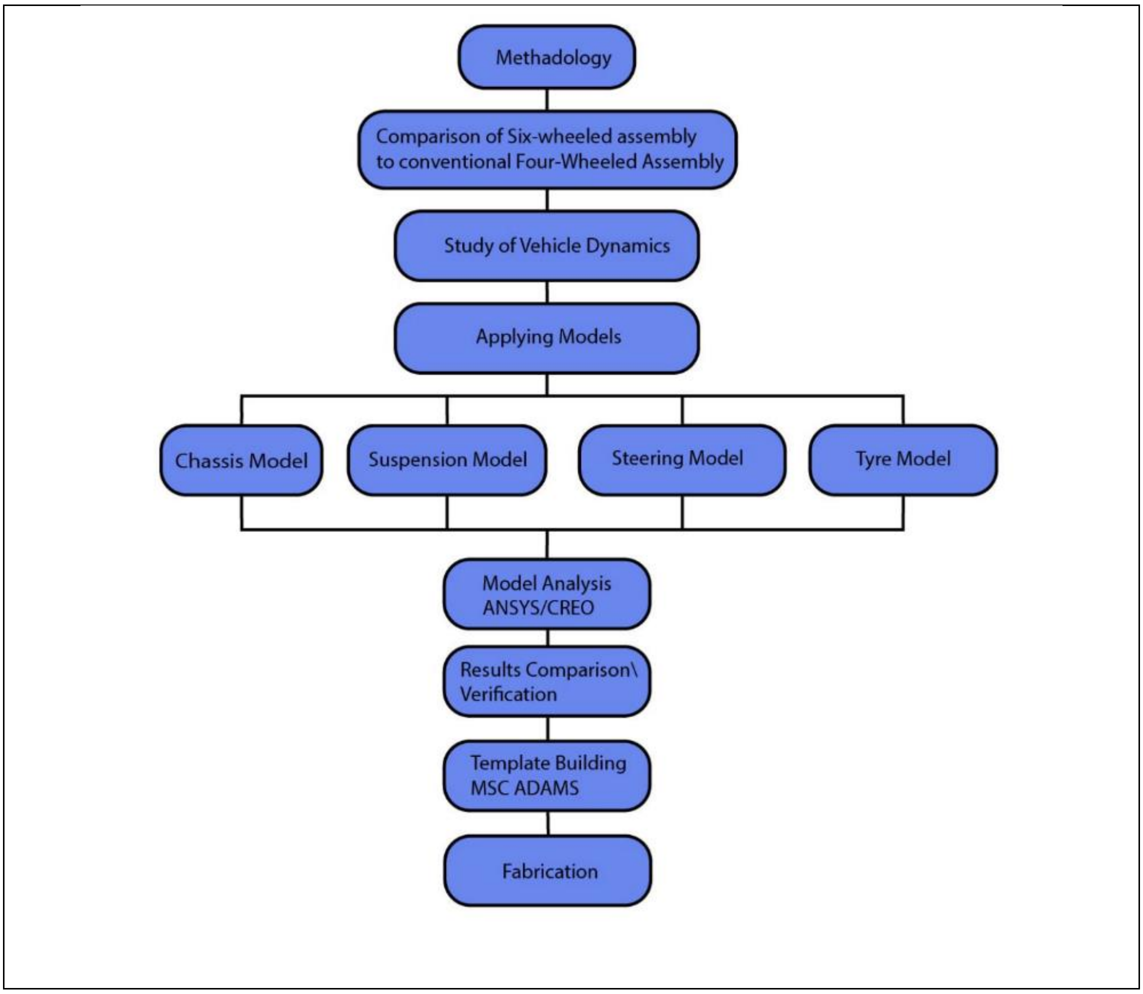

Table 3: Decision Making

11.1 Engine Selection

Internal Combustion (IC) Engine is one of the most fundamental components of the ATV. It can be referred to as the heart of the vehicle. It is used to convert chemical energy from the burning fuel to mechanical energy to drive ATV. As the ATV has been designed to work on AWD i.e., a 6x6 drive, it is very important to study the characteristics of the engine to have a working and sustainable design. The engine that we have selected is 125cc, Air cooled, Automatic Clutch with 4 Gears (3 forward and 1 reverse). This engine is widely used in ATVs and Quad bikes due to its compact size and adequate power and torque that makes it one of the most feasible designs.

The Engine specifications are as follows: [20]

SPECIFICATIONS	
Displacement	125cc
Horsepower	8.33
Type	Horizontal, single-cylinder, 4-stroke, air-cooled
Compression ratio	9: 1
Front sprocket	420 - 17mm - 14T
Transmission	4-speed 3 forward 1 reverse gear
Bore x Stroke	2.06" x 2.19”, (52.4mm x 55.5mm)
Top Engine Mount	92mm
Bottom Engine Mount	82mm
Bolt to Bolt	152mm (6")
Rated Power & Rotating Speed	5.8 kw/7500r/min±375 r/min
Max. Torque & Rotating Speed	8.5 Nm. / 5000r/ min±250 r/min
Idle speed	1500 r/min±100r/min
Ignition	CDI
Displacement Volume V_d	1.25 m^3

Clearance Volume V_c	0.156 m^3

Table 4: Engine Parameters

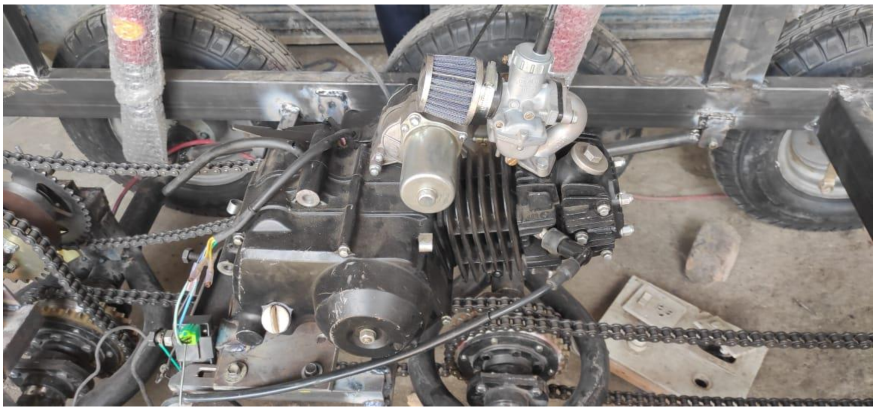

Figure 35: 125 cc Engine

The Engine gives drive to the rear axle which is connected to a sprocket and a damper. The rear axle provides torque to the rear differential which transmits it to the rear wheels. The torque is then transmitted to the next axle i.e., the middle axle and torque is transmitted to the middle axle wheels through a differential on the axle. Similarly using the same mechanism, the torque is transmitted to the front axle and to the front wheels via a differential. In this way the engine supplies the torque to all the wheels making it an AWD vehicle. All this torque is transmitted via chains connecting all the three axles.

11.2 Transmission

The power generated by the engine is transmitted to the driving wheels by a series of mechanism commonly known as transmission system. It consists various components such as clutch, gear box, propeller shafts, transfer box and axles but mainly the clutch and the gear box are referred to as the transmission system. Transmission system can be defined as a mechanical device which varies the engine torque according to the Driver’s requirement. It enables the gear ratio between the drive wheels and engine to adjust the car speed from slowing down and speeding up. This main purpose is served by the gear box which is defined as the mechanical device which provides the variation in the torque produced, as per our requirement.

There are mainly 2 types of transmissions

Manual Transmission:

Manual transmission consists of a clutch pedal and a gear shifter. It consists of a set of gears along with input and output shafts. It consists of a flywheel along with a pressure plate and a clutch which enables the driver to shift the gears which are mentioned on the shift lever. This transmission is better for offroad and high torque load usage, reliable and easier to service and maintain. The cons include that not everyone can drive and requires a higher learning curve.

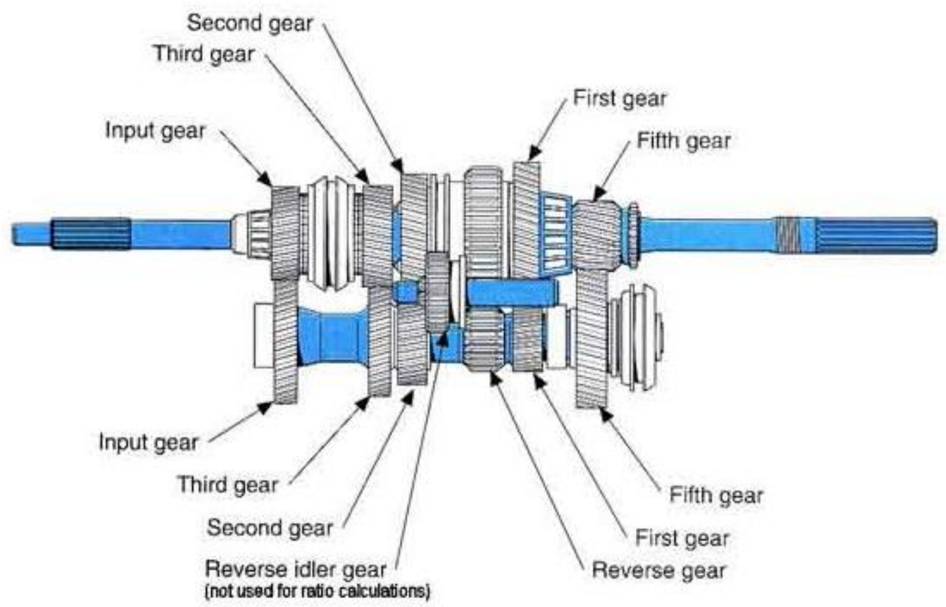

Figure 36: Manual Transmission[21]

Automatic Transmission:

Automatic transmissions usually do not have a clutch pedal like the one used in manual transmission. Conventional automatic transmissions use planetary gears to shift the gears according to the engine speed. It uses a torque converter that acts as a fluid coupling that is used to transfer the rotating power from the engine to the transmission. It is used as a substitute of clutch in automatic transmission.

It requires less driver input. Most of the cars are using automatic transmission all over US and Europe. It is a lot easier to operate and can be operated by almost everyone. It has less fuel efficiency as compared to manual transmission but there is not much difference.

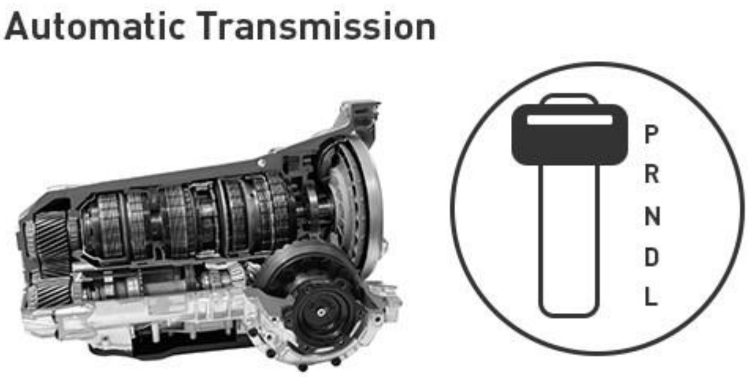

Figure 37: Automatic Transmission[22]

11.2.1 Selection

We have used a 125cc automatic, air-cooled engine in our ATV. In an automatic transmission, the driver simply selects D on the shifter and the car does all hard work. Using fluid pressure, the vehicle automatically completes gear changes on its own. The heart of the automatic transmission is the planetary gear set. This part is responsible for creating the different gear ratios that the transmission uses. [23]

Providing the pressure necessary to activate the bands and clutches that determines what gear the vehicle should be in is automatic transmission fluid. This fluid not cools and lubricates the moving parts of the transmission but it helps drive the vehicle. [23]

11.3 Driver Seat

A driver seat is an inseparable part of an automobile. It not only provides a seating space, but also support, protect, and provide comfortable seating postures to the occupants. It is a complex system as it has to provide comfort as well as ensure health and safety of the driver. It consists of seat adjustments such as height, back recline, fore and aft adjustments etc. It also has to account for the uneven road conditions which induce vibrations in the vehicle. The safety systems may consist of seat belts, air bags and advanced head restraints. If the seat is designed poorly, it can affect the health and psychological conditions of the driver, who at times have to be on the road for more than 8 hours per day in rough terrains. Therefore, it is essential to carefully design the driver by considering all the parameters. [24]

11.3.1 Major Components of Seat

Main components of a driver's seat are seat frame, anchorage, seat cushion/padding, seat back, seat adjustments, reclining mechanism with lever, head restraints system, seat cover/trim, and suspension springs. A cut section of driver seat components and systems is shown ahead. [24]

Figure 38: Modern Vehicle Seat [1]

11.3.2 Design Considerations

For the comfort and health of the driver, a good seat should be designed in accordance with the sitting postures. Static and dynamic data is analyzed for proper design of a safe and comfortable seat. Certain factors are considered during seat design, [25] such as:

- The seat must accommodate the driver's shape and size.
- The seat should position the driver within reach of all controls without any obstruction in the vision of the driver.
- The seat should be comfortable for an extended period.

- Safety should be taken into account while designing the seat without compromising on the comfort
- The seat should not cause postural stress, vibration, muscular effort, impact and shock which leads to backache and lower back pain.

11.3.4 Seat Location

This question is often asked that why do driver's seat not in the middle but on the side. Well, the real reason is that in the early days of car manufacturing, the steering column was a straight shaft connecting the steering wheel to the front axle. So, because the engine was in the middle between the frame rails, the steering column had to be to the side.

Middle seating is not the best solution for streets, but to get the best weight distribution and race feel, it is an essential position for the driver. Normally, you would see such a seating layout only in a dedicated racecar. But for the normal, legal roadway, it is a poor decision to have the seat in the middle because of visibility and safety.

Positioning the driver on the side near the middle of the road helps the driver to see further forward around bends. For a bend that curves to the same side that the car is driving on, the driver is away from the inside of the bend, so can see much further around it.

There are multiple cars with the driver's seat in the middle. The most famous is the McLaren F1. Others include McLaren 720S, 2020 McLaren Speedtail, Ferrari 365 P Berlinetta Speciales, Porsche 911 etc.

In our ATV, we have placed the driver seat in the front-center of the vehicle because of its compact size and shape. The seat in the middle will make it easier to handle the steering and braking system of the vehicle along with monitoring the gauge panel or the dashboard.

11.4 Brakes Selection

We are using drum brakes in the vehicle. Each tire is having individual brake in order turn the vehicle as we are using skid steering. In order to turn left all the brakes on the left three tires are applied and right three tires will keep moving. To turn right all the three brakes on the right tires will be applied and left tires will keep moving. We have used drum brakes because they can apply more stopping power for a given amount of force applied to the brake pedal than can disc brakes and they are self-energizing. Also, some drum brake designs use servo action that enables one brake shoe to help apply the other for increased stopping power.

Figure 39: Mechanical Drum Brakes

11.5 Tire Selection

Keeping in view the above types and criteria, the tire we have selected is, 135 X 10 tire which means that it has a tire radius of 10 inches and width of 135 mm. We have selected this tire for 2 reasons

First is that it is a heavy-duty tire with a good reliable tread pattern. It is a bias tire with a ply rating of 10. It can serve a good purpose for all types of terrain of ATV. As there are 6 wheels, it provides an increased number of contact patches and traction due to which these tires can be used effectively. These can also be used on low pressure

Second reason is the market availability and economy. ATV offroad tires have more width but are very expensive. We can use these tires instead which does not compromise a lot on the performance but reduces the price by more than half of the percentage.

Figure 40: Tires Selected

11.6 Suspension Selection

For our ATV, we decided not use any suspension system. Instead, we decided to use non-pneumatic or low-pressure tires after studying different tire models. With good enough ground clearance, these tires will provide enough dampening for rough terrains without requiring any suspension system.

To protect our vehicle from wear and tear and structural damage, we decided to only equip our ATV with shock absorbers used in CD70/Jh70 motorcycle.

All six shock absorbers are made of steel and aluminum, with a total length of 430 mm. The spring has a thickness of 7mm. They have a working capacity of 300kgs/pair and weight of 3.8 kg. [26]

Figure 41: Shock absorber of ATV

11.7 Steering Selection

We have tried to achieve skid steering for the following reasons

- Skid steering can be compact, light, require few parts, and exhibit agility from point turning to line driving using only the motions, components, and swept volume needed for straight driving.
- For skid steering the motion of the wheels is limited to rotation about one axis. Therefore, a centralized drive can pass the drive torques directly to each wheel. For

explicit steering since the wheels move about two axes the torque transmission is more difficult. If a centralized drive is used the torque must pass through universal joints and drive shafts which have inefficiencies.

- Skid steering is more beneficial for vehicles having more than 2 axles as the ackerman steering geometry becomes very complex
- Skid steering allows the vehicle to undergo small radius turns and rotate in less space which is advantageous
- It has major advantages on offroad terrains as compared to plane roads
- It can be operated without using a differential.

11.7.1 Kinematic Analysis:

The kinematic analysis of skid steering allows a preliminary determination of wheel velocities given the vehicle dimensions, the desired radius, and the desired turn rate. However, as in the previous kinematic models, no forces are studied.

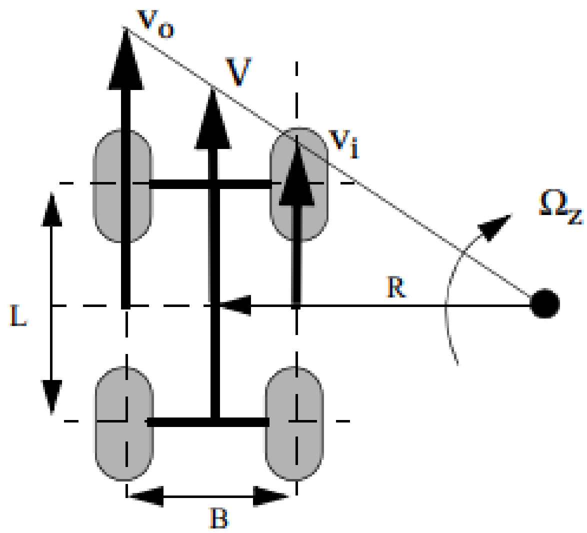

Figure 42: Kinematic Diagram

v_o	Outside wheel velocity
Vi	Inside wheel velocity
V	Vehicle velocity
Ω_z	Angular Velocity
R	Vehicle turn Radius
L	Wheelbase
B	Track Base

Table 5:Nomenclature

The radius of the turn can be calculated from similar triangles.

$$\frac{v_o}{v_i} = \frac{R + B/2}{R - B/2}$$

$$R = \frac{\frac{B}{2\left(\frac{v_o}{v_i} + I\right)}}{\frac{v_o}{v_i} - I} = \frac{B}{2}\left(\frac{v_o + v_i}{v_o - v_i}\right)$$

However, this radius will only be achieved if no slippage occurs between the wheel and the soil. To account for the slippage of the outer wheels, i_o and the inner wheels,

$$R' = \frac{B}{2}\left(\frac{v_o(I - i_o) + v_i(I - i_o)}{v_o(I - i_o) - v_i(I - i_o)}\right)$$

The turn rate or yaw velocity can be found from the following:

$$\Omega_z = \frac{v_o + v_i}{2R} = \frac{v_i\left(\frac{v_o}{v_i} - I\right)}{B}$$

Again, in order to account for the slippage:

$$\Omega_z' = \frac{v_o(I - i_o) + v_i(I - i_i)}{2R'} = \frac{v_i\left(\frac{v_o(I - i_o)}{v_i} - (I - i_i)\right)}{B}$$

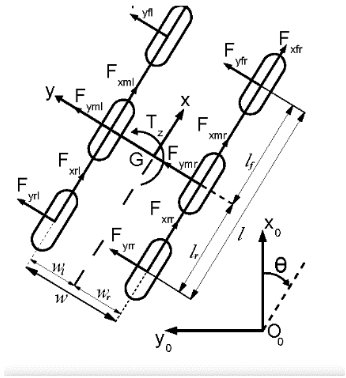

Figure 43: Lateral and Longitudinal forces on Six Wheels

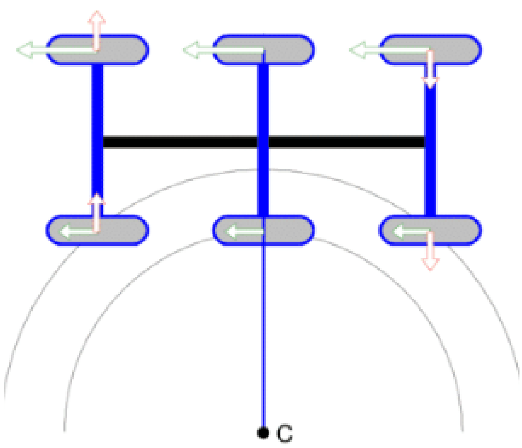

Figure 44: Center of Rotation of Six Wheel

11.8 Physical Parameters

While off-roading it is crucial to know the vehicles capabilities and to read the terrain according to the vehicle specifications. Parameters like angle of approach, departure and breakover angle are important. These angles are different from ground clearance which is also very essential for an off-road vehicle. These angles are to be calculated after selecting the ground clearance for the vehicle. We have designed the vehicle by studying angles for other offroad vehicles.

11.8.1 Angle of Approach:

Angle of approach is the steepest angle between the vehicle and the terrain that the vehicle can climb or transverse. In simple words, this angle defines how much height the vehicle can climb without its front bumper hitting the obstacle. It is the angle between the first contact point of the bumper and the first contact point of the wheel with the obstacle. As Illustrated in the figure:

Figure 45: Maximum Approach Angle

It depends on the height of the lowest point of the vehicle and the size of the tire. We have used 10-inch tires. To get a large angle of approach, we had to design a bumper having a greater height as compared to normal low nosed vehicles which are designed for speed. Offroad vehicles are primarily not designed for speed but for the ability to transverse.

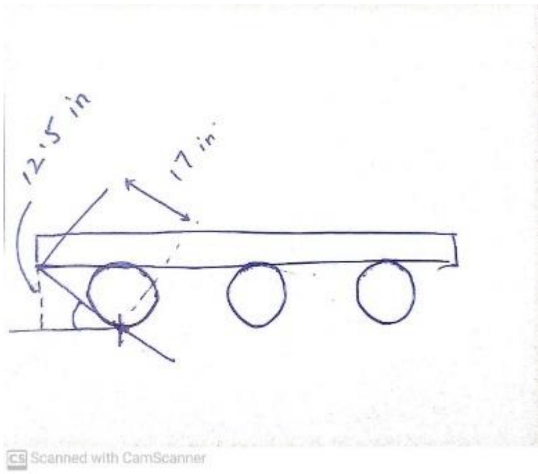

Figure 46: Approach Angle Calculation

By using trigonometry,

$$\sin\vartheta = \frac{P}{H}$$

The Angle of approach was found to be approx. **47^{o}**.

The factors affecting our design were,

- Vehicle Nose Length: It is the length of the nose that extends in front of the wheels. The longer the nose, the shorter the angle
- Tire Size: In order to further increase the angle, larger tires are to be used.

Angle of Departure:

It is the counterpart of approach angle. It is the angle with the ground and the line passing through the vehicles rear lowest point (essentially the bumper) and the rear tire's contact point. It determines how steep terrains the vehicle can descend. To stay away from complications for the driver, the angle of approach and departure are designed mostly for the same value so that the driver can easily surpass the terrain. It is also calculated physically as shown in the following figure:

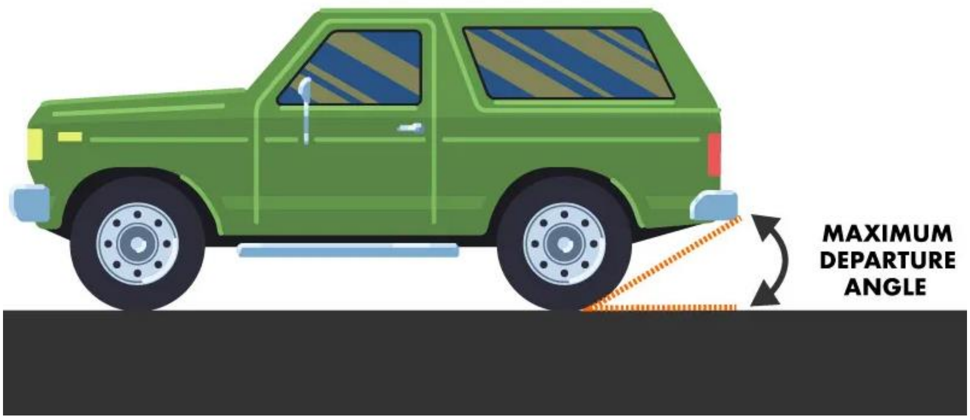

Figure 47: Figure Showing Departure Angle

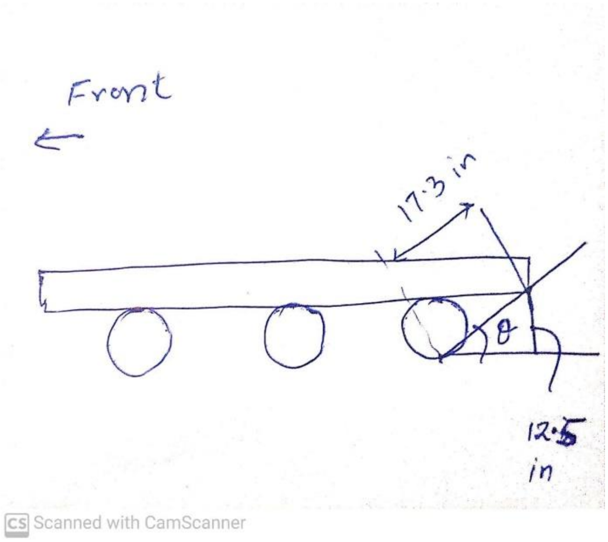

Figure 48: Departure Angle Calculation

By using,

$$\sin \vartheta = \frac{P}{H}$$

We get angle similar to approach angle at **46.8º**.

It depends on the following factors:

- Length of rear end: The further the rear end expands, the lower will be the angle.
- Tire Size: It also depends on the tire size. Larger tires will give a larger angle of departure.
- Toe hitch: If a tow hitch is present in the vehicle beneath the rear bumper, it also decreases the angle of departure.

Breakover Angle:

It is also known as the ramp angle. It is defined as the angle that determines how steep an obstacle the vehicle can transverse without damaging the underside of the car.

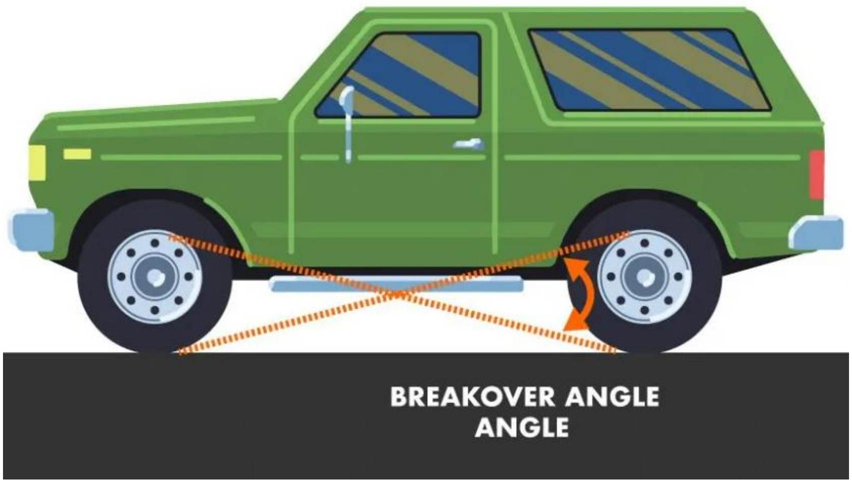

Figure 49: Figure Showing Breakover Angle

It is calculated using the following formula:

$$Breakover\ Angle = 2\ \times \tan^{-1}(\ 2 \times \frac{GC}{wheelbase})$$

This angle is mostly used in 4 wheeled vehicles. We have not considered this angle as the place where the vehicle is mostly said to touch the ground, is having an extra 2 wheels which make it safe from hitting the ground.

https://www.ordealist.com/approach-departure-breakover-angle/

Tire Rolling Circumference:

The rolling circumference is the distance travelled by the wheel without slipping in one revolution. The circumference changes slightly due to speed and load. The dynamic rolling radius is greater than static rolling radius. Changes in this parameter may indicate profile wear or tread wear. It is also input for numerous other calculations like traction force and gradeability. Rolling Circumference, RC is calculated by using

$$\mathrm{RC} = 2 \times \pi \times \mathrm{SLR}$$

Where SLR is static loaded radius for the wheel

When the wheel is not attached to the vehicle then,

SLR = R

Where R = Outer tire radius

When the tire is fitted to the vehicle and load is applied, it makes a flat contact patch with the terrain or ground which reduces the outer radius. In this case,

$$SLR = 0.96 \times R$$

So the equation becomes

$$RC = 2 \times \pi \times 0.96 \times R$$

Where R = (2 × 5.31) + 10

R = 20.62 inches

Figure 50: Rolling Circumference of the ATV Tire

So, RC becomes,

$$RC = 124.37\ inches$$

11.9 Achievements of Project

The major achievement is to obtain a 6x6 AWD using three live axles with differentials. The Engine gives the power to the rear axle. The rear axle is fixed with a sprocket and a damper that is used to shift the power from the engine to the differential. The damper is placed to compensate the jerk while the starting and stopping of the engine. This protects the chain and ensures smooth functioning.

Secondly the achievement is to implement steering of the vehicle. The ATV, because of its Six Wheel configuration (All axles are places at an equal distance) cannot operate on conventional or Ackerman steering. It is working on skid steering mechanisms. Military Vehicles operating on skid steering, use a control differential that contains planetary gears along with brakes all compacted in a single assembly enclosed in the housing. It basically serves as a clutch, acceleration, and braking assembly. Due to the cost and time factor, we were unable to design a control differential. To obtain skid steering, we have used independent brakes that are controlled by 2 handlebars/sticks. The sticks apply the brakes. As soon as the brakes are applied, the differential transmits the power to the other side of the axle and this in turn gives a skidding rotation due to which the vehicle can be steered.

This vehicle provides mobility. It tackles different terrains due to its AWD capabilities. There are numerous uses in which the vehicle can be applied. It can be used for surveying, recce and patrolling. The main objective while designing the vehicle was to make it capable for military applications. Many different attachments can be made on the vehicle. For instance, it can be designed to accommodate 2 persons and be fitted with Light Machine Guns (LMGs). Survey lights, scopes and other equipment can be fitted. There is a possibility of unmanned operation of the vehicle. Similar vehicles are being used by different militaries around the world.

It can be used for amphibious usage. Another advantage of Six Wheeled is that it can be fitted with tracks to increase the mobility for loose and soft terrains. Tires with increased width can be used by making a few adjustments. The vehicle is designed such that the parts can be replaced, and adjustments can be made. For example, there are screws that can be used to adjust the flex and slag in the chain that is driving the vehicle.

Chapter 12: Finite Element Modelling

12.1 Chassis

Structural elements such as chassis can be modeled using FEM techniques. A proper finite element model of the chassis has been developed. The 3d model of the chassis has been modeled on PTC Creo Parametric and then imported to Ansys to model the chassis using beam elements.

12.1.1 Material Selection

Our actual chassis has been fabricated using Mild steel. The material has very close properties to structural steel and there was no library of mild steel so structural steel has been used. The main properties of structural steel are shown below.

Material	Structural Steel
Modulus of Elasticity	190-210 GPa
Poisson's Ratio	0.27- 0.3
Tensile Strength	2.5e8 Pa
Yield Strength	187-758 MPa

Table 6: Material Properties of Structural Steel

12.1.2 Material Selection

As mentioned before, the model has been created on Creo 8.0.2 and then imported to Ansys.

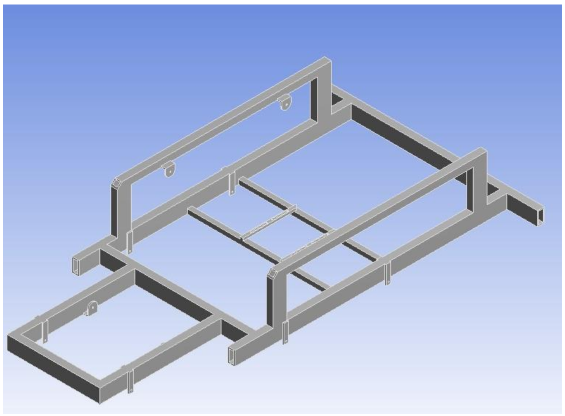

Figure 51: 3D Model of Chassis

12.1.3 Meshing

The software breaks down the CAD model into smaller pieces called elements. The process of this breakdown is known as Meshing. When the mesh is of higher quality, the mathematical representation of the model will be more accurate. The meshing is done using 10 node tetrahedral element as shown below.

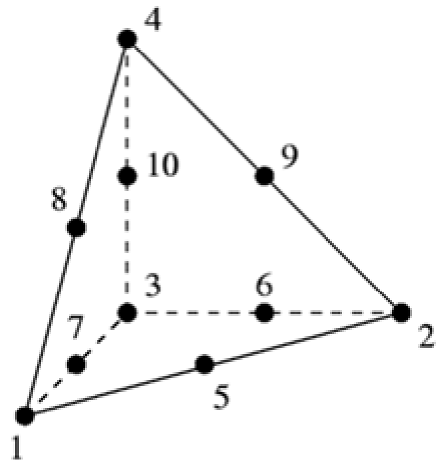

Figure 52: 10 node tetrahedral element

After a high-quality meshing, we get the following meshed CAD model of the chassis.

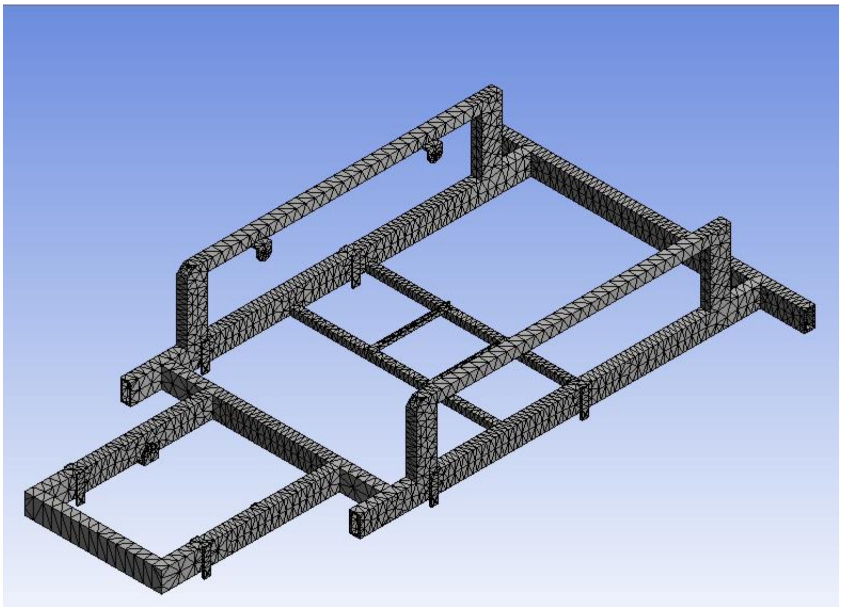

Figure 53: Meshed Chassis Model

12.1.5 Loading and Boundary Conditions

The chassis is loaded by static forces from the engine, the body, and the cargo. Our 125cc engine has a curb weight of 22 kg or 215.6 N. This will be distributed evenly on the two brackets at the center where the engine will be mounted. Similarly, the weight of the body plus cargo is estimated around 175kg or 1750 N which will be distributed evenly throughout the outer perimeter of the chassis.

The fixed supports are the points where the chassis is connected to the body, the suspensions and to the differentials. All are shown below,

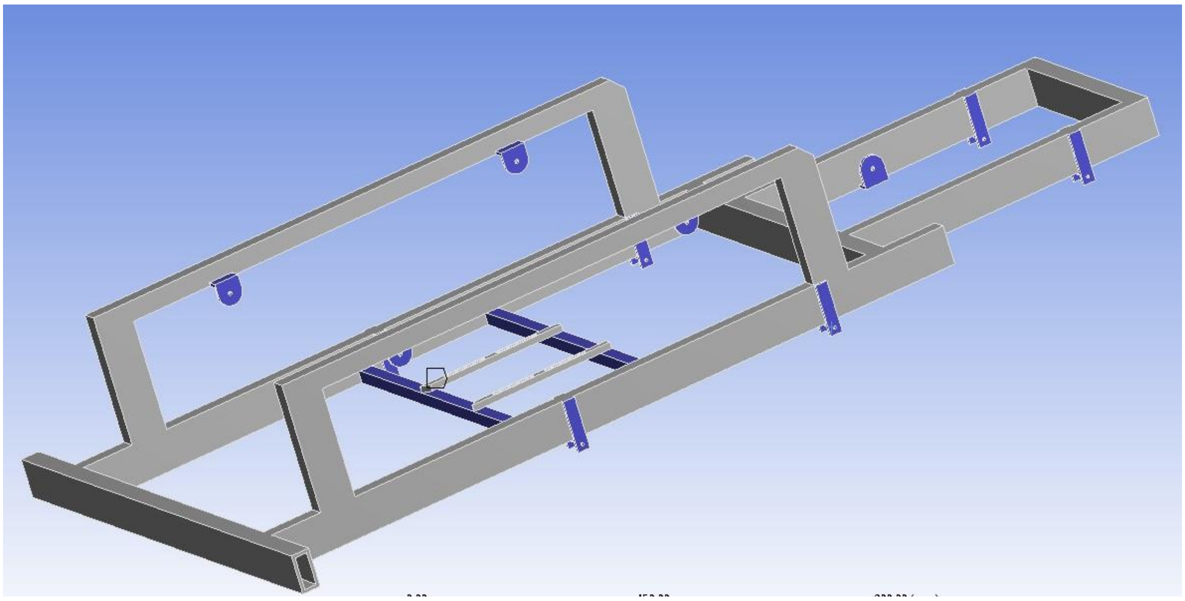

Figure 54: Highlighted areas showing Fixed Support points

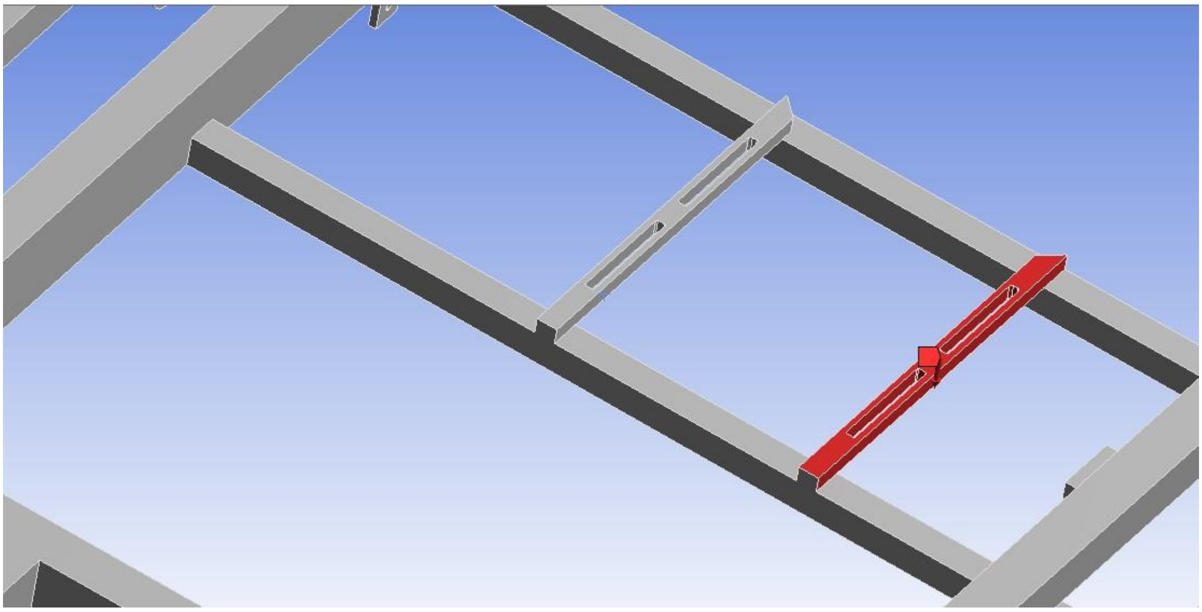

Figure 55: Half of engine weight being loaded on one bracket

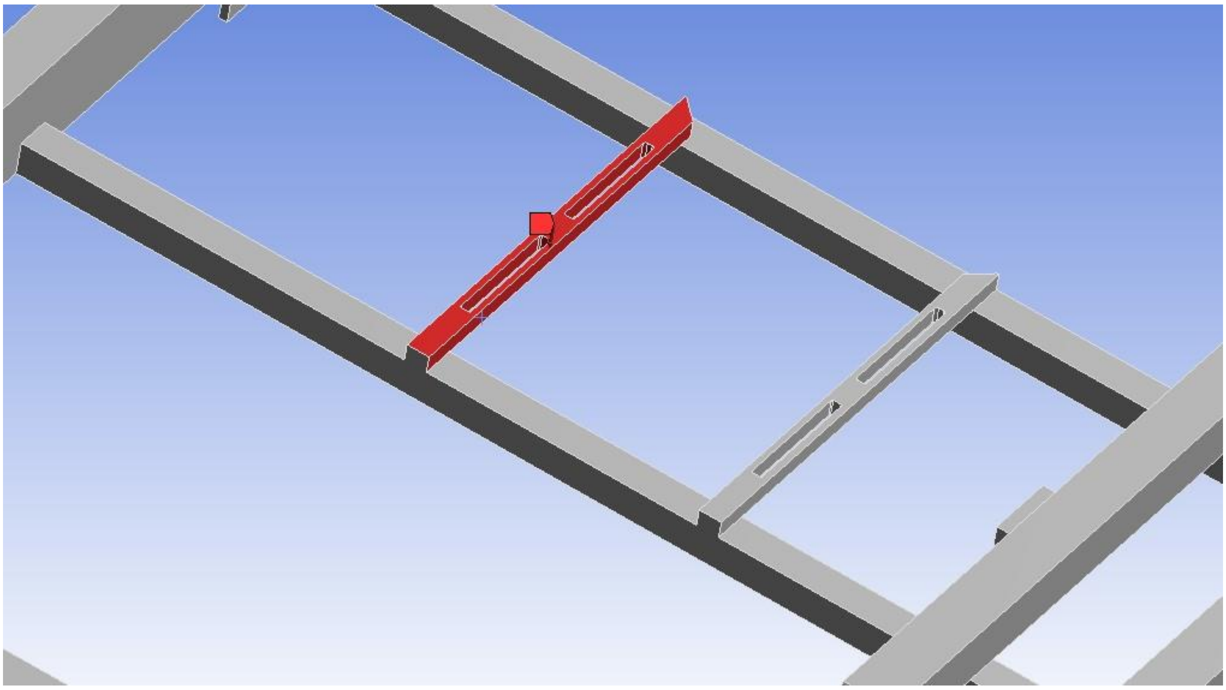

Figure 56: Half being loaded onto the other bracket

The bracket is around 0.5 inch thick with 0.5 inch wide. Grooves have been made to allow engine to be bolted down as well as to adjust its position.

The overall weight distribution on the chassis is shown below

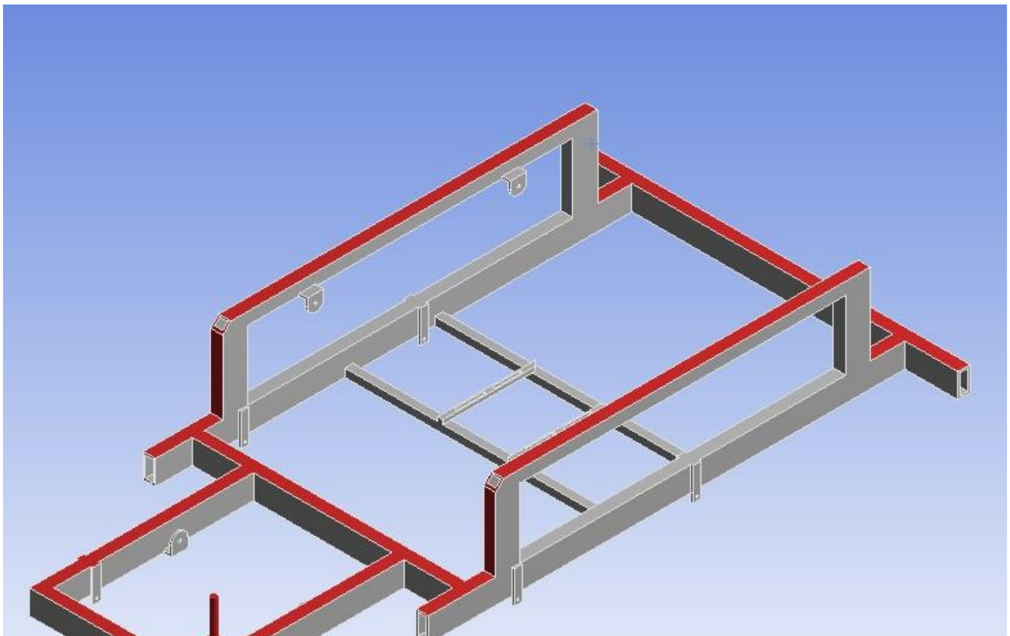

Figure 57: Body and cargo weight distribution on the chassis

12.1.5 Result

After the analysis, the maximum generated Von Mises stress on the brackets is around 1.06 MPa. Similarly, around the total deformation shows that maximum deformation is at the rear beam of about 0.01613 mm which is very little hence the chassis is structurally stable.

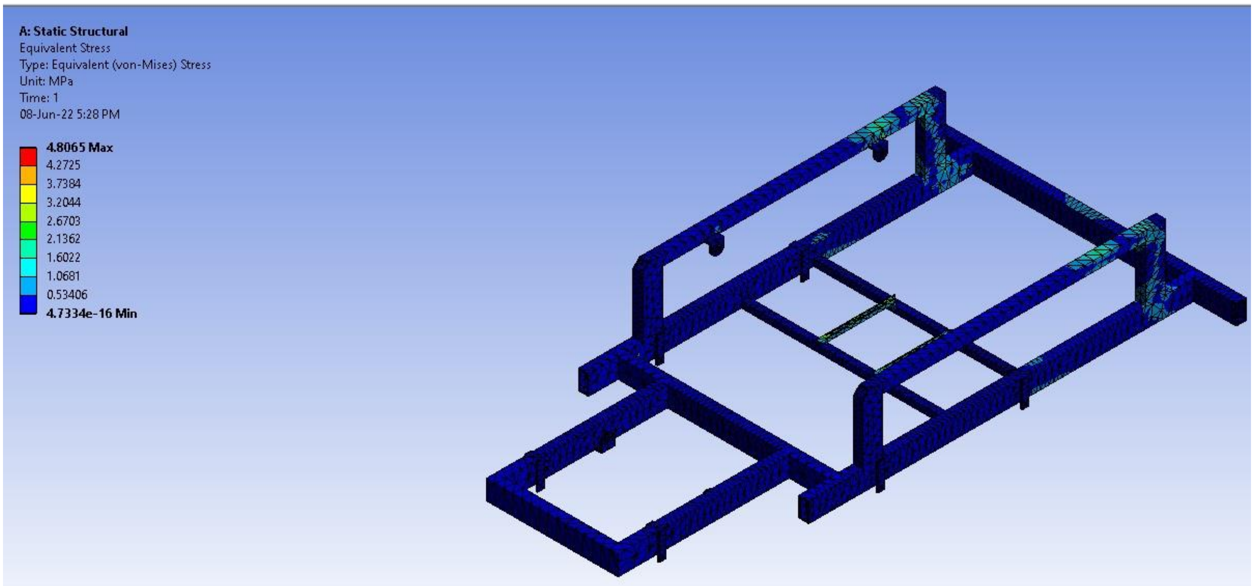

Figure 58: Equivalent Von Mises Stress

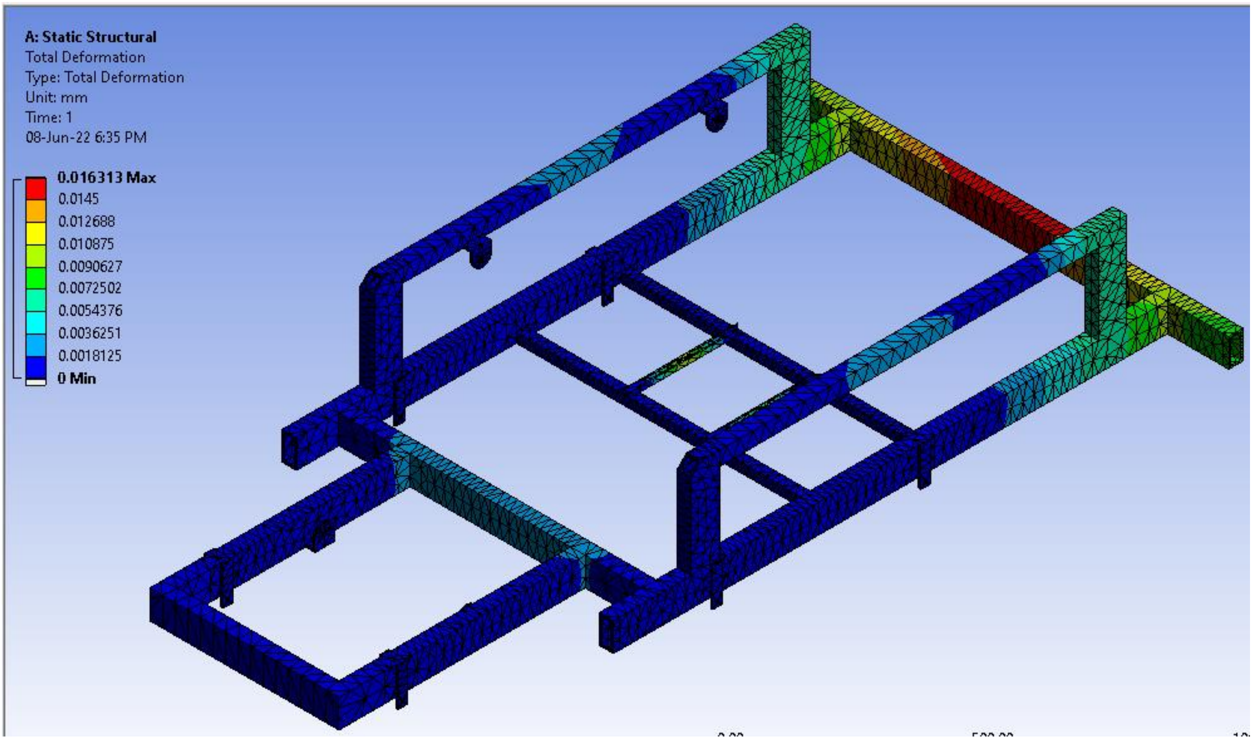

Figure 59: Total Deformation on the order of mm.

Object Name	*PRT0001*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Behavior	None
Material	
Assignment	Structural Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	1219.2 mm
Length Y	355.6 mm
Length Z	2070.1 mm
Properties	
Volume	1.4843e+007 mm^3
Mass	116.51 kg
Centroid X	1.3877e-004 mm
Centroid Y	31.069 mm
Centroid Z	176.95 mm
Moment of Inertia Ip1	4.9238e+007 $kg \cdot mm^2$
Moment of Inertia Ip2	6.2788e+007 $kg \cdot mm^2$
Moment of Inertia Ip3	1.662e+007 $kg \cdot mm^2$
Statistics	
Nodes	41323
Elements	20380
Mesh Metric	Orthogonal Quality
Min	4.88154070226177E-05
Max	0.906824831555465

Average	0.174182992218524
Standard Deviation	0.146931048323532

Table 7: Geometrical Properties obtained from Ansys

12.2 Differential Pipe

FEM analysis is done on the differential shaft to test is structural rigidity.

12.2.1 Material Selection

The differential shaft has been fabricated using Mild steel. The material has very close properties to structural steel and there was no library of mild steel so structural steel has been used. The main properties of structural steel are shown below.

Material	Structural Steel
Modulus of Elasticity	190-210 GPa
Poisson's Ratio	0.27- 0.3
Tensile Strength	2.5e8 Pa
Yield Strength	187-758 MPa

Table 8: Material Properties of Structural Steel

12.2.1 Model

The shaft is modelled on Creo Parametric 8.0.2.

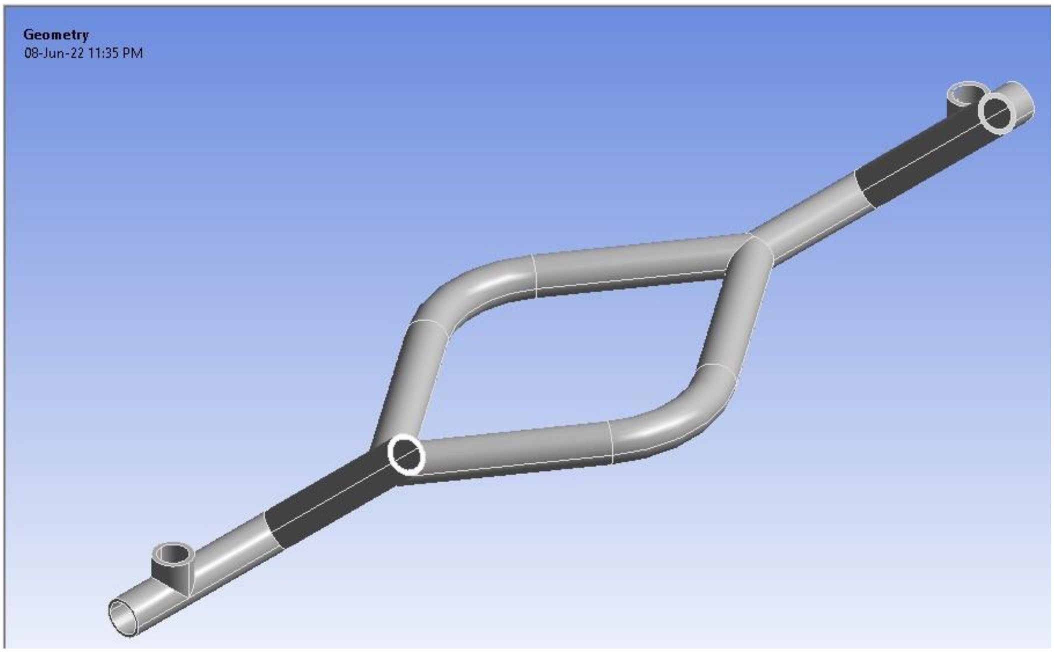

Figure 60: CAD Model of Differential Pipe

12.2.2 Mesh

The software breaks down the CAD model into smaller pieces called elements. The process of this breakdown is known as Meshing. When the mesh is of higher quality, the mathematical representation of the model will be more accurate. The meshing is done using 10 node tetrahedral element as shown below.

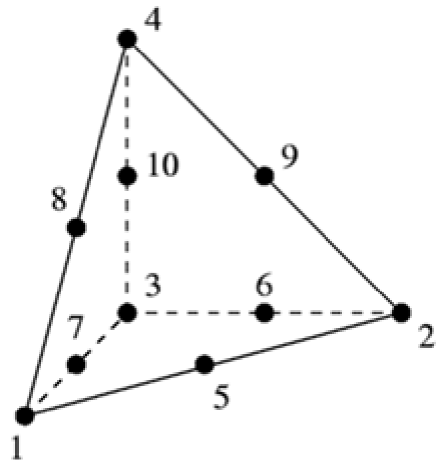

Figure 61: 10 node Tetrahedral Element

A high-quality meshing gives us

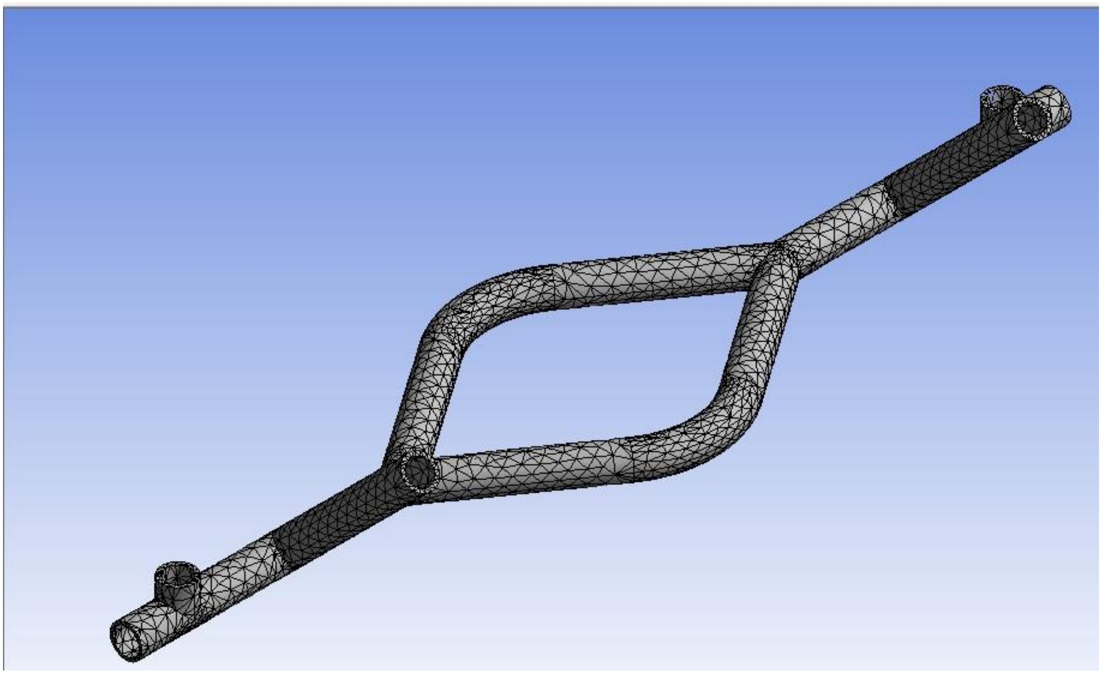

Figure 62: Meshed Differential

12.2.3 Loading and Boundary Conditions

The differential is connected to the tires through its two ends and to the two suspensions through the small connecting rods welded near its ends. The suspension pair can sustain a weight of 300 kg or about 175 kg each. Shown below,

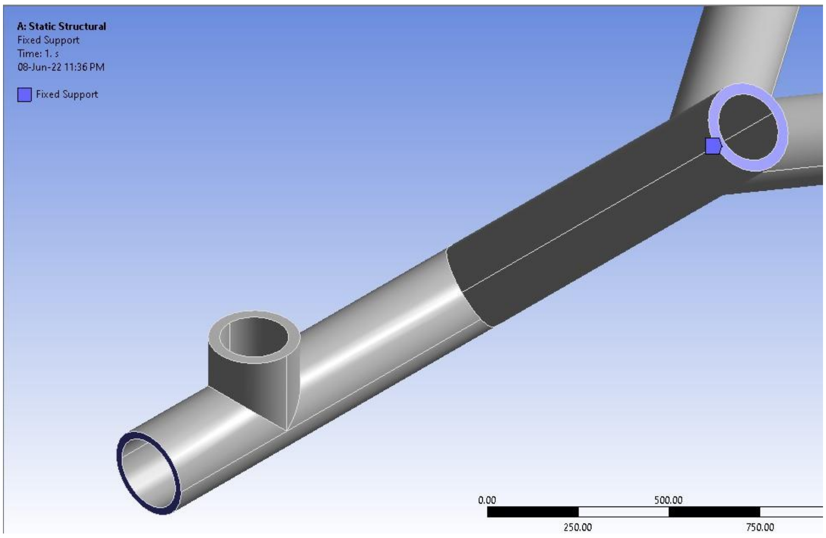

Figure 63: Fixed Supports shown

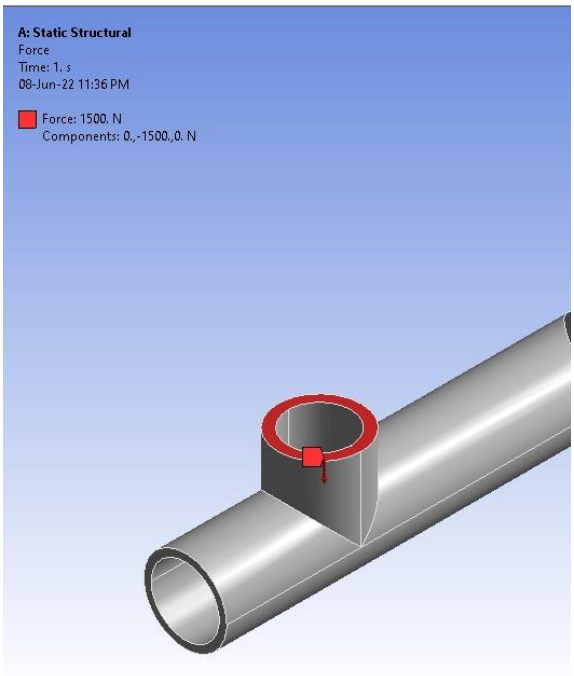

Figure 64: Loaded part of the differential that is connected to the suspension

12.2.4 Results

After the analysis, it can be seen that the maximum stress that can be endured by the differential pipe is around 0.451187 MPa as shown by the Von Mises stress

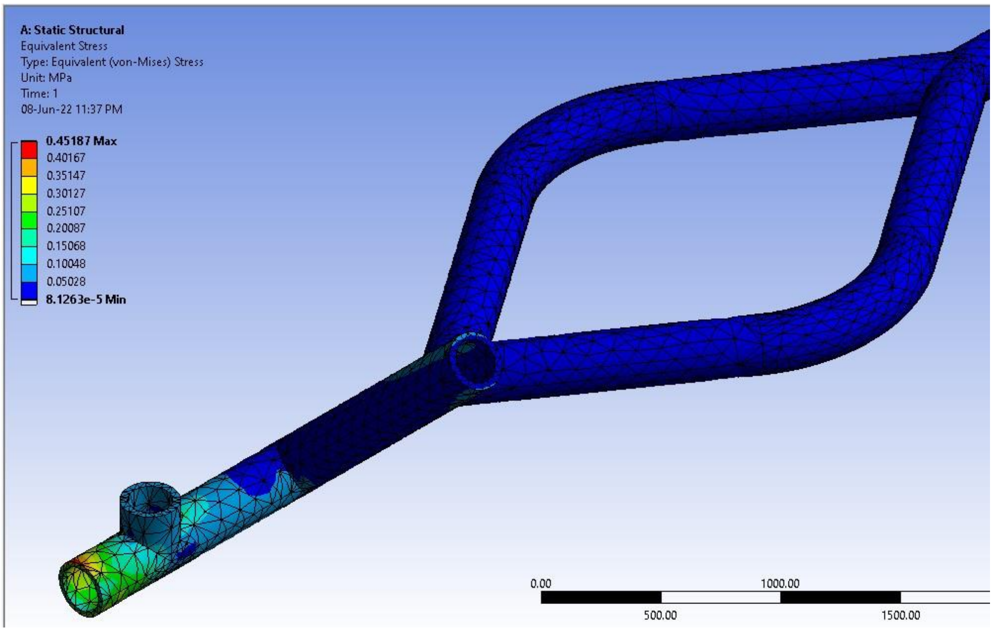

Figure 65: Equivalent Von Mises Stress showing max stress at the edges

Similarly, the maximum deformation is about 0.0038 mm which indicates very little to no deformation. Hence, our differential is structurally stable.

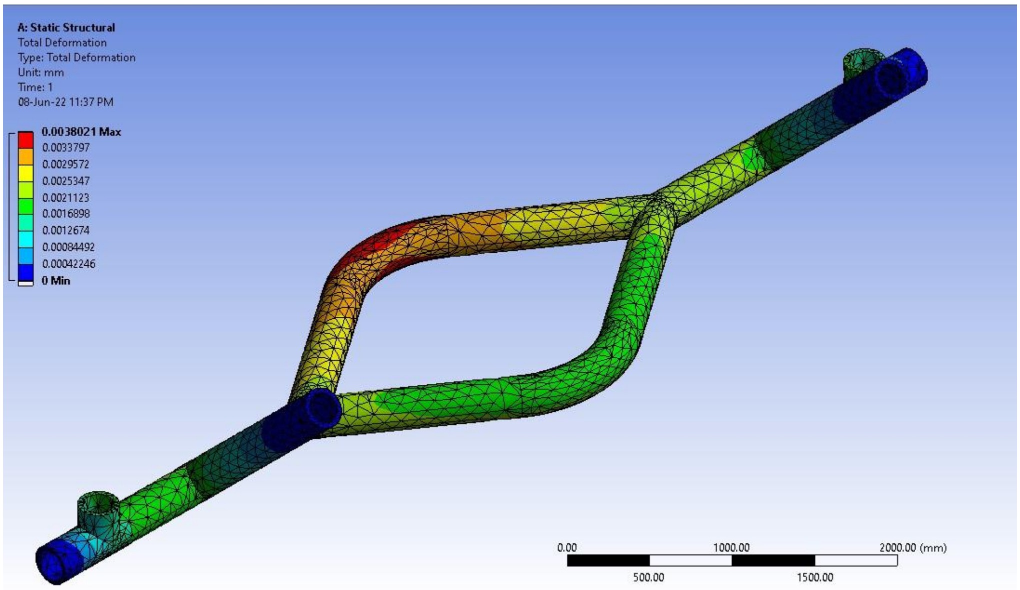

Figure 66: Total Deformation on the Differential

Object Name	*PRT0001*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Behavior	None
Material	
Assignment	Structural Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	2182. mm
Length Y	1294.4 mm
Length Z	7373.4 mm
Properties	
Volume	3.0003e+008 mm³
Mass	2355.3 kg
Centroid X	121.21 mm
Centroid Y	125.49 mm
Centroid Z	0.55683 mm
Moment of Inertia Ip1	8.7545e+009 kg·mm²
Moment of Inertia Ip2	9.2705e+009 kg·mm²
Moment of Inertia Ip3	7.566e+008 kg·mm²
Statistics	
Nodes	37864
Elements	19776
Mesh Metric	None

Table 9: Geometry Details from Ansys Workbench

Chapter 13: Prospects

We designed and manufactured our ATV with parts and materials based on those available in the market locally. There is much room for improvement in the structural design of this vehicle if new parts are used according to international standards. Imported parts can be procured to improve the structure and chassis of the vehicle.

Moreover, we have procured the parts which were economical for us. Due to financial restraints, we procured 135 x 10 mm bias ply tires which can be replaced by non-pneumatic or low-pressure tires of larger tires. Then, we would no longer even require the shock absorbers that we have used to dampen road vibrations to protect the vehicle from wear and tear. Our vehicle would then be practically working without any suspension system which is basically our desired design specification. Also, using such tires, the tire-terrain interaction would be much better than the current set of tires. The manueverability, stability, traction, off-roading capabilities would improve. The vehicle would have a much better grip and traction on soft soil, icy or snowy road, or muddy tracks. By using a more efficient engine and drivetrain, the torque and power can be improved. Better internal cosmetics can be employed. Simply a better locking differential can be used since it is crucial for good off- roading.

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