ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Material Engineering

Improvement of Structure and Body of Three Wheeler Vehicle

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering

By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "**Improvement of Structure and Body of Three Wheeler Vehicle**" in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from February 2017 to September 2017 under the supervision of N. Ramesh Babu Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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Student

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name	Signature	Date
N. Ramesh Babu	______________	________________

Advisor

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Approved by board of Examiners

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List of Acronyms and Symbols

CAD	Computer Aided Design
F_D	Drag Force
C_D	Drag Coefficient
DOF	Degree of Freedom
FEA	Final Element Analysis
FEM	Final Element method
Hz	Hertz
IPT	Intermediate Public Transport
Kmph	Kilo meter per hour
F_L	Lift Force
C_L	Lift Coefficient
Mpa	Mega Pascal
m	Mass
PSQCA	Pakistan Standard and Quality Control Authority
%	Percentage
ρ	Density
P	Power
RE	Rear Engine
F_r	Rolling resistance
SAE	Society of Automotive Engineers
TWV	Three Wheeled Vehicle
η_t	Transmition Efficiency
ω_n	Natural Frequency
W	Weight
3D	Three dimensional

kg/m^3	Kilogram per meter cube
A	Area
f_s	Factory of safety
F	Force
V	Velocity
N	Newton
m^2	Meter Squared
m/s^2	Meter per second squared
mm	Millimeter
V_f	Final Velocity
V_i	Initial Velocity
F_t	Total Resistance
kN	Kilo Newton
kW	Kilowatt
σ_y	Yield Strength
σ_{max}	Maximum stress
&	And

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Abstract

Three wheeler vehicles are used as one of the major public transportation systems in Ethiopia society. They have played very important role in a short distance transport system in Ethiopia especially in city and town. It is important to evaluate the current strength of three wheeler vehicle depending on their load carrying capacity, service and use. The purpose of this thesis is to improve the design of body and structure of three wheeler vehicles in order to bring significant change in their overall activity. To fulfill the objectives of this study the following main activities were performed. CAD model was prepared by using CATIA V5R19 software, structure analysis was done by using finite element analysis (FEA) with ANSYS 16.0 software. Also for impact analysis such as frontal, rear, side and rollover static impact analysis finite element analysis software was used and aerodynamic drag analysis was done by using CFD software. The current work of the thesis was made by the important parameters such as strength, performance, weight and safety. Designing the overall body shape and structure improve vehicle stability and handling. The modified structure increases the strength of vehicle and the rollover static crash simulation which makes strong roof structure during collision. This rollover impact simulation is used to bring great change in order to protect occupants from rollover accidents. Also a modified the outer surface of the vehicle aerodynamically in order to reduce the effect of drag force which in turn results in reduction of fuel consumption. The models were entirely designed using the software CATIA V5R19. Simulation of model dimensions 2625 x 1300 x 1710 mm was conducted using CFD software Fluent16.0 in order to reduce the drag force. Computation fluid dynamics (CFD) method was important to analyze the variation of aerodynamic effect on the models with the change of body shape. From the study, it was found that 24.6% of the total drag of the original (Model-1) was reduced on the model-2 that is equivalent to 4.93 KW of an engine brake power at 60 km/h in speed. Also 8.1% of fuel can be saved for the every 60 Km/h.

Keywords: *Three wheeler vehicle, FEA, Passengers Ergonomics, Structure and CFD.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Transportation is an essential part of today's life. It has been an essential part of most societies of the past. The adequacy of transportation system is a fair index of a country's economic development. (Hay, 1977) transportation can be considered the movement of people, goods and the facilities used for that purpose. Three Wheeler vehicles (TWV) of various types form a very important part of the transportation system in India. They are used as "Intermediate Public Transport (IPT)" in most cities moving either as taxi or operating on fixed routes like omnibuses. Some of them also operate from city borders to small towns and villages in the outskirts to ferry passengers. A large number of them are designed as goods carriers and operate as intra-city goods transport vehicles. There are several reasons for the popularity of three wheeled vehicles. In addition to the low initial and running costs, the other major reason is the ability of the vehicle to be maneuvered into small spaces on narrow streets, which are characteristic of most of the cities and towns. They occupy small parking space and they are easy and cheap to maintain. From the users perspective they offer reliable service that is cheaper than a four wheeled taxi but is faster and more dependable than a city bus. It is estimated that each three wheeler provides benefit in India. Their predominant role in the transport sector which shows that over the last few years, the sales numbers of three wheelers (all categories together) have almost been matching the sales numbers of all other commercial vehicles taken together. The commercial vehicles referred to above include light and heavy passenger and goods vehicles such as buses, trucks, light trucks, minibuses etc [1].

The three wheeled vehicle is a very common public transport vehicle in India, with a maximum speed of about 65 km/h. Similar vehicles are used throughout the world, especially in Asian countries, for public transport as well as to carry freight [2]. Three wheeler transport vehicles known as auto rickshaws are a common means of public transportation in many countries in the world and are an essential form of urban transport in many developing countries such as India and the Philippines. Three wheelers usually refer to tricycles, which are variously known as auto rickshaws. Many three wheelers which exist in the form of motorcycle based machines are often called trikes and often have the front single wheel and mechanics similar to that of a motorcycle and the rear axle similar to that of a car. Often such vehicles are owner constructed using a portion of a rear engine and rear drive. Three wheeled automobiles can have either one wheel at the back and two at the front, (for example: Morgan Motor Company) or one wheel at the front and two at the back (such as the Reliant Robin) [3] [26]. Today, small vehicles play a significant role in our daily life and very popular in urban community. Low fuel consumption, small dimensions and affordable prices are some reasons for such popularity [56]. Three Wheeled vehicles are also placed in this category and are considered as small urban vehicles which are also used in countries such as China and India as transporter vehicles and sometimes for cargo transfer reasons [57].

Nowadays, because of their fuel consumption and ease of driving and parking in populated cities, they are gaining more attention. For instance, some three wheelers have already being used as part of the public transportation system in several countries. Three wheelers are less common world wide than two wheelers. India has the largest three wheeler market in the world; sales in 2010-2011 were expected to be around half a million units approximately the same amount as all commercial road vehicles taken together (light commercial vehicles, trucks, buses etc) . Other markets are in Africa, Central America and South Asia mainly Bangladesh and Sri Lanka [27]. In the passenger carrier segment, three wheelers commonly operate as taxi, where they often provide an important transport service to people without access to a private vehicle or public transport [25]. Around 80% of the Indian three wheeler market in 2009-2010 was made of three seated passenger carriers (auto-rickshaws) [27]. Typically they have a fabric hood, open sides and are steered by a handle bar like one in a scooter. They have small engines and can hold speeds of up to 65 km/h [25]. Three wheelers are also used as goods carriers for intra-city carriage of small payloads. Most of these vehicles have a pay load capacity of 0.5-1 tonne and they accounted for 17% of the Indian three wheeler market in 2009-2010 [27].

The automotive industry is facing tremendous engineering challenges over several years to meet the requirements generated by the fuel shortage, fuel cost, pollution control, raw material cost, and safety. In meeting these challenges a wide variety of new models has been emerged or entered into the market in search for better strength and safety and fuel efficiency. As a result, three wheeled motor vehicles have been developed for the purpose of public and private transport, all over the world and in particular in developing countries. Three wheeled motor vehicles, typically used in India and most of the developing countries have their front steering with one wheel similar to those of motor cycles and motor scooters and the two rear wheels are driving wheels with a differential and suspension, which are similar to those of automobiles. Even though there are many modifications and improvements done still there are strength shortcomings [40].

Nowadays, automobile companies are involved in the design of more efficient vehicles improving the energetic efficiency and making them smaller for the best use of the current roads and streets. The idea of smaller, energy efficient vehicles for personal transportation seems to naturally introduce the three wheel platform. Opinions normally run either strongly against or strongly in favor of the three wheel layout. Advocates point to a mechanically simplified chassis, lower manufacturing costs, and superior handling characteristics. Opponents decry the three wheeler's propensity to overturn. Both opinions have merit. Three wheelers are lighter and less costly to manufacture. And today's tilting three wheelers, vehicles that lean into turns like motorcycles, point the way to a new category of personal transportation products of much lower mass, far greater fuel economy, and superior cornering power. Today, auto manufacturers to design more efficient vehicles to improve energy and also to make them smaller in order to better use on streets and roads are modern. A three wheeled vehicles an automobile having either one wheel in the front for steering and two at the rear for power, two in the front for steering and one in the rear for power, or any other combination of layouts [53,54]. The chassis and body are made of pressed steel and include a bench seat each for the driver and the passengers.

In today's world one of the most challenging problems that we face is providing optimal, efficient, cost effective and also environmentally friendly transport services. According to Aworemi, Salami, et al. (2008), the demand for public transport depends on two factors. First the desire to make a particular trip and to do so by public transport. Second the characteristics and nature of the public transport modes that is available. Providing an optimal public transport service which maximizes social welfare is a major challenge confronted with transport stakeholders in developing countries. Further, increasing urbanization, population and industrial development is increasing the demand for urban transport services [55].

Generally Bajaj three wheelers become very famous mode of transportation in urban community of Ethiopia. The demand for such vehicles is growing very much day to day. Ethiopia is importing three wheelers and their spare parts due to lack of local automobile industries, spending lot of foreign exchange, negatively effecting the economical growth of the country. It carries three passengers and driver. Three wheelers will continue to play an important part in the urban transportation system. Due to their large and fast growing numbers there is a sense of urgency to accelerate the process of further technology. Three wheelers as intermediate public transports have significant shares of urban mobility.

1.2 Statement of the Problem

As we know during designing and manufacturing the most vehicles body should fulfill some basic requirements. For example, the body of vehicle should be light and it should provide sufficient space for passengers and luggage. These three wheeler vehicles (Bajaj) do not fulfill these basic requirements. So some people fear and have less interest to use these types of vehicles. Because there is lack of passengers' ergonomics and risk level is very high during running on the road. There is no roof structure to protect passengers from rollover accident and there is no good strength. Also they produce more emissions running on road because of they have monocoque structure or unit body structure. This monocoque structure has heavier in weight at the chassis and bottom part of the body. Therefore, tubular space frame structure is required to improve problems from these vehicles. So this new (modified) structure which makes strong roof structure during rollover impact case. It is concerned that light weight & less vibration. Therefore, it is safe for driver and passengers.

1.3 Objectives of the Study

1.3.1 General Objective

General objective of this thesis is to improve the design of body and structure of three wheeler vehicles.

1.3.2 Specific Objectives

The specific objectives are as follows

- To collect the data related to body of the three wheeler Bajaj
- To model the shape of the existing body and improved body using CATIA software.
- To collect the data for passengers ergonomics
- To analyse the model for its strength using finite element analysis (FEA) software.
- To analyse the model for aerodynamic drag using CFD software.
- To study rollover impact analysis using FEA software.

1.4 Significance of the Study

The significance of this work is as follows:

- Helps to increase load carrying capacity of vehicle.
- Improves strength of the vehicle.
- Reduces fuel consumption and emissions.
- Improves the safety and comfort of the passengers.

- Beneficiaries: Automobile industries, Companies, Society and Country as a whole.

1.5 Scope of the Study

The scope of this study includes improving body structure of three wheeled vehicle by design and modification. It includes the steps like modeling using CATIA software, strength analysis by FEA (Finite element analysis) software and aerodynamic drag analysis by CFD software.

1.6 Limitations of the Study

The limitations of the study are mainly unavailability of detailed drawing of the TWV body. However as our main focus is improvement of body and structure of three wheeler Bajaj this does not have much problem. The capacity of the available computer is also limited the work. This limitation also forced the meshes to be as optimized as possible which is to be compatible to fluent software and the geometry had to be simplified in order to reduce the cell number not more. The other point is that the design of tubular space frame structure was made by using FEA and here analytical modeling is not made.

1.7 Organization of the Study

This study consists of five chapters. Chapter one provides a brief introduction about three wheeler vehicles which include background of the study, statement of the problem, objectives, significance of the study, scope of the study, limitations of the study and organization of the study. Chapter two considers the literature review based on previous work done in related field and important concepts or aspects are included in this chapter. Chapter three describes the methodology of the research procedure which includes technical specification of Bajaj three wheeler, CAD modeling and finite element analysis (FEA) with boundary conditions, meshing and CFD (computational fluid dynamics) analysis includes geometry, mesh generations and boundary conditions are discussed in detail in this Chapter. The simulation results and discussions consider finite element analysis such as equivalent stress, shear stress, principal stress, safety factor, displacement and impact analysis which includes frontal impact, rear impact, side impact, rollover static impact analyses and modal analyses are briefly described. Also CFD analysis which includes velocity distributions, pressure distributions, aerodynamic drag force, drag coefficient, calculation of power required, fuel consumption reduction and passengers' ergonomics analysis are considered in chapter four. In the last chapter, the final conclusions and recommendations for further work are summarised.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

A majority of three wheeled vehicles used in India are designed to carry three passengers in addition to the driver and are called auto-rickshaws. In most of the larger cities these vehicles operate as less taxi for which they are equipped with tariff meters approved by the local authorities. The 'auto-rickshaw' is constructed in the simplest possible manner to minimize its cost, weight and fuel consumption. Its design is considered to be the most optimum in terms of material inputs and operating efficiency for performing the intended task at the least cost. The chassis and body are made of pressed steel and include a bench seat each for the driver and the passengers. A hood made out of fabric is provided to protect the occupants from rain and sun. A windshield protects the front but the sides are usually open [1].

Three wheelers in India are expected to surpass half a million in sales in financial year 2010 and 2011. These three wheelers play a critical role in providing point to point as well as feeder service in all urban and semi-urban areas. Given the importance of three wheelers in improving personal mobility in India, careful attention must be paid to the possibility of reducing emissions and fuel consumption from these vehicles. Bajaj manufactures and sells motorcycles, scooters, auto-rickshaws and most recently, cars. Bajaj Auto is India's largest exporter of motorcycles and three-wheelers [3]. Bajaj Auto Limited is an Indian two-wheeler and three-wheeler manufacturing company [4]. Bajaj Auto manufactures and sells motorcycles, scooters and auto rickshaws. Bajaj Auto is a part of the Bajaj Group [5]. Bajaj Auto's exports accounted for approx. 35% of its total sales. 47% of its exports are made to Africa. Bajaj Auto is one of the oldest manufacturers of two and three wheelers in India, operating since the 1960's. It started primarily as a scooter manufacturer and over the course of time switched the segment to produce motorcycles.

Today Bajaj three wheeler vehicles play a significant role in our daily life and very popular in urban community. Many fate changing strategic and operational decisions can be taken by the people, some expected and others are necessary. Bajaj three wheelers motor vehicles carry three passengers and driver. They will continue to play an important part in the urban transportation system. Then three wheelers Bajaj as intermediate public transports have significant shares of urban mobility.

2.2 Bajaj three Wheeler Vehicle

Bajaj Auto is the fourth largest manufacturer of two and three wheelers in the world. It is the largest three wheeled vehicle producer in India. The Bajaj auto rickshaws are very common on the Ethiopian market. Bajaj is the world's largest producer and India's largest exporter of three wheelers [5]. It has got a monocoque frame and a steel body; it carries three peoples, while the chassis is built from sheet metal [6]. Nowadays this type of Bajaj is found in Ethiopia market. Current studies focus on Bajaj RE.

2.3 Shape and Structure description of three wheeler vehicle

2.3.1 Shape Optimization Concept

"Vehicle shape optimization in automotive Industry" by Fredrique Muyl et al, (2001) [7] has given the important aspects of the shape optimization tool for complex industrial flow. The Navier-Strokes equations are solved with a commercial CFD code on an unstructured mesh surrounding the shape to optimize.

"Reducing drag forces in future vehicles", project in the course road vehicle and aerodynamic design, MTF 235, AUTUMN (2002) [23] by Alexander Diehl et al, Chalmers university of technology, has explained the relationship between drag force and speed of the vehicle, drag force and change in drag coefficient and several ways to reduce the drag coefficient of a vehicle.

Alam et al, [22] stated that over 80% of the required total vehicle power is essential to overcome the aerodynamic resistance (and the remaining power is used for rolling resistance), they mentioned that causes extra drag to the total system hence extra fuel cost. Their primary objectives of this were to experimentally measure the aerodynamic drag generated by various vehicle add-ons under a range of vehicle operating speeds. Their study was conducted using a reduced scale (25%) detailed model of a production vehicle manufactured in Australia. They related the aerodynamic drag coefficient to fuel consumption and performed a detailed analysis of fuel savings.

Wood [24] considered the assessment of the role of fluid dynamic resistance and/or aerodynamic drag and their relationship to energy consumption in the United States. His data indicates that 16% of the total energy consumed in the United States is used to overcome aerodynamic drag in transportation systems. He suggested that application of existing pressure drag reduction technologies to all ground vehicles within the United States will reduce yearly energy costs by 20 billion dollars.

2.3.2 The Vehicle Structure

Safety engineers design and manufacture vehicle body structures to withstand static and dynamic service loads encountered during the vehicle life cycle. Exterior shapes provide low aerodynamic drag coefficient. The interior provides adequate space to comfortably accommodate its occupants. The vehicle body together with the suspension is designed to minimize road vibrations and aerodynamic noise transfer to the occupants. In addition, the vehicle structure is designed to maintain its integrity and provide adequate protection in survivable crashes.

The automobile structure has evolved over the last ten years to satisfy consumer needs and demands subject to many constraints, some of which may be in conflict with each other. Among these constraints are materials and energy availability, safety regulations, economics, competition, engineering technology and manufacturing capabilities. Current vehicles body structures include two categories: body over frame structure or unit body structure. The body over frame structure of a passenger car or a sport utility vehicle consists of a vehicle body, frame and front sheet metal. The vehicle body provides most of the vehicle rigidity in bending and in torsion. In addition, it provides a specifically designed occupant cell to minimize injury in the event of crash. In frontal impact, the frame and front sheet metal absorb most of the crash energy by plastic deformation. The three structural modules are bolted together to form the vehicle structure. The vehicle body is attached to the frame by shock absorbing body mounts designed to isolate from high frequency vibrations. Unit body structures comprise most passenger cars introduced in the U.S. since the early 1980's. These vehicles combine the body, frame, and front sheet metal into a single unit constructed from stamped sheet metal and assembled by spot welding or other fastening methods. The construction of the unit body structure, also known as unit frame and body or frame less body is claimed to enhance whole vehicle rigidity and provide for weight reduction [47] [48].

The vehicle contains the following main parts; the chassis and engine, structural body, interior and exterior parts. The vehicle body structure comprises of six main components; the left frame side, the right frame side, the front frame side, the back frame side, the top frame side and the bottom frame side. The top frame side is sometime called the roof frame side. The bottom frame side is also called "the floor frame side". The left and the right side are similar. Then the top frame or the roof frame is considered as the critical part that is needed to be a strength part in order to be ensured safety for the passengers. This part must be sufficiently strong. It must be supported by the total weight from different loads such as interior components, passenger carrying loads even the aerodynamic load

[8]. The majority of mass produced vehicle bodies over the last six decades were manufactured from stamped steel components. Manufacturers build only a few limited production and specialty vehicle bodies from composite materials or aluminum. Although a patent for all steel body was granted in 1900, until the 1920's, automakers built vehicle bodies from a composite of wood panels joined with steel brackets. Steel sheets were added over the panels to provide a better surface to hold the paint. As metallurgists improved the formability of sheet steel and toolmakers built durable dies capable of stamping millions of parts and spot weld technology allowed for joining large body shells, the all steel vehicle body became a reality.

Recently, there have been growing concerns over fuel consumption and pollution caused by the increasing number of automobiles, and the automotive industry is under great pressure to reduce fuel consumption and emissions. The shortages of energy sources and global warming have put increasing pressure on the investigation of new materials and the development of new products and technologies for the automotive industry. There are a number of approaches for improving vehicle energy efficiency and lowering emission rates. These approaches include drive train efficiency improvements, alternative fuel systems, downsizing engine capacity with turbocharging or supercharging, aerodynamic design and vehicle weight reductions [60] [61] [62].

Among these technologies, reducing structural weight is one of the most important ways of reducing fuel consumption and improving the performance of vehicles. Weights have increased recently due to some specific demands of passenger comfort and safety procedures. In addition to these issues, some of the legal engine requirements concerning emission rates and accordingly engine systems will add extra loads to the mass transit vehicles. Fuel economy and greenhouse gas emission standards have proven to be one of the most effective tools in controlling fuel demand and greenhouse gas emissions; there is therefore great societal and legislative pressure motivating automotive weight reduction [63] [64].

Cheah et al, [13], Lutsey [14], Witik et al, [15] stated that reductions in weight can be achieved by a light weight material, in which conventional materials in automotive engineering such as steel, plastic and iron are replaced with lighter and special alternatives such as aluminum, high strength steel and composite. Materials such as steel and aluminum still play a significant part in automotive applications. Improvements in the quality of casting metals and processing technologies have been leading to improve strength and reduce wall thickness, leading to light weight and more reproducible components [16].

Ungureanu et al, [17] developed a sustainability evaluation methodology for computing the potential benefits of using lighter materials, such as aluminum, in auto body applications. They stated in their study that the current equipment and processes are well suited for steel based components and processes would be needed to manufacture aluminum components. In comparing candidate materials that can be used in the automotive industry, aluminum and HSS are the most cost effective at large production volume scales, and their increasing use in vehicles is likely to continue. Cast aluminum is most suited to replace cast iron components, stamped aluminum for stamped steel body panels, and HSS for structural steel parts. Composites are also expected to replace some steel in the vehicle but to a smaller degree given high cost inhibitions [18]. Lightweight materials have been increasingly used in transportation vehicles due to their excellent mechanical properties. To reduce weight and improves fuel efficiency, which translates into long-term cost savings. There are various applications to decrease the weight of mass transit vehicle structures by replacing the body structure or individual components with lightweight materials. Much weight reduction has been achieved by material substitution and innovative design techniques in several parts [29] [20] [21].

The above researchers' concept shows materials such as steel and aluminum are significant part in automotive applications for weight reductions. Material likes aluminum is very important to resist corrosion. Also current research concept shows materials like structural steel very important to give better strength and sheet metals are used to reduce weight. Then sheet metal leads to produce better components strength and reduce wall thickness. It is an integrative technique that utilizes all fields of optimized design, manufacturing techniques. It is a technique to reduce the mass of an entire structure and its single elements while increasing the functional quality. Basic requirements for body structure materials include good corrosion resistance and recyclability. Body materials should also provide sufficient strength and controlled deformations under load to absorb crash energy, yet maintain sufficient survivable space for adequate occupant protection should a crash occur. Further, the structure should be light weight to reduce fuel consumption.

2.3.2.1 Monocoque or Integral Structure

Monocoque structures consist of sheets, beams or other kinds of metal components united by welding and resulting in a rigid structure in one piece. Monocoque structures are used now a day for the majority of the vehicles. It is efficient in terms of using space, so the interior space is wide. It is not cost effective to manufacture them in small quantities; however it is easy in mass produce. They can be economically produced due to the high automation which allows the manufacture. Monocoque structure uses more metal material than any other type of structure, consequently, it is heavier. Nevertheless, after having an accident the repairing is quite difficult. Less noise and vibration are produced compared with any other type of structure. Any kinds of reform in the structures are almost impossible to implement. Because it is geometrically very complicated, Sheet steel pressings and spot welds are used to form an integral structure. Stress distribution is function of applied loads and relative stiffness between components. Stress distribution can be analyzed by finite element analysis [58].

2.4 Impacts Analysis

2.4.1 Frontal Impact Analysis

The frame is made of steel members. The steel members are usually connected in such a way that the members undergo pure compression or tension. The Load required for frontal impact is obtained by creating where the vehicle is moving at a top speed of 65 kmph undergoing a head on collision with rigid body. A frontal crash is a two impact event. In the first (primary) impact, the vehicle strikes a barrier, causing the front end to crush. Kinetic energy of the vehicle is expended in deforming the vehicle’s front structure. The second (secondary) impact occurs when the occupant continues to move forward as a free flight mass and strikes the vehicle interior or interacts with or loads the restraint system. Some of the kinetic energy is expended in deforming the vehicle interior and in compressing the occupant’s torso. The remaining kinetic energy is dissipated as the occupant decelerates with the vehicle. During the secondary impact, injury may occur while the occupant is loading the interior system, if the impact loading or severity exceeds the injury threshold level. The kinetic energy of the occupant’s torso should be dissipated gradually for the impact to be non injurious. If there is more velocity between the occupant and the interior, much of the kinetic energy must be dissipated during the impact of the occupant with the interior system. If the second impact is of a very short duration, the resulting force on the occupant can exceed human tolerance levels. The kinetic energy dissipated during the second impact is a function of the occupant’s mass and of the more velocity of the occupant to the interior [51] [52].

2.4.2 Rear Impact

Rear impact collisions occur when a slower moving or stationary vehicle is struck from behind by a vehicle moving at a faster rate of speed. For cases of rear impact, the seats should be designed with high back rests and integrated head rests to help keep the head, neck and upper torso in safe alignment during the dynamics of a crash.

2.4.3 Side Impact

Side impact mechanisms come into play when the vehicle is involved in an intersection collision or when the vehicle veers off the road and impacts sideways utility pole, tree or other obstacle on the roadside. A side impact can accelerate a vehicle sideways [71]. For side impacts, the vehicle must have strong frame members and rocker sections that are at the outer most side of the vehicle body or if the main structural frame members are further in corner serve as extensions.

2.4.4 Rollover Impact Analysis

A rollover is a type of vehicle crash in which a vehicle tips over on to its side or roof. Rollovers have a higher fatality rate than other types of vehicle collisions [41]. Vehicle rollovers are divided into two categories: tripped and untripped. Tripped rollovers are caused by forces from an external object, such as a curb or a collision with another vehicle. Untripped crashes are the result of steering input, speed and friction with the ground [42]. The current research work concentrates on tripped rollover. Untripped rollovers occur when cornering forces destabilize the vehicle. As a vehicle rounds a corner, three forces act on it: tire forces (the centripetal force), inertial effects (the centrifugal force) and gravity. The cornering forces from the tire push the vehicle towards the center of the curve. This force acts at ground level, below the center of mass. The force of inertia acts horizontally through the vehicle's center of mass away from the center of the turn. These two forces make the vehicle roll towards the outside of the curve. The force of the vehicle's weight acts downward through the center of mass in the opposite direction. When the tire and inertial forces are enough to overcome the force of gravity, the vehicle starts to turn over. The most common type of tripped rollovers occur when a vehicle is sliding sideways and the tires strike a curb, dig into soft ground or a similar event occurs that results in a sudden increase in lateral force. The physics are similar to cornering rollovers. In a 2003 report, this was the most common mechanism accounting for 71% of single vehicle rollovers [43].

Another type of tripped rollover occurs due to a collision with another vehicle or object. These occur when the collision causes the vehicle to become unstable, such as when a narrow object causes one side of the vehicle to accelerate upwards, but not the other. A side impact can accelerate a vehicle sideways. The tires resist the change and the coupled forces rotate the vehicle [44].

A rollover can also occur as a vehicle crosses a ditch or slope. Slopes steeper than 33% (one vertical unit rise or fall per three horizontal units) are called "critical slopes" because they can cause most vehicles to overturn [45]. A vehicle may roll over for other reasons, such as when hitting a large obstacle with one of its wheels. Rollover crashes are particularly deadly for the occupants of a vehicle when compared to frontal, side or rear crashes, because in passenger vehicles, the roof is likely to collapse in towards the occupants and cause severe head injuries.

2.5 Crashworthiness

First used in the aerospace industry in the early 1950's, the term "crashworthiness" provided a measure of the ability of a structure and any of its components to protect the occupants in survivable crashes. Similarly, in the automotive industry, crashworthiness concerns a measure of the vehicle's structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads. Occupant packaging can provide additional protection to reduce severe injuries and fatalities. Crashworthiness evaluation is obtained by a combination of tests and analytical methods. Currently vehicle crashworthiness is evaluated in four distinct modes:

- Frontal
- Side
- Rear
- Rollover crashes

2.5.1 Crashworthiness Requirements

The vehicle structure should be sufficiently stiff in bending and torsion for proper ride and handling. It should minimize high frequency fore-aft vibrations that give rise to harshness. In addition, the structure should yield a deceleration pulse that satisfies the following requirements for a range of occupant sizes, ages and crash speeds for both genders [46] [47] [48].

- Deformable, yet stiff and front structure with some parts to absorb the crash kinetic energy resulting from frontal collisions by plastic deformation and prevent intrusion into the occupant compartment, especially in case of offset crashes and collisions with narrow objects such as trees. Short vehicle front ends, driven by styling considerations, present a challenging task to the crash worthiness engineer.
- Deformable rear structure to maintain integrity of the rear passenger compartment and protect the fuel tank.
- Properly designed side structures and doors to minimize intrusion in side impact and prevent doors from opening due to crash loads.
- Strong roof structure for rollover protection.

- Properly designed systems that work in harmony with the vehicle structure to provide the occupant with optimal ride down and protection in different interior spaces.

2.6 Forces on Vehicle Body

When the vehicle is moving at a considerable speed there are several forces are applied to vehicle in different directions.

2.6.1 Aerodynamic Forces

Aerodynamics is the way objects move through air. Anything that moves through air is affected by aerodynamics. Since they are surrounded by air, even vehicles are affected by aerodynamics [33]. “Aerodynamics” is a branch of fluid dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Understanding the motion of air (often called a flow field) around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties. The use of aerodynamics through mathematical analysis, empirical approximation and wind tunnel experimentation form the scientific basis. The natural environment for a ground vehicle takes place in the atmospheric region, where the interaction with the atmosphere creates forces. The relative motion to the atmosphere generates aerodynamic forces on the vehicle’s surfaces. In order to model the fluid motion properly it is essential to understand and apply the fluid dynamic and thermodynamic principles. In automotive aerodynamics the analysis is divided into external and internal flow categories [28].

Current thesis is concentrating on the external flows. Generally the external flows characteristics are governed by the geometrical configuration and Reynolds number of the flow. External flows are differentiated into three major term called the drag, lift and stability [29]. A moving vehicle relative to the atmosphere with a velocity vector is affected with two types of aerodynamic forces. On the opposite direction of the motion the force is called drag, while the perpendicular component is defined as lift. The shape of the vehicle and atmospheric conditions have a key role to determine the aerodynamic loads. It is a sensitive balance of the lift (pitching moment) and side forces (yawing moment), while the rotating moment has a role only in extreme cases [31].

2.6.1.1 Drag Force

Aerodynamic drag force is the force acting on the vehicle body resisting its forward motion. This force is an important force to be considered while designing the external body of the vehicle. The drag coefficient is a common measure in automotive design as it pertains to aerodynamics. Drag is a force that acts parallel and in the same direction as the air flow. The drag coefficient of automobile impacts the way the automobile passes through the surrounding air. When automobile companies design a new vehicle they take into consideration the automobile drag coefficient in addition to the other performance characteristics. Reducing the drag coefficient in an automobile improves the performance of the vehicle as it pertains to speed and fuel efficiency. The drag coefficient is dimensionless quantity that describes vehicle aerodynamic resistance and is useful tool for comparing different vehicle shapes [59, 86]. The Aerodynamic drag force is calculated by the following formula:

$$F_D = \tfrac{1}{2}\,\rho\, A\, C_D V^2 \tag{2.1}$$

Where

- F_D is drag force
- ρ is air density
- V is velocity of the vehicle
- A is frontal area of vehicle
- C_D is drag coefficient.

Drag is a sum of mechanical forces generated on the surface of an object due to the interaction with the fluid. In automotive aerodynamics drag is a major concern of study, since the magnitude of it is largely affect the vehicle characteristics such as fuel consumption. Acting drag force can be divided into two sources, but the physical origin makes them dependent to each other. In case of viscous flow the boundary layer has a strong influence on the external flow development, like separation where the adverse pressure gradient causes the detachment. The drag consists a pressure source term normal to the surface (pressure drag). In other approach the aerodynamic drag is an integral of static pressure and friction over the surface of the vehicle [32].

Total drag is formally defined as the force corresponding to the rate of decrease in momentum in the direction of the undisturbed external flow around the body. This decrease is calculated between stations at infinite distances upstream and downstream of the body, so it is the total force or drag in the direction of the undisturbed flow. It is also the total force resisting the motion of the body through the surrounding fluid.

Drag Reduction

In the above sections the origin and physical phenomena is introduced to define drag. For vehicle aerodynamics primary issue is to decrease drag. Also vehicle Company's objective is possible to reduce the drag [49]. Drag can be reduced by controlling the separations location with flow intervention near the wall region with or without additional external energy using devices [50]. Therefore, shape modification and improvement techniques on the vehicle body which reduces drag of the vehicle.

2.6.2 Lift Force

Lift force acting on the vehicle body vertically. Lift force causes the vehicle to get lifted in air as applied in the positive direction, whereas it can result in excessive wheel down force if it is applied in negative direction. Engineers try to keep this value to a required limit to avoid excess down force or lift [86, 90]. The formula usually used to define this force is written as:

$$F_L = \tfrac{1}{2} \rho A C_L V^2 \tag{2.2}$$

Where

- F_L is lift force
- ρ is air density
- V is vehicle of the vehicle
- A is frontal area of the vehicle
- C_L is lift coefficient.

2.6.3 Rolling Resistance Force

Rolling resistance force is due the tires deforming when contacting the surface of a road and varies depending on the surface being driven on.

2.6.4 The Normal Force

The normal force is the force exerted by the road on the vehicle's tires. Because the vehicle is not moving up or down (relative to the road), the magnitude of the normal forces equals the magnitude of the force due to gravity in the direction normal to the road.

2.7 Factors Contributing to Flow Field around Vehicle

The major factors, which affect the flow field around the vehicle, are the boundary layers, separation of flow field, friction drag and pressure drag.

2.7.1 Boundary Layer

Ludwig Prandtl first defined the aerodynamic boundary layer in a paper presented on August 12, 1904 at the third International Congress of Mathematicians in Heidelberg, Germany. This allows aerodynamicists to simplify the equations of fluid flow by dividing the flow field into two areas: one inside the boundary layer and the one outside the boundary layer. In this boundary layer around the vehicle and it plays a major role in drag of the vehicle. The viscosity is neglected in the fluid regions outside this boundary layer since it does not have significant effect on the solution. In the design of the body shape and the boundary layer is given high attention to reduce drag [33] [34] [35]. There are two reasons why designers consider the boundary layer as a major factor in aerodynamic drag. The first is that the boundary layer adds to the effective thickness of the body, through the displacement thickness, hence increasing the pressure drag. The second reason is that the shear forces at the surface of the vehicle causes skin friction drag, which arises from the friction of the fluid against the skin of the object that is moving through it [34].

2.7.2 Flow Separation

During the flow over the surface of the vehicle, there are some points when the change in velocity comes to stall and the fluid starts flowing in reverse direction. This phenomenon is called ‘separation’ of the fluid flow. This usually occurs at the rear part of the vehicle. This separation is mostly dependent on the pressure distribution, which is removed by the outer layer of the flow. This separation causes the flow to change its behavior behind the vehicle and thereby affects the flow field around the vehicle. This phenomenon is the major factor to be considered while studying the wake of the vehicle [33].

Flow separation which governs the pressure drag component can be divided into two types. The first type is where the separation line is perpendicular to the flow direction. A significant pressure loss behind the body is occurring due to the vortex field kinetic energy dissipation in the wake region (separation zone), where depression and low velocities are characterizing the flow. The other type is when the separation line is closing an angle with the flow direction. It leads to a three dimensional separation, which induce suction (pressure drag) behind the body. These two separations are in relationship and have a very complex three dimensional. So different angle of attacks leads to vortex breakdowns and vortex burst which is a highly important area to understand the physics behind it. It is a major research area in the topic of drag reduction. The previous paragraphs are introducing the drag and the fluid mechanical background to understand this force component. As a measure of the drag, it can be expressed as a dimensionless coefficient and so it is easier to compare different vehicles. Traditionally this drag representation is used, but there exists advanced approaches, where not only the surface integrals are in the formula, but it takes into account the vortex evolution in the rear wake of the flow in order to understand the relationship between components. Onorato et al [39] is introducing a simplified model based on the momentum equation.

2.7.3 Friction Drag

Every material or wall has a distinct friction, which resists the flow of fluids. Due to molecular friction, a stress acts on every surface of the vehicle. The integration of the corresponding force component in the free stream direction leads to a friction drag. If the separation does not occur, then friction drag is one of the main reasons to cause overall drag. The friction drag in a viscous flow is present all over the wall. Due to the molecular friction, shear stress is acting on the surface. The integration of this force component along the wall in the free stream direction is called the friction drag. For streamlined bodies like airfoils or flat bodies, where separation does not occur, this component is the dominant term of the drag [30]. The pressure drag is the dominant source for automotive flows, compared to the friction drag from the shear stresses. Generally the pressure distribution along a vehicle body or a vehicle consist a high pressure area in front (stagnation), and a low pressure area at the rear in the separation zone (wake). The flow separation is highly determines the pressure drag, thus it is important to understand the detachment of the flow.

2.7.4 Pressure drag

Behind the vehicles, there is a high pressure change, which leads to the separation of the flow separation in fluid flow. The front part of the flow field shows high pressure value, whereas on the rear part flow separates leading to a high suction in the area. As we integrate the force component created by such high change in pressure, the resultant is called as ‘pressure drag’. Pressure drag is generated by the resolved components of the forces due to pressure acting normal to the surface at all points [32, 39].

2.8 Vehicle Axis System

The coordinate system used in vehicle according to SAE J670e. The x-axis points to the forward direction or the longitudinal direction, the y-axis which represents the lateral direction and the z-axis points to the ground. In most studies related to handling and directional control, only the X-Y plane of the vehicle is considered. The vertical axis, Z, is often used in the study of ride, pitch, and roll stability type problems. Longitudinal direction: forward moving direction of the vehicle. There are two different ways of looking at the forward direction, one with respect to the vehicle body itself, and another with respect to a fixed reference point. The former is often used when dealing with acceleration and velocity of the vehicle. The latter is used when the location information of the vehicle with respect to a starting or an ending point is desired. Lateral direction: sideways moving direction of the vehicle. Again, there are two ways of looking at the lateral direction with respect to the vehicle and with respect to a fixed reference point. The body of the vehicle has been modeled with six DOF three linear motions along x, y and z-axes and three rotational motions about three axes (roll, pitch and yaw).

2.9 Passengers Ergonomics

It is possible to carry a great number of passengers in public transport units, but in attention to the users comfort and safety. In three wheeler vehicles (Bajaj) passengers' ergonomics problem is a big issue. This study focuses only passengers' ergonomics of three wheeler vehicles (Bajaj) not include driver ergonomics. The main aim of this study is to gather anthropometric data necessary for the design and manufacture of passenger seats as well as to compare the data with that of the passenger seats presently in use.

2.9.1 Ergonomics

According to Pheasant (1996), the word ergonomics comes from the Greek words for work (ergos) and natural law (nomos). The science of ergonomics was founded at a conference in 1949 and is an interdisciplinary science which studies how a work is performed, which tools are used the place where a work is performed and ergonomic aspects of the working environment. Ergonomics has one branch such as anthropometry. Ergonomic theories can also be used to determine optimal seating position for different situations.

The ergonomics is the study of the dealings between people and apparatus the factor that has an effect on the interface for the seat. Ergonomics study of equipment and devices that make fit for the human body that gives you more comfort and desirable seat. Its purpose is to improve the performance of systems by improving human seat interaction. This can be done by designing in a better interface. Consumer expectation for automobile seat comfort continues to rise. Main aim to improve the interface between occupant and vehicle [Kulkarni, 2011]. Ergonomics satisfies the condition of occupational health and safety, productivity, comfort and discomfort. Ergonomics is the application of methodical philosophy, method and statistics care from a range of discipline for the maturity of engineering system in which individuals play a note valuable responsibility [Bridger,1995],[Grujicic 2010] and [Kroemer,1994]. The Institute for Occupational Ergonomics (IOE) (1999) defines ergonomics as a research or work philosophy to understand the requirements and abilities of people in the consideration of safety and comfort. Generally ergonomics based on anthropometry data.

2.9.2 Anthropometry

The word anthropometry means “measurement of man” and that is a good description. Anthropometrics is usually presented as a collection of statistical data describing the distribution of bodily dimensions within a specific population. Together with an understanding of ergonomics, anthropometric data is a useful tool when designing any product indicates to interact with human operators. Kroemer et al. (2001) states that the science of anthropometry deals with the measurements of the human body meaning the size, shape, strength and working capacity of a human. Anthropometric data tells us about the variety of human measurements based on documented studies.

Ergonomics criteria stand for two those are physiological and anthropometric. Ergonomics associated to anthropometry data which have been measured input phase of restful seating position. Anthropometry data deals with the measurement which is best suitable for the individual’s body through which occupants will get more and more comfort. Anthropometry basically human parameter which has an account of design of seat according to the occupant need regarding safety and comfort. Therefore, according to the vehicle seat is main factor to enhance the comfort level [Nishith, 2014].

2.9.3 Passengers Seat

Comfort is an attribute that today’s consumers demand more and more. The seat has an important role to play in fulfilling these comfort expectations. Comfort is a feature that today’s clients demand more and more. The seat has a vital role to play in rewarding these comfort prospects. For the drivers and passengers relieves regarding seat of the vehicle is a main role to enhance comfort and safety of drivers (passengers) and sitting time period concern [Fai, 2007], [Rauterberg, 2010] and [Kittusamy, 2004].

2.10 Software

2.10.1 ANSYS

ANSYS is general purpose finite element analysis software package. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behavior of the product. Generally ANSYS is computer simulation tool for simulating the response of materials to short duration severe loadings from impact and high pressure [93]. ANSYS Mechanical is a finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. This computer simulation product provides finite elements to model behavior and supports material models and equation solvers for a wide range of mechanical design problems. ANSYS Mechanical also includes thermal analysis and coupled physics capabilities involving thermal structural and thermo electric analysis [95]. ANSYS Fluent (CFD) and related software are Computational Fluid Dynamics software tools used by engineers for design and analysis [98]. The class will describe how to use the code as well as basic finite element simulation concepts and results interpretation. The following figure 1 indicates an overview of ANSYS 16.0 software work bench.

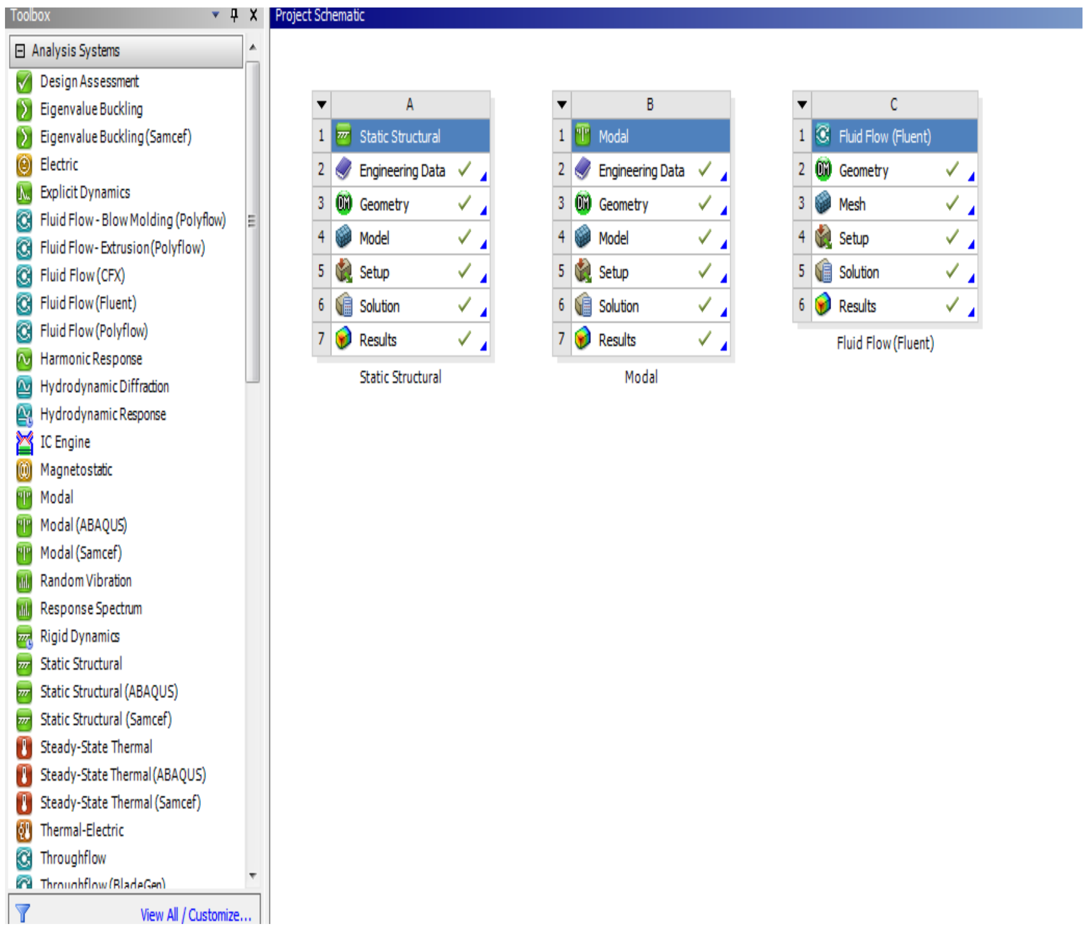


Figure 1: An overview of ANSYS 16.0 work bench

2.10.2 Finite Element Method

It is a numerical method seeking an approximated solution of the distribution of field variables in the problem domain that is difficult to obtain analytically. It is done by dividing the problem domain into several elements. Known physical laws are then applied to each small element, each of which usually has a very simple geometry. This powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications. FEM has substantially decreased the time to take products from concept to the production line [9]. It is primarily through improved initial prototype designs using FEM that testing and development have been accelerated [10]. Generally, benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, a faster and less expensive design cycle, increased productivity, and increased revenue [9].

Finite Element Analysis (FEA) has also been proposed to use in stochastic modeling for numerically solving probability models [11] [12]. Finite Element Analysis (FEA) is a type of computer program that uses the finite element method to analyze a material or object and find how applied stresses will affect the material or design. FEA can help determine any points of weakness in a design before it is manufactured. The analysis is done by creating a mesh of points in the shape of the object that contains information about the material and the object at each point for analysis.

2.10.3 CFD

According to Oleg Zikanov [37] CFD can be defined as “CFD (Computational fluid dynamics) is a set of numerical methods applied to obtain approximate solution of problems of fluid dynamics and heat transfer.” According to this definition, CFD is not a science by itself but a way to apply methods of one discipline (numerical analysis) to another (heat and mass transfer). The physical characteristics of the fluid motion can usually be described through fundamental mathematical equations, usually in partial differential form, which govern a process of interest and are often called governing equations in CFD.

CFD or Computational fluid dynamics is a branch of fluid mechanics that, with the help of computers, uses numerical methods to solve and analyze problems involving fluid flows. Computers are used to carry out calculations using an iterative procedure where in the solution accuracy improves with every iteration. The underlying equations that are solved in CFD problems are the Navier-Stokes equations. In the laminar regime, the flow of the fluid can be completely predicted by solving the steady-state Navier-Stokes equations, which predict the velocity and the pressure fields.

Jiyuan Tu, Guan Heng Yeoh and Chaoqun Liu [36] have discussed how to solve mathematical equations with using CFD. In order to solve mathematical equations, computer scientists convert them by using high-level computer programming languages into computer programs or software packages. The computational part simply means the study of the fluid flow through numerical simulations, which involves employing computer programs or software packages performed on high speed digital computers to attain the numerical solutions.

Advantages of CFD

With the rapid advancement of digital computers, CFD is poised to remain at the forefront of cutting edge research in the sciences of fluid dynamics and heat transfer. Also, the emergence of CFD as a practical tool in modern engineering practice is steadily attracting much interest and appeal. There are many advantages in considering CFD. The theoretical development of the computational sciences focuses on the construction and solution of the governing equations and the study of various approximations to these equations. CFD complements experimental and analytical approaches by providing an alternative cost effective means of simulating real fluid flows. Particularly, CFD substantially reduces lead times and costs in designs and production compared to experimental-based approach and offers the ability to solve a range of complicated flow problems where the analytical approach is lacking [36]. CFD has the capacity of simulating flow. Furthermore, CFD can provide rather detailed, visualized, and comprehensive information when compared to analytical and experimental fluid dynamics [37]. Although CFD is advantageous, it cannot easily replace experimental testing as a method to gather information for design purposes. Despite its many advantages, the researcher must consider the inherent limitations of applying CFD. Numerical errors occur during computations; therefore, there will be differences between the computed results and reality [38].

Factory of safety

Factory of safety is a term describing the load carrying capacity of a system beyond the expected or actual loads. Essentially, the factor of safety is how much stronger the system is than it usually needs to be for an intended load

Factory of safety is given by:

$$\text{Factory of safety} = \frac{\text{Tensile Yield Strength}}{\text{Designing stress}}$$

$$f_s = \frac{\sigma_y}{\sigma_{max}} \tag{2.3}$$

CHAPTER THREE

3. METHODS AND MATERIALS

3.1 Methods

To fulfill the objectives of this study, the method followed includes the following activities.

- *Data Collection*: Data collected from different sources. By measuring the basic dimensions of existing Bajaj three wheeler vehicle and collecting data from Bajaj three wheeler vehicle Company. Necessary documents also were collected from the company. The data related to Passenger ergonomics was collected through questionnaire.
- *Preparation of CAD Model*: The CAD model for existing structure and also new structure was prepared by using CATIA V5R19 software.
- *Importing of CAD model to ANSYS*: The model prepared in CATIA was imported to ANSYS workbench following appropriate procedure before analysis.
- *Structural Analysis:* Structure analysis (Stress, deformation...etc.) was done by Finite element analysis (FEA) with ANSYS 16.0 Workbench.
- *Impact Analysis:* The impact analysis such as frontal, rear, side and rollover static impact analysis was done by using finite element analysis (FEA).
- *Modal Analysis:* A modal analysis of the vibration characteristics (natural frequencies and mode shapes) of a structure was done by using ANSYS 16.0 software.
- *Aerodynamic Analysis:* The aerodynamic drag analysis was done by using CFD with ANSYS Fluent 16.0 workbench.
- *Analysis of Passengers ergonomics*: The obtained data through questionnaire related to passenger seat ergonomics was analyzed.

Materials required

- Materials used to accomplish this research are software like CATIA and ANSYS.
- Measuring instruments like tape measure (meter) and Calipers.
- Other items was used to accomplish this research Laptop Computer, Flash disk, digital Camera, Stationary materials, books, journals,... etc .

3.2 Specification of three Wheeler Vehicle (Bajaj RE)

Technical specification and necessary data of three wheeler vehicle has been collected from three wheeler Bajaj companies and by measuring of existing three wheeler dimensions. Company data and measured data that are approximately similar to the specification of the vehicle. All necessary information of three wheeler vehicle is shown in table 1.

Table 1: Specification of three wheeler vehicle (Bajaj RE)

Engine	
Name	Bajaj RE 4-stroke
Engine	Four stroke, spark ignition, forced air cooled
No of cylinders	One
Bore	63.5 mm
Stroke	62.8 mm
Engine displacement	198.88 CC
Maximum net power	7.45kW at 4500 $\pm$ 250 rpm
Maximum net torque	17.30Nm at 3500 $\pm$ 250 rpm
Compression pressure	12+ 0.5 kg/cm2
Compression ratio	9:1
Idling speed	1200$\pm$150 rpm
Ignition system	Electronic, d.c. type
Ignition timing	3^o BTDC upto1500 rpm and 17^o BTDC up to 2500 rpm
Lubrication	Pressurized Lubrication by Separate Oil Sump
Fuel	Petrol
Fuel Tank Capacity	Full: 8 litres and Reserve: 1.5 litres
Carburetor	Side draft 18mm equivalent venture
Spark plug	2 nos

Spark plug gap	0.6 up to 0.8mm
Starting	Electric Start
Transmission	
Clutch	Wet, multi disk type
Transmission (gear)	4-speed forward+ 1reverse
Overall gear ratios	
1^{st} gear	32.558:1
2^{nd} gear	19.065:1
3^{rd} gear	11.862:1
4^{th} gear	8.25:1
Reverse gear	28.59:1
Differential	Integral with Engine
Differential gear ratio	Forward 2.192:1, Reverse 1.925:1
Suspension	
Front	Anti drive type, constant rate coil spring and double acting
Rear	Independently sprung wheels by trailing arms with helical
Chassis and Body	
Frame type	Constructed from pressed steel sheets and sections welded
Brakes	
Front	Hydraulic expanding shoe type size 170mm * 29.5 wide
Rear	Hydraulic expanding shoe type size 170mm * 29.5 wide
Hand	Mechanical expanding shoe type on rear wheels
Parking	Mechanically operated on rear brakes
Wheel outer diameter	400mm
Wheel rims (front and rear)	8 in×3 in
Tyre Size	4-8,4P.R.

Tyre pressure	
Front	2.1kg/cm^2 (30 psi)
Rear	2.4 kg/cm^2 (34 psi)
Electrical System	12 volt d.c.
Battery	12v ,32 Ah
Head lamp	35/35 W
Tail/stop lamp	5/21 W
Side indicator lamp	10 W
Pilot lamp	5 W
Reverse lamp	10 W
Indicator	2 W
Horn	12 V d.c
Wiper system	Electrical wiper motor
Dimensions	
Length	2625 mm
Width	1300 mm
Height	1710 mm
Wheel base	2000 mm
Wheel track	1150 mm
Ground clearance	180 mm
Turning circle radius	5760 mm
Weight	
Kerb weight	348 kg (the weight of motor vehicle without occupant or baggage)
Gross vehicle weight	678kg
Maximum play-load including driver	310 kg
Maximum front axle weight	210 kg
Maximum rear axle weight	430kg
Performance	
Maximum speed	65 km/h
Climbing ability	18% maximum

3.3 Modeling existing three wheeler Vehicle Structure (CAD model)

The model has been done using the overall dimensions length is 2625mm, width 1300mm and height is 1710mm. Bars with circular cross sections and diameters of 25mm and 3mm thickness have been modeled in CATIA V5R19 software for roofing purpose. Finally each part assembled together before going to finite element analysis. Figure 2 shows 3D model of existing vehicle structure.

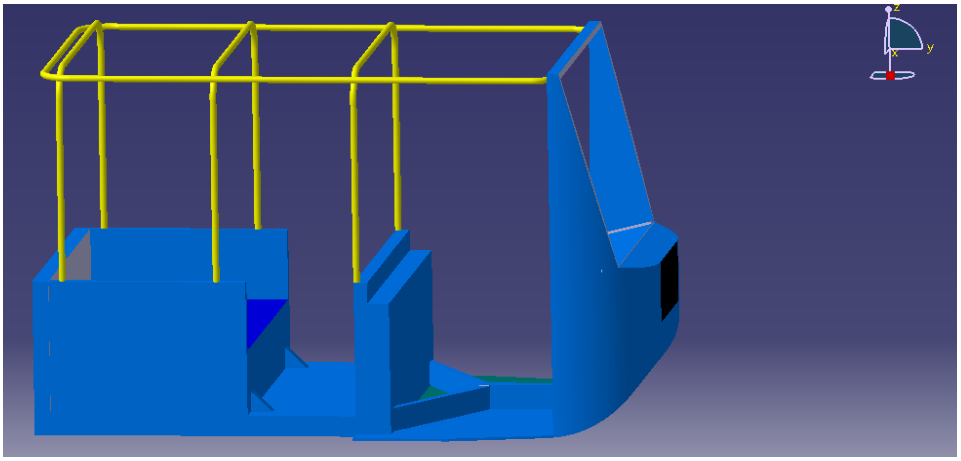


Figure 2: 3D model of existing three wheeler structure

3.4 Modeling new (modified) three wheeler Vehicle Structure (CAD model)

This model has been done using the overall dimensions length is 2625mm, width 1300mm and height is 1710mm. Bars with circular cross sections and diameters of 36 mm and 3mm thickness have been modeled in CATIA V5R19 software. Finally each part assembled together before going to finite element analysis. Figure 3 shows 3D model of new vehicle structure.

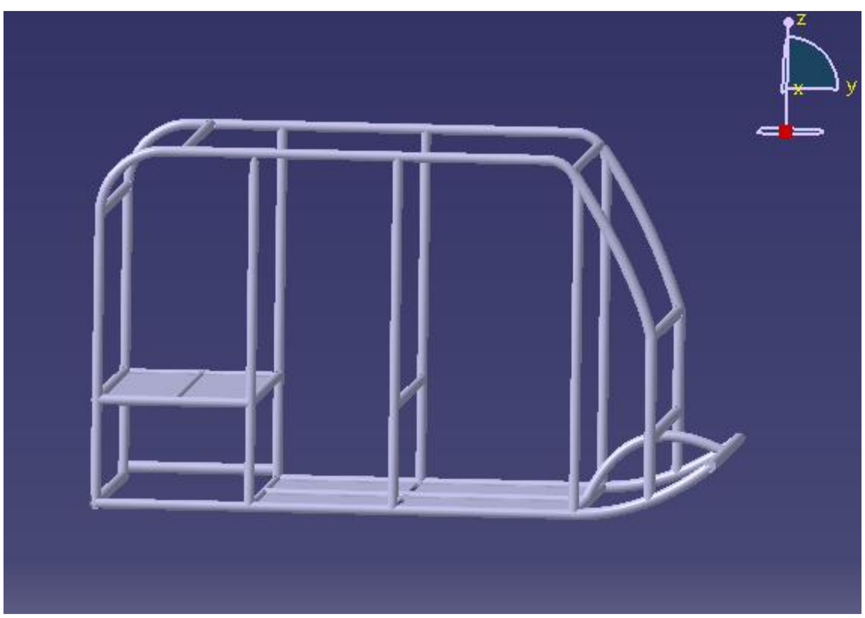


Figure 3: 3D CATIA model of new structure

Figure 3 shows tubular space frame structure which is found to be better. Using this structure the TWV will be safer and good for mass production. The space frame design is a very popular option for chassis type, as it is a low cost, simple to design and easy to construct. Space frame has a high strength and the mechanical components and the bodywork are attached on it. This structure gives some advantages. It has a great strength to carry heavy loads and a high rigidity to withstand high elastic and dynamic stresses. Since the space frame systems are tubular form, it will provide maximum strength and minimum deflection compared to the other chassis types. This system also protects the bodywork from bending or torsion effects.

3.5 FEA Simulation Procedures

3.5.1 Loads and Boundary Conditions for FEA

Total weight of three wheeler vehicle having all components without occupant or baggage is, 348 kg (3413.88 N). This will be applied at the center of gravity of the frame. Maximum pay load including driver is 310 kg applied at seat points of each passenger and driver. For each will have 78 kg (765.18 N) weight. The TWV chassis model is loaded by static forces from its own body and load from passengers, driver, and other baggage weight. For this model, the maximum loaded Gross vehicle weight is 678 kg. The load is assumed as a uniform distributed obtained from the maximum loaded weight divided over the total length of chassis frame. Maximum front axle weight is 210 kg (2060.1N), which is the part of the Gross vehicle weight that loaded on front tire so that it uses as a vertical reaction force at front tire. Maximum rear axle weight is 430 kg which is the part of the Gross vehicle weight that loaded on rear left and rear right tires, so that it uses as a reaction force. For the two rear tires there is a 215 kg (2109.8N) reaction load each. Since loads and boundary conditions of new model is the same as existing model. So our aim is to get better strength and reduce weight in comparison to the existing model. Look at the following figure 4 loads and boundary conditions of the existing model (existing structure). Also the figure 5 indicates loads and boundary conditions of the new model (modified structure).

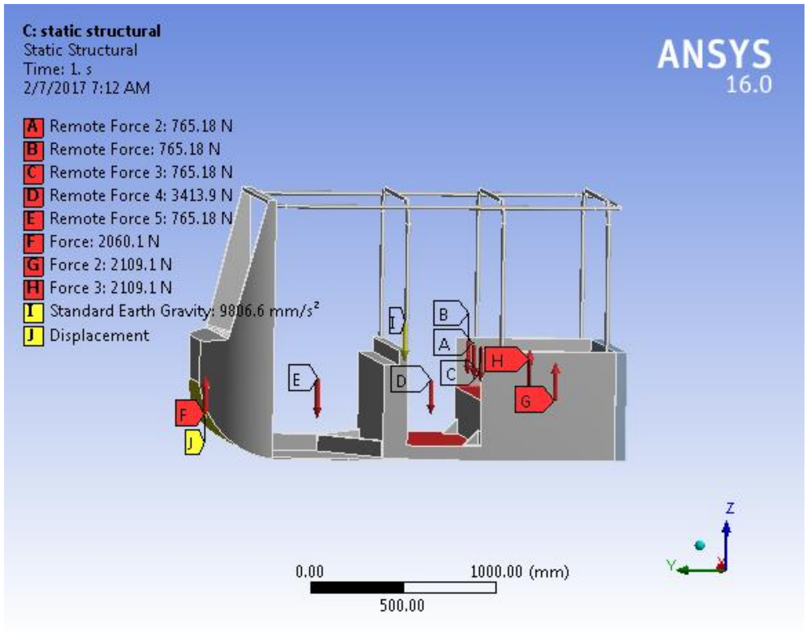


Figure 6: Loads and Boundary Conditions of the existing model

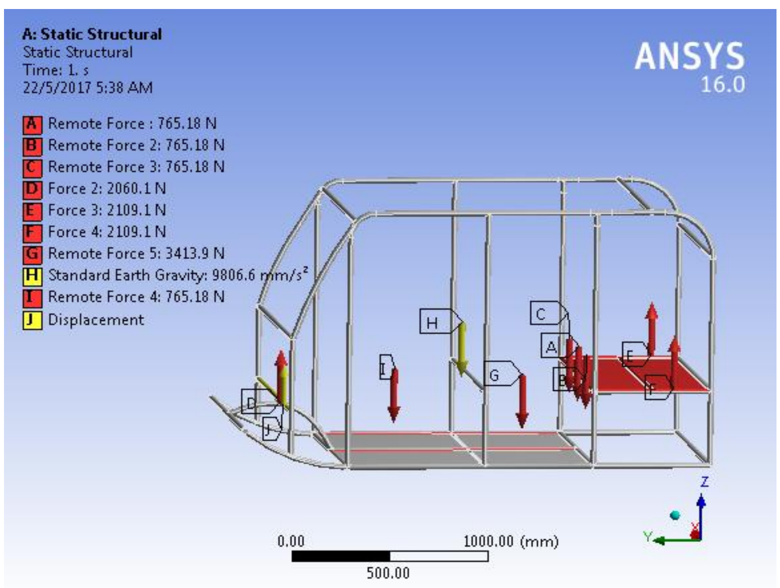


Figure 7: Loads and Boundary Conditions of the new model

3.5.2 Mesh

Meshing is basically the process of dividing the CAD model into very small elements which are solved simultaneously to evaluate the behavior of the entire system. It is also known as piecewise approximation. The figure 6 shows meshed model which has 47760 nodes and 20812 elements**.** Also figure 7 shows meshed model which has 158946 nodes and 83399 elements.

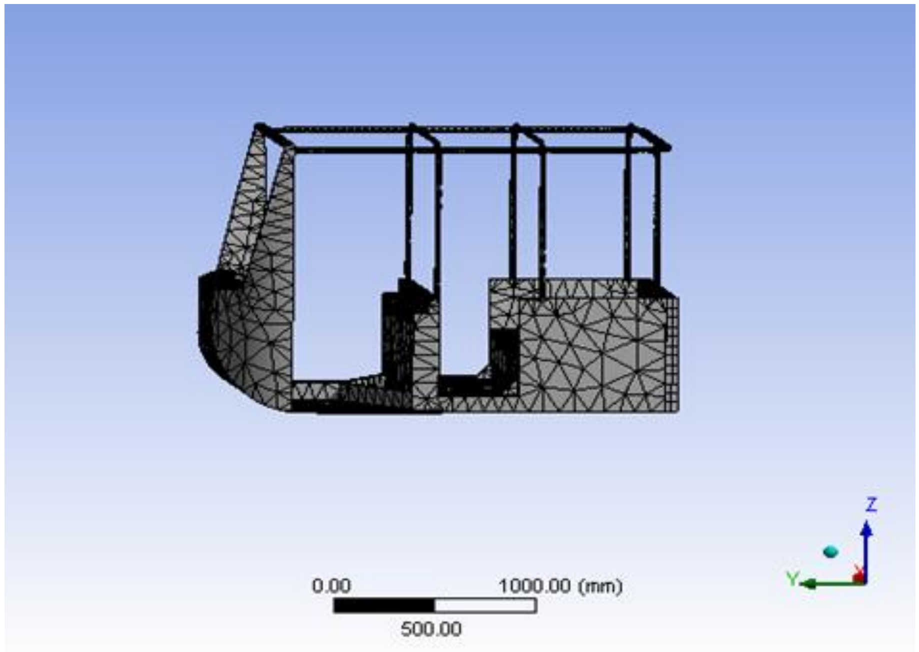


Figure 8: Mesh of existing model structure

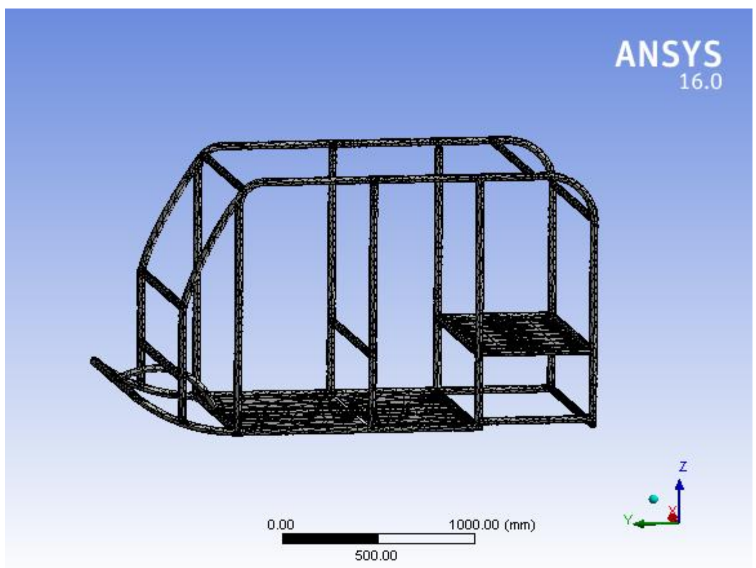


Figure 9: Mesh of new model structure

3.6 CFD Simulation procedure

3.6.1 Vehicle Geometry Modeling

This process involved computer aided design (CAD) software like CATIA V5R19. For modeling the geometry, 3D modeling software CATIA V5R19 was used. The modeling process involved importing the vehicle CAD model from CATIA to ANSYS software. Figure 9 shows the front part of the model 2 is modified rake angle (α) = 35^0. All dimensions are in mm.

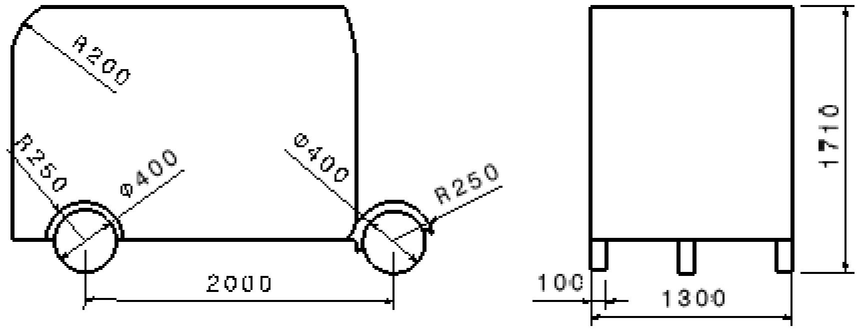


Figure 10: CAD drawing for existing model

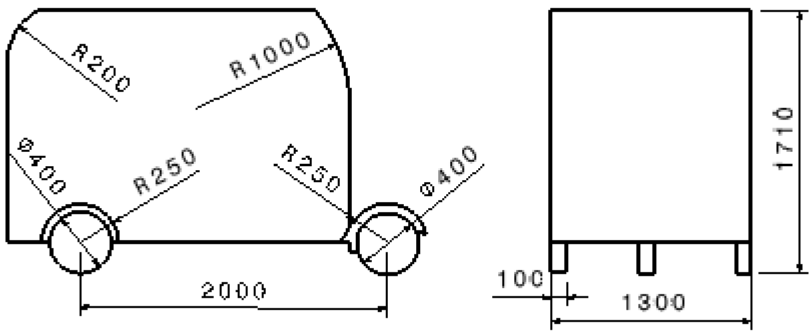


Figure 11: CAD drawing for new model

3.6.2 Creating Fluid Enclosure

In order to simulate the air flow around the vehicle, a fluid volume needs to be created which will encompass the vehicle. This was done by creating an enclosure around the vehicle and subtracting the vehicle body. This enclosure acts as the air domain. To reduce the overall computational cost and time, the vehicle was considered symmetric laterally.

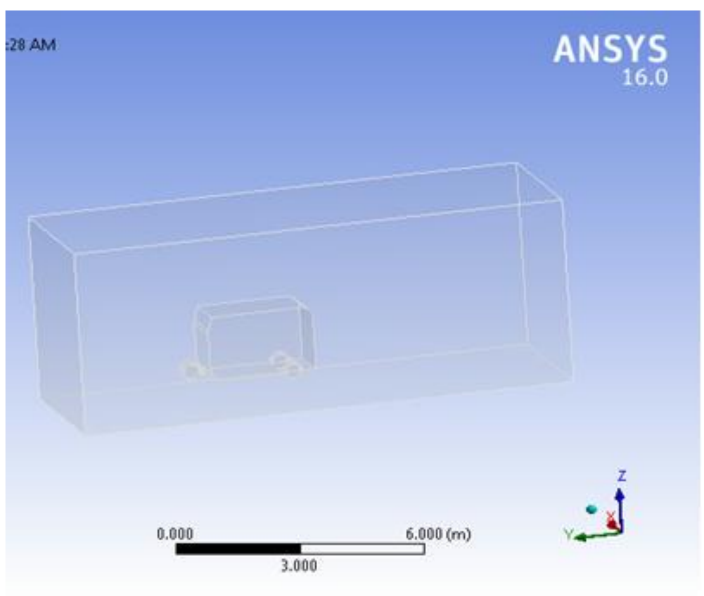


Figure 12: Model 1 inside Enclosure

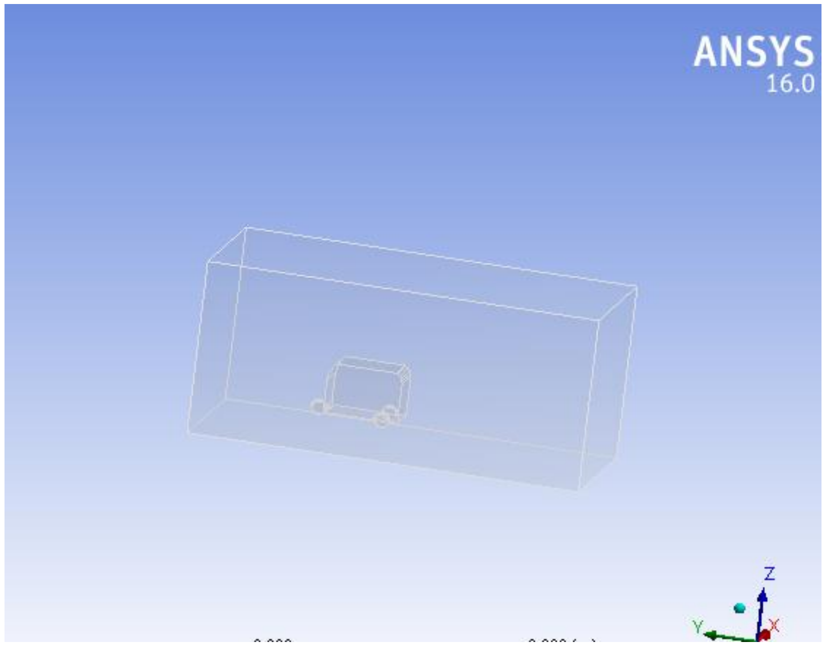


Figure 13: Model 2 inside Enclosure

3.6.3 Mesh Generation

While generating the mesh, sizing functions were used wherever necessary in order to obtain accurate lift/drag parameters. Mesh generation constitutes one of the most important steps during the preprocess stage after the definition of the domain geometry. CFD requires the subdivision of the domain into a number of smaller, non overlapping sub domains in order to solve the flow physics within the domain geometry that has been created; this results in the generation of a mesh or grid of cells (elements or control volumes) overlaying the whole domain geometry.

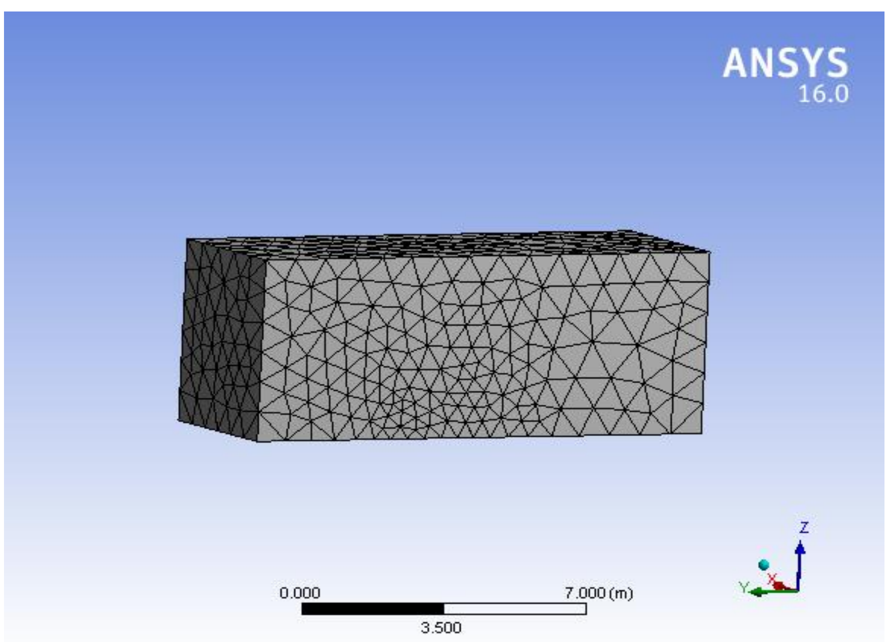


Figure 14: Mesh generated

3.6.4 Boundary Conditions

The complex nature of many fluid flow behaviors has important implications in which boundary conditions are prescribed for the flow problem. A CFD user needs to define appropriate conditions the real physical representation of the fluid flow into a solvable CFD problem. Every different setup of the CFD domain needs to have an initialization, which is fulfilled by the boundary conditions input [36]. The CFD code usually has this facility to define the boundary conditions of the CFD problem, where each cells at specific boundary are given finite values. The enclosure inlet plane was named “velocity-inlet”. Air coming through the inlet was given a velocity of the vehicle in kmph. The road and the vehicle body were both made walls. The surrounding enclosure surfaces, being imaginary surfaces, were all named symmetry planes having a no slip condition. The outlet was named a “pressure-outlet” with its pressure set constant and equal to atmospheric pressure.

- Velocity boundary condition at the inlet of the control volume;V= 50km/h, 60km/h and 70 km/h
- Boundary condition reference area, A = 2.223 m^2, density of air, ρ = 1.225 kg/m^3
- No-slip condition at the surface of the model.
- Moving boundary condition on the ground surface of road.

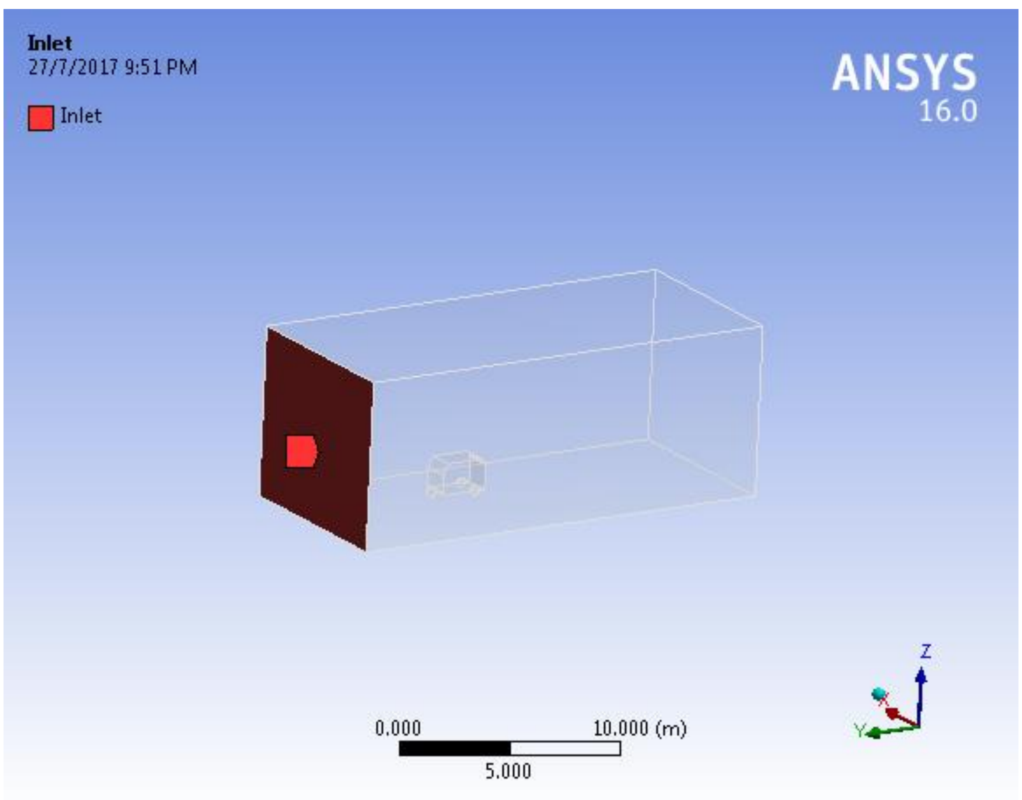


Figure 15: Boundary Conditions

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 Finite Element Analysis of the TWV Structure

About finite element analysis already explained in the methodology. In this chapter FEA simulation result of both models were discussed clearly. This FEA process leads to a set of linear algebraic simultaneous equations for the entire system that can be solved easily to yield the required field variable. Strength is the ability of a material to resists the externally applied forces without breaking of yielding.

4.1.1 Finite Element Analysis of the existing TWV Structure

Material selection for structural analysis provides the desired strength, endurance and safety to the vehicle. To choose the optimal material we need an extensive study on the properties of different materials. For structural steel material properties are given in the following table 2.

Table 2: Materials for the three wheeler vehicle

Material	Structural Steel
Yield Tensile Strength	250 Mpa
Ultimate Tensile Strength	460 Mpa
Yield compressive Strength	250 Mpa
Poisson’s Ratio	0.3
Young’s modulus (E)	200000 MPa
Bulk modulus	1.6667E+5 MPa
Shear modulus	7.6923E+4 MPa

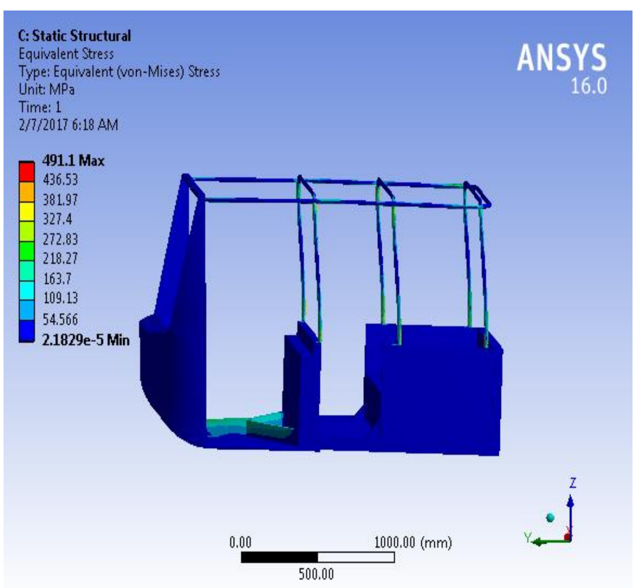
4.1.1.1 Static Structural Analysis of existing Model

A static strength analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. This analysis determines the displacements, stresses, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Figure 4 shows loads and boundary conditions of the existing model during static structural analysis.

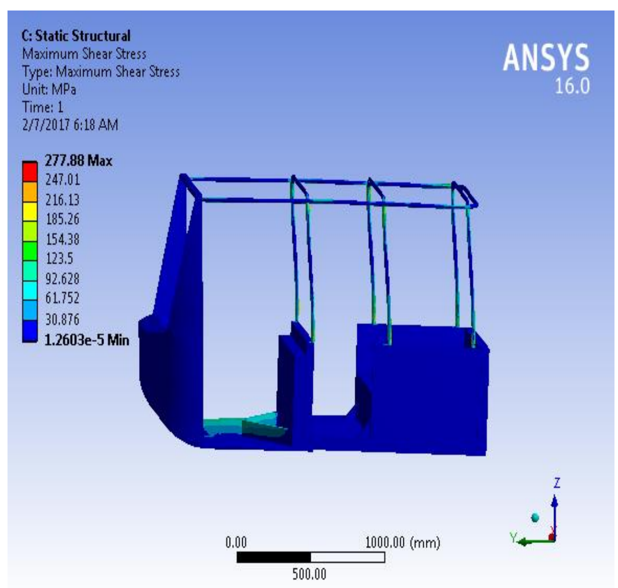
Table 3: Simulation result of static analysis of existing model

Result Type	Equivalent or von misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	2.1829e-5	1.2603e-5	-138.01	00.16535	0.50906	-23.689
Maximum	491.1	277.88	481.43	24.421	-	0.26336

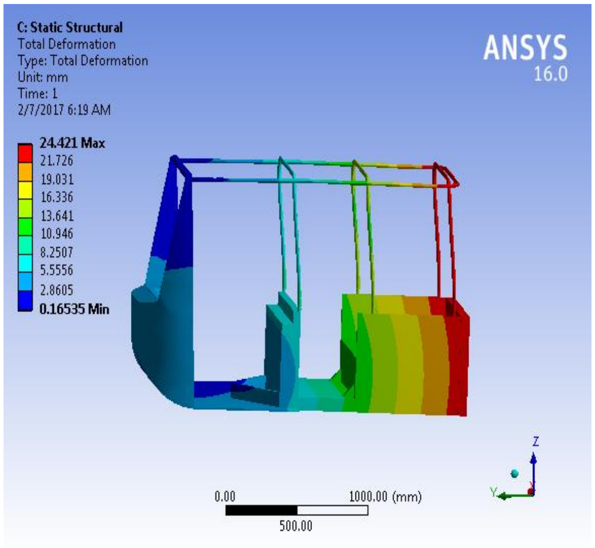
The maximum equivalent stress safety tool is based on the maximum equivalent stress failure theory for ductile materials, also referred to as the von Mises-Hencky theory. The theory states that a particular combination of principal stresses cause failure if the maximum equivalent stress in a structure equals or exceeds a specific stress limit. The maximum shear stress safety tool is based on the maximum shear stress failure theory for ductile materials. The theory states that a particular combination of principal stresses causes failure if the maximum shear equals or exceeds a specific shear limit, where the limit strength is generally the yield strength of the material.



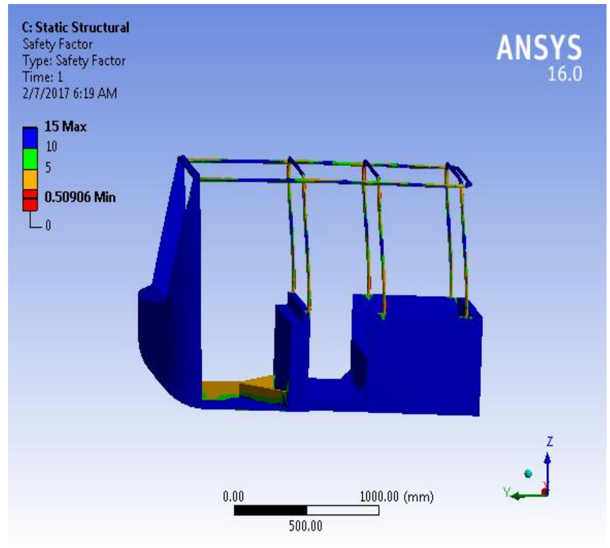
a) Equivalent Stress



c) Maximum Shear Stress



b) Total Deformation



d) Safety Factor

Figure 16: Static Simulation result of a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of existing model

4.1.1.2 Impact Simulation of Existing Model

4.1.1.2.1 Frontal Impact Simulation

The Load required for frontal impact is obtained where the vehicle is moving at a top speed of 65 kmph undergoing a head on collision with rigid body. The mass of the vehicle including the driver and passengers is 678 kg. The various loads are calculated using basic mechanics [89, 92]. Since the front impact is instantaneous, the time of impact was assumed to be 0.15s.

$$F = m * a \tag{4.2}$$

Gross mass of the vehicle, m = 678 kg

Velocity of the vehicle, v = 65 kmph = 18 m/s

Time of impact, t = 0.15 s

Acceleration, = $\frac{v_f - v_i}{t} = \frac{0-18}{0.15}$ = 120 m/s^2

Impact force, F = m ∗ a = 678*120 = 81.360 kN

Where v_f is final velocity of the vehicle, v_i is initial velocity of the vehicle, m is mass of the vehicle, t is time of impact, a is acceleration and F is impact force. The point of application of these loads will be the actual attachment points between the impact front heads see in figure 15. Model used is full model of the three wheeler vehicle with boundary conditions at suspension mounting points Uy = Ux = 0 and at rear corner points all DOF = 0.

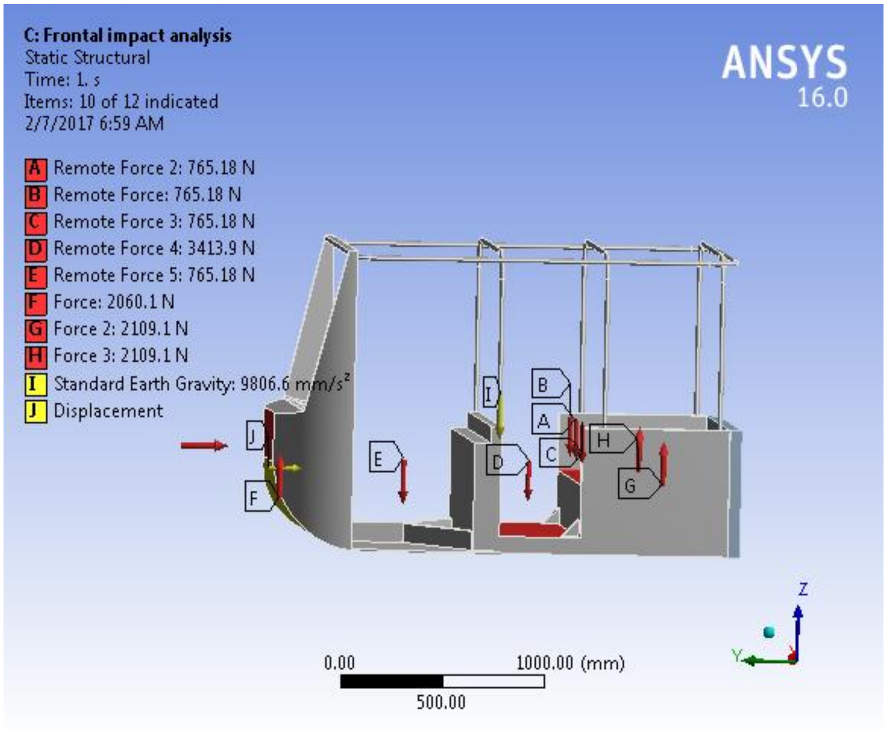
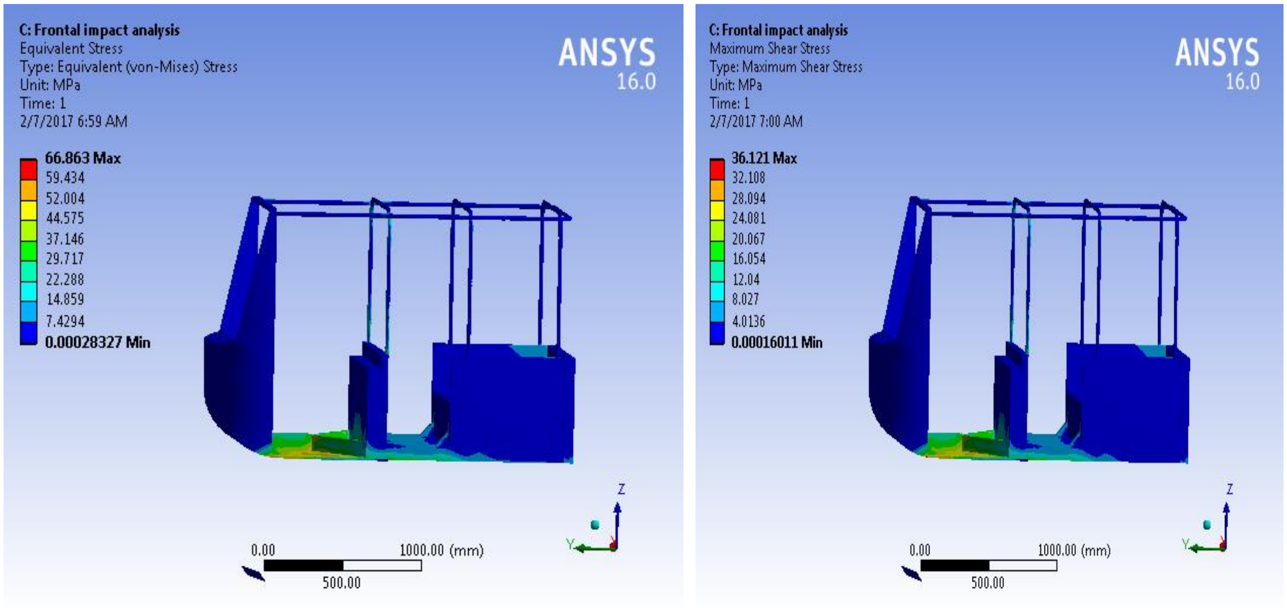


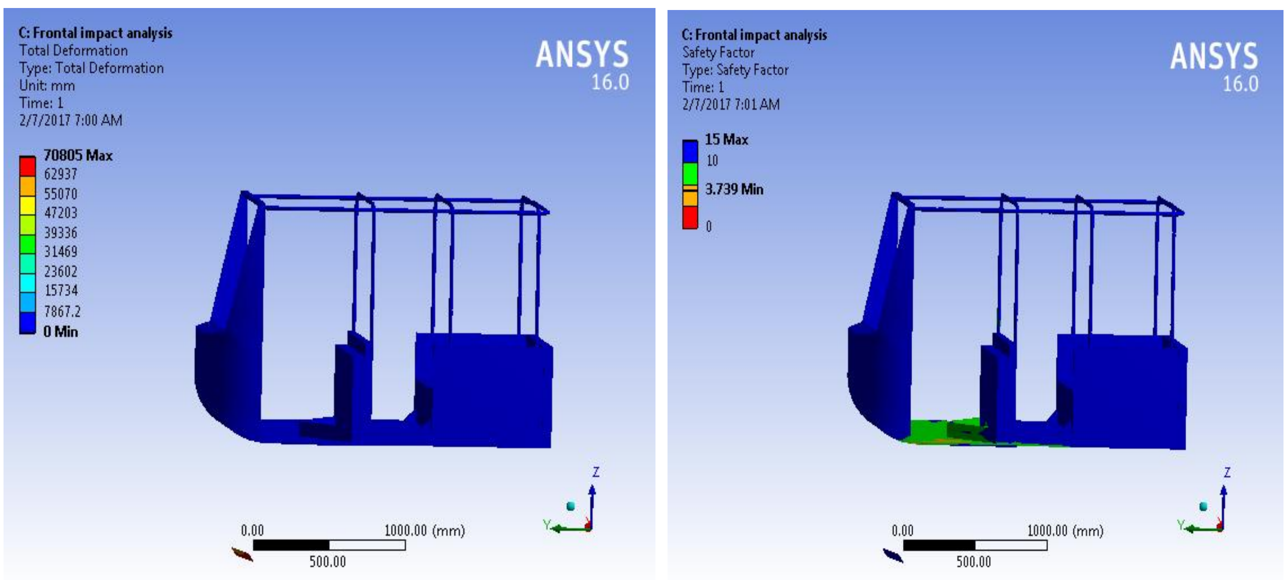
Figure 17: Loads and Boundary Conditions Frontal impact of the existing model

Table 4: Frontal impact simulation result of existing model

Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	0.00028327	0.00016011	-13.192	0	3.739	-5269.2
Maximum	66.863	36.121	53.97	70805	-	4062.7



a) Equivalent Stress c) Maximum Shear Stress



b) Total Deformation d) Safety Factor

Figure 18: Frontal impact Simulation of a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of existing model.

4.1.1.2.2 Side Impact Simulation

The side impact loading analysis of the chassis of the Bajaj three wheeler is carried out to ensure the safety of the driver and passengers for any collisions on the side with another vehicle. In the side impact test the chassis is aligned sideways relative to the oncoming vehicle. The load required for the side impact is obtained where one vehicle is moving towards the other's side at a top speed of

65 kmph. The mass of the vehicle including the driver and Passengers is 678 kg. The loads to be applied to the chassis are calculated as follows [71].

Gross mass of the vehicle, m = 678 kg

Velocity of the vehicle, v = 65 kmph = 18 m/s

Time of impact, t = 0.30 s

Acceleration, a = $\frac{v_f - v_i}{t} = \frac{0 - 18}{0.30}$ = 60 m/s^2

Impact force, F = m∗a = 678* 60 = 40.680 kN

Where v_f is final velocity of the vehicle, v_i is initial velocity of the vehicle, m is mass of the vehicle, t is time of impact, a is acceleration and F is impact force.

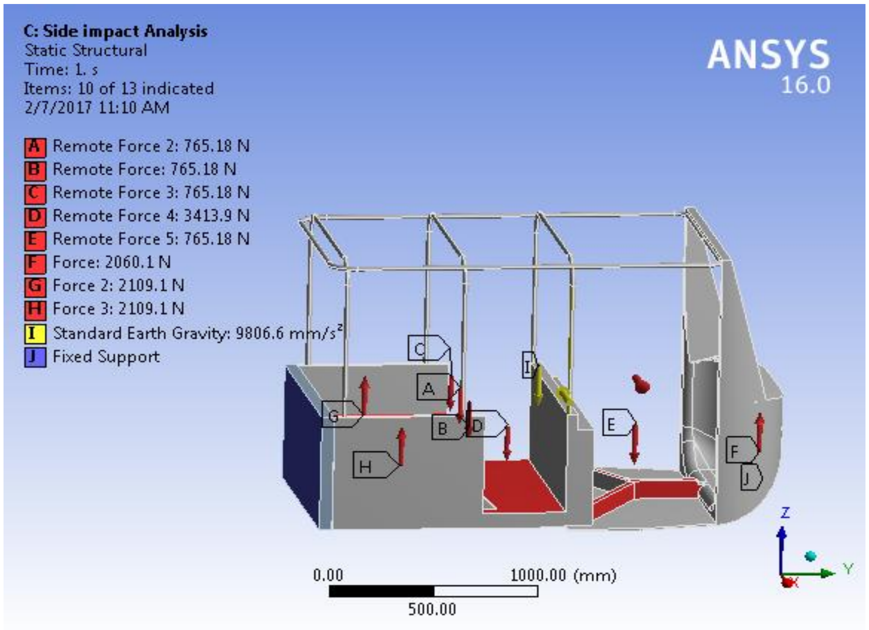
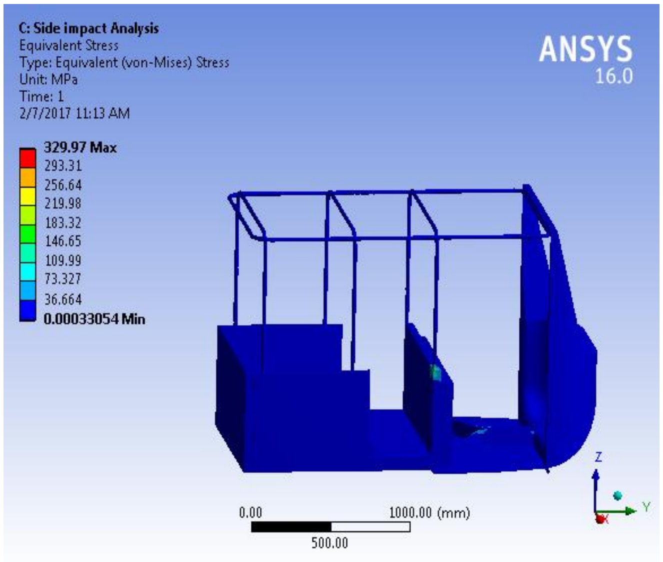


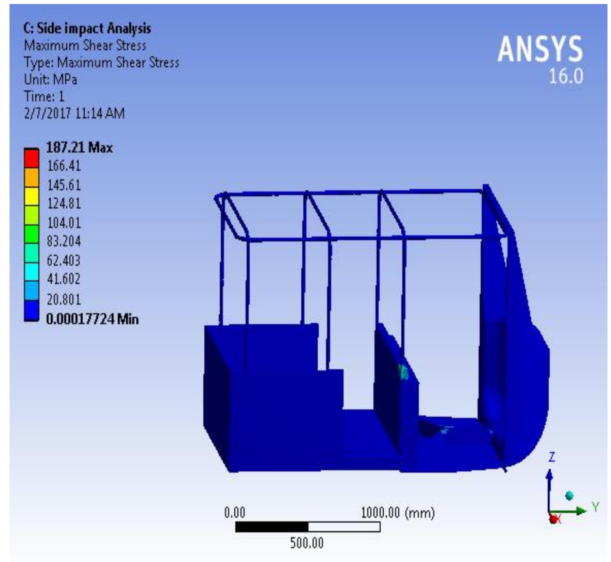
Figure 19: Loads and Boundary Conditions side impact of the existing model

Table 5: Side impact simulation result of existing model

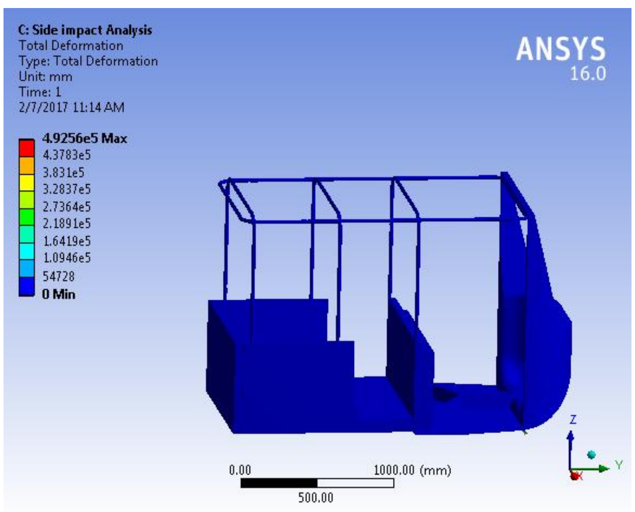
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	0.00033054	0.0001772	-60.767	0	0.75764	-2.8367e5
Maximum	329.97	187.21	431.6	4.9256e5	-	4.8319e5



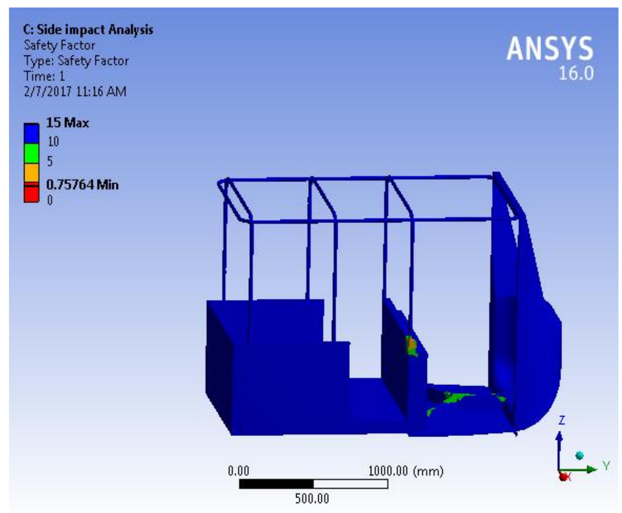
a) Equivalent Stress



c) Maximum Shear Stress



b) Total Deformation



d) Safety Factor

Figure 20: Side impact Simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of existing model

4.1.1.2.3 Rear Impact Simulation

The rear impact load calculation is similar with frontal impact load required. So the Load required for rear impact is 81.360 kN load apply at the rear. The boundary conditions are used at suspension mounting points Ux = Uy = 0 and at front corner points all DOF = 0.

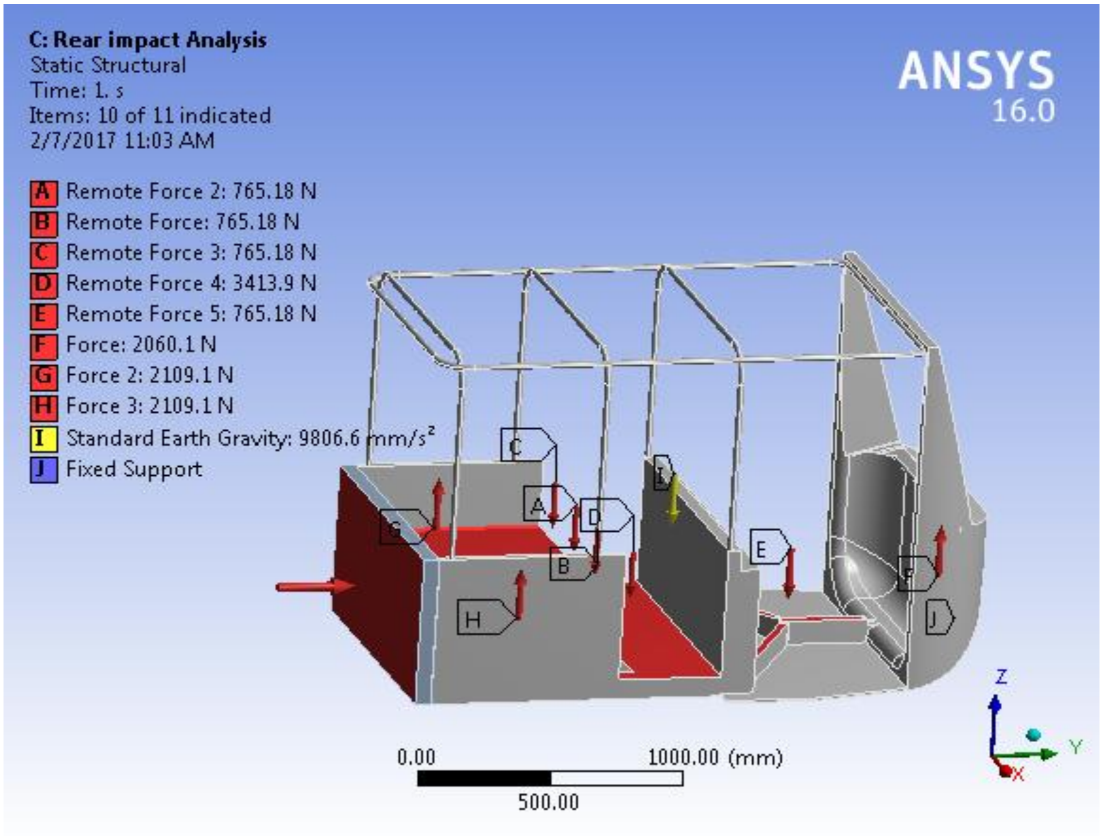
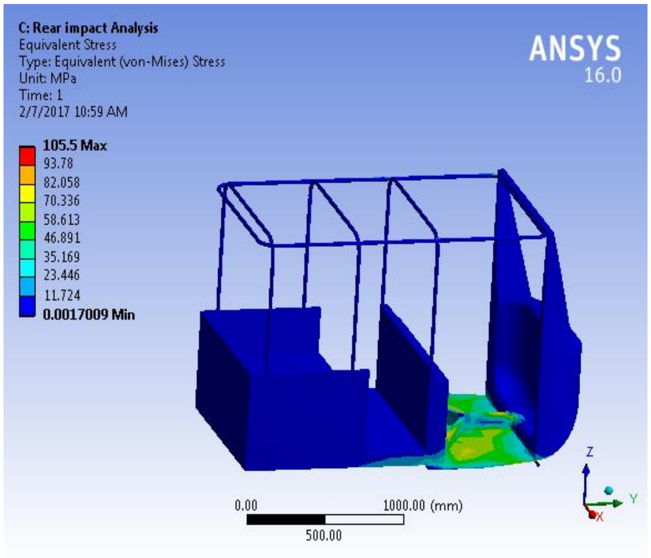


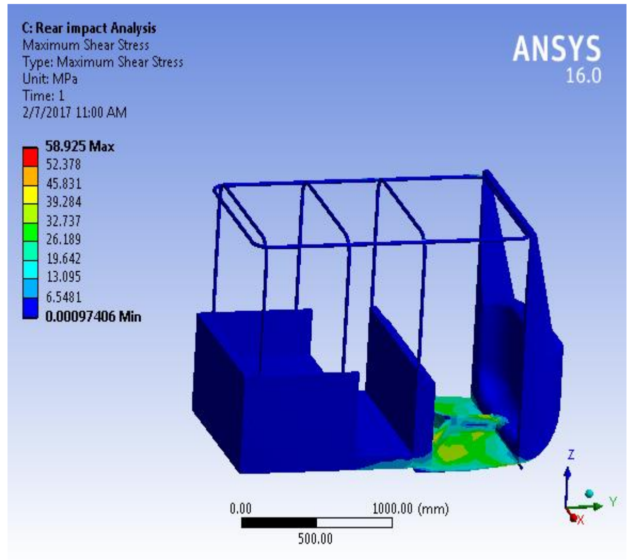
Figure 21: Loads and Boundary Conditions Rear impact of the existing model

Table 6: Rear impact simulation result of existing model

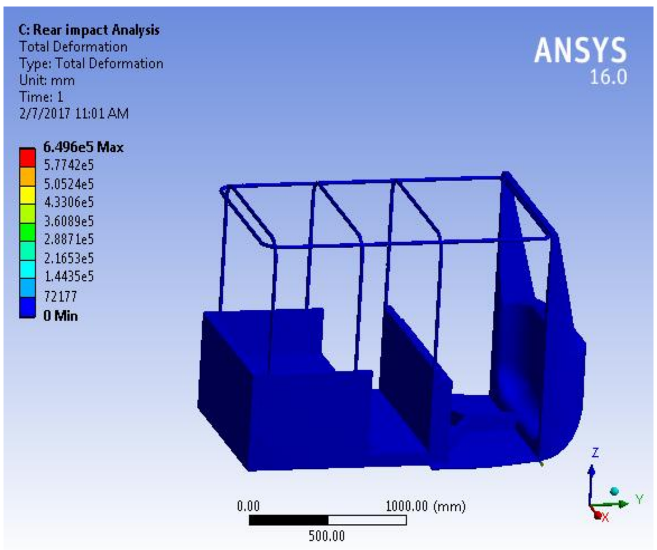
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	0.0017009	0.00097406	-19.566	0	2.3696	-24037
Maximum	105.5	58.925	89.908	6.496e5	-	95650



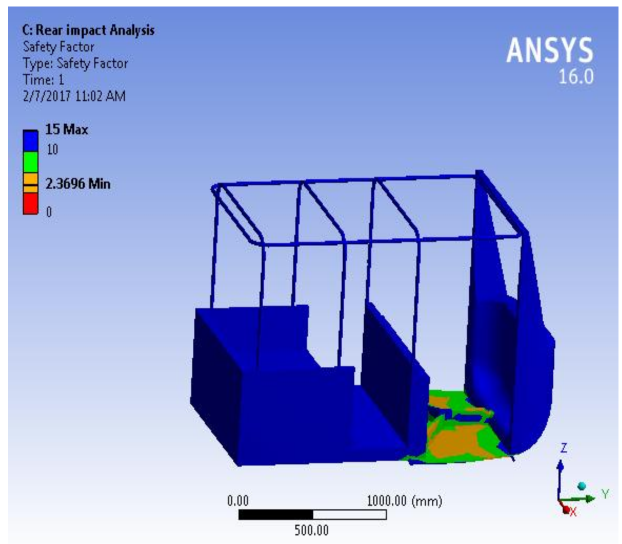
a) Equivalent Stress



c) Maximum Shear Stress



b) Total Deformation



d) Safety Factor

Figure 22: Rear impact Simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of existing model

4.1.1.2.4 Rollover impact simulation

The rollover impact analysis is performed to design the strong roof structure for maximum safety during the roll over incidents. The optimized parameters obtained from front impact and side impact analysis is used as input for the rollover impact loading analysis. The load required for the roll over impact loading analysis is obtained by using 50% of the load used for the frontal impact analysis as follows [69].

Impact force, $F = 0.5 * \text{Frontal impact load} = 0.5 * 81.680 \text{ kN} = 40.680\text{kN}$

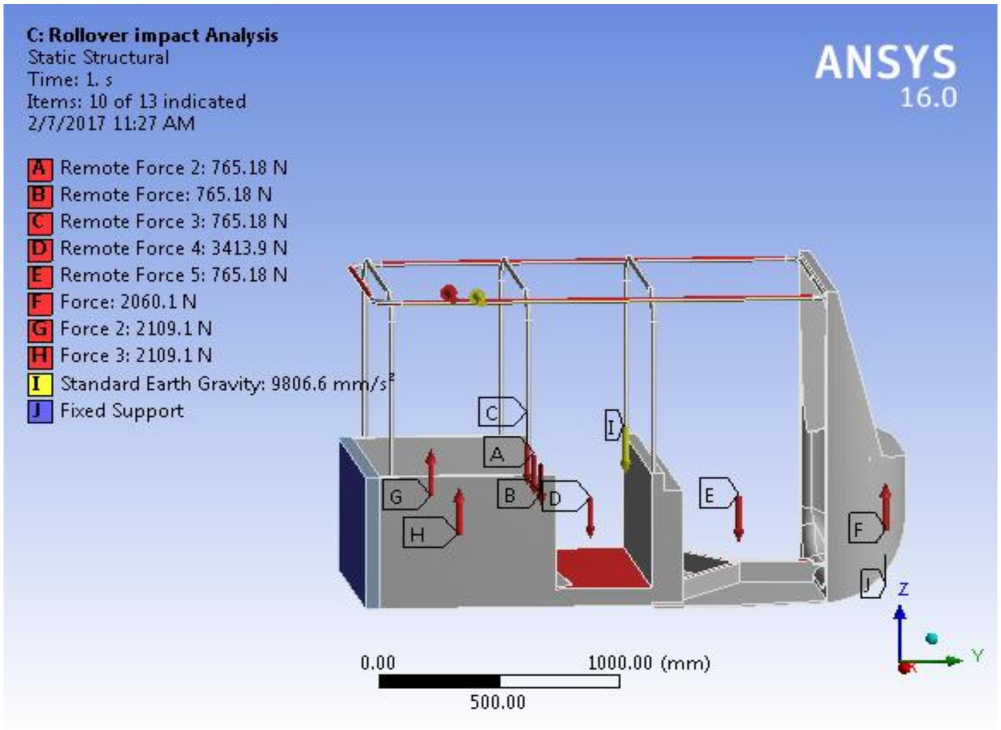
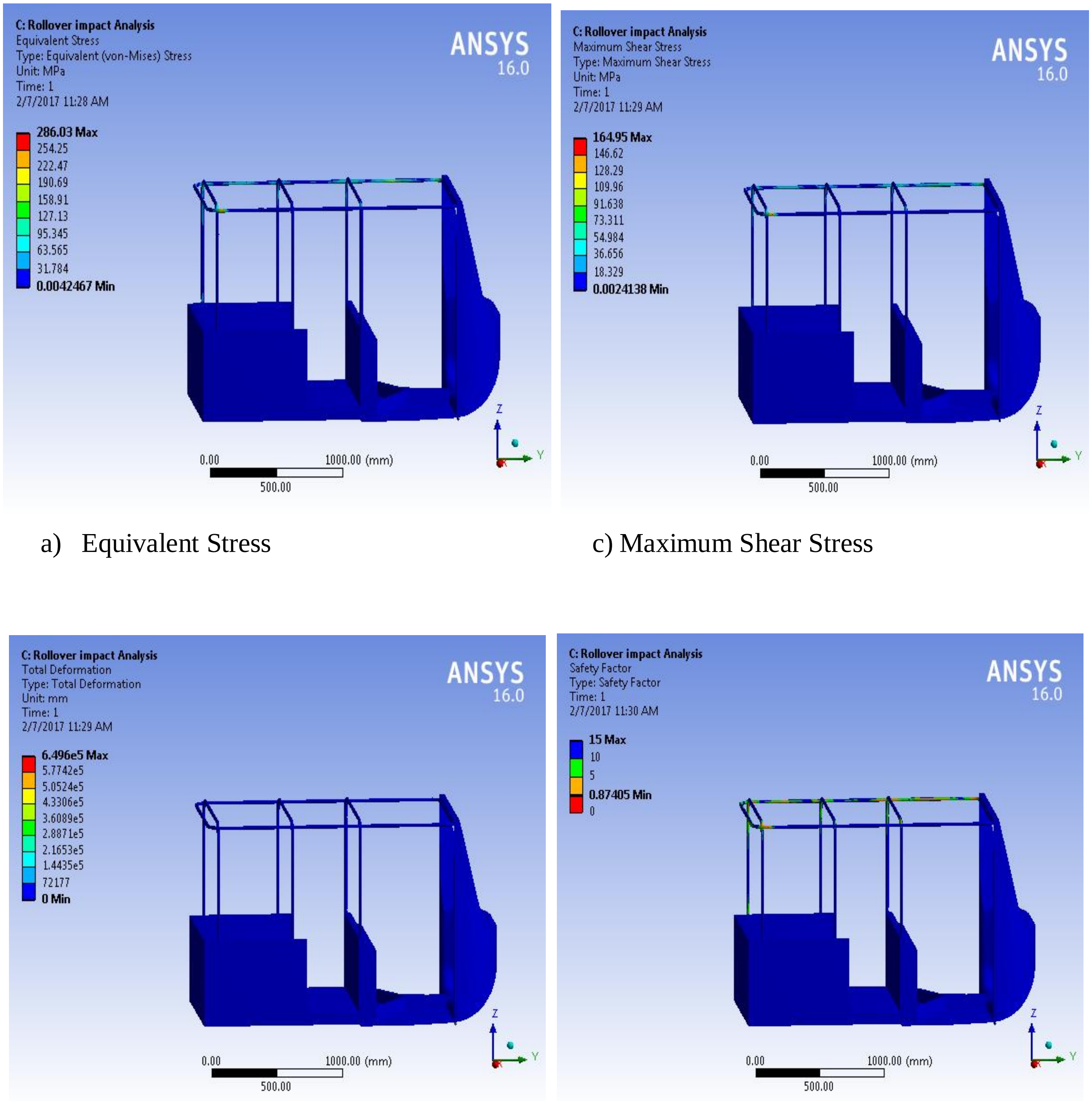


Figure 23: Loads and Boundary Conditions rollover impact of the existing model

Table 7: Rollover impact simulation results of existing model

Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	0.0042467	0.0024138	-97.515	0	0.8745	-24637
Maximum	286.03	164.95	389.12	6.496e5	-	95650



a) Equivalent Stress

c) Maximum Shear Stress

b) Total Deformation

d) Safety Factor

Figure 24: Rollover impact simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of existing model.

4.1.2 Finite Element Analysis of the new (modified) Structure

4.1.2.1 Static Structural Analysis of new Model

A static strength analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. This analysis determines the displacements, stresses, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Figure 23 shows loads and boundary conditions of the new model static structural analysis.

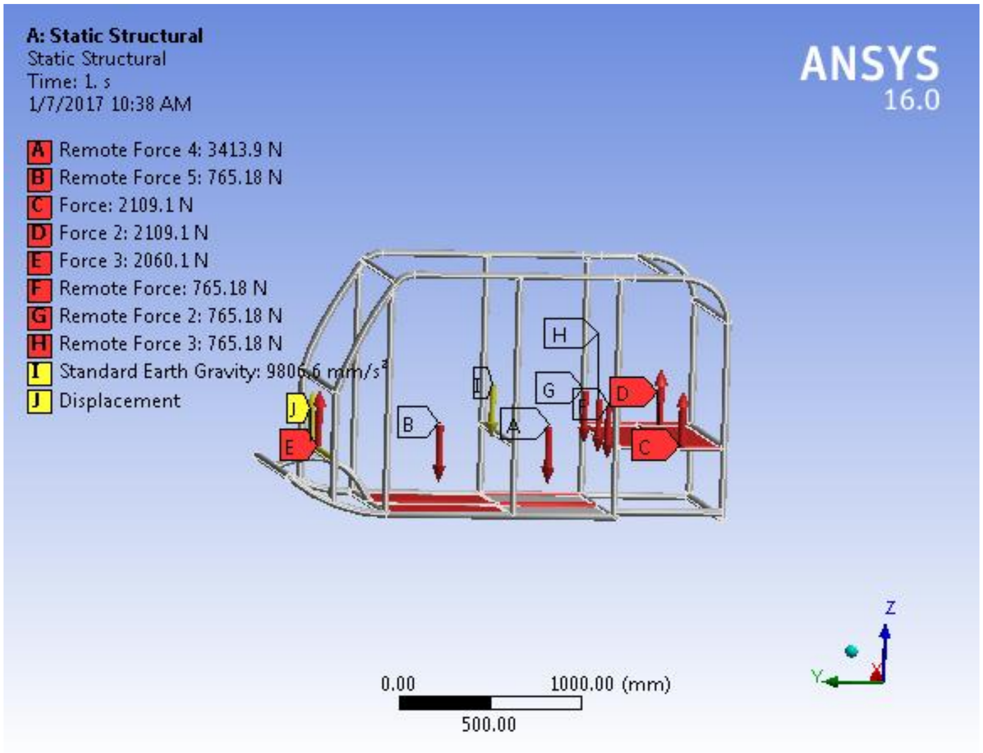
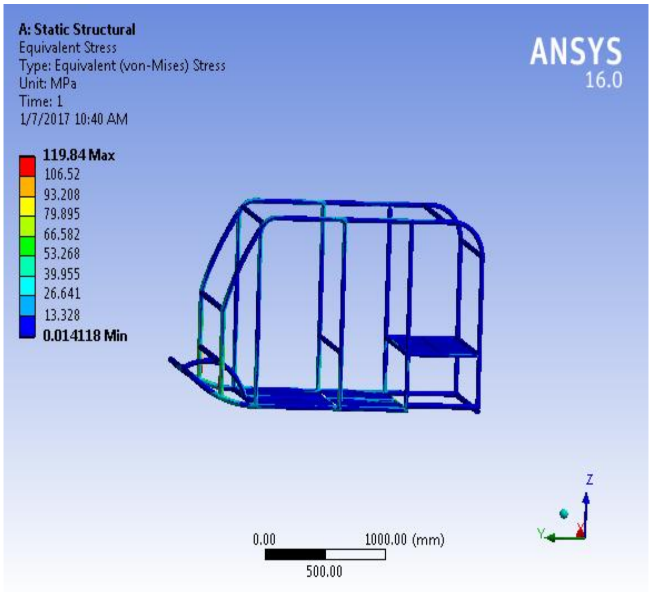


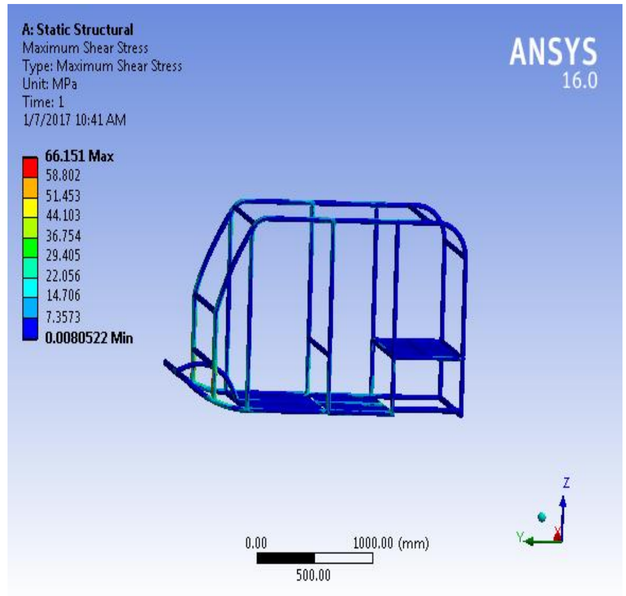
Figure 25: Loads and Boundary Conditions of the new model Static Structural Analysis

Table 8: Static simulation result of the new model

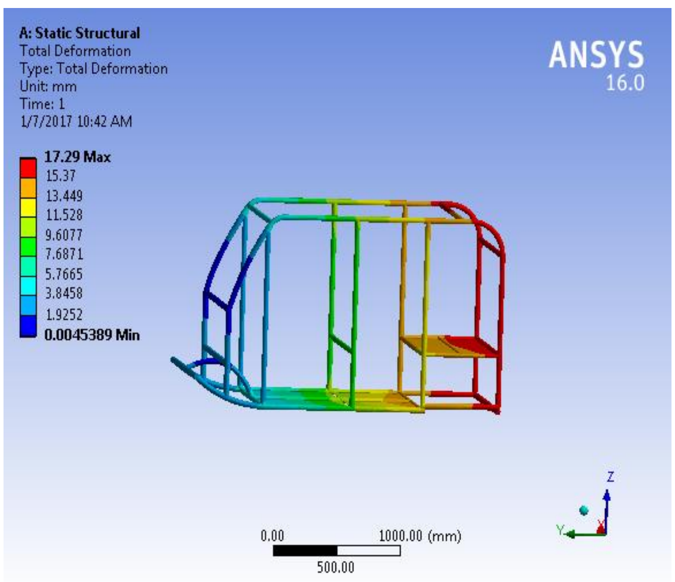
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	0.14118	0.0080522	-20.993	0.0045389	2.0862	-16.942
Maximum	119.84	66.151	119.89	17.29	-	1.8978



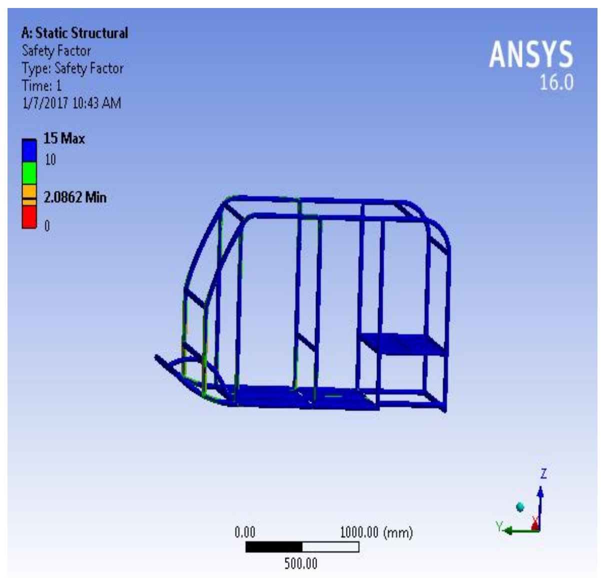
a) Equivalent Stress



c) Maximum Shear Stress



b) Deformation



d) Safety Factor

Figure 26: Static Analysis a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of new model

4.1.2.2 Crash Simulation of the new Model

4.1.2.2.1 Frontal Crash Simulation

The Load required for frontal crash is obtained where the vehicle is moving at a top speed of 65 kmph undergoing a head on collision with rigid body. The mass of the vehicle including the driver is 678 kg. The loads are calculated using basic mechanics [89, 92]. Since the front impact is instantaneous, the time of impact was assumed to be 0.15s.

Gross Mass of the vehicle, m = 678 kg

Velocity of the vehicle, v = 65 kmph = 18 m/s

Time of impact, t = 0.15

Acceleration, $a = \frac{v_f - v_i}{t} = \frac{0 - 18}{0.15} = 120\ m/s^2$

Impact force, F = m $*$ a = 678*120 = 81.360kN

The point of application of these loads will be the actual attachment points between the impact front heads see in figure 25. Model used is full model of the three wheeled vehicle with boundary conditions at suspension mounting points Uy = Ux = 0 and at rear corner points all DOF = 0.

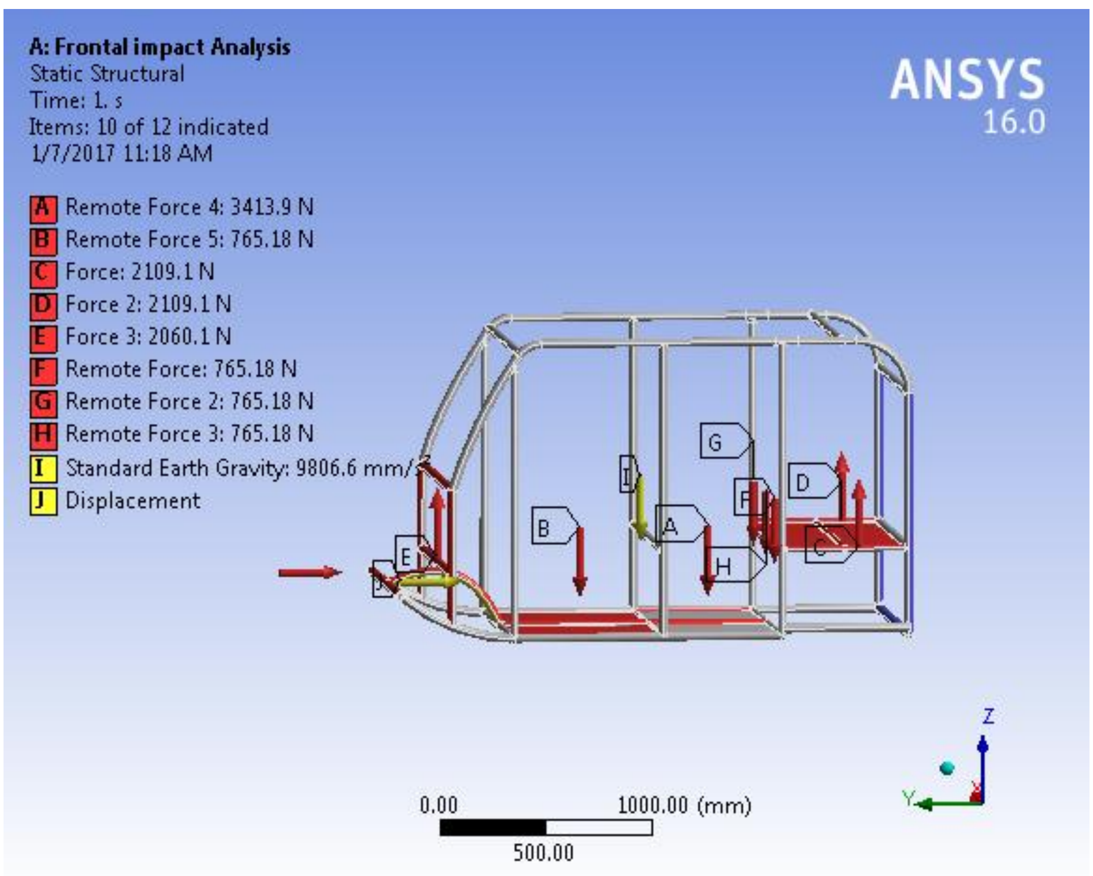
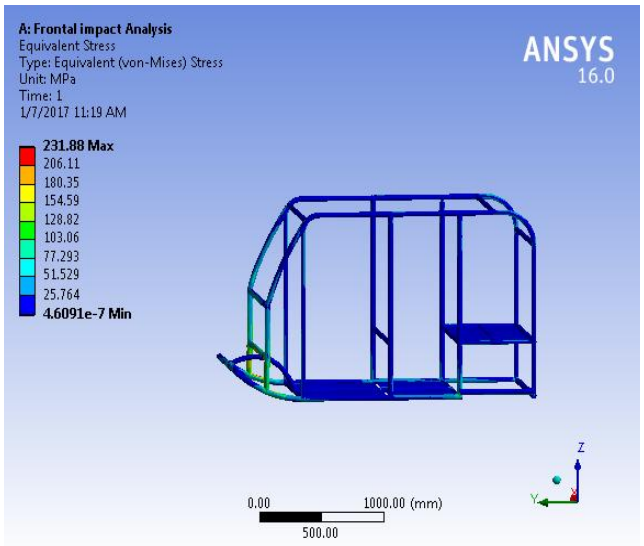


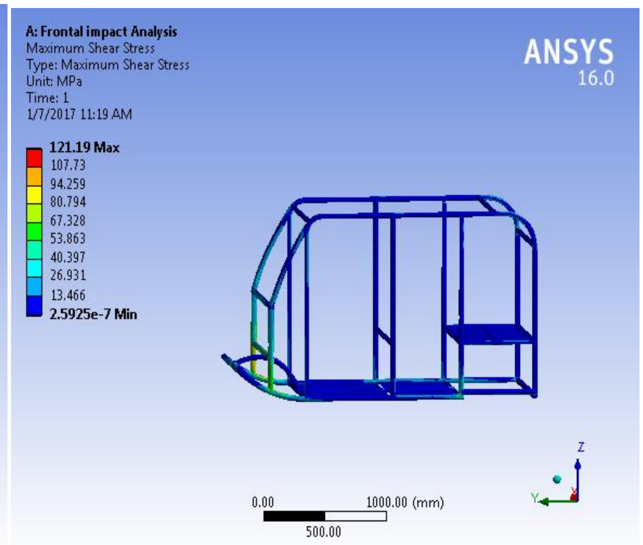
Figure 27: Loads and Boundary Conditions Frontal Crash of the new Model

Table 9: Frontal Crash Simulation result of the new model

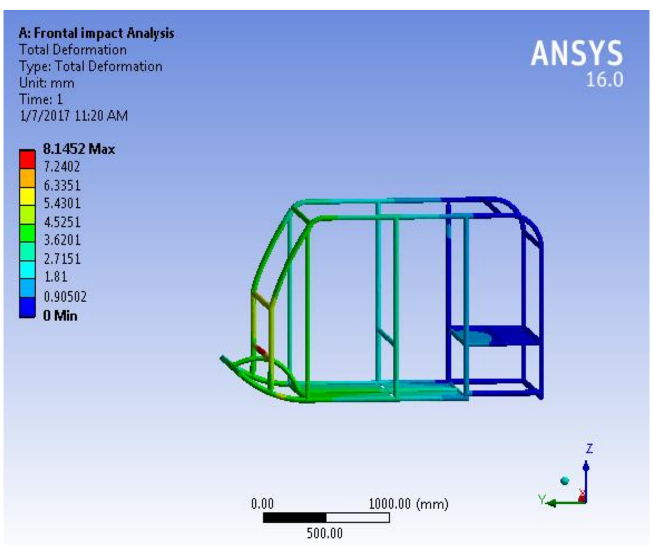
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	4.6091e-7	2.5925e-7	-74.806	0	1.0781	-4.5619
Maximum	231.88	121.19	211.67	8.1452	-	0.26963



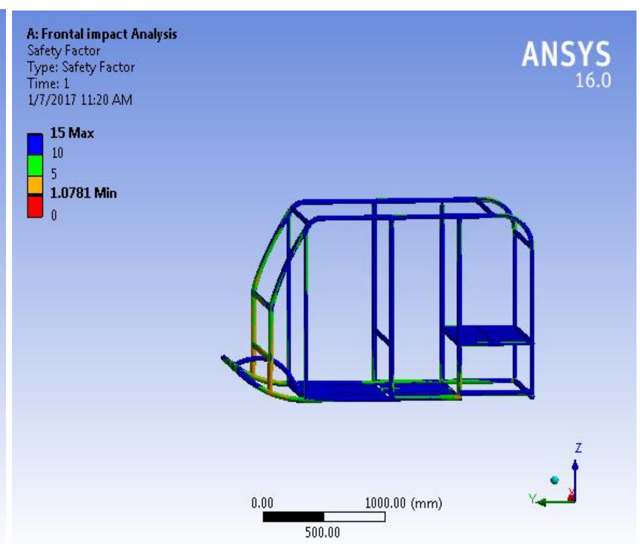
a) Equivalent Stress



c) Maximum Shear Stress



b) Total Deformation



d) Safety Factor

Figure 28: Frontal Crash Simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of new model.

4.1.2.2.2 Side Crash Simulation

The side impact loading analysis of the chassis of the Bajaj three wheeler is carried out to ensure the safety of the driver and passengers for any collisions on the side with another vehicle. In the side impact test the chassis is aligned sideways relative to the oncoming vehicle. The load required for the side impact is obtained where one vehicle is moving towards the other's side at a top speed of 65 kmph. The mass of the vehicle including the driver and passengers is 678 kg. The loads to be applied to the chassis are calculated as follows [71].

Gross Mass of the vehicle, m = 678 kg

Velocity of the vehicle, v = 65 kmph = 18 m/s

Time of impact, t = 0.30 s

Acceleration, a = $\frac{v_f - v_i}{t}$ = $\frac{0-18}{0.30}$ = 60 m/s^2

Force, F = m * a = 678* 60 = 40.680 kN

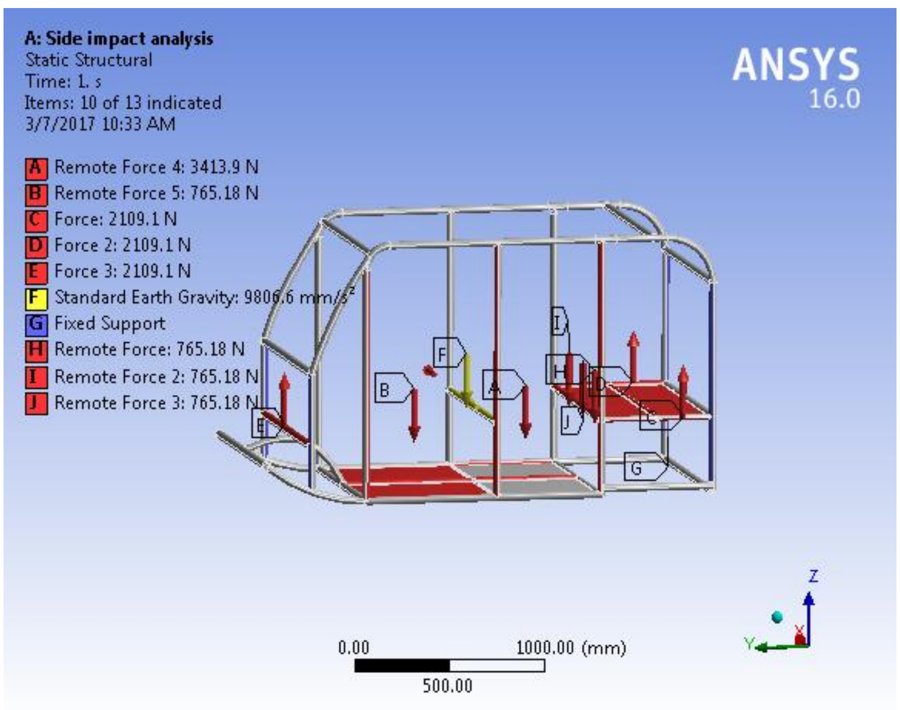
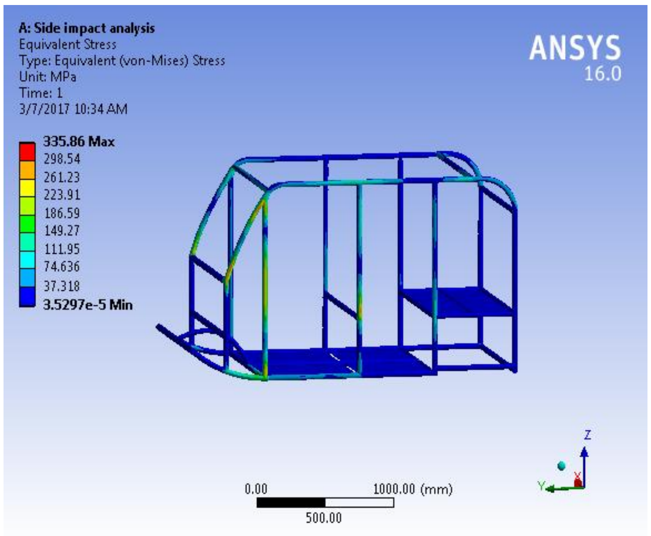
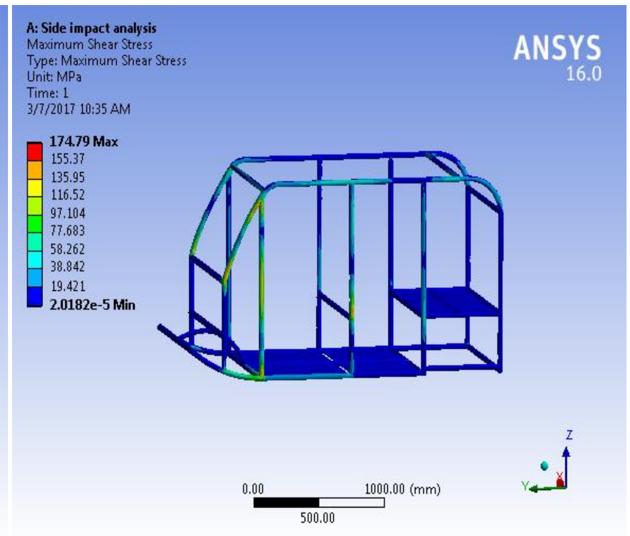


Figure 29: Loads and Boundary Conditions Side Crash Static Analysis of the new Model

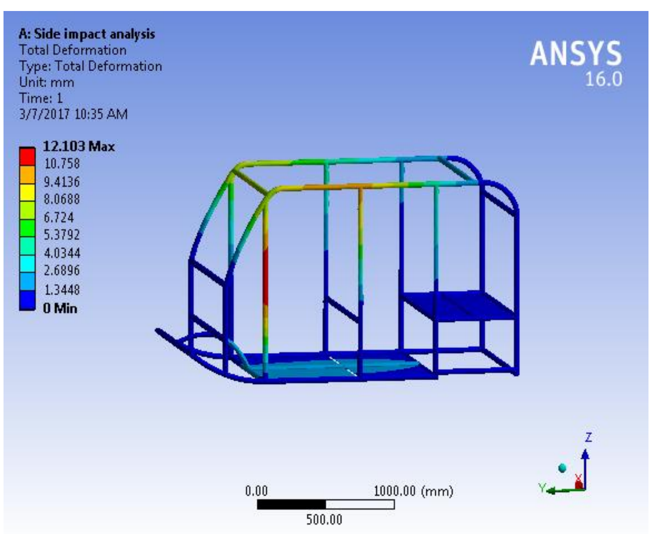
Table 10: Side crash simulation result of the new model

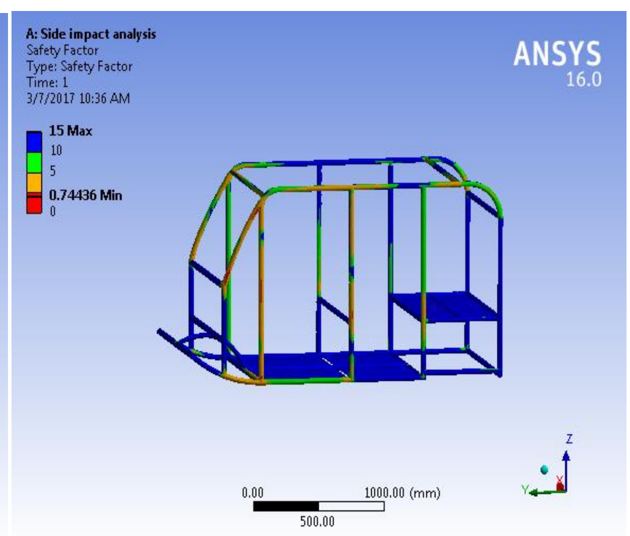
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	3.5297e-5	2.0182e-5	-127.15	0	0.74436	-0.90662
Maximum	335.86	174.79	309.88	12.103	-	1.7126





a) Equivalent Stress c) Maximum Shear Stress





b) Total Deformation d) Safety Factor

Figure 30: Side Crash simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of new model

4.1.2.2.3 Rear Crash Simulation

The rear impact load calculation is similar with frontal impact load required. So the Load required for rear impact is 81.360 kN load apply at the rear. The boundary conditions are used at suspension mounting points Ux = Uy = 0 and at front corner points all DOF = 0.

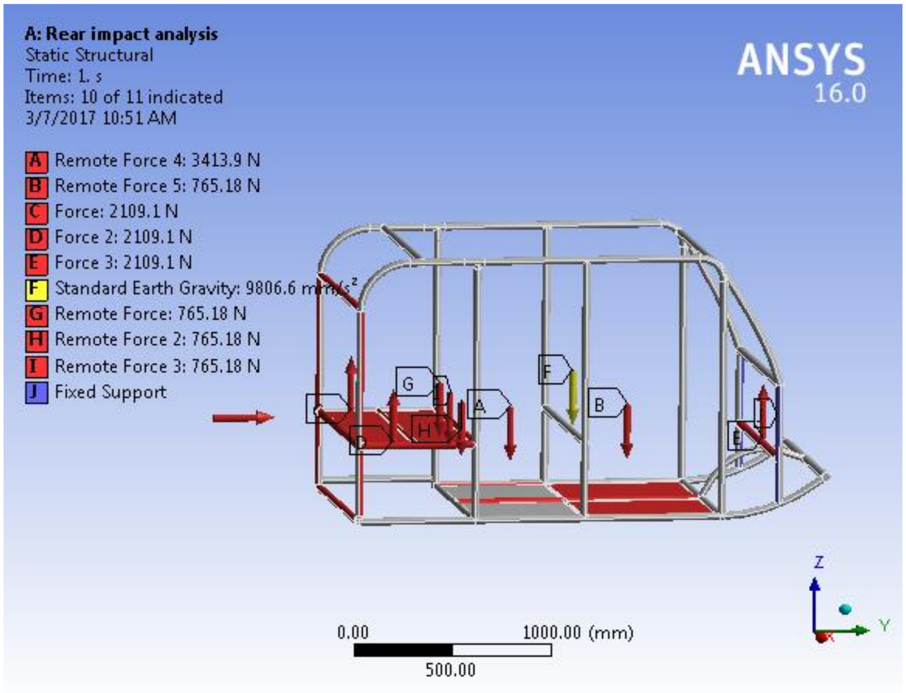
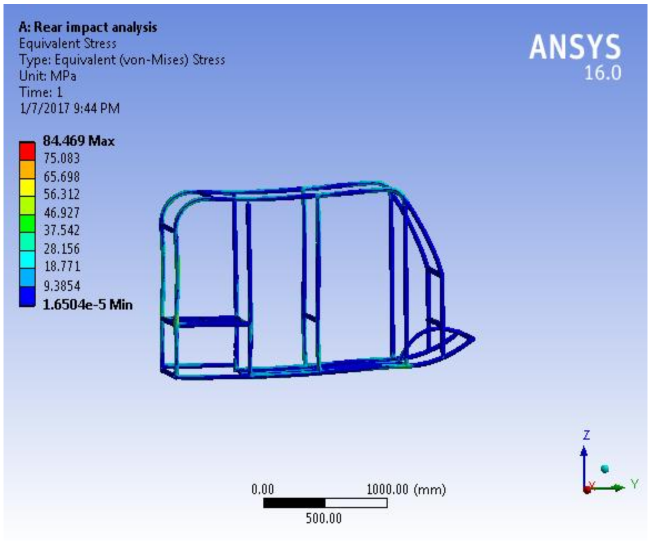


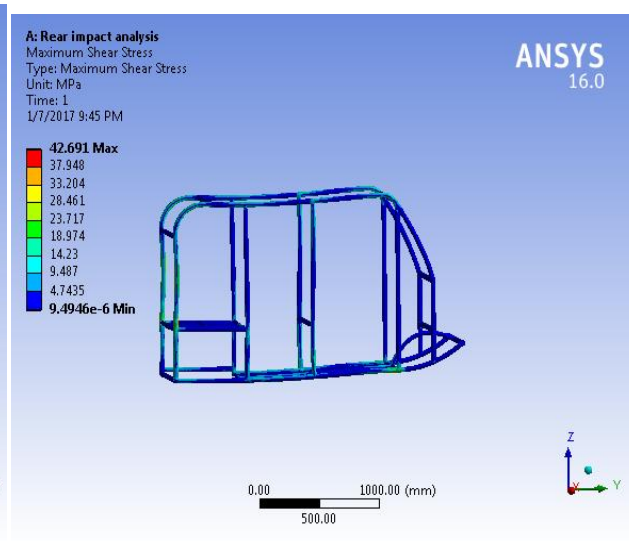
Figure 31: Loads and Boundary Conditions Rear crash Static analysis of the new model

Table 11: Rear crash simulation result of the new model

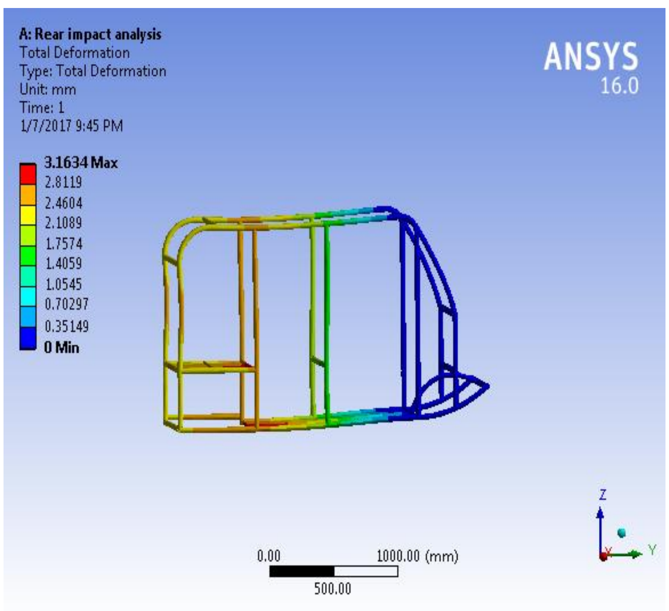
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	1.6504e-4	4.5823e-6	-24.585	0	2.9597	-0.39666
Maximum	84.469	42.691	81.501	3.1634	_	0.8853



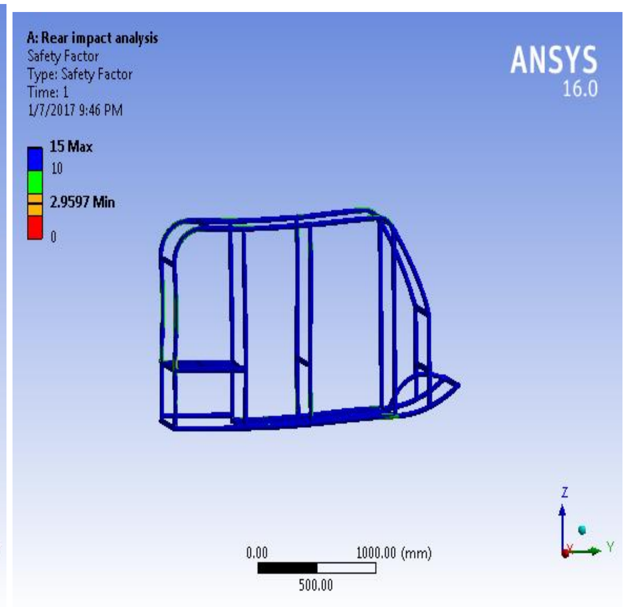
a) Equivalent Stress



c) Maximum Shear Stress



b) Total Deformation



d) Safety Factor

Figure 32: Rear crash simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of new model

4.1.2.2.4 Rollover Crash Simulation

The rollover crash analysis is performed to design the strong roof structure for maximum safety during the rollover incidents. The optimized parameters obtained from front impact and side impact analysis is used as inputs for the rollover impact loading analysis. The load required for the rollover impact loading analysis is obtained by using 50% of the load used for the frontal impact analysis as follows [69].

Impact force, F = 0.5 * Frontal impact load = 0.5 ∗ 81.680 kN = 40.680kN

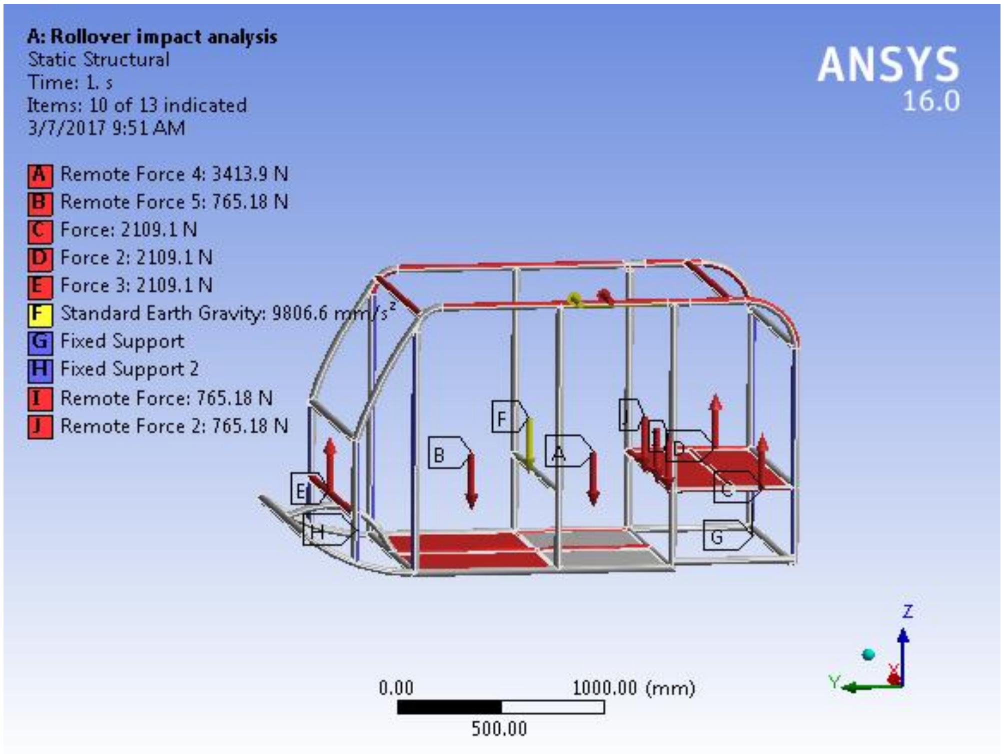
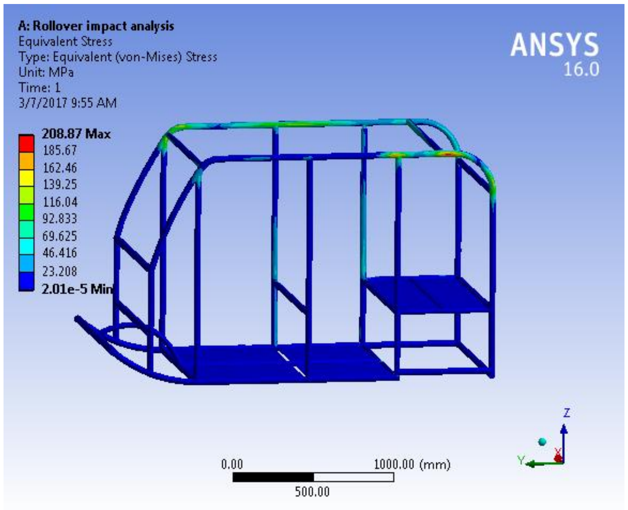


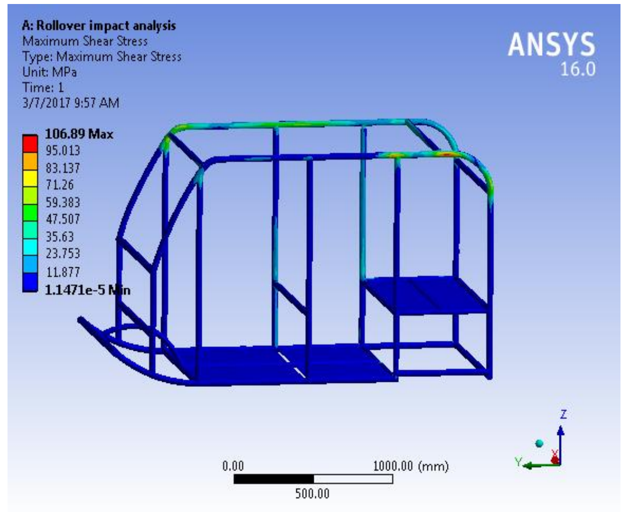
Figure 33: Loads and Boundary Conditions rollover crash static analysis of the new model

Table 12: Rollover crash simulation result of the new model

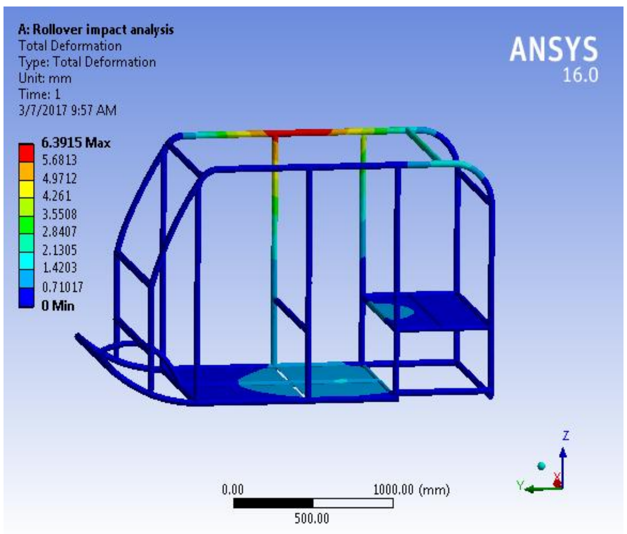
Result Type	Equivalent or von-misses stress (MPa)	Maximum shear stress (MPa)	Maximum principal stress (MPa)	Total deformation (mm)	Safety Factor	Directional deformation (mm)
Minimum	2.01e-5	1.1471e-5	-38.45	0	1.1969	-0.51051
Maximum	208.87	106.89	238.42	6.3915	-	1.4897



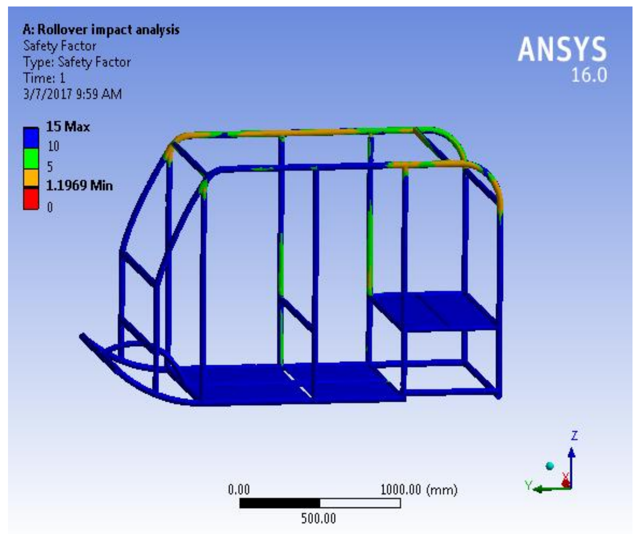
a) Equivalent Stress



c) Maximum Shear Stress



b) Total Deformation



d) Safety Factor

Figure 34: Rollover Crash Simulation a) Equivalent Stress b) Total Deformation c) Maximum Shear Stress and d) Safety Factor of new model.

4.1.3 Comparison Results of the both Models

We will see the results of the existing model and the new model in comparison. Different cases of the analysis are compared in each case and remarks have been given. The remark is given to the new model strength status when compared to the existing model strength.

4.1.3.1 Static Case

From table 13 is observed that for the new model Von-miss stress and maximum principal stress and maximum shear stress are less than that of existing model. Therefore, new model structure is better than existing model. This shows that the new model is stronger without material wastage.

Table 13: static case results

Type analysis	Existing model	New model	Remark
Von-miss stress (MPa)	491.1	119.84	Better
Maximum shear stress (MPa)	277.88	66.151	Better
Maximum principal stress (MPa)	481.43	119.89	Better
Total deformation (mm)	24.421	17.29	Better
Safety factor	0.50906	2.0862	Better

4.1.3.2 Impact Case

4.1.3.2.1 Frontal Impact

We can see from table 14 results of equivalent stress, maximum shear stress and maximum principal stresses are below the material strength for both existing and new models. But when we see the displacement values the modified structure is extremely reliable than the existing one. In this frontal impact case new modified structure is much better than existing one. We can say using modified structure (tubular structure) design is safer in the case of frontal impact.

Table 14: Frontal Impact

Type analysis	Existing model	New model	Remark
Von-miss stress (MPa)	66.863	231.88	Better
Maximum shear stress(MPa)	36.121	121.19	Better
Maximum principal stress (MPa)	53.97	211.67	Better
Total deformation (mm)	70805	8.1452	Better
Safety factor	3.739	1.0781	Better

4.1.3.2.2 Side Impact

Table 15 indicates equivalent stress, maximum shear stress and maximum principal stresses of both existing and new models results are highly improved. But displacement result of new model is much better than existing model in the case of side impact.

Table 15: Side Impact

Type analysis	Existing model	New model	Remark
Von-miss stress (MPa)	329.97	335.86	Good
Maximum shear stress(MPa)	187.21	174.79	Better
Maximum principal stress (MPa)	431.6	309.88	Good
Total deformation (mm)	4.9256e5	12.103	Better
Safety factor	0.75764	0.74436	Better

4.1.3.2.3 Rear Impact

Table 16 shows results of equivalent stress, maximum shear stress and maximum principal stresses of both existing and new models are under material strength. But when we see the displacement values the new model is extremely reliable than the existing model. This shows that the new model design has high strength and safe in case of rear impact.

Table 16: Rear Impact

Type analysis	Existing model	New model	Remark
Von-miss stress (MPa)	105.5	84.469	Better
Maximum shear stress(MPa)	58.925	42.691	Better
Maximum principal stress (MPa)	89.908	81.501	Better
Total deformation (mm)	6.496e5	3.1634	Better
Safety factor	2.3696	2.9597	Better

4.1.3.2.4 Rollover Impact

In the case of rollover impact results of equivalent stress, maximum shear stress and maximum principal stresses of modified structure is much better than existing one shown in the table 17. This indicates the improved structure has high strength and safety. Also the displacement value and safety factor is much better for new model. Therefore, in general the new structure is better than existing model in the case of rollover impact.

Table 17: Rollover Impact

Type analysis	Existing model	New model	Remark
Von-miss stress (MPa)	286.03	208.87	Better
Maximum shear stress(MPa)	164.95	106.89	Better
Maximum principal stress (MPa)	389.12	238.42	Better
Total deformation (mm)	6.496e5	6.3915	Better
Safety factor	0.8745	1.1969	Better

4.2 Modal Analysis

A modal analysis is typically used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure while it is being designed. Our aim here is to build a dynamically stable chassis to withstand three wheeler vehicles during its mobility. We had to optimize the frame so that it can withstand all static and dynamic loads as well as being light in weight. The excessive vibrations cause lot of failure to the frame due to the harsh conditions in which the vehicle is driven. Here we are finding the natural frequency of the frame under its self weight. Generally, the natural frequency of the model can be calculated using the following equation [82, 86].

$$\omega_n = \sqrt{\frac{K}{m}} \tag{4.3}$$

Where ω_n is natural frequency, m is the mass and k stands for stiffness.

Table 18: List of frequencies with respect to mode shapes of new model

Mode	Frequency [Hz]
1	0
2	0
3	0
4	3.1412e-003
5	4.4876e-003
6	5.5354e-003

From the this modal analysis the result of natural frequency is less up to six mode of structure and it is used for simply understanding the behavior of structure for next crash analysis to avoid resonance with respect to vibration formed during externally applied force. The mode shapes that were obtained from the analysis are as follows.

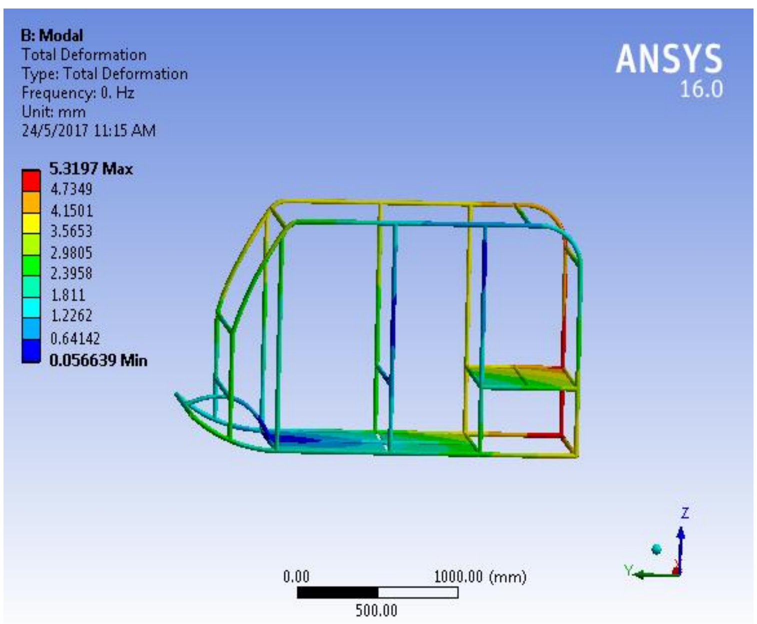


Figure 35: First mode shape of vibration

The First mode shape explains about the rear part of the chassis vibrates with a zero natural frequency.

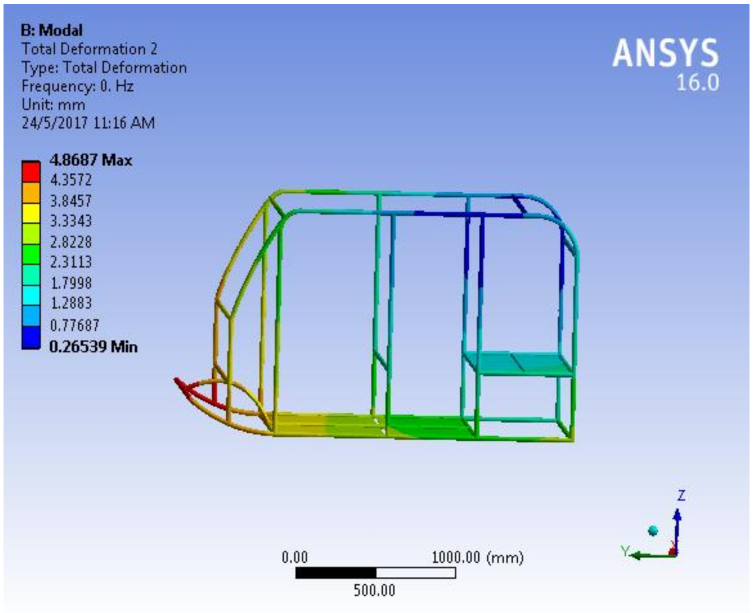


Figure 36: Second mode shape of vibration

In this mode shape also the frontal part of the frame experiences longitudinal vibrations with a zero frequency.

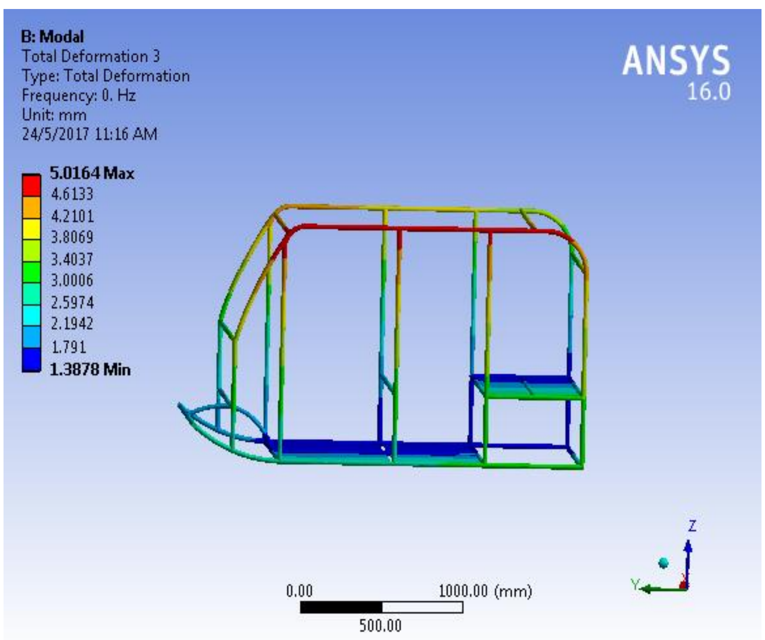


Figure 37: Third mode shape of vibration

In this mode shape the entire upper frame and beams connecting them vibrate with zero natural frequency.

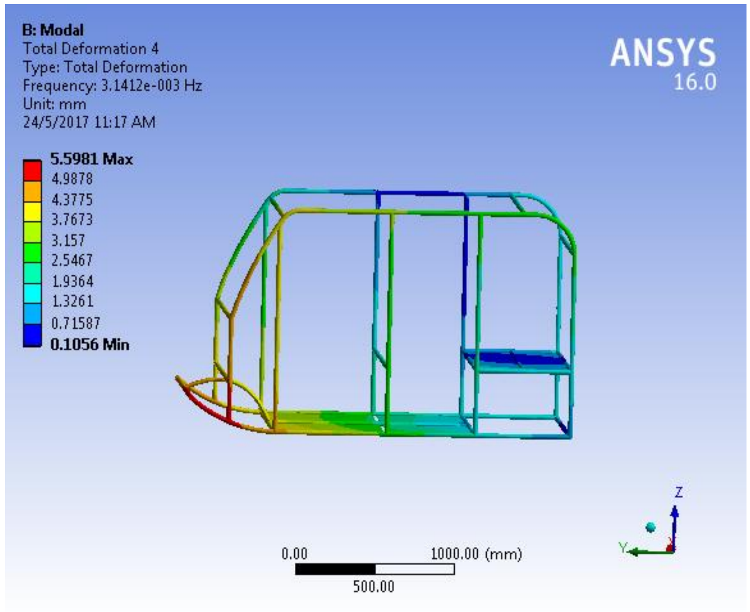


Figure 38: Fourth mode shape of vibration

In this mode shape, the frontal structure vibrates with a frequency of 3.1412e-003 Hz.

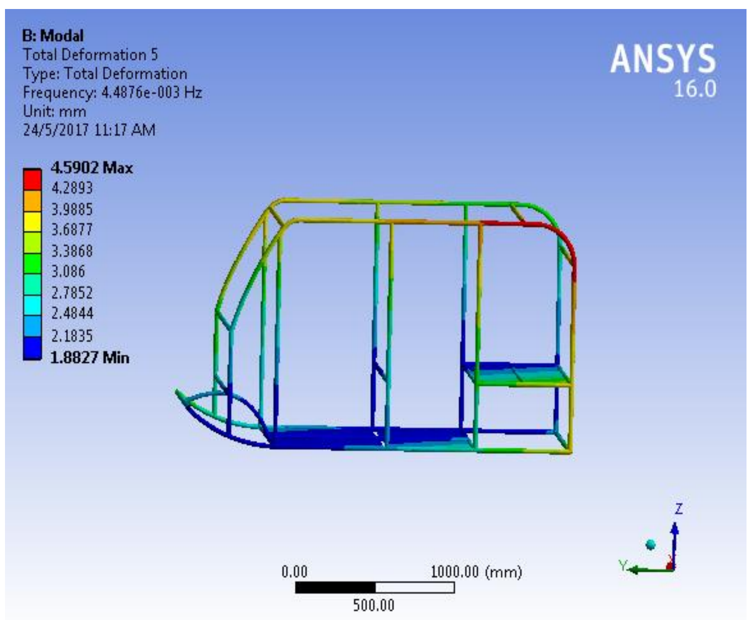


Figure 39: Fifth mode shape of vibration

In this mode shape the entire upper frame and beams connecting them vibrate with a natural frequency of 4.4876e-003 Hz.

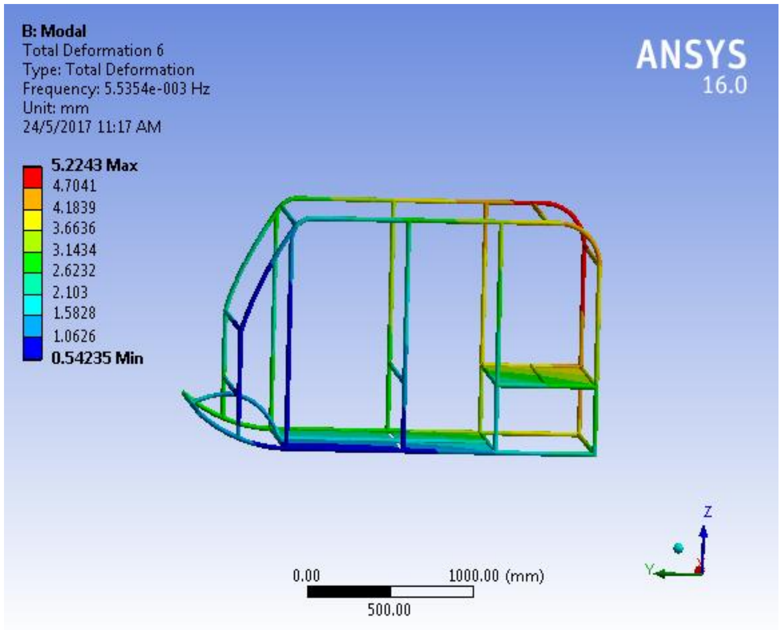


Figure 40: Six mode shape of vibration

In the sixth mode shape the upper frame and the beams connecting the rear end vibrate with a frequency of 5.5354e-003 Hz.

4.3 Aerodynamic analysis using CFD software

CFD analysis of flow over the vehicle is carried for three speeds between 50 km/h to 70 km/h for both models. Results are obtained for three different velocities for both the models. Coefficient of drag always depends on shape of the vehicle body.

4.3.1 Aerodynamic Pressure and Velocity Distribution of the Models at Various Speeds

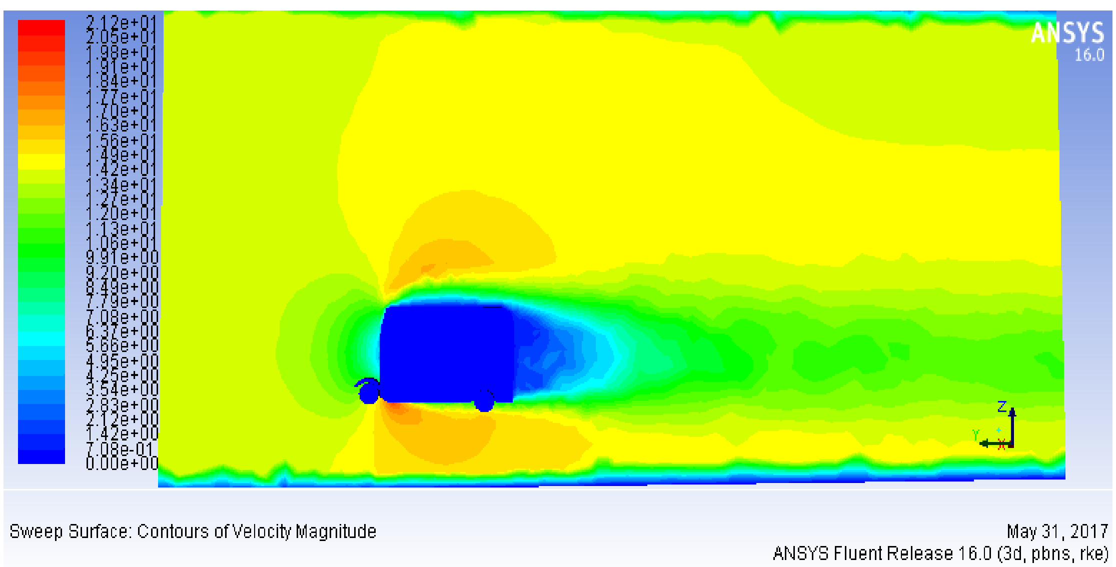


Figure 41: Velocity distribution of Model 1 at 50 Kmph

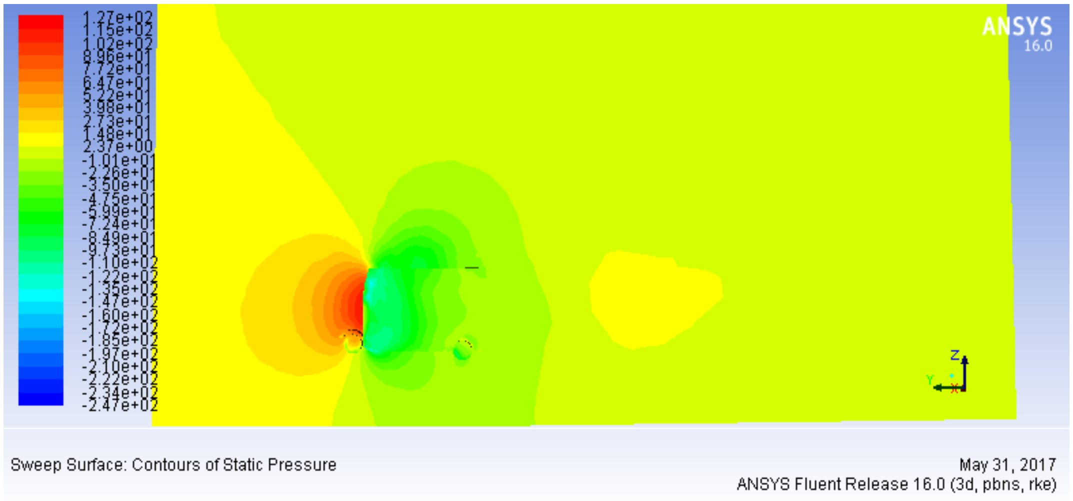


Figure 42: Pressure distribution of Model 1 at 50 Kmph

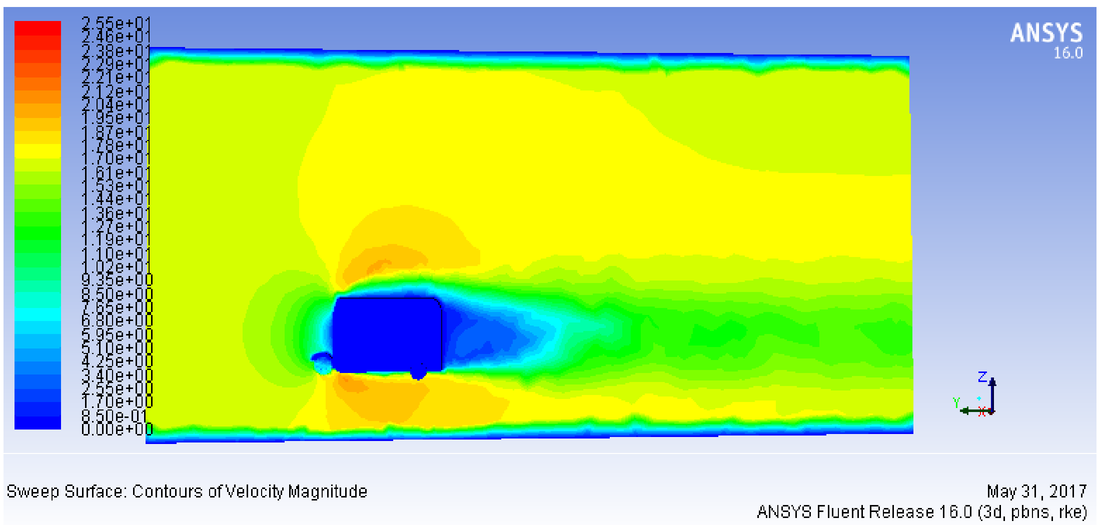


Figure 43: Velocity distribution model 1 at 60 Kmph

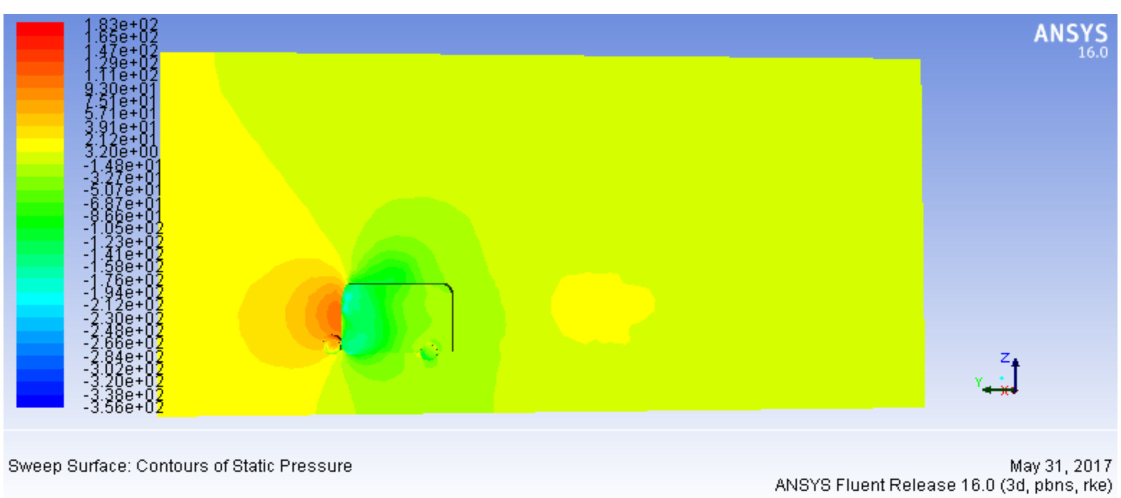


Figure 44: Pressure distribution of Model 1 at 60 Kmph

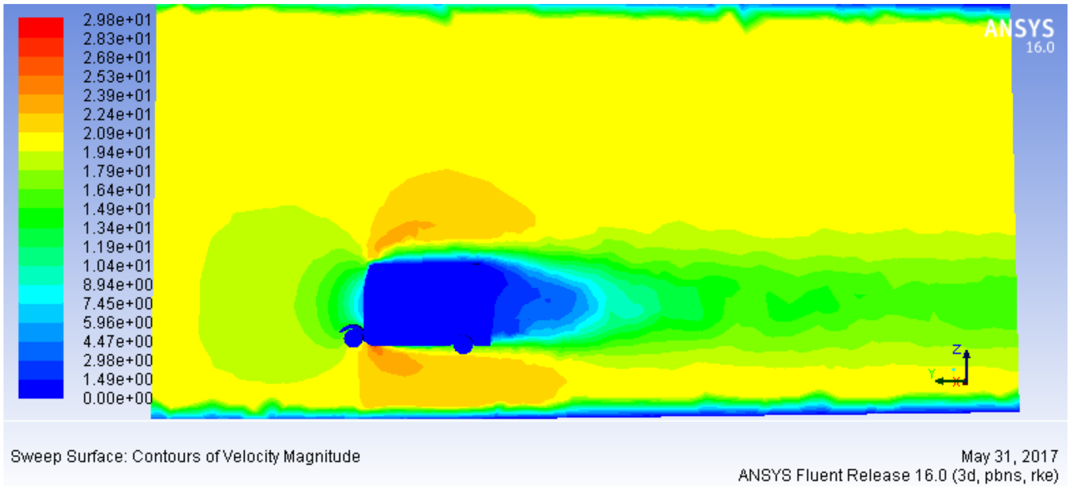


Figure 45: Velocity distribution of Model 1 at 70 Kmph

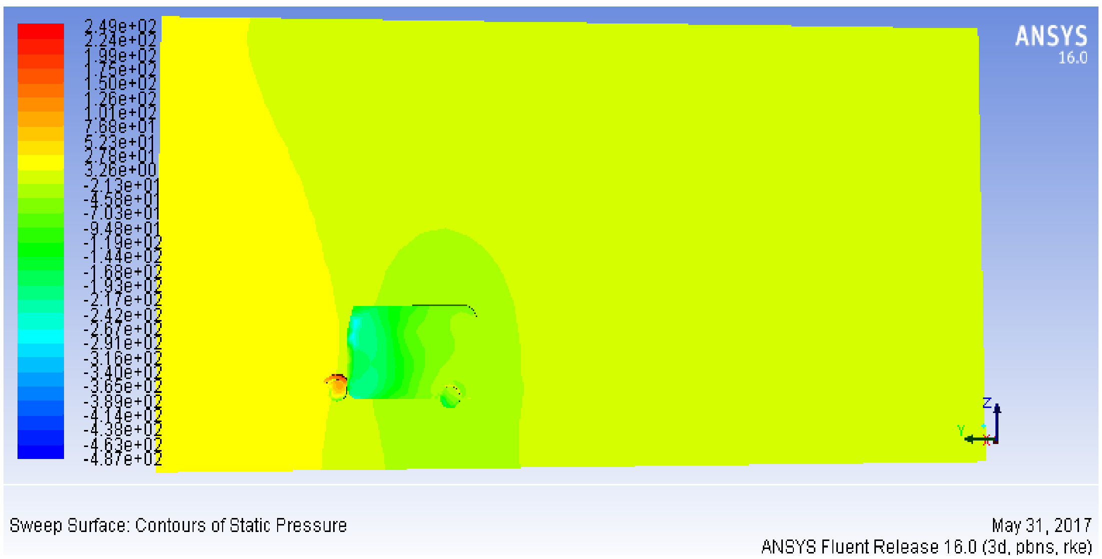


Figure 46: Pressure distribution of Model 1 at 70 Kmph

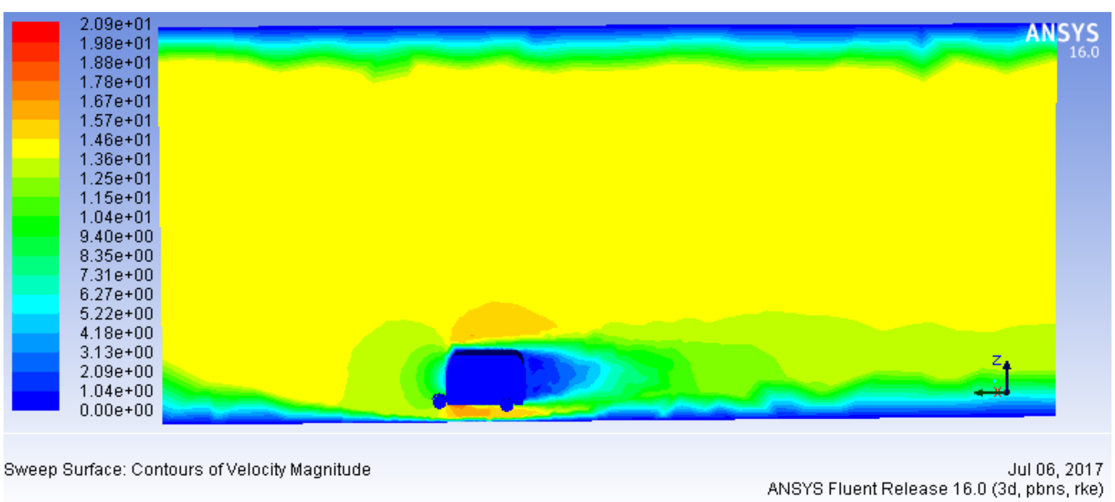


Figure 47: Velocity Distribution of Model 2 at 50 Kmph

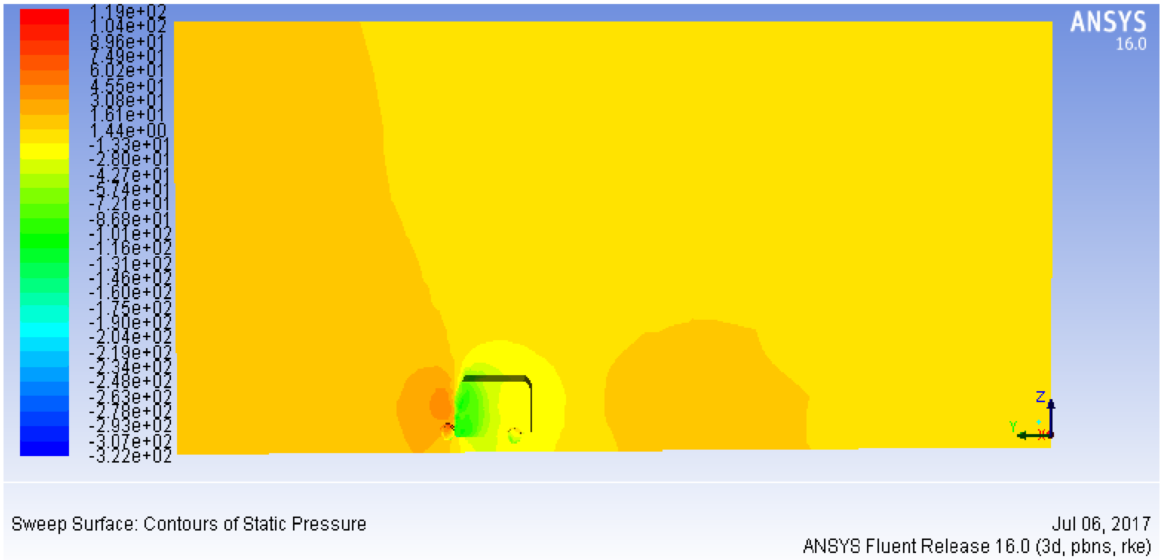


Figure 48: Pressure Distribution of Model 2 at 50 Kmph

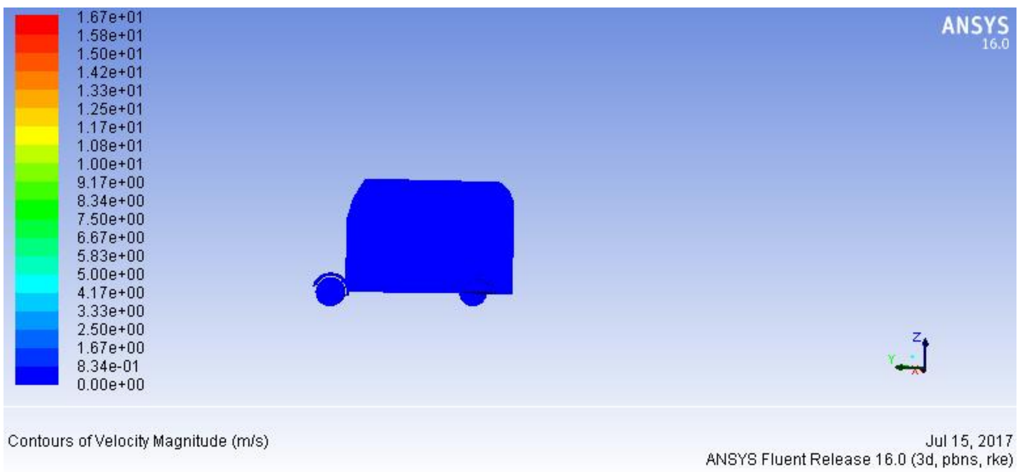


Figure 49: Velocity Distribution of Model 2 at 60 Kmph

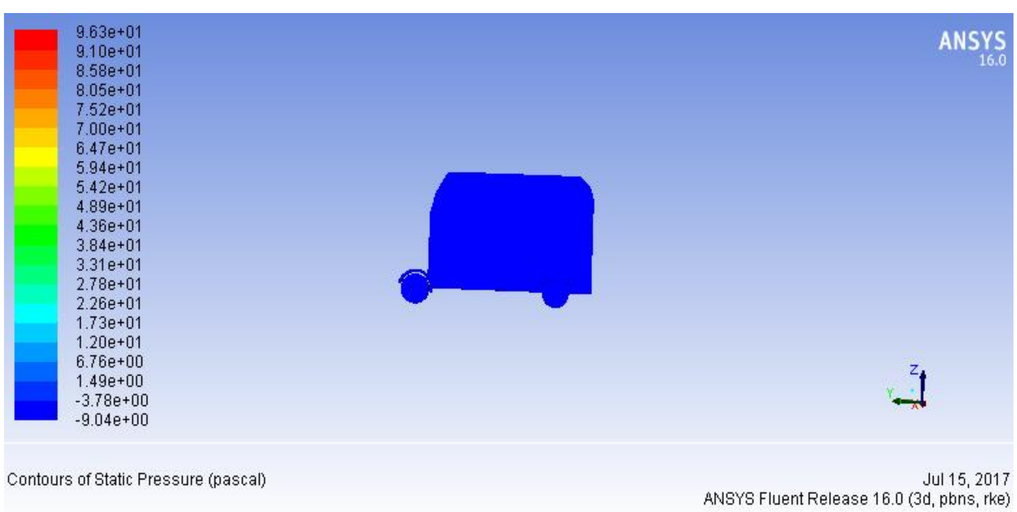


Figure 50: Pressure Distribution of Model 2 at 60 Kmph

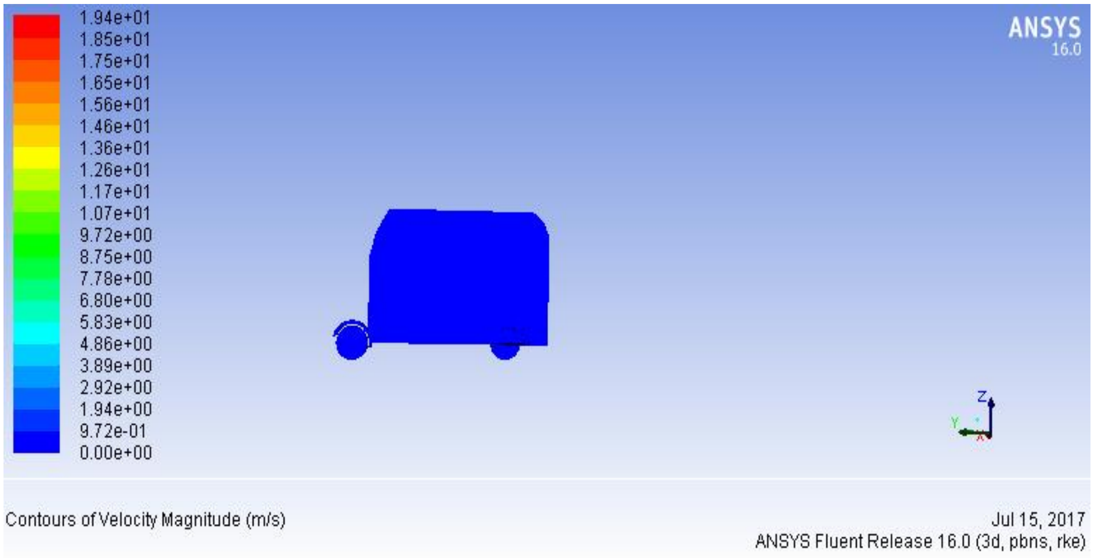


Figure 51: Velocity Distribution of Model 2 at 70 Kmph

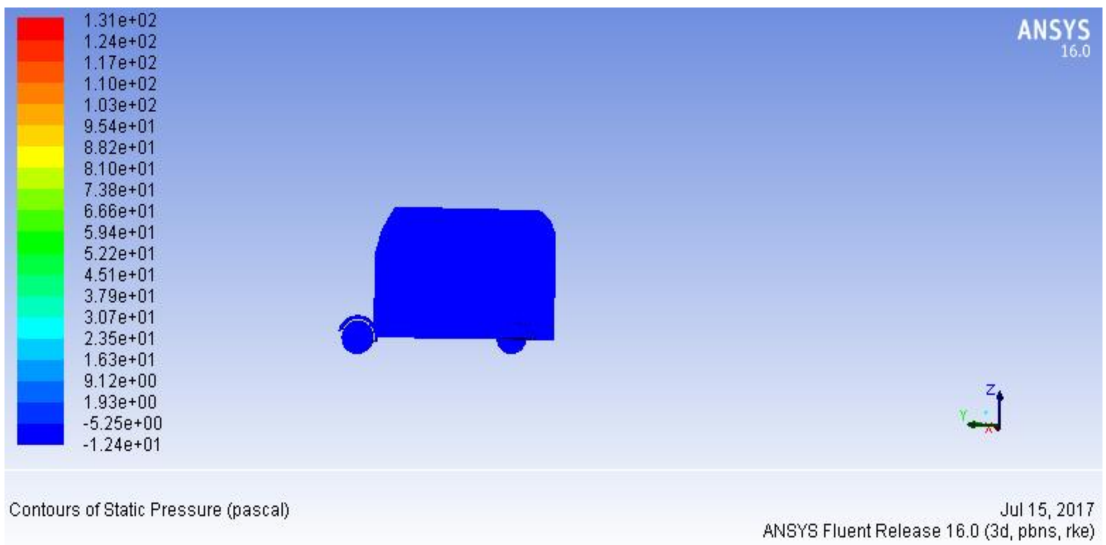


Figure 52: Pressure Distribution of Model 2 at 70 Kmph

The pressure distribution in figures 40, 42 and 44 shows that high pressure developed on the body of the model 1which indicates more drag in this model. Pressure distribution on front region of the model shows the pressure developed when air strikes the front region of the model. Pressure occupies the frontal region which develops a huge resistance for the vehicle to move forward. The figures 46, 48 and 50 show the pressure distribution of the modified model (model 2) in various speeds. It shows the pressure acting on it is reduced when compared to Model 1.

4.3.2 Drag Coefficient

For the analysis of aerodynamic performance of the model on its running condition the static pressure distribution on the surface of the vehicle was analyzed. The drag coefficients (C_D) at different speeds for both models are given in the table 19.

Table 19: Drag coefficient (CD) at various speeds

Speed in Kmph	Speed in m/s	Drag coefficient (C_D)	
		Model 1	Model 2
50	13.89	0.604	0.562
60	16.67	0.623	0.572
70	19.44	0.641	0.594

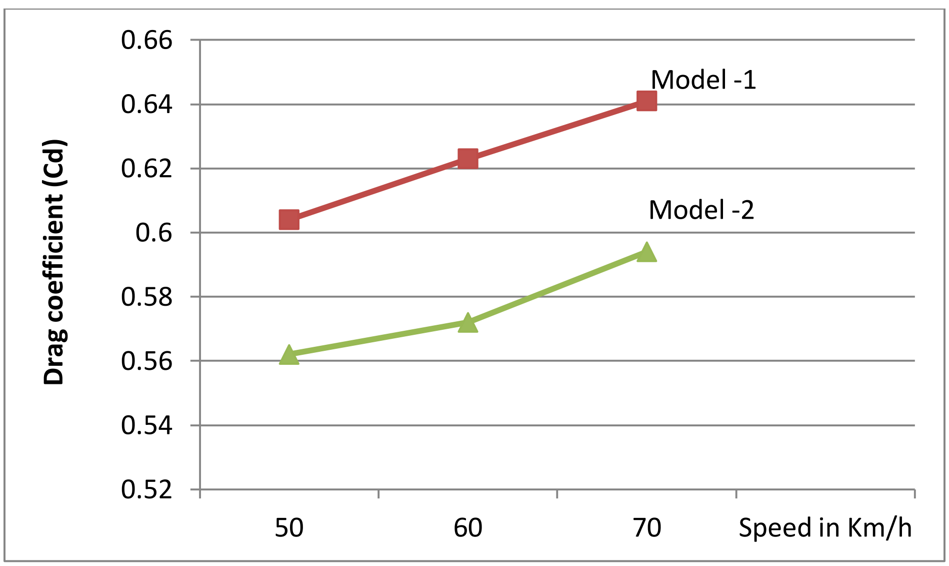


Figure 53: Drag Coefficient Vs Speed

Table 19 and figure 51 show the comparison of drag coefficient acting on the original model and the new model at different vehicle speeds. The drag coefficient decreased as it is observed. From table 20 the percentage of drag coefficient reduction from model 1 to model 2 is approximately 7 %, 8.1 % and 7.8% at 50, 60 and 70 kmph respectively.

Percentage of drag coefficient reduction [79]

Reduction rate of the drag coefficient (C_d) of model-2 with respect to the model-1.

$$C_D = \frac{C_D \text{ original model} - C_D \text{ new model}}{C_D \text{ original model}} \times 100\% \quad (4.4)$$

Table 20: Reduction rate of the drag coefficient (CD)

Models	Speed (kmph)	Drag Coefficient (C_d)	C_d reduction in percentage (%)
Model1	50	0.60	---
	60	0.62	----
	70	0.64	---
Model 2	50	0.56	7
	60	0.57	8.1
	70	0.59	7.8

4.3.3 Drag Force

Drag Force (N) [78, 86]

$$F_D = 1/2\ \rho\ A\ C_D V^2 \quad (4.5)$$

Where

- F_D is drag force
- ρ is air density
- V is velocity of the vehicle
- A is frontal area of vehicle
- C_D is drag coefficient

Table 21: Drag Force Vs Speed

Speed in Km/h	Speed in m/s	Drag Force in N	
		Model 1	Model 2
50	13.89	158.67	121.79
60	16.67	236.48	178.26
70	19.44	329.83	252.16

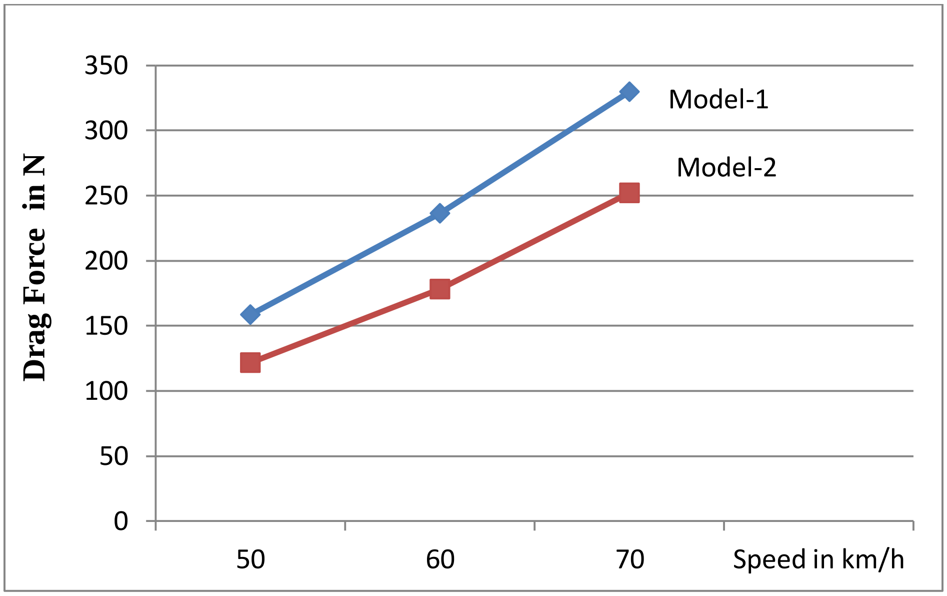


Figure 54: Drag Force Vs Speed

Above table 21 and figure 52 show the comparison of drag force acting on the original model and the new designs at different vehicle speeds. The total drag force is reduced from 158.67 N to 121.79 N at 50 kmph with model 2. The drag force for model 2 is less than model 1. From the study, it was found that 24.6% of the total drag of the original (Model-1) was reduced on the model-2 that is equivalent to 4.93 KW of an engine brake power at 60 km/h in speed and 8.5% of fuel can be saved for the every 60 Km/h.

4.3.4 Rolling Resistance

$$Fr = (0.015+0.00016V)\ W\ [78] \quad (4.6)$$

Where, V = Vehicle speed in m/s,

W = Weight of vehicle in N and

Fr = Rolling Resistance in N

Table 22: Rolling Resistance at Various Speeds

Speed in Km/h	Speed in m/s	Rolling Resistance in N	
		Model 1	Model 2
50	13.89	114.55	114.55
60	16.67	117.51	117.55
70	19.44	120.46	120.46

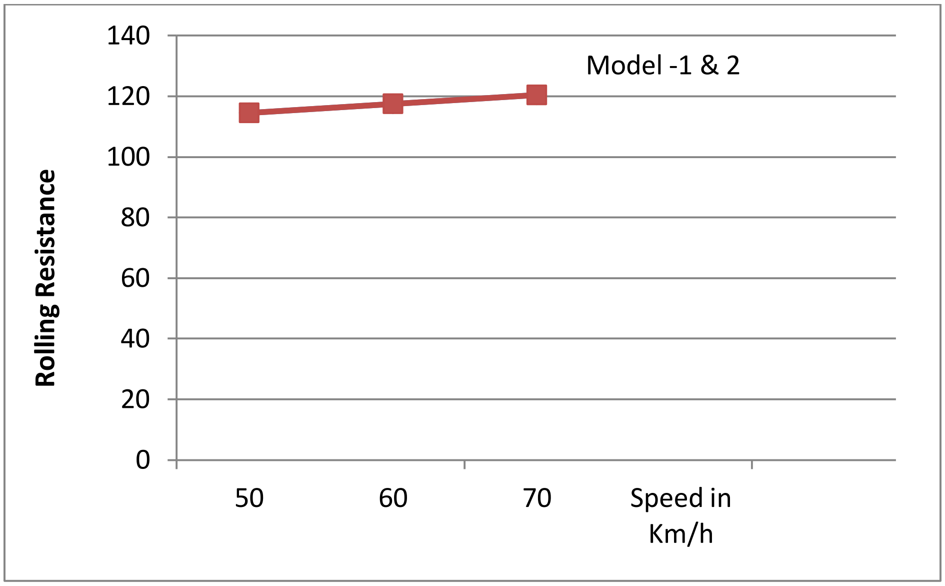


Figure 55: Rolling Resistance Vs Speed

The above graph indicates rolling resistances of the models are equal at various speeds. The reason that the speed and weight of the models are the same.

Total Resistance (N) [78]

$$F_t = F_d + F_r + F_g \tag{4.7}$$

Where, F_d is Drag force, F_r is Rolling resistance, F_g is Gravitational force but, $F_g = 0$ (leveled surface) = W Sinθ

Table 23: Total Resistance at Various Speeds

Speed in Km/h	Speed in m/s	Total Resistance in N	
		Model 1	Model 2
50	13.89	273.22	236.34
60	16.67	353.99	295.81
70	19.44	450.29	372.62

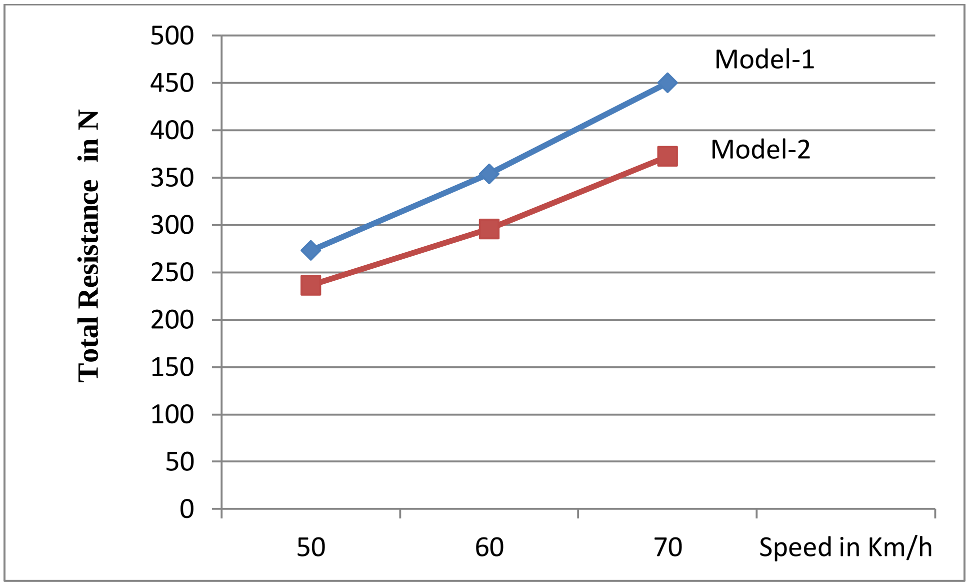


Figure 56: Total Resistance Vs Speeds

4.3.5 Power Requirement

The power required to pull the vehicle against the resistance in a level surface is calculated and their corresponding values for differential speeds were given below.

Power Required (KW) [78]

$$P = F_t V / n_t \tag{4.8}$$

Where, P = Power

F_t = Total Resistance

V = Vehicle Speed

n_t = Transmission efficiency

Table 24: Power Requirement at Various Speeds

Speed in Km/h	Speed in m/s	Power Required (kW)	
		Model-1	Model-2
50	13.89	4.216	2.954
60	16.67	6.556	4.931
70	19.44	9.726	7.243

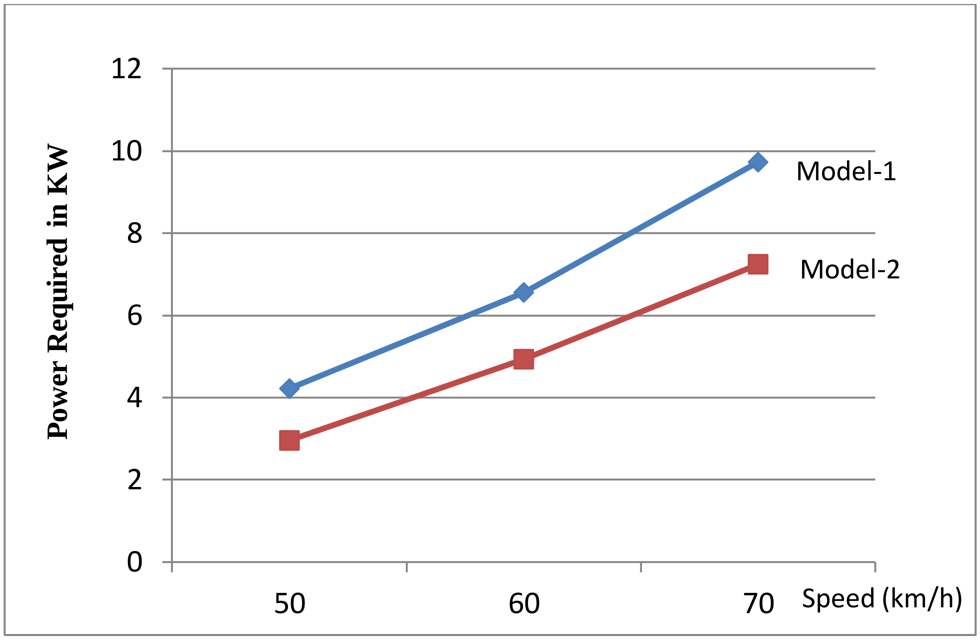


Figure 57: Power Required Vs Speed

The above graph indicates power requirements at various speeds for model 1 and model 2 respectively. The result shows the power required by model 1 is greater than model 2. That means model 1 consumes more fuel than the model 2.

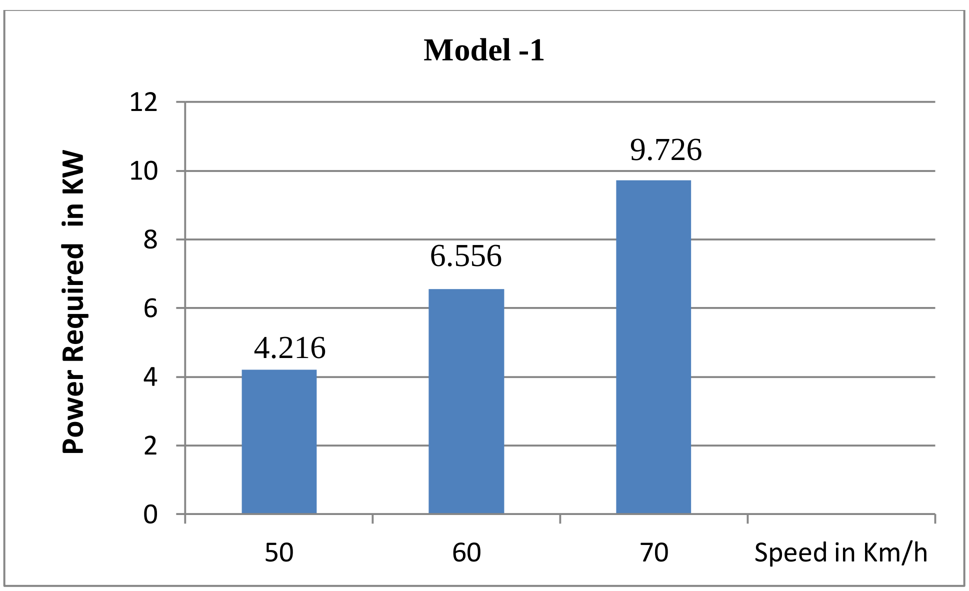


Figure 58: Power required model-1 at various speeds

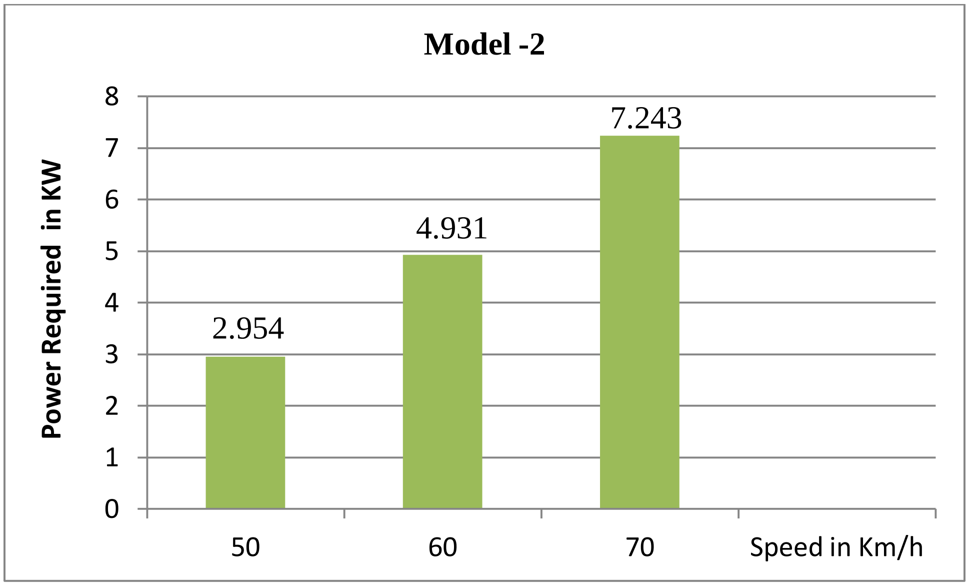


Figure 59: Power required model-2 at various speeds

4.3.6 Calculation of Fuel Consumption

Fuel consumption has the relation with the percentage reduction of coefficient of drag [76].

Percentage of fuel reduction = 3/5 [percentage of drag reduction]

Table 25: Fuel saving in percentage (%)

Models	Speed in kmph	Drag coefficient (C_d)	C_d reduction in percentage (%)	Fuel saving (%)
Model1 1	50	0.604	---	---
	60	0.623	---	---
	70	0.641	---	---
Model 2	50	0.562	7	4.2
	60	0.572	8.1	5.0
	70	0.594	7.3	4.4

The above table 25 shows that there is 5.0% amount of fuel can be saved in model 2 compared to model 1 at a speed of 60 kmph. Therefore, model 2 is better than from model 1.

4.4 Ergonomics Assessment of Passengers seat in three Wheeler Vehicle (Bajaj)

In three wheeler vehicles (Bajaj) passengers' ergonomics problem is a big issue. This study focuses only passengers' ergonomics of three wheeler vehicles (Bajaj) not include driver ergonomics. The main aim of this study is to gather anthropometric data necessary for the design and manufacture of passenger seats as well as to compare the data with that of the passenger seats presently in use.

Jeong & Park (1990) and Bridger (1995) noted that physical dimensions of furniture, equipment, clothing and workspaces are specified using anthropometric data to achieve proper ergonomic design. Thus the use of anthropometric data in design may constitute improvement in the health and comfort of the users (Barroso et al., 2005). Similarly, Xiao et al. (2005) noted that anthropometric data is needed for ergonomically correct design of safe and efficient workplaces, equipment and tools.

4.4.1 Ergonomics Data Collection Techniques and Sources

The data collection method indicates in order to assess the current status of passenger seats comfort in three wheeler Bajaj in Adama city. To this study source of data collected measuring existing passenger seat dimensions and anthropometric measurements of necessary anthropometric dimensions (Appendix B) (Molenbroek et al., 2009). Anthropometric measurements focus on 145 passengers from them 84 males and 61 females by riding in Bajaj, waiting and asking passengers to take measurements.etc. Generally this indicates the age ranged between 18 and 58 years for this study all the measurements were taken from the passengers who travel from Adama city. Then comparing existing passenger seat and anthropometric data using mean value to know the difference between them and identify the problem. The values are given in tables shown below.

Anthropometric dimensions (body dimensions) are important to Bajaj seat design dealing with the human shape and size. As shown in Appendix B, the dimensions of passengers which are necessary to seat design are 1-sitting height (SH), 2-sitting to shoulder height (SSH), 3-buttocks to popliteal length (BPL), 4-popliteal height (PH), 5-shoulder breadth (SB) and 6-hip breadth seated (HB) were measured.

4.4.1.1 Measurement of Passengers Seat Dimensions

Measurement for seat dimensions evaluation is important tool in the development of three wheeler Bajaj seat to fulfill the criteria of ride comfort. The dimensions of existing passenger seats of Bajaj three wheeler are assessed by taking measurements on seat height, seat width, seat depth, back rest height and back rest width using meter.

4.4.1.2 Measurement of Passengers' Anthropometric Dimensions

Anthropometric dimensions (body dimensions) are important to Bajaj three wheeler seat design dealing with the human shape. As shown in Appendix B, the dimensions of passengers which are necessary to seat design are 1- sitting height (SH), 2-sitting to shoulder height (SSH), 3-buttocks to popliteal length (BPL), 4-popliteal height (PH), 5-shoulder breadth (SB) and 6-hip breadth seated (HB) were measured. The main aim of this study is to gather anthropometric data necessary for the design and manufacture of passenger seats as well as to compare the data with that of the passenger seats presently in use.

a) Statistical Summary of Respondents

In this study, there are 145 participants with 58% males and 42% females involved. The following table 26 shows statistical summary of passengers ages (years) from 18-58 which involved in this study. The passenger ergonomics data was obtained through questionnaire related to passenger seat.

Table 26: Statistical Summary of Passengers age from 18-58 years

	Age (years)	Height (cm)
Minimum	18	165
Maximum	58	186
Mean	36.4	175
Standard deviation	10.9	7.3

4.4.2 Evaluation three wheeler Bajaj Seat Dimensions

The seat dimensions are considered as the most primary constraints of the occupant posture when sitting in the vehicle. The seat design is on the other hand based on the anthropometry of target users. Reed (Reed et al. 1994) highlights the importance to define anthropometric measurements and relate them to the seat parameter in focus. For example, hip width (anthropometric dimension) needs to relate to seat width (seat parameter). Bajaj three wheeler existing passenger seats dimensions mean value for each seat dimensions evaluation is shown in table 27.

Table 27: Dimensions of existing passengers seat of three wheeler vehicles (Bajaj) in cm

Seat dimensions in cm	
	Mean
Seat height	41
Seat width	36.7
Seat depth	35
Backrest height	40
Backrest width	36.7

4.4.3 Evaluation Anthropometric Dimensions

Table 28: Anthropometric dimensions of passengers in cm

Anthropometric dimensions in cm		
	Mean	SD
Height	175	7.3
PH	42.5	6.5
HB	38.6	1.64
BPL	48.5	5.7
SH	78.75	4.1
SSH	56.9	4.8
SB	44	3.8
Note: SD-Standard deviation, PH-Popliteal height, HB-Hip breadth, BPL-Buttocks to popliteal length, SH-Sitting height, SSH-Sitting to shoulder height, and SB-Shoulder breadth.		

Usually the occupant packaging and vehicle seat design guidelines use the anthropometric boundary values of 5th percentile female and 95th percentile male (Roe RW 1993; Albert 1996; Reed & Flannagan 2000; Parkinson & Reed 2006). The summary of the anthropometric dimensions of the passengers in terms of means, standard deviations, and fifth, fiftieth, and ninety fifth percentiles are presented in table 29.

Table 29: Anthropometric dimensions of passengers in cm

Anthropometric dimensions			Percentile		
	Mean	SD	5^{th}	50^{th}	95^{th}
Height	175	7.3	165.1	177	184
PH	42.5	6.5	38.1	45.5	52.9
HB	38.6	1.64	30.1	32.3	38.9
BPL	48.5	5.7	42.1	48.3	56.5
SH	78.8	4.1	71.2	81.3	84.9
SSH	56.9	4.8	51.1	58	64.5
SB	44	3.8	37.1	45	48.9

Note: SD-Standard deviation, PH-Popliteal height, HB-Hip breadth, BPL-Buttocks to popliteal length, SH-Sitting height, SSH-Sitting to shoulder height, and SB-Shoulder breadth.

Table 30: Comparing existing seat dimensions and passengers' anthropometric dimensions in cm

Anthropometric Dimensions		Seat dimensions		Difference
	Mean		Mean	
PH	42.5	Seat height	41	1.5
HB	38.6	Seat width	36.7	1.9
BPL	48.5	Seat depth	35	13.5
SSH	56.9	Backrest height	40	16.9
SB	44	Backrest width	36.7	7.3

Generally table 30 shows that significant differences exist between the means of 'popliteal height (PH)' and 'seat height'; 'hip breadth (HB)' and 'seat width'; 'buttocks to popliteal length (BPL)' and 'seat depth'; 'sitting to shoulder height (SSH)' and 'backrest height'; 'shoulder breadth (SB)' and 'backrest width'. Thus, there is the discomfort experienced by the passengers that use the seats due to this mismatch. Also Pakistan Standard and Quality Control Authority (PSQCA) three wheeler auto vehicles passenger seat standard shows every passenger shall be provided with at least (minimum) 38 cm (15″) x 38 cm (15″) seats [65]. The existing seat dimensions of three wheeler Bajaj shows in table 30 not fulfills this standard. It violates Pakistan Standard and Quality Control Authority rules of the three wheeler vehicles. This which indicates seat dimensions discomfort for passengers. Therefore, anthropometric dimensions bring a significant improvement in passenger seats and it makes comfort for passengers. So the passenger seats of three wheeler vehicles (Bajaj) need improvement or modification. Moreover, the passengers' body dimensions and seat dimensions were compared. The result shows mismatch between the passengers' bodily dimensions and the seat dimensions. It was thus concluded that as per table 30, the current study shows a mismatch between the dimensions of existing passenger seats of Bajaj and the anthropometric dimensions of passengers. This suggests that anthropometric data of the passengers was not employed in the design and manufacturing of the seats. This study is an indication that seats in the three wheeler Bajaj and passengers' anthropometric dimensions are at variant nationwide.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5. 1 Conclusion

- This thesis work was divided into three subgroups in order to analyze all the main aspects of the vehicle. The subgroups were structural design, aerodynamics shape improvement and passenger ergonomics assessment. The design work for each of the subsystems of the vehicle were made by the selection of components while keeping in mind the strength, performance, weight and safety. The primary goal was to build the lightest frame, to make passenger safety and to maximize performance of the vehicle.
- The designed structure is analyzed for the static and impact loads. The optimized parameters from each analysis are carried over to the next analysis following the order of front, side, rear and roll over impacts respectively. The chassis and body frame was designed as the vehicle can withstand better crash and static types of loads. The chassis and body structures have been improved by optimizing the number of tubes using FEA analysis. The important option of structure of this vehicle is to be performed using the tubular space frame. With this work it is understood that tubular structure increased the strength of the structure with reduction in weight. This system allows some advantages. It has a great strength to carry heavy loads and a high rigidity to withstand high elastic and dynamic stresses. This system also protects the bodywork from bending or torsion efforts.
- The aerodynamic design of this vehicle is an area where a lot of improvements will appear in the near future, in concern of drag reduction. The aerodynamics of TWV has been described in order to get notions about how to reduce drag resistance. Analysis was completed successfully in 3D by using CFD software. By taking in account the boundary conditions; velocity, pressure, density of air and the frontal area of the vehicle. Thus it is possible to produce the body shape with optimum frontal area that will offer less resistance to the air moving in the opposite direction. Models of the body have been modeled for performing numerical analysis using CFD software. Velocity used for fluent analysis is 50 kmph, 60 kmph and 70 kmph. It was found that the least drag force was acting on new model. The percentage reduction in drag force of new model from existing model is found to be 24.6%. By this modification the coefficient of drag is reduced in model 2 are approximately 8.1%. Fuel consumption of about 5.0% can be reduced from 60 kmph to 70 kmph. Thus, I believe this improvement in fuel efficiency will have a high impact on the reduction of fuel consumptions.

5.2 Recommendation

Based on the analysis it is possible to make certain recommendations to bring a significant change in this research. The following suggestions are forwarded as the result of the present study:

- There are a lot of drag reduction possibilities that can be applied to change the geometry of the model to a more stream lined shape that will also have a great effect on turbulence reduction but, more expertise is required in concerned area.
- In order to make the passengers to feel comfortable, passenger seats of Bajaj should be ergonomically designed.
- It is recommended that while designing seats, designers should use guidelines for seat dimensions proposed by the Society of Automotive Engineers (SAE).
- It is recommended for other researchers to work on ergonomics design of passenger seats of other transport vehicles as well.

5.3 Future Work

As a future work it is recommend that the following to be included in further research.

- The current work did not include the vehicle to vehicle crash, therefore, in the future analysis of frontal, rear, side and rollover frame structures during vehicle to vehicle can be done.
- Further reduction in weight is possible by means of shape optimazation and structural analysis.
- Rollover during impact case is done in current research but rollover during steering is not done, therefore, in the future analysis it should be done.
- Stability analysis can be performed in the future.

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APPENDICES

Appendix A. Questionnaire Prepared For Concern Sample Population in Adama City

This questionnaire is prepared by a student of the Adama Science and Technology University, graduate program. The aim of the questionnaire is to assess anthropometric data to improve Bajaj three wheeler passenger ergonomics. The data collected will remain confidential.

Write and Tick to Respond it ( )

1. Address --

2. What is your gender?

Male------------------ Female--------------------

3. Age -------------------

4. Marriage Condition: Married------- Divorced------- Widowed------ Separated-------- Single---

5. What is your educational level?

Primary education (1—8) --------------------☐

Secondary education (9—10) ---------------☐

Preparatory education (11—12) -------------☐

Some College----------------------------------☐

College Diploma-------------------------------☐

College Degree---------------------------------☐

Post graduate degree---------------------------☐

Undergraduate degree-------------------------☐

No qualification--------------------------------☐

6. Occupation

Government employee-------------------------☐

Self employed-----------------------------------☐

Unemployed-------------------------------------☐

Out of work--------------------------------------☐

Home maker-------------------------------------☐

Student---☐

Unable to work ---------------------------------☐

Teacher---☐

Others --☐

7. How long have you been in Adama (Nazreth) city?

Less than a year----------------------------------☐

1—2 years---☐

3---5 years---☐

6—7 years---☐

8—10 years --☐

Above 10 years-------------------------------------☐

8. Which type of motor vehicles do you use most of time to travel in city?

Three wheeler vehicle (bajaj) -----------------------------☐

Four wheeler vehicles ---------------------------------------☐

Two wheeler vehicles ---------------------------------------☐

9. Do you use Bajaj three wheeler vehicles? If your answer is 'Yes'.

Daily ---☐

Weakly---☐

Monthly--☐

Sometimes--☐

10. Have you faced or observed passenger ergonomics problem in Bajaj three wheeler vehicles in your journey?

Yes ----------------☐ No ------------☐

11. If your answer is 'Yes'.

Not enough for passengers----------------------------------☐

More problems ---☐

Few problems--☐

Other ---☐

12. Bajaj three wheeler passenger seats match or mismatch with your body dimensions?

It is match ----------------☐ It is mismatch-------------☐

13. If your answer is 'mismatch'. It is mismatch with your

Sitting Height (SH) ---☐

Sitting to Shoulder Height (SSH) -------------------------☐

Buttocks to Popliteal length (BPL) -----------------------☐

Popliteal Height (PH) -------------------------------------☐

Shoulder Breadth (SB) ---------------------------------☐

Hip Breadth (HB) ---------------------------------------☐

14. Do you know your body dimensions? If your answer is 'Yes'. Putt all dimensions in centimeter (cm)

a) Your Stature -- cm

b) Your Sitting Height (SH) --------------------------- cm

c) Your Sitting to Shoulder Height (SSH) ------------ cm

d) Your Buttocks to Popliteal length (BPL) ---------- cm

e) Your Popliteal Height (PH) ------------------------- cm

f) Your Shoulder Breadth (SB) ----------------------- cm

g) Your Hip Breadth (HB) ----------------------------- cm

15. If you don't know your body dimensions. Do you agree to measure your body?

Yes -------------------☐ No ----------------☐

16. If your answer is 'Yes'.

i) Stature (height) --- cm

ii) Sitting Height (SH) -------------------------------------- cm

iii) Sitting to Shoulder Height (SSH) ---------------------- cm

iv) Buttocks to Popliteal length (BPL) -------------------- cm

v) Popliteal Height (PH) ----------------------------------- cm

vi) Shoulder Breadth (SB) ---------------------------------- cm

vii) Hip Breadth (HB) -- cm

17. How do you comment Bajaj three wheeler passenger seats? Please write either in positive or negative out looks you have.

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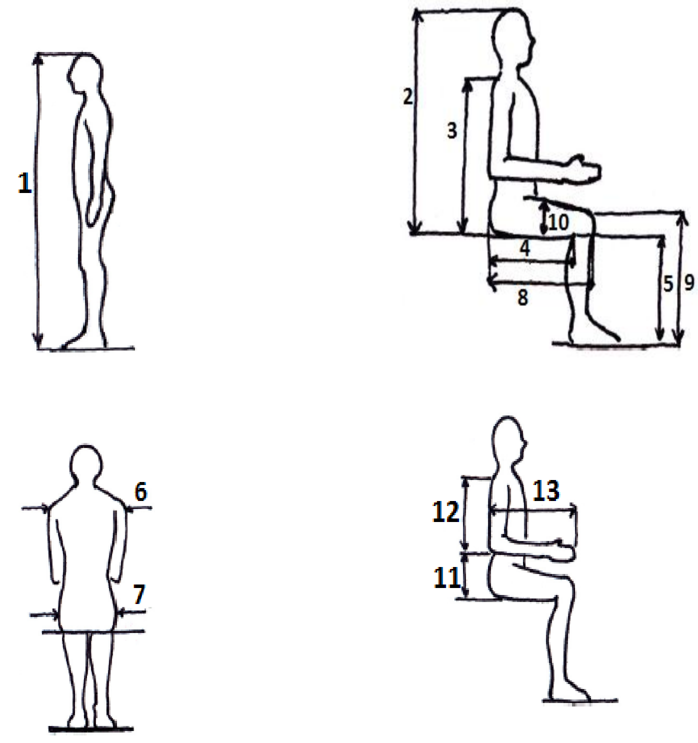
18. Write any additional comments you think are important to solve problems from Bajaj three wheeler vehicles?

Thank you for your help with this study!!

Appendix B. Anthropometric Dimensions Measured for Study

Anthropometric estimations for Ethiopia adults aged 18-58 years with all dimensions in millimeters, (Pheasant, 1996).



1. Stature (S) or height (H)
2. Sitting height (SH)
3. Sitting to shoulder height (SSH)
4. Buttocks to popliteal length (BPL)
5. Popliteal height (PH)
6. Shoulder breadth (SB)
7. Hip breadth seated (HB)
8. Buttock-knee length (BKL)
9. Knee height (KH)
10. Thigh thickness(TT)
11. Sitting elbow height(SHE)
12. Shoulder-elbow length (SEL)
13. Elbow-fingertip length(EFL)