Designing of Fuel Tank with Increased Capacity and Improving Its Location for Better Stability of Three Wheeled Vehicle

Haileyesus Aderaw Kebede

A Thesis Submitted to
The Department of Mechanical Engineering
School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for Master of Science in Automotive Engineering

Office of Graduate Studies
Adama Science and Technology University

June, 2023
Adama, Ethiopia

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Adviser: Dr. Ramesh Babu Nallamothu

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DECLARATION

I hereby declare that this Master Thesis entitled **“Designing of Fuel Tank with Increased Capacity and Improving Its Location for Better Stability of Three Wheeled Vehicle”** is my own work and has not been submitted to any university for a similar purpose. The references used in this proposal are duly recognized by proper citations.

Haileyesus Aderaw Kebede	________________________	______________________
Name of the student	Signature	Date

RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Designing of Fuel Tank with Increased Capacity and Improving Its Location for Better Stability of Three Wheeled Vehicle"** prepared under my guidance by Haileyesus Aderaw Kebede submitted in partial fulfillment of the requirements for Master of Science in automotive engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Ramesh Babu Nallamothu	____________________	____________________
Major advisor	Signature	Date

APPROVAL PAGE

I, the advisor of the thesis entitled **"Designing of Fuel Tank with Increased Capacity and Improving Its Location for Better Stability of Three Wheeled Vehicle"** and developed by Haileyesus Aderaw Kebede; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Ramesh Babu Nallamothu	___________________	___________________
Major advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Haileyesus Aderaw have read and evaluated the thesis entitled **"Designing of Fuel Tank with Increased Capacity and Improving Its Location for Better Stability of Three Wheeled Vehicle"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of Master of Science in Automotive Engineering.

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ACRONYMS

ATVs	All-Terrain Vehicles
TWV	Three Wheeled Vehicle
NHTSA	National Highway Traffic Safety Administration
ANSYS	Analysis of Systems
FEA	Finite Element Analysis
CFD	Computational Fluid Dynamics
CFL	Courant-Friedrichs-Lewy Condition
CG	Center of Gravity
VOF	Volume of Fluid

NOMENCLATURE

$\frac{a_{threshold}}{g}$	Static Stability factor (-)
b	Track Width (m)
h	Height of Center of Gravity (m)
L	Wheel Base (m)
$l1$	Longitudinal Location of cg w.r.t. Rear Axle (m)
δ	Density (kg/m^3)
ϑ	Poisson's Ratio (-)
C	Courant number (-)
Δt	Time step size (s)
U	Velocity of Mesh (m/s)
Δx	Length b/n Mesh Elements (m)
V	Volume (m^3)
g	Acceleration Due to Gravity (m/s^2)
$\tan\phi$	The Slope of the Free Liquid Surface (^{0})
μ	Dynamic Viscosity (kg/m-s)
a	Centripetal Acceleration (m/s^2)
R	Vehicle Curvature radius (m)
θ	Angle of Inclination of Vehicle
N	Force (N)
Cm	Moment Coefficient
$\dot{m}_{pq}$	Mass transfer from phase q to phase p (kg)
P	Pressure (pa)
X_{cg}	Center of Gravity in the X (m)
Y_{cg}	Center of Gravity in the Y (m)
Z_{cg}	Center of Gravity in the Z (m)

ABSTRACT

In the automotive industries, Fuel tank is an essential part for vehicles operation along with other functional systems. It is a container specially designed as an integral part of the fuel system for a specific car model and used to carry & supply fuel to the engine via fuel filter, fuel pump. In Ethiopia, it is observed that due to smaller size of the fuel tank of three wheeled vehicles more frequent visit to fuel filling station leading to wastage of time in waiting in long queues near fuel station. Also, the current location of the fuel tank observed to be causing some stability problems. General feedback is obtained from the interviews of the drivers, vehicle owners and technical persons. The data surveyed at Bishoftu and Adama on February 2023 are collected, analyzed and organized and the compromises are made along with the vehicle weight and the amount of fuel tank capacity needed. Then the method, the location, mounting techniques and stability analysis of the three wheeled vehicle are performed. Hence, mounting new designed part is carried out at the bottom of the passenger seat. In doing so, a fuel tank mounted at its bottom optimizes the center of gravity since the height of center of mass of the vehicle lowered by 30mm to the ground. Therefore, the vehicles rollover resistance can be increased. This study made a new design of fuel tank for three-wheeler vehicles in which its capacity increased twice the amount of the existing fuel tank and keeps the vehicles rollover stability. The methods that are used to model the modified fuel tank design and analysis of this thesis work involved SOLIDWORKS software and ANSYS FLUENT Computational Fluid Dynamics (CFD) software for sloshing analysis. The CFD results of comparative sloshing analysis at partially filled (50% fill level) of fuel tank with and without baffles are performed and conclusions are carried out. Therefore, Due to the combined acceleration motion, parameters defining stability of the tank as well as the vehicle such as sloshing forces, vertical forces and roll moments computational simulation are carried out at the existing, a new fuel tank with baffle and without baffles systems. A baffle of a fuel tank presented the largest benefit in reducing the sloshing impact. Finally after analysis performed, mileages of fully filled existing fuel tank and new fuel tank are about 136 km and 272 km respectively. To fill once the driver waits for average of 5 hours and works for about 2 days for the existing fuel tank and 4 days for the new fuel tank.

Keywords: Analysis, Sloshing, Rollover Stability, CFD

CHAPTER ONE

INTRODUCTION

1.1 Background

Three-wheeler transport services have steadily increased since the 1950s across Africa, Asia, and Latin America. Following sharp growth in the manufacture of inexpensive motorbikes and three-wheelers in Asian nations, this trend has increased during the past 20 years.

The production and use of motorcycles and three-wheelers gradually shifted (southward and eastward) throughout the second part of the twentieth century. Production on a large scale decreased in Europe and the USA while increasing in Japan, India, and China. Despite the fact that more and more Japanese designs are being produced outside of Japan thanks to joint ventures in China, India, Vietnam, Indonesia, and other nations, this trend is still going strong.

The number of motorcycles and three-wheelers in use has expanded significantly over the past thirty years, and their costs have decreased relative to people's earnings. For instance, motorbikes costing more than USD 2000 were available to purchase in many African nations, including Tanzania, in the 1980s. Today, Chinese and Indian motorcycles are considerably more reasonably priced, costing around USD 600. Currently, there are around 150 million motorcycles in India, making up about 80% of all motorized vehicles. Motorcycles are primarily utilized for personal transportation in some nations, such as India and Nepal. Motorcycles, on the other hand, play a significant role in many nations' transportation systems. In fact, the expansion of motorcycle taxi services that allow purchase prices to be paid for from the cash generated by motorcycle taxi fees has significantly fueled their rapid growth in sub-Saharan Africa since the start of the twenty-first century (Starkey P, 2016).

Around 1950, the Indian Bajaj company began to offer three-wheelers made with parts from Italian Piaggio scooters (three-wheelers known as "scooters" had previously been used in Italy as inexpensive freight vehicles), and this is when the use of three-wheelers for transportation services really began to take off. The three-wheeled Bajaj scooter, which could accommodate two or three passengers in its rear seat, gained popularity as a low-cost, point-to-point urban taxi. They started to take the place of bicycle rickshaws and were given the name "auto-rickshaws." In order to make the German Tempo freight three-wheeler more suitable for routebased transport service operations, Bajaj also modified it into a larger vehicle with two rear seats that could accommodate six passengers. Bajaj quickly overtook other three-wheeler manufacturers as the largest in the world. By 2018, India was producing over a million three-wheelers annually, with a third of those being exported, notably to an excessive number of African nations (SIAM, 2019).

At the moment, Ethiopia is rapidly updating its transportation infrastructure, including its roads and railroads. Alongside the growth of the infrastructure, the automobile industry also began to expand, however they are merely assembling facilities. The Indian-made three-wheeler taxis first arrived in Ethiopia in 2005. They have gained a lot of traction as a practical mode of transportation known as Bajaj. Apart from the capital of Addis Abeba, it has been noted that the Bajaj is expanding its reach into all of Ethiopia's main cities and rural areas. At the same time, they are replacing older modes of transportation like horse-drawn carriages. Due to the availability of numerous brands, both the price and demand are skyrocketing. At the same time, it is discovered that both the market environment and the competitive landscape are rapidly changing. The enormous popularity of this mode of transportation has highlighted the necessity to comprehend how customers feel about the services provided. Due to its accessibility and cost, passengers are turning to auto rickshaws as a form of transportation (Mohd A.Shaikh 2019).

Several studies on travel behavior, such as those by Ben-Akiva and Morikawa (1990) and Koppelman & Wen (1998), explore issues like fare, frequency of service, waiting time, and trip time, among others.

According to visual observation and drivers' feedback in Ethiopia, three wheelers fuel tank capacity has evolved as one of the biggest challenges, because three-wheeler vehicles are challenged in refilling the fuel. The vehicles fuel tank is quite small due to the vehicle's limited ability to carry gasoline; additionally, due to the thousands of vehicles that are currently on the road in each city, producing crowds or very lengthy queues at stations. Particularly for the vehicles working in a rural area with absence of nearby gas stations is serious.

The long queue of three wheelers waiting near the gas station is shown in figure 1.1.

Figure 1.1: Long queue of three-wheeler vehicles near fuel station.
Photographer: Yasuyoshi Chiba/AFP/Getty Images

Automobile fuel tanks restrict the amount of fuel evaporation to prevent leaks. According to the many types of vehicles, it differs in design, size, and capacity. Plastic, steel, and aluminum are just a few of the materials used to construct fuel tanks. It is made of pressed steel or flame resistant. Even though most fuel tanks are manufactured, some are still built by metalworkers or, in the case of bladder-style tanks, by hand. Fuel tank construction involves a set of precise steps. To accurately gauge the tank's size and shape, the craftsman typically builds a prototype out of foam board. The location of the outlet, drain, fluid level indication, seams, and baffles, among other design considerations that have an impact on the tank's structural integrity, are then addressed. The craftsman must then choose the alloy, temper, and thickness of the sheet he used to construct the tank. The basic shell, ends, and/or baffles for the tank are made by bending various parts of the sheet after it has been cut to the required shapes. Internally the tank has baffle plates arranged in parallel to the sides of the tank to give the necessary rigidity to the tank and to prevent fuel surging when the automobile accelerates, rounds a corner etc. Openings are added for the filler neck, drain, and fuel-level sending unit at the end of construction.

Fuel is kept in tanks that are installed on vehicle frames. Depending on the application, fuel tank capacity varies from vehicle to vehicle. Typically, trucks are equipped with fuel tanks that hold more than 150 gallons. The design of fuel tanks is a difficult issue as well. Tanks come in a variety of designs, including cylindrical, rectangular, and D-shaped tanks. According to the amount of fuel needed for a particular application, most popular tanks are either cylindrical or rectangular. The optimum tanks for maximum gasoline uptake are rectangular ones. Because of the visual appeal and fashionable appearance of trucks, the gasoline tank is typically shaped like a cylinder. Using mounting brackets, the gasoline tanks are fixed to the vehicles' frames.

P. J. Alvarado "Automobile manufacturers started using plastic to make fuel tanks in the middle of the 1980s." HDPE is the material used to make plastic gasoline tanks. Manufacturers may lighten the overall weight of their cars thanks to HDPE, a durable and lightweight polymer. Better design flexibility, increased corrosion resistance, and cheaper manufacturing costs are further advantages in addition to its light weight (American Plastics Council, 2003). Full height baffles, like those found in traditional steel fuel tanks, cannot be employed in plastic tanks due to limitations in the way they are made. Therefore, excessive fuel movement within a plastic fuel tank may result in sloshing noise that would not be present in a steel fuel tank.

1.2 Statement of the Problem

Most commonly, as all aware, three-wheeler transportation is the most widely used mode of transportation service provider. The space where fuel is stored in the vehicle's crucial section is quite small due to the vehicle's limited ability to carry gasoline; therefore, frequent trips to the gas station are necessary. Additionally, due to the thousands of vehicles that are currently on the road in each city, drivers are filling up their tanks more regularly, producing crowds or very lengthy queues at stations and waiting for an hour or more, or even six to eight hours. Consider the vehicles operating in a rural area (village) with no nearby gas stations as being extremely seriously unwell. Therefore, the drivers are compelled to purchase fuel on the illicit market, which is much more expensive, and others are compelled to refuel by awakening in the middle of the night, which is undoubtedly extremely unsafe and may result in the loss of life or property. On the other hand, due to the combined acceleration motion, parameters defining stability of the tank as well as the vehicle such as sloshing forces, vertical forces and roll moments causes the vehicle ability to rollover. As the result, to reduce a sloshing impact, baffle plates for new fuel tank is necessary to build. Again the three-wheelers are inherently less stable than four-wheel vehicles, and they risk tipping over if they accelerate quickly into tight turns or apply heavy brakes. Therefore, performing the gasoline tank capacity maximization and maintaining stability of the vehicle is part of this thesis work.

1.3 Objectives

1.3.1 General Objective

- The general objective of this thesis work is to design the fuel tank with increased capacity and improve its location for better stability of three-wheeler vehicle.

1.3.2 Specific Objectives

The specific objectives are as follows:

- To optimize the position and number of baffle plates for minimizing the sloshing effect in partially filled fuel tank.
- To conduct simulation for sloshing analysis.
- To relocate the fuel tank with proper mountings.
- To study the effect of fuel tank on stability of the vehicle.
- To study on benefits gained in regards to mileage, waiting time in queues etc.

1.4 Scope of the Study

The scope of this thesis work deals modification of the fuel tank with increased capacity and a better design which minimizes anti-slosh properties of fuel and optimizes its location for better stability of three wheeled vehicle. In Ethiopia the main and popular transportation sector which is available everywhere is the three-wheeler vehicle. This study focused their problems to bring the solutions by considering their big service, a less fuel station availabilities and made a new design of most secure and safe fuel tank for three-wheeler vehicles in a better location. The methods that are used to model the modified fuel tank design is SOLIDWORKS software whereas for sloshing analysis ANSYS FLUENT Computational Fluid Dynamics (CFD) software are involved. The results of CFD analysis and discussions as well as conclusions and recommendations for future works are incorporated in this thesis work.

1.5 Limitation of the study

Modification made on the fuel tank to increase the fuel capacity added some mass of 8.2kg on the vehicle and the thesis work is only done on ANSYS FLUENT software but implementation is limited, it has to reach at the market for serving the community by fabricating the product. Next, ANSYS software and better computer was not available and finding it was very challenging as well as time taking.

1.6 Significance of the Study

It is expected to:

- Reduce the down time of the vehicle.
- Improve passenger service.
- Increase income.
- Reduce stations personnel intervention.
- Saves the time of the driver and reduce the fatigue while waiting at the gas stations.
- Improves vehicle stability.

1.7 Organization of the Thesis

This thesis work is organized with the following chapters. Chapter one is an introduction that comprises the background of the study, statement of the problem, general and specific objectives, scope of the study, limitation of the study, significance of the study, and organization of the study. Chapter two presents literature review related to the study that emphasizes the study of design and fluid sloshing analysis of fuel in the fuel tank and three-wheeler vehicle stability. Chapter three describes materials and methodology of the thesis work in order to address the general and specific objectives of this thesis work. Chapter four describes mathematical modeling to represent the fluid flow during sloshing in the form of mathematical equations and creating fluent solver model development for analysis of fuel tank. Chapter five describes and discusses results computational fluid dynamics of fuel tank with and without baffle to investigate the effects of baffle configurations for modified three wheeler vehicle fuel tank when it is subjected to combined lateral and longitudinal. Chapter six describes conclusions and recommendation to conclude the findings of the work conducted and recommendation for future research in the form of summary.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

In this chapter, the summary of the literature surveyed during the course of this research has been presented. This survey of literature is expected to provide the background information and thus to select the objectives of the present research on fuel tank construction, sloshing and its better location for vehicle stability. Over the years, the problem of sloshing has been investigated by a number of researchers by using different methods or techniques. To characterize the liquid slosh behavior inside a partially full tank, some people have used experimental analysis, while others have used computational analysis or other analytical methods. Before proceeding to studies describing liquid sloshing, here there are studies related to fuel tank are described.

2.2 Theoretical Background

2.2.1 Definition of Fuel

A substance that releases heat energy when ignited at a high enough temperature is called a fuel. Solid, liquid, or gas fuels are all possible. Almost all fuels are hydrocarbons, which are substances made of carbon and hydrogen. Liquid fuels are typically used in internal combustion engines. Natural petroleum is the primary source of liquid fuel. It is distilled and then processed to create products like kerosene, naphtha, and diesel fuel. The common fuels for automotive engine use are gasoline, diesel fuel and gas.

Petroleum (petrol) is a naturally occurring fossil fuel produced by the decomposition of organic matter that has been subjected to extreme heat and pressure over millions of years, particularly zooplankton and algae. Petrol is mainly utilized as a fuel to run equipment, heaters, and cars. Plastics and other items can be made from petroleum byproducts. Petrol has a very low flash point (-43°C), is highly flammable, and significantly contaminates soil and water when spilled. Because of this, the production of fuel tanks and the storage of fuel are closely regulated. All of our fuel tanks are fully compliant with UK laws and created for the secure storage and dispensing of fuel.

2.2.2 Definition of Fuel Tank

Automotive fuel tank is a part of an engine system where the gasoline or diesel fuel is stored and released into the engine of a car. The tank is connected to the engine's gasoline supply components by steel lines and rubber hoses. Fuel is transferred from the tank to the carburetor or fuel injection system via the fuel pumps. Before the fuel enters the engine, one or more fuel filters filter out water, debris, and other pollutants. The incoming air is cleaned by a different filter at the engine air inlet. Fuel vapors from the tank, the carburetor, and other components of the fuel system are prevented from escaping into the atmosphere by evaporative emission controls. In order to meet an engine's operational requirements from a light load to a full load, the carburetor or fuel injection system atomizes and vaporizes the gasoline and mixes it with air in the appropriate ratios.

According to Mohd. Tanveer akhtar et al.'s (2015) study, the gasoline tank is a safe place for an automobile to store flammable liquids that could explode. A good fuel system depends on the tank's design, construction, position, venting, spill and leak dispersion, and maintenance. Therefore, this study is looking into the fuel tank design investigation on commercial vehicles.

2.2.3 Fuel Tank Nomenclature (RE-4S PETROL, CNG, LPG Spare Parts Catalogue)

Albert Boecker, Karlsruhe (2004) presented a fuel tank has a plurality of fuel System components therein and is formed by incorporating the fuel System components into the fuel tank as it is being formed. The parts of the fuel system could be installed on a carrier and placed in a compartment alongside the carrier. The gasoline tank was subsequently formed to wrap the parts and carrier. To minimize gaps in the formed fuel tank, it is preferable for all electrical, fuel, and vapour lines to exit from a single aperture of the fuel tank.

The components of the fuel tank assembly complete are shown as follows in figure 2.1;

1) Fuel tank
2) Cap fuel tank-petrol
3) Ring o cap
4) Fastening bolt
5) Washer
6) Tank Unit
7) Fuel pipe (fuel tank to fuel filter)

8) Fuel filter
9) Hose clip
10) Fuel pipe (fuel filter to fuel pump)
11) Electronic solenoid fuel pump
12) Fuel pipe (fuel pump to fuel cock)
13) Assembly Fuel Cock
14) Fuel pipe (fuel cock to carburetor)
15) Carburetor

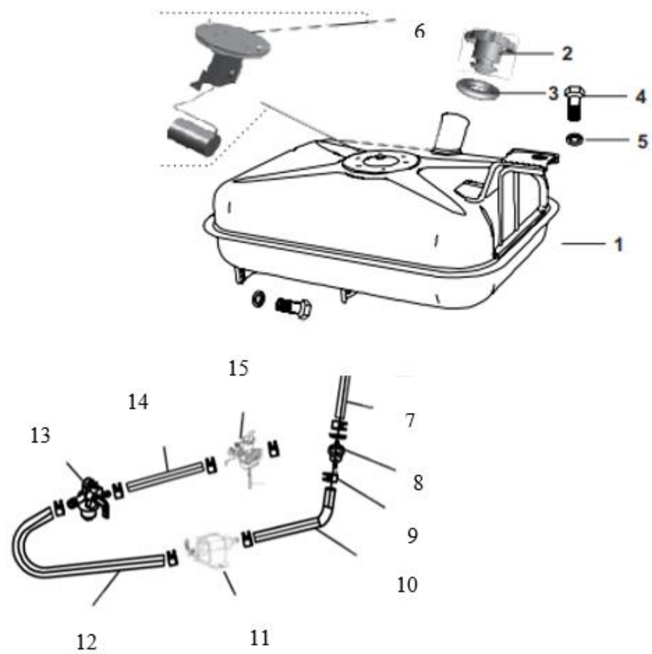


Figure 2.1: Fuel Tank Nomenclature (RE-4S PETROL, CNG, LPG Spare Parts Catalogue)

2.2.4 Theory of Fuel Tank

According to Gajendra G (2015), a fuel tank design is very important for vehicle performance prospective & safety concern. Steel was used in its construction due of its tremendous strength and longevity. The container is secure for combustible liquids. The vehicle contains a number of systems, including the fuel, hydraulic, and exhaust systems. The fuel system is the most crucial and significant of all the systems. The fuel system of automobile vehicles should perform within major safety parameters related to flammable substances and chassis body system may undergo undesirable vibration due to disturbance from road and fuel tank system. The fuel tank bracket should be rigid and dampened to reduce vibration caused by the road. For the purpose of fastening the fuel tank to the frame, brackets, straps, or a combination of both are used to mount the fuel tank.

The surface of the gasoline tank for mounting on the car's body's frame encourages the development of many types of views in new designs. In order to increase the size of the gasoline tank and help in fixing it to the frame, this study explores several forms of the fuel tank's external surfaces (David Gayland Surridge 2000).

Attilio De Biasi, et al (2015) presented an assembly for mounting a fuel tank on a vehicle frame rail and a technique for doing so are needed to optimize the vehicle assembly process and reduce the time needed for the fuel tank mounting. The fuel tank mounting assembly includes a fuel tank, support brackets that each have two supporting tabs, and tank strap assemblies that attach to the support brackets to secure the fuel tank to the tank support brackets. In order to couple the fuel tank to the vehicle for later permanent attachment, particularly at a subsequent assembly line station, receiver brackets are fastened to the vehicle's frame rail. The receiver brackets have two alignment notches that are sized to receive the two tabs of the fuel tank support brackets.

The mounting of the fuel tank to a support frame, which includes a sub-frame with a fuel level indicator mounted to a base and fastened to a mounting bracket (Kouji Shiratsuchi 1984).
Fuel Tanks for the automotive vehicle by Corrodi, R and Gordon, H (2004); Steel tank or plastic tank that is the question. Like Shake spear’s “Hamlet, Prince of Denmark” this is probably what all those responsible for fuel tanks have asked themselves, time and time again.

Original equipment manufacturers (OEMs) are giving the historically terne-coated steel used for gas tanks a closer look as Peter J. Alvarado states: weight and cost savings drive changes in performance standards for automotive materials. In this article, steel and plastic are compared for use in gas tanks based on performance characteristics and a market study. Current OEM activities as well as legislative issues are included.

The standard for automotive gas tanks has traditionally been terne-coated steel, which has an 8% tin-lead coating. However, a number of concerns are altering the performance requirements and endangering the use of steel goods. Legislation, an increased necessary part life of ten years or 241,350 kilometers, as well as permeability, weight, packaging, safety, and cost, are the main motivators for a material change. In this article, the original equipment manufacturers (OEM) performance features of the steel and plastic substitutes are examined in the crucial areas of manufacturability, cost, design, weight, safety, corrosion, and recyclability. Steel is still a cost-effective material that satisfies all of the necessary performance requirements, according to a comparison of the various plastic and steel substitutes. It is still necessary to compare the costs of the new plastic tanks (multilayer or barrier coated) with the new steel tanks in more detail. Legislative and regulatory pressures are the root cause of many of the drives, including lead reduction, clean fuels, permeability, and weight (Peter J. Alvarado 1996).

Utilizing multilayer plastic vessel fluid systems, fuel frame tank permeation and leakage are controlled. Today's motorized vehicles are typically made of plastic or metal. Fuel can leak from an instrument's sensor portion, joints between metal pieces, etc. In the case of plastic tanks, the plastic itself may cause fuel loss. Many composite materials are employed in manufacturing. However, compared to metal tanks, there is an increase in the permeability of the fuel. Improvements have been concentrated on adding barrior layers, resulting in tanks having multilayer walls to reduce emissions from plastic and composite tanks. (Mark Nulman 2001).

By Delbarre P. and Rod A. (1999), "Barrier Technologies Applied to Plastic Fuel Tanks Comparison of Their Performance." Polymers are now the ideal materials to use in fuel tank systems due to their low density, good processability and recyclability, outstanding chemical resistance, and particular mechanical strength. High Density Polyethylene is recognized as that industry's best technological and financial compromise. However, in general, HDPE provides a poor barrier to hydrocarbons, especially light ones like those found in gasoline, because of its chemical makeup and structure. Then, experts in the Fuel Tank System domain created a number of ways to deal with the attribute of HDPE in order to meet the ever-stricter rules on air quality and emissions.

According to Steven F. Aulph (1999), every car employs a gasoline tank as a storage space for its fuel. The majority of fuel tank assemblies consist of a tank shell with internal baffles that serve as supports and sloshing prevention mechanisms.

In manufacturing a conventional steel tank, two half-shells are formed by a process called sheet metal deep-drawing. Before soldering these two half-shells together to form a fuel tank, full height baffles can be installed. These full height baffles contain" holes to allow limited fuel movement between compartments. On the other hand, the technology of blow-molding is used to create plastic gasoline tanks. An extruded plastic tube (parison) is blown outward to fill the mold cavity, forming the gasoline tank. The plastic tank construction makes it impossible to add full height baffles. Baffles can only be included into the mold to a partial height.

According to Jadhav et al. (2018), one of the main obstacles for e-commerce players that leads to a longer path from the OEM to the delivery hub and from the delivery hub to the client is the capacity of gasoline tank leads. Fuel prices vary from state to state because of taxes. theft incidents have increased. Calculating FE (Mileage) is challenging because of how frequently fuel is filled. Design for a 395 liter gasoline tank and its packaging are already in the car. He accepted the task of fitting a second 395 liter fuel tank into the same frame, which is quite challenging owing to the limited space and hefty load.

On the basis of H. V. Chavan et al., the fuel tank in square-shaped is located on the right long member of the vehicle and has a two-liter fuel capacity. The engine cabin's vacant space was made use of by the plastic fuel tank, which has a three-liter fuel storage capacity (an increase of one liter) and is installed on the vehicle's body inside the engine compartment. The engine cabin had plenty of empty room, and it was far more suitable, safe, and secure than the old one.

2.3 Sloshing Analysis

Liquid sloshing refers to the free surface motion of the liquid caused by external excitation in a partially filled container. Numerous engineering sectors use liquid sloshing, including the construction of fuel tanks for automobiles, liquid transportation containers on highways, ships, and spacecraft, seismically excited storage tanks, dams, and nuclear reactors. Sloshing causes highly concentrated, localized impact pressure on the walls that could lead to structural damage as well as enough force to influence the stability of the vehicle carrying the liquid container. The type of motion, the strength and frequency of stimulation, the tank's design, the degree of fill, and the characteristics of the liquid all affect the amplitude of the liquid's free surface motion. (M. S. Celebi 2002).

The calculation of the hydrodynamic pressure distribution, forces, moments, and natural frequencies of the free-liquid surface is the fundamental issue with liquid sloshing. The dynamic stability and functionality of moving containers are directly impacted by these variables. Typically, there are two separate parts to the hydrodynamic pressure of liquids in moving rigid containers. The acceleration of the tank is directly related to one component. The portion of the fluid that is traveling at the same tank velocity is what causes this component. The second pressure is referred to as "convective" pressure and symbolizes liquid flowing on a free surface. To describe the sloshing component, mechanical models like mass-spring-dashpot or pendulum systems are typically used. Numerous significant phenomena, including the linear and nonlinear effects of sloshing for both inviscid and viscous liquids, have been taken into account in the numerical, theoretical, and experimental investigations of sloshing waves conducted over the past several decades (A. Vakilaad Sarabi 2012).

Liquid sloshing is the movement of liquid at the free surface inside a container that is only partially filled as a result of disturbances or forces from outside. This has a significant impact on how well a vehicle performs. The sloshing of fuel frequently results in strange noises and vibrations. The size of the holes or aperture in the baffles greatly affects the amount of sloshing. Beyond the usual size, increasing the orifice's size has little to no significant impact on the sloshing qualities Anirudh G. S (2019).

2.3.1 Causes for the Occurrence of Sloshing in a Tank

According to Reddy (2017), there are two main reasons of sloshing inside a tank of liquid:

1) Sudden changes in the direction of the vehicle, such as abrupt braking.
2) Strict road turns that could result in roll-over incidents.

2.3.2 Factors Which Influence the Intensity of Sloshing

According to Reddy (2017), a number of variables affect how much liquid sloshes inside a moving tank are;

1) Fill level
2) Tank shape
3) Liquid type
4) Tank motion

2.3.3 Influence Analysis of Different Baffles on fluids sloshing

Baffles are like bulkheads that have holes in them to let the fluid flow through. The baffles help control the forward and backward liquid movement, to minimize the internal movement of fluids and keep them evenly dissipate the force of fluid moving, side-to-side movement of the fluid can still cause tank vehicles to overturn on curves.

According to Dr. Jim Johnson (2003), these attempts are to install anchored and floating foam baffles inside the fuel tank and to insert inflatable baffles made of plastic or rubber compound. Johnson mentioned that the above methods usually do not solve the problem. The only promising method is to integrate baffle shape design into the mold. Because these "built-in" baffles contain holes to allow fuel movement, the baffle’s shape, size and location become critical factors to reduce the sloshing noise. Several students at the Department of Mechanical and Industrial Engineering of University of Toronto had tried to analyze this fuel sloshing problem. These students used computer simulations and sound measurements on actual slosh experiments to analyze this problem. Their results were very helpful toward the current research.

Rakheja, S. (2009) published Influence of Tank Design Factors on the Rollover Threshold of the Partially Filled Tank Vehicles. This paper provides a brief overview of general-purpose tank vehicles, which are frequently subject to slosh loads during highway maneuvers due to variations in the weight density of the liquid cargo. The size of the destabilizing forces and moments brought on by liquid slosh is closely related to the tires, suspension, articulation mechanism, weights and dimensions, tank geometry, and fill level of the tank. To show the destabilizing effects of liquid slosh, the rollover limit of the tank vehicle is compared to that of an equivalent rigid cargo vehicle. For a variety of tank design considerations, the tank vehicle's rollover threshold is evaluated. It is explored how tank size and cross-section affect the rollover threshold of tank vehicles. According to the study's findings, the geometry of the tank's cross-section has a significant impact on the lateral load shift and, consequently, the rollover threshold. An ideal sequence for unloading different compartments is described along with an investigation of the articulated vehicle's rollover threshold while carrying a compartmented tank.

In order to reduce maneuver-induced transient and steady-state fluid slosh forces and moments in a partially-filled tank vehicle, Kandasamy (2010) investigated the effectiveness of numerous baffle designs, including conventional, partial, and oblique baffles. Three alternative fill levels, 40 percent, 60 percent, and 80 percent, were evaluated. Simulations with simultaneous lateral and longitudinal acceleration were performed using a CFD model to simulate a braking-in-a-turn movement. The findings made it abundantly evident that typical baffles effectively control fluid slosh in the longitudinal direction but offer little resistance to slosh in the lateral direction. Under simultaneous lateral and longitudinal acceleration excitations, an oblique arrangement of baffles provides a significant amount of resistance to both lateral and longitudinal fluid slosh. Furthermore, although anti-slosh effectiveness in the longitudinal direction was comparable to that of the conventional baffle, partial baffles are typically ineffective in lateral slosh. Due to fluid being trapped in the lower region of the tank between two successive baffles or between the baffle and the end cap, the presence of baffles not only reduces the peak pitch moment but also produces lower steady values. The conventional baffle tank displays this behavior at lower fill levels, but at intermediate fill levels, compared to other baffles, the steady-state moment magnitude is higher.

Kandasamy et al. (2014) discuss the efficiency of various baffle designs for fuel tanks that are only partially full. The open surface of liquid cargo in road tankers may experience a significant excursion for relatively slight motion of the container. This issue is frequent in cars, airplanes, and tankers. A 3D model of a partially filled fuel tank is created in order to investigate the anti-slosh characteristics of various baffle designs under various cargo loads.

Using sheet hydroforming, Huiwen Hu, Jin-Fu Wang, and Kai-Ti Fan (2015) demonstrated how to create an aluminum gasoline tank for an automobile that was initially built of steel. First, a finite element model is developed, which includes a punch, blank, blank holder, binder, and die cavity. The forming procedure is simulated using the commercial code LS-DYNA. Simulations are used to investigate the design parameters that are used for the prototype experiment, such as pressure, holding force, punch feeding, and blank trimming geometry. The simulation findings are then verified using the aluminum fuel tank prototypes that have been constructed. Using sheet hydroforming, the experimental results demonstrate that models can accurately forecast the geometry, size, thickness distributions, and location of the maximum thinning ratio of aluminum fuel tanks.

Wang et al. (2019) performed parameter analysis on the impacts of the shape and size of internal bodies in a circular tank on fundamental frequencies and sloshing forces using an iso geometric scaled boundary finite element technique. A well-known mass-spring model was proposed by Housner (1963) to depict the continuous liquid in cylindrical tanks.

The main focus of Xue et al. (2019) was on the variations in sloshing wave dynamics and kinematics for the same amount of liquid in storage vessels of different shapes. The sloshing dynamics and pressure distribution for liquid storage containers receive a lot of attention, while the anti-sloshing issue for the storage vessels in the investigation receives much less focus. To reduce free sloshing, interior devices like circular or vertical baffles can be used in storage tanks. Xue et al. used tests to study the hydrodynamic pressure-inhibiting effects of several types of vertical baffles. However, when paired with other complex systems that may require numerous tests, conducting experiment research on the sloshing of liquid in tanks with multiple different baffles may need large amounts of tests. The theoretical method is better suited to produce parameter analysis for light liquid sloshing than the current numerical and experimental investigations.

2.4 Influence of Stability of Three-Wheeler Vehicle

The tricycle is a three-wheeled vehicle (TWV), often known as a trike or three-wheeler. According to Gawade et al. (2004), as seen in Figure 2.2, they are mostly employed for commercial purposes in African and Asian nations.

Figure 2.2: Three-wheeled vehicle (TWV)

When compared to four-wheeled vehicles and commercial motorcycles, the vehicle is cheaper, safer, and better equipped to navigate dense urban traffic. Due to the difference in weight from automobiles and jeeps, it is fuel-efficient and produces around 33% fewer greenhouse gases per passenger (Goodarzi et al., 2015). All of these factors have increased its use. The use of these TWVs is not without some safety concerns, though. Compared to cars with four wheels, they are more prone to accidents. Despite having a top speed of roughly 60 km/h, three-wheeled vehicle stakeholders attested that the vehicle can topple when negotiating a turn. This places some limitations on their usage.

The old scooter motorbikes served as the basis for the TWV's development, with little attention paid to stability. The high center of gravity is a result of the occupants' erect seating positions (Mukherjee et al., 2007). There are going to be instability issues given that the vehicle is narrow and cannot lean inwards when negotiating a turn to counteract the influence of centrifugal force (Berote et al., 2008; Dardaine et al., 2008). As a result of this instability, the TWV presents difficulties, particularly in the area of property and life protection. According to Huston et al. (1982) and Valkenburgh et al. (1982), a TWV can be engineered to be as safe as a four-wheeled vehicle.

A three-wheeled vehicle is more likely to roll over while rounding a turn because it has a smaller base than a four-wheeled equivalent. Huston (1982) demonstrated this by contrasting a four-wheeled standard vehicle with a non-tilting three-wheeled vehicle. Karnopp (1992) proposed that the vehicle should tilt like a motorbike. The dynamics of a narrow tilting vehicle and a way to manage the leaning angle of tilting vehicles were further explored by Hibbard and Karnopp (1993).

According to Starkeyetal (2019), Qingqi three-wheelers are inherently less stable than four-wheel vehicles and can roll over if they travel at a high speed over tight curves or turn while applying heavy braking. There is no 'crumple zone' like in current cars to absorb impacts.

Although they offer a flexible, affordable mode of transportation, these three-wheeled vehicles are prone to rolling over. Three-wheeled vehicle rollovers have caused major injuries to the occupants and even fatalities. Three-wheeled vehicles were involved in 5% on average of all traffic-related fatalities reported in India from 2009 to 2011. There were 8% serious injuries. 3.5% of the overall transport was thought to be its portion (Gov. India 2009-2011).

Due to the vehicle's rollover and crashworthiness features, this suggests a substantial hazard to human life. 29% of fatalities are caused by tempos, trucks, tractors, and mechanized agricultural vehicles (MAV). The majority of MAVs and tempos have rigid chassis three-wheeled vehicle versions. Public and commercial transportation is extremely important in Pakistan, since just 8 out of every 1000 people possess a car (A. Ahmed, 2007). 51% of all registered vehicles are two- and three-wheelers. The fact that reported accidents make up less than 2.5% of actual data was also highlighted. There is no split of three- and two-wheeled vehicles in the reported accident data, yet both account for more than 60% of fatalities.

According to Jooma et al. in Karachi, the number of people killed in accidents involving three-wheeled vehicles increased by 33% in 2011. Due to their poor safety record (Standards for ATVs 2006), three-wheeled all-terrain vehicles (ATVs) have been banned in a number of nations. The reported accidents have been linked to their frequent rollover crashes. According to Bangladesh Road Transport Authority's accident data, three-wheeled vehicle rollovers occurred in 75% of single-vehicle incidents. Many individuals in India favor this kind of transportation, making them susceptible to similar mishaps.

Driver error was found to be the primary factor in 77.5% of accidents that were reported (Gov. India 2009-2011). This involves overreacting excessively to emergencies, improper speed, etc. This shows the potential for active chassis control technologies to contribute to mitigating crashes. Research into the dynamics of wheeled platforms and related control systems at various levels, together with intensive testing, have been motivated by the need to reduce the risk to human life and eliminate the impacts of human error when operating vehicles. The adoption of such technologies has been mostly driven by cost effectiveness.

With reference to Figure 2.3, an analytical prediction of rollover stability was made using the limiting value of lateral acceleration as stated in equation (2.1). The static stability factor, also referred to as the ratio $\frac{a_{threshold}}{g}$, is used by the NHTSA to rate the propensity of a vehicle to roll over (M. Walz, 2005).

$$a_{threshold} < \frac{b}{2h}\ \frac{l1}{L} \tag{2.1}$$

Where the equations are for three wheeled delta vehicles

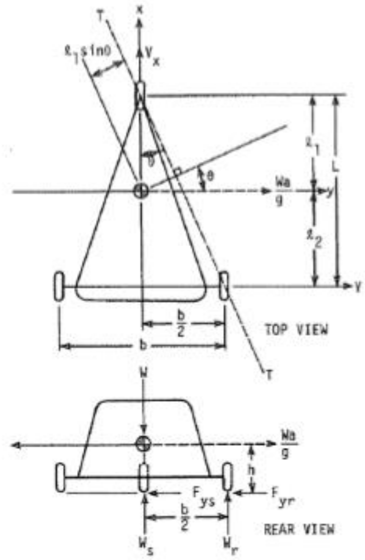


Figure 2.3: Three wheeled vehicle rollover axis

For the vehicle limit handling boundaries, linear tire behavior was employed instead of the static stability factor, which ignored the compliance of the suspension components. By Raman et al. (1995), three wheeled motorized vehicles that are often utilized in Asia were examined. The car was depicted as having a rigid triangular body, with wheels at each corner attached by vertical suspension damper combinations. Camber changes during vehicle roll were neglected. In comparison to the inertia of the sprung mass, transmission and suspension inertia were considered to be minimal. We used the specifications of a well-known commercial three-wheeled vehicle. Simulated maneuvers included constant power turns, rapid turns, and avoiding with braking. The avoidance maneuver while braking maneuver showed the vehicle to be most susceptible to rollover. According to research by T. Gillespie (1992), the quadratic term in the relationship between roll stiffness and track width can be used to explain how the increase in track width has an increasing impact on stability. While a vehicle's center of gravity is affected linearly by height, and stability declines as height increases. It was established that the effect of suspension was nonlinear. The equivalent roll stiffness, which doubles with a unit increase in stiffness of both rear suspension springs, can be used to clarify it. A smaller roll angle also helps to reduce the displaced center of gravity's overturning moment. With an increase in suspension stiffness, a drop in ride quality is expected. Damping has been shown to increase stability. Once more, the ride quality suffers as a result.

According to the Ethiopian Ministry of Transport, three-wheelers, also known as "Bajaj," are the primary forms of transportation in Ethiopia's secondary cities, where the usage of three-wheelers is still expanding quickly. The use of these cars is prohibited in Addis Abeba but legal in other Ethiopian cities where they are prevalent. Due to the high number of dirt roads, the road network on which these vehicles travel is significantly underdeveloped. With the exception of the major secondary cities like Dire Dawa, Bahir Dar, Jimma, or Hawassa, most Ethiopian towns lack regular bus networks, therefore three-wheelers fill the demands of the transportation. However, they appear to have a considerable impact on traffic jams, air pollution, and accidents. Furthermore, it's not certain if all "Bajaj" drivers adhere to the charge schedule established by the government (official fares seem incredibly cheap in comparison to actual investment and operating costs).

The Reporter journal (2023) reports that 54% of Bajaj passengers regard the company's drivers to be not just unlikable and unpleasant, but also unfair and engaging in risky driving. The tiny wheel base, relatively tall design, and weak engine of Bajajs, which make for an unstable vehicle, particularly on steep, hilly, country roads, worry both men and women passengers who frequently use this means of transportation.

2.5 Effect of Factors Effecting Rollover Propensity on Directional Stability

According to several researchers, the research of passive factors influencing a three-wheeled vehicle's propensity to roll over. RAJA A. A (2015), summarized the effects as given in Table 2.1.

Table 2.1 Factors effecting roll over resistance

	Parameter	Rollover Effect
1	Track width	As track width increases, rollover resistance increases.
2	Height of CG	Rollover resistance increases as cg height decreases.

3	CG's longitudinal position with respect to the rear axle	When cg gets closer the rear axle, rollover resistance increases.
4	Increasing suspension stiffness	Rollover resistance increases. The beneficial effect diminishes with increasing stiffness.

2.6 Research Gap

From the above Literature review, it is obvious that most researchers studied about fuel tank materials, mountings and baffles design as well as sloshing effects. On the other hand, three-wheeler vehicle existing fuel tank is constructed without baffles and it’s mounted at the top of either left or right side of the rear direction. According to given summary in Table 2.1 related to the researches done and most researchers studied, it is obvious that, three-wheelers are typically less stable than four-wheel vehicles, and they risk tipping over if they travel quickly through tight turns or brake forcefully while turning. Therefore, in this thesis work extending capacity, studying the baffles effects and impacts of fuel tank on stability of the vehicle are carried out to increase the effect of rollover resistance whereby addressing decreasing center of gravity height and optimizing fuel tank construction by constructing baffle system in the fuel tank, changing the location. As the result, to keep stability of the vehicle, changing the location of mounting from top of rear side of the vehicle to bottom of passenger seat is performed. And modeling is done by SOLIDWORKS software and the CFD sloshing analysis by ANSYS FLUENT software are investigated to analyze the anti-slosh properties of fuel in the fuel tank.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

In this chapter, in order to address the general and specific objectives of this work a well-designed methodology is followed. The Fuel tank parts are designed and constructed using SOLIDWORKS. Once the part is designed then imported in to ANSYS-FLUENT 2023 R1 software to study CFD sloshing effect analysis.

3.2 Materials

The following major components of the materials to be used are listed in Table 3.1.

Table 3.1: List of Material

No	Item
1	Steel material
2	SOLIDWORKS software
3	ANSYS/ANSYS FLUENT software

Steel is the currently used material for the existing fuel tank. The reason is the following,

- Steel is strong and durable.
- Steel is a common material because it is inexpensive.
- Steel is less likely to experience stress cracks,
- It is rust-resistant, and is simple to weld.

Materials used in this thesis work are;

Fuel Tank

The safest place to store flammable liquids is a fuel tank. Although any storage tank may be referred to as such, the phrase is usually used to refer to the area of an engine system where fuel is kept and then released into an engine.

Metal or plastic are the two materials most frequently utilized to make fuel tanks. Fuel tanks made of metal (steel or aluminum) are often constructed by welding stamped sheet metal components together. Blow molding is typically used to create plastic fuel tanks, allowing for the utilization of more intricate shapes. The analysis took into account both the new, higher capacity fuel tank and the existing fuel tank.

Tank Composition: Steel

Steel is the currently used material for the fuel tank. Here, steel is the material taken into account for the study, and the table below lists the material's qualities. For the tank, the von-mies stress, deformation, and shear stress are determined. Table 3.2 lists the qualities of the steel materials that should be used.

Table 3.2: Material properties of Steel

Properties	Material - Steel
Young's Modulus	2.1E N/mm^2
Density (δ)	7890 kg/m^3
Poisson's Ratio(ϑ)	0.3
Yield Strength	210 MPa

a) SOLIDWORKS software

SolidWorks is a computer-aided design (CAD) and computer-aided engineering (CAE) product by Dassault Systems that specializes in solid modeling. This software is used to model the part design of existing and new fuel tank and internal baffles.

b) **ANSYS-FLUENT software**

The leading fluid simulation program, Ansys Fluent, is renowned for its superior accuracy and comprehensive physics modeling capabilities. The most recent and well-known analysis software, this package uses FEA to resolve structural, meshing, and other analysis problems.

A numerical approximation method known as the finite element method divides a complicated structure into several small components, or pieces, and these small parts are referred to as finite elements. Small nodes, also known as connecting points, are used to link these tiny components together. The structural analysis technique, which is also known as the finite element approach and is quickly taking over as the major analysis tool for designers and analysts, uses matrix algebra to solve the simultaneous equations.

Dynamic analysis in 3-D rectangular tank CFD is used in this ANSYS fluent sloshing simulation of gasoline. By numerically resolving the underlying mathematical equation, computational fluid dynamics (CFD) is a branch of fluid dynamics that may examine fluid flow, heat and mass transport, chemical processes, and other related phenomena. Both industrial and non-industrial applications make extensive use of this strong computational method. Based on finite volume techniques, CFD works.

The three fundamental steps of computational fluid dynamics (CFD) are as follows:

- Pre-processing includes creating geometry and meshing.
- Simulation includes choosing physical models, solving the governing equations over a meshed model, and
- Post-processing and results analysis require qualitative and quantitative examination of predicted physical values.

To import the model from the SOLIDWORKS software for mesh generation, use the ANSYS workbench platform. Once the mesh has been created, the meshing file is exported to the FLUENT solver for capable pre-, processing, and processing.

c) Load

The fuel tank is particularly designed to store fuel. Thus, the load that is considered in this study is the gasoline with all its properties such as density, viscosity. The behavior of the forces and moments throughout the tank's motion as well as the surge effect of the fluid's instability have been taken into account.

3.3 Methodology

In order to address the general and specific objectives of this thesis work a well-designed methodology is followed. Various steps included in the methodologies are listed below and shown in figure.

3.3.1 Literature review

Literature survey about design and analysis of fuel tank are the key methodology for this thesis work that helps about what others done and identified, studied about fuel tank materials, mountings and baffles design as well as sloshing effects. On the other hand, three-wheelers can roll over if they travel quickly through tight turns or brake suddenly when turning. They are inherently less stable than four-wheel vehicles.

The current location of fuel tank and its inner construction are shown in figure 3.1, 3.2 and 3.3. In figure 3.3, the tank as shown in the picture is constructed without baffles.

Figure 3.1: Rear side of three-wheeler Figure 3.2: Three-wheeler vehicle existing fuel tank

Figure 3.3: Inner side of existing three-wheeler vehicle fuel tank

3.3.2 Data collection

Data collection is one the important stages in the research activity and carried out after the researcher made the design of the research in accordance with the problem that are researched. The necessary data are collected by using primary or secondary data collection through visiting various websites.

The research used combination of primary and secondary sources of data to address the key research objectives and results.

- The primary sources.

  The data was obtained from the field using primary data sources like, observations of long queues at fuel stations, survey analysis and observation of existing fuel tank, feedback from customer and vehicle owners, and interviews to drivers, gas stations and technical persons.
- The secondary source.

  Secondary sources used are referring web sites and books, discussion with an advisor and CFD software such as ANSYS.

As the problems stated, three-wheeler vehicle drivers are challenged in filling up their tanks more regularly, producing crowds or very lengthy queues at stations and waiting for an hour or more, or even six to eight hours. The reasons behind the problem are its vehicle's crucial section of the fuel tank is quite small due to the vehicle's limited ability to carry gasoline and additionally, due to the thousands of vehicles that are currently on the road made challenging.

Therefore, data collection methods were focused on the primary and secondary sources techniques. Data are collected, analyzed and organized; the compromise is made along with the vehicle weight and the amount of fuel tank capacity needed.

Using interviews, the primary data sources of information covered a wider in the study area. It is used to gather primary data from the individual respondents. The interviews, sample sizes of 50 included are drivers, vehicle owners and technical persons.

First, it’s better to introduce the interviewer’s feedback to estimate the accuracy of the average information provided by them. The all feedback given shows the three-wheeler vehicle fuel tank carrying capacity are eight liters but from all the only one vehicle driver informed as its vehicle fuel tank carrying 11 liters this is according to his vehicle brand is different. And the vehicles average mileage per a liter is about 17 kilometers.

Results of data collected in average looks the following;

- Time wasting for refilling is about five hours
- Refilling the fuel tank in average of one and half days to two days interval (i.e., two days working almost one days for refilling)
- 8 liters fuel tank capacity
- Distance traveling in one liter is 17km/l
- Average distance traveled per day is about 70km/l
- Demands of the fuel tank capacity to carry is at least double (i.e., a total of 16 liters)

3.3.3 Location of new fuel tank

After data is collected, analyzed and organized, a compromised amount of fuel capacity is increased from the existing fuel tank. The tank is mounted at the bottom of the vehicle. In doing so, a vehicle is made heavy at its bottom in order to keep its center of gravity as low as possible. A lower center of gravity helps vehicle to keep its stability.

For vehicle stability purpose the new fuel tank is mounted at the bottom of passenger seat, to know where the place is mounted it is better shown in figure 3.4.

Figure 3.4: Three-wheeler vehicle, RE-4S petrol-Global Bajaj (https://global.globalbajaj.com/en/Brands/RE/RE4S-Petrol)

As soon as the tank is mounted at the bottom of the vehicle, electronic solenoid fuel pump as shown in figure 3.6 is compulsory to deliver fuel from the tank to carburetor. The mechanism of fuel delivering is shown in figure 3.4.

Figure 3.5: Fuel supplying demonstration

Figure 3.6: Electronic solenoid fuel pump

3.3.4. Work flow of the research

Figure 3.7 depicts the process in the form of a flowchart.

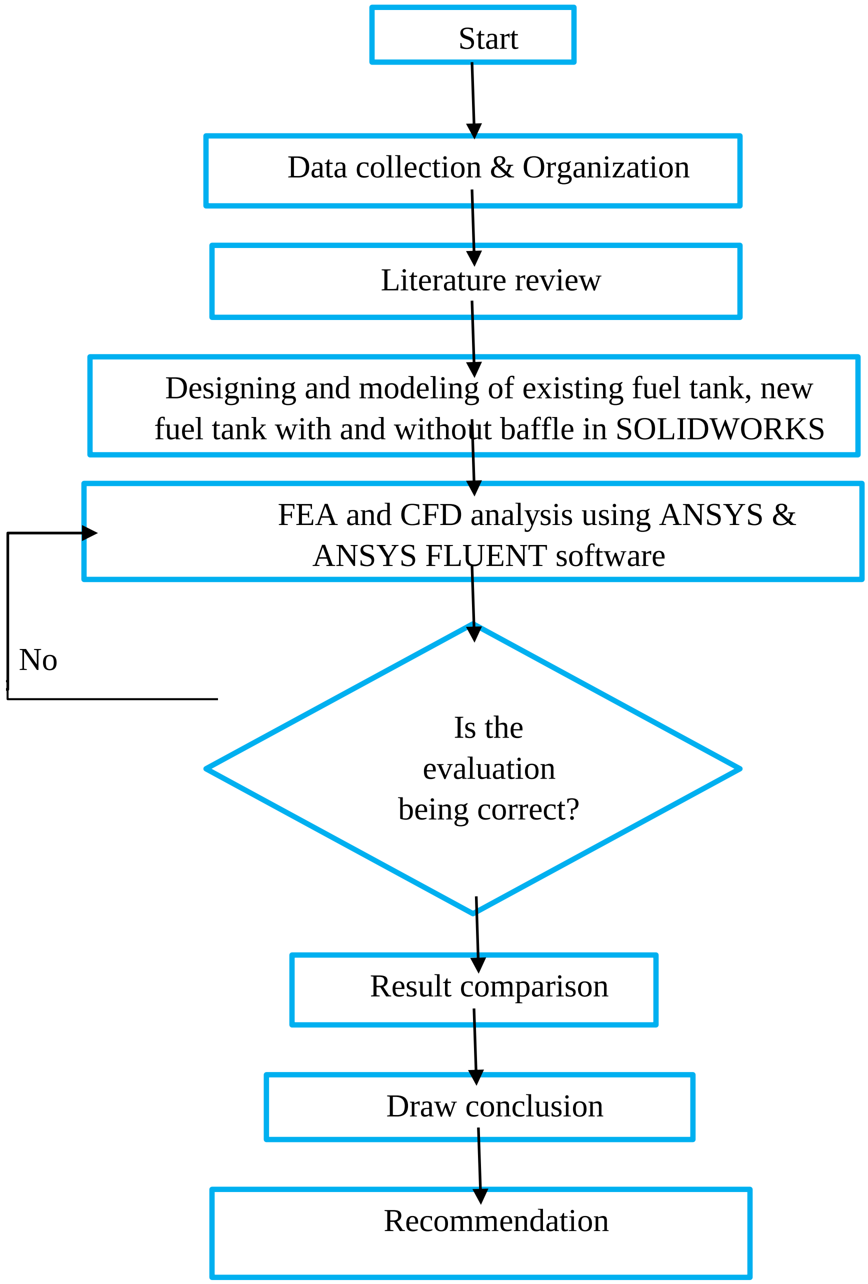


Figure 3.7: Work Flow of the Research

3.3.5. Design of new fuel tank

Existing fuel tank has eight liters fuel storage capacity. The proposed fuel tank is increased fuel storage capacity of eight liters and a total amount of sixteen liters. The part is designed as per the available space in the suitable location (i.e., at the bottom of the passenger seat which keeps the vehicles stability). After design is accomplished, the 3-D model for the existing fuel tank and the new fuel tank are modeled by SOLIDWORKS and analyzed the mesh and their fuel sloshing investigated by CFD analysis of ANSYS FLUENT software.

Fuel tank geometrical and volume data for the proposed new fuel tank

Material = steel

Volume = 16 liter

- Horizontal tank formula, Volume= length×width×height

Where,

Length=400mm

Width =250mm

Height =160mm.

Volume= 0.4m×0.25m×0.16m=0.016m^3

- Converting Volume to Liters

0.016m^3×1000 = 16 liters

Theoretical calculations

Calculation of Weight

- It takes into account both the tank's capacity and self-weight.

Steel is the tank's material.

Density = 7890kg/m^3

Capacity of the tank = 16 L

Petrol mass density = 700-800kg/m^3

- Converting kg/m^3 to kg/liter = 750kg/m^3

= 0.75kg/l

So for 16 liters, petrol (gasoline) mass is 0.75kg/l×16 l = 12 kg

- Self-Weight formula for tank

Self-weight = 2L×H×t+2L×W×t+2W×H×t

$= 2t\ (L\times H+L\times W+W\times H)$

Where,

Thickness= t= 1mm=0.001m, assumption

Length=400mm=0.4m

Width =250mm= 0.25m

Height =160mm=0.16m

Self-weight of tank material = $2t\ (L\times H+L\times W+W\times H)$ ×density of the Steel

$= 2\times 0.001(0.4\times 0.16+0.4\times 0.25+0.25\times 0.16)\times 7890 kg/m^3$

= 3.22 kg, without baffles.

Baffle weight= $t\times W\times H\times$density of the Steel

$= 0.001\times 0.25\times 0.16\times 7890 kg/m^3$

= 0.32 kg, weight of single baffle.

= 2×0.32 kg = 0.64kg, weight of two lateral baffles.

Solenoid fuel pump weight=0.5kg

Total Mass of the tank= self-weight+ baffle weight+ solenoid fuel pump weight

= 3.22kg+0.64kg+0.5kg

= 4.36kg

Total Mass of the tank with petrol= Total mass of the tank+ Mass of the gasoline

=4.36kg+12kg

=16.36kg

Total Weight of Tank = (Mass of gasoline+ Mass of the tank) ×gravitational acceleration

$= (12\ kg+4.36\ kg)\times 9.81\ m/s^2$

$= 16.36\ kg\times 9.81\ m/s^2$

= 160.49 N

Internal Pressure of Petrol Tank

- Pressure Equation (P) $=\delta\times g\times h$

Where, δ = Petrol (gasoline) density (kg/m^3)

g = gravity (m/s^2)

h = height of fluid(m)

- Standard Values

Petrol (gasoline) density= 750 kg/m^3

- Tank Dimension

Thickness= t= 1mm=0.001m

Length=400mm=0.4m

Width =250mm= 0.25m

Height =160mm=0.16m

- Pressure (P) P= $\delta \times g \times h$

$= 750\ kg/m^3 \times 9.81 m/s^2 \times 0.16m$

$= 1177.2 N/m^2$

Fuel tank geometrical and volume data for the existing fuel tank

- Converting Volume to Liters to kg

For 8 liters, petrol (gasoline) mass is 0.75kg/l×8 l = 6 kg

- Self-Weight formula for tank

Self-weight = 2L×H×t+2L×W×t+2W×H×t

= 2t (L×H+L×W+W×H)

Where,

Length=350mm=0.35m

Width =214mm=0.214m

Height =110mm=0.11m

Thickness= t= 1mm=0.001m

Self-weight = 2t (L×H+L×W+W×H) ×density of the Steel

$= 2\times0.001(0.35\times0.11+0.35\times0.214+0.214\times0.11)\times7890 kg/m^3$

= 2.16kg

Total Mass of the tank= self-weight+ Mass of gasoline

= 2.16kg+6kg

= 8.16 kg

Total Weight of Tank = Total Mass of the tank×gravitational acceleration

$= 8.16\ kg \times 9.81\ m/s^2$

$= 8.16\ kg \times 9.81\ m/s^2$

= 80.05 N

Modification made on the fuel tank to increase the fuel capacity added some mass on the vehicle.

- Total mass difference from the new fuel tank to the existed fuel tank

  = Total mass of the new fuel tank- Total mass of the existed fuel tank

  = 16.36kg-8.16kg

  =8.2kg is added on the vehicle.

Benefits of new designed fuel tank

Results of data collected in average looks the following;

- Time wasting for refilling is about five hours
- Refilling the fuel tank in average of one and half days to two days interval (i.e., two days working almost one days for refilling)
- 8 liters fuel tank capacity
- Distance traveling in one liter is 17km/l
- Average distance traveled per day is about 70km/l
- Demands of the fuel tank capacity to carry is at least double (i.e., a total of 16 liters)

Once a fuel tank is filled, the vehicle can travel 17km/l. therefore in 8-liter fuel tank capacity the mileage of the vehicle is = Average travel distance per liter×fuel tank volume in liter

= 17 km/l×8 l

= 136 km

Therefore, the vehicle can travel 136 km after the fuel tank is once filled.

For refilling the tank after once filled is = average distance traveled per filled/average distance traveled day

= 136km/70km

= 1.9 days

On the other hand, for a new fuel tank of 16-liter capacity the mileage of the vehicle is

= Average travel distance per liter×new fuel tank volume in liter

= 17 km/l×16 l

= 272 km

Therefore, the vehicle can travel 272 km after the new fuel tank is once filled.

Difference of traveling distance in km = 272-136km = 136km

For refilling the tank after once filled is = average distance traveled per filled/average distance traveled day

= 272km/70km

= 3.8 days

In 1.9 days, the driver is waiting for average of 5 hours for the existing fuel tank whereas 3.8 days for 5 hours for the new fuel tank.

This means for a new fuel tank once the driver waits five hours, doesn’t return to the fuel station for about the next four days whereas for the existing fuel tank the driver returns in the next two days for refilling.

Therefore, increasing the volume by 8 liters increased the mileages of the vehicle and saves the time of the driver and reduces the fatigue while waiting at the gas, reduce the down time of the vehicle, improve passenger service, increase income, reduce stations personnel intervention, etc.

3.3.6 Survey Findings

In order to do the Numerical analysis and simulation, all the necessary data about the existing and new fuel tank are collected. Based on the dimension from survey findings fuel tanks are designed and modeled by using SOILDWORKS software and analysis is performed through ANSYS-FLUENT software.

The survey is mainly focused on knowing the following points.

- Dimension of the three-wheeler body
- Dimension of the existed and new fuel tank
- Dimension and type of the baffle

Dimension of the three-wheeler body

Dimension of the body may vary depending on the vehicle type, and the dimension of RE-4S engine is given on table 3.3.

Table 3. 3: Dimensions of the three-wheeler body, existing and proposed fuel tank

Parameter	Length(mm)	Width(mm)	Height(mm)
Three-wheeler vehicle	2635	1300	1710
Existing fuel tank	350	214	110
Proposed fuel tank	400	250	160

Chassis Type: Kerb Weight: 348 Kgs Monocoque chassis; and Pay Load: 330 Kgs
Length x Width x Height: 2635 mm X 1300 mm X 1710 mm and Ground Clearance: 200 mm
Wheel Base: 2000 mm (Bajaj RE 4S world's largest selling three-wheeler).

3.3.7 SOLIDWORKS Modeling

The 3-D object is modeled in SOLIDWORKS software as shown in figure 3.8, 3.9, 3.10, 3.11, 3.12 and 3.13 below. The existing fuel tank is a small size and without baffles and the proposed new fuel tank is with and without baffles. The geometry of new fuel tank without baffles is modeled to study simulation to investigate baffle configuration. The three-wheeler vehicle model is for center of mass purpose. Then the existing and the new fuel tank are exported to ANSYS work bench platform in IGES format for generation of mesh. After meshing, meshing file is export to FLUENT solver for capable pre-processing, processing and post-processing.

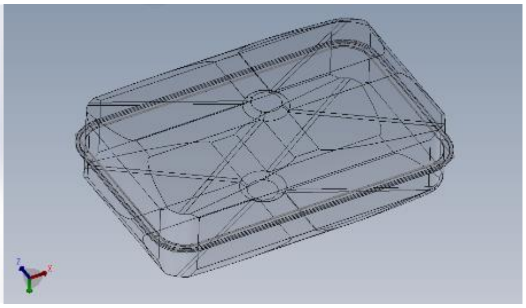



Figure 3.8: 3D Model of three-wheeler vehicle   Figure 3.9: 3D Model of existing fuel tank

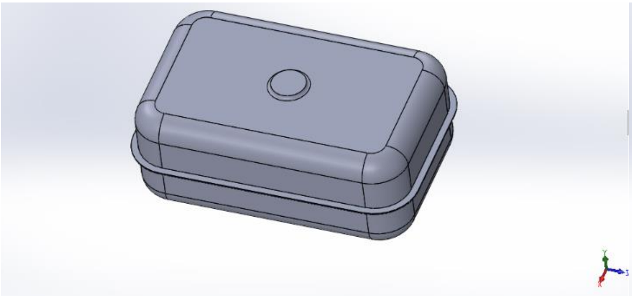
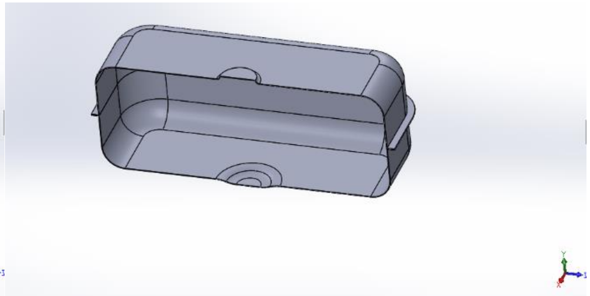
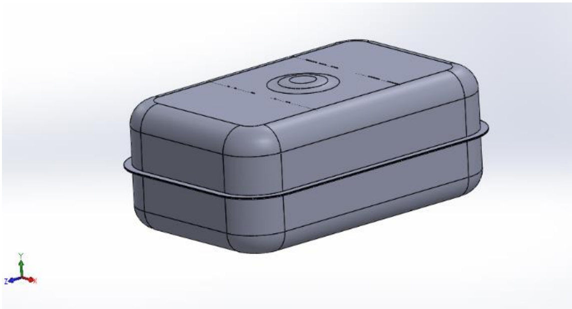



Figure 3.10: New fuel tank without baffles
Figure 3.11: Cross-sectional view of new fuel tank without baffles



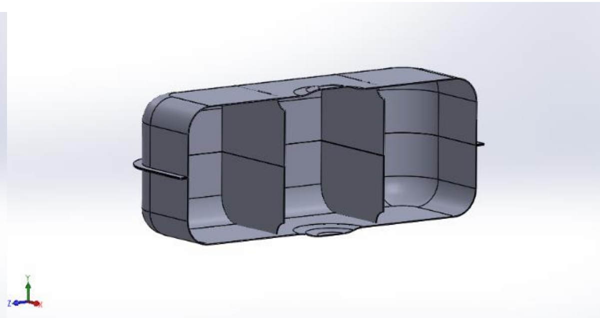


Figure 3.12: New fuel tank with baffles
Figure 3.13: cross-sectional view of new fuel tank with baffles

Dimension and type of the newly constructed baffle

To separate each liquid compartment, baffles inserted in a tank to reduce the movement of fuel sloshing in order to reduce yaw instability during braking or cornering. Baffles are added strength or to reinforce the tank, increase stability to the tank and also to reduce damage of the tanker wall. The dimension of the baffles is given in a table 3.4 and the figure 3.14.

Table 3. 4: Dimension of the new fuel tank baffle

Parameter	Dimension (mm)
Length	250
Width	80
Thickness(t)	1

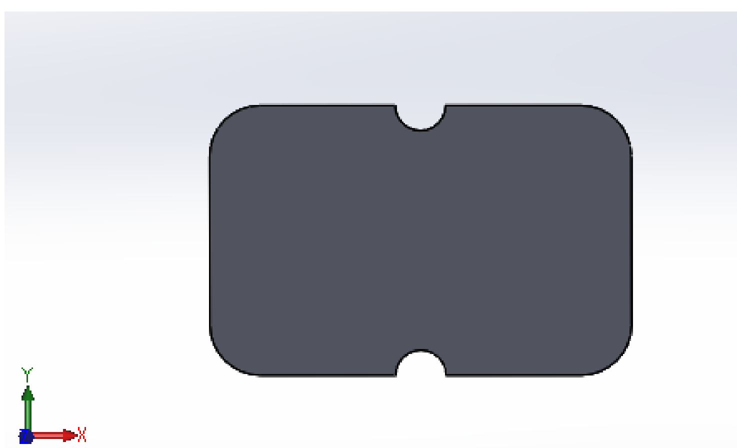


Figure 3.14: Baffles of new fuel tank

3.3.8 Location and mounting of the new fuel tank

The vehicles new fuel tank location is made at the bottom of the vehicle. For purpose of vehicle stability, the new fuel tank is mounted at the bottom of passenger seat between the two tubular chassis frames by mounting brackets. For further the figure 3.15 shows the place where it is mounted.

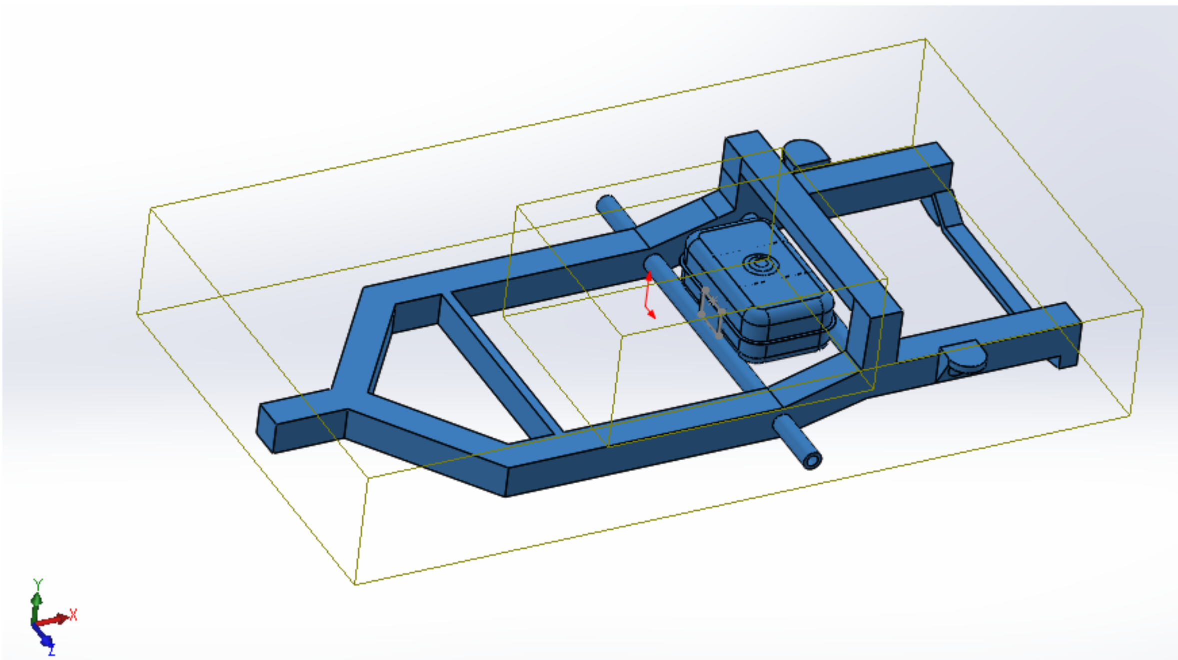


Figure 3.15: Location and mounting of new fuel tank with chassis

3.4 Rollover Stability of the Vehicle under Static Condition

(S. J. Ojolo, 2020) describes the development of mathematical equations to examine the TRV stability. The static model on a banked road is depicted in Figure 3.16 below for the purpose of calculating the rollover stability factor and the center of gravity height h.

Where, θ = is the vehicle's inclination.

The model's fundamental presumptions are that the load distribution is symmetrical about the x-axis and that the influence of tire depression resulted on by load transfer is negligible.

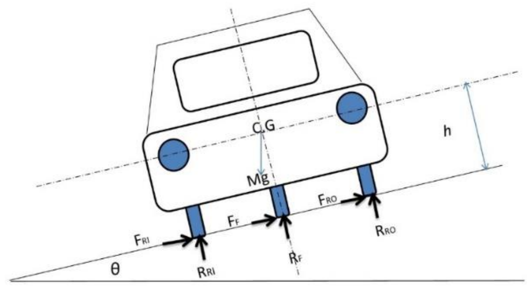


Figure 3.16: Three-wheeled vehicle on a banked road

By resolving forces about the plane of motion vertically and horizontally, the governing equations are obtained:

$$F_{RI} + F_F + F_{RO} = mg \sin \theta \quad (4.18)$$

$$R_{RI} + R_F + R_{RO} = mg \cos \theta \quad (4.19)$$

$$FF = \frac{L2}{WB} \text{ mgsin } \theta \quad (4.20)$$

$$RF = \frac{L2}{WB} \text{ mgcos } \theta \quad (4.21)$$

$$R_{RI} + R_{RO} = \frac{L1}{WB} \text{ mg cos } \theta \quad (4.23)$$

Where W_B is wheelbase and W_T is the wheel-track

Taking moment about center of gravity:

$$h(F_{RI} + F_F + F_{RO}) = \frac{WT}{2} (R_{RI} - R_{RO}) \quad (4.24)$$

Substituting equation (4.18) and (4.23) in (4.24) to eliminate R_{RO}:

$$h(\text{mg sin}\theta) = \frac{WT}{2} (R_{RI} - (- R_{RI} + \frac{L1}{WB} \text{ mgcos } \theta)) \quad (4.25)$$

Rearranging equation (4.25):

$$R_{RI} = \frac{L1}{2WB}\text{mgcos}\theta + \frac{h}{WT}\text{mg sin}\theta \quad (4.26)$$

Similarly, substituting equation (4.18) and (4.23) in (4.24) to eliminate R_{RI}:

$$h(\text{mg sin } \theta) = \frac{WT}{2} (- R_{RO} + (- R_{RO} + \frac{L1}{WB} \text{ mg cos } \theta)) \quad (4.27)$$

Rearranging equation (4.27):

$$R_{RO} = \frac{L1}{2WB}\text{mgcos } \theta - \frac{h}{WT}\text{mg sin}\theta \quad (4.28)$$

When the vehicle is blocked from sliding as θ is increased, at limit of rollover, R_{RO} will become zero,

Therefore the equation (4.28) becomes:

$$\frac{L1}{2WB}\text{mgcos }\theta = \frac{h}{WT}\text{mg sin}\theta \tag{4.29}$$

Or

$$\frac{L1}{2WB}\cos\theta = \frac{h}{WT}\sin\theta \tag{4.30}$$

Therefore, the Static Stability Factor (SSF) is defined as:

$$\tan\theta = \frac{L1}{WB}\frac{WT}{2h} \tag{4.31}$$

Rearranging equation (4.31), where h is the vehicles center of gravity height:

$$h = \frac{L1}{WB}\frac{WT}{2\tan\theta} \tag{4.32}$$

Since rollover angle can be used to access or determine other parametric parameters, equation (4.32) can be utilized to calculate the height of the center of gravity for a TWV.

3.5 Rollover Stability Model under Dynamic Condition

The three-wheeled vehicle model travelling in a circle with radius R is shown in Figure 3.17. The model's fundamental presumptions are, vehicle is moving in horizontal with constant tangential velocity, that aerodynamic drag force has no influence, that the distribution of the load is symmetric about the x-axis, and that the depression of the tire caused by load transfer has a negligible effect. Using force and torque equations, mathematical equations were created from the model to assess how the dynamic behavior of the TWV influences rollover stability.

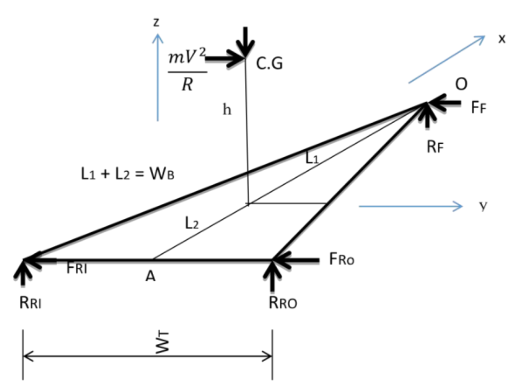


Figure 3.17: Rollover dynamic stability model

If there is no slide, the lateral frictional resistance from the three wheels (FRI + FF + FRO) balances the centrifugal force acting at the center of gravity (C.G) of the vehicle in the direction of the y-axis, while the rear wheels' reactions because of the weight of the vehicle are given as L1/WB (mg).

Therefore, the equations become:

$$\frac{mV2}{R} = F_{RI} + F_{RO} + F_F \quad (4.33)$$

$$R_{RO} + R_{RI} = \frac{L1}{WB}\,mg \quad (4.34)$$

Moment about A-O (about x-axis) eliminates RF, the equation becomes:

$$\frac{mV2}{R}\,h = \frac{WT}{2}\,(R_{RO} - R_{RI}) \quad (4.35)$$

Substituting equation (4.34) in (4.35):

$$\frac{mV2}{R}\,h = \frac{WT}{2}\,\frac{L1}{WB}\;mg - R_{RI}\,WT \quad (4.36)$$

At the rollover stability limit, the inner wheel reaction will be zero ($R_{RI} = 0$),

Therefore:

$$\frac{mV2}{R}\,h = \frac{WT}{2}\,\frac{L1}{WB}\;mg \quad (4.37)$$

Where V is rollover velocity (V_R) wereas a is the centrifugal acceleration

$$\frac{V2}{R} = a = \frac{WT}{2h}\,\frac{L1}{WB}\;g \quad (4.38)$$

Rearranging Equation (4.38):

$$\frac{a}{g} = \frac{WT}{2h}\,\frac{L1}{WB} \quad (4.39)$$

The dynamic stability factor is expressed in dimensionless equation (4.39). The factor of dynamic stability is in the opposite direction to the lateral friction coefficient (μ). When the factor of dynamic stability is less than the coefficient of lateral friction, such that:

$$\frac{a}{g} = \frac{WT}{2h}\,\frac{L1}{WB} < \mu \quad (4.40)$$

Because the force of lateral friction will prevent the car from sliding, the vehicle will then roll over, which is not desirable in vehicle design. Under emergency conditions, sliding issues are simpler to manage than rollover ones (Huston et al., 1982).

When the factor of dynamic stability is greater than the coefficient of lateral friction, then sliding of the vehicle will occur before rollover exists based on Equation (24), which is the desirable option in vehicle design.

$$\frac{a}{g} = \frac{WT}{2h}\,\frac{L1}{WB} > \mu \quad (4.41)$$

According to equation (4.38), the equation (4.42) defines the vehicles rollover velocity (V_R):

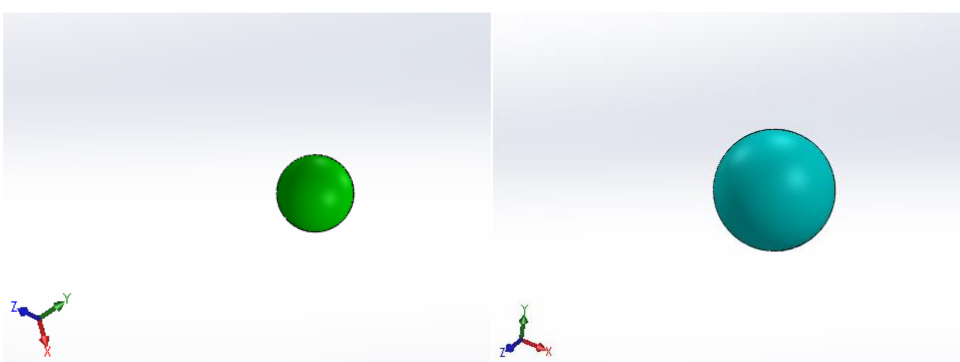
$$V = \sqrt{\frac{WT}{h}\frac{L1}{WB}\ gR} \tag{4.42}$$

Dynamic reactions owing to acceleration and deceleration (Huston et al., 1982), aerodynamic reactions due to drag force (Sachdeva and Kamiyo, 2015; Rajamani, 2012), gyroscopic couple, and Coriolis force are some other dynamic reactions that might be integrated into the fundamental equation (4.39). When these reactions are combined, L1's value becomes L1A. The final equation becomes: since all other variables remain constant.

$$\frac{a}{g} = \frac{WT}{2h}\frac{L1A}{WB} \tag{4.43}$$

3.6 The effect of fuel tank on stability of the vehicle

According to the new location of the vehicles new fuel tank mounted at the bottom of passenger seat between the two tubular chassis frames by mounting brackets, the center of mass of the vehicle is changed and optimizes the center of gravity height. The figure 3.18 a and b shows the sphere of equal mass of the existing fuel tank material with fuel and new fuel tank material and the fuel respectively at 100% fill condition to identify the center mass. The figure 3.19 shows the references for the x, y and z coordinate systems to measure the centroid. The values of center mass of the three-wheeler vehicle with existing fuel tank is shown in figure 3.20.



a) b)

Figure 3.18: Mass representing sphere for both the existing and new fuel tank with petrol

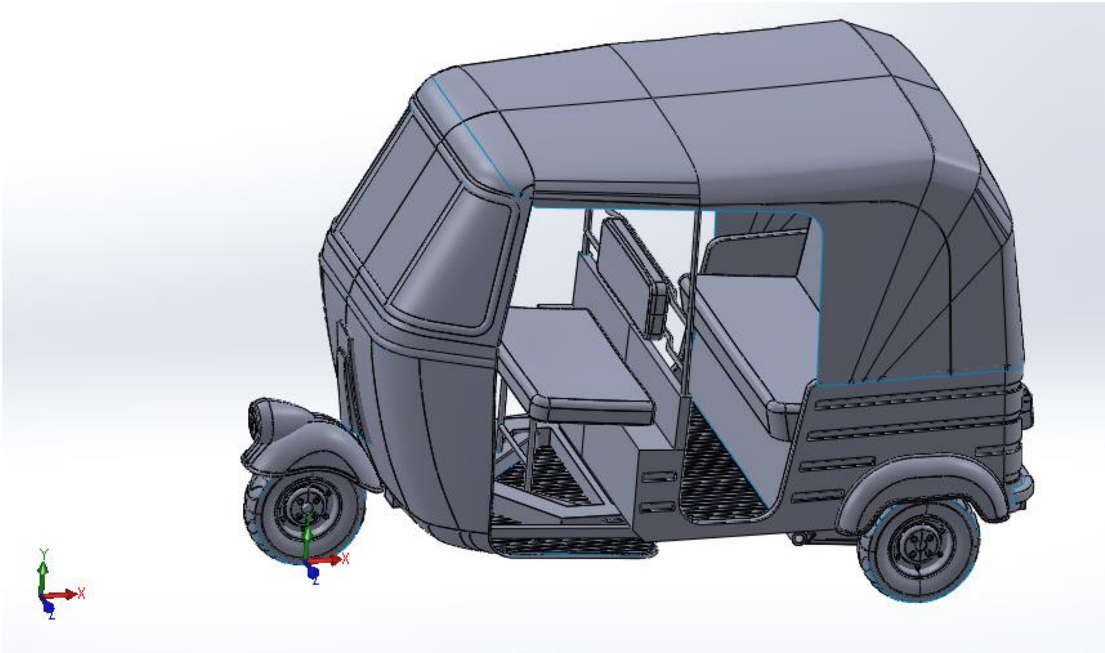


Figure 3.19: Coordinate system for reference

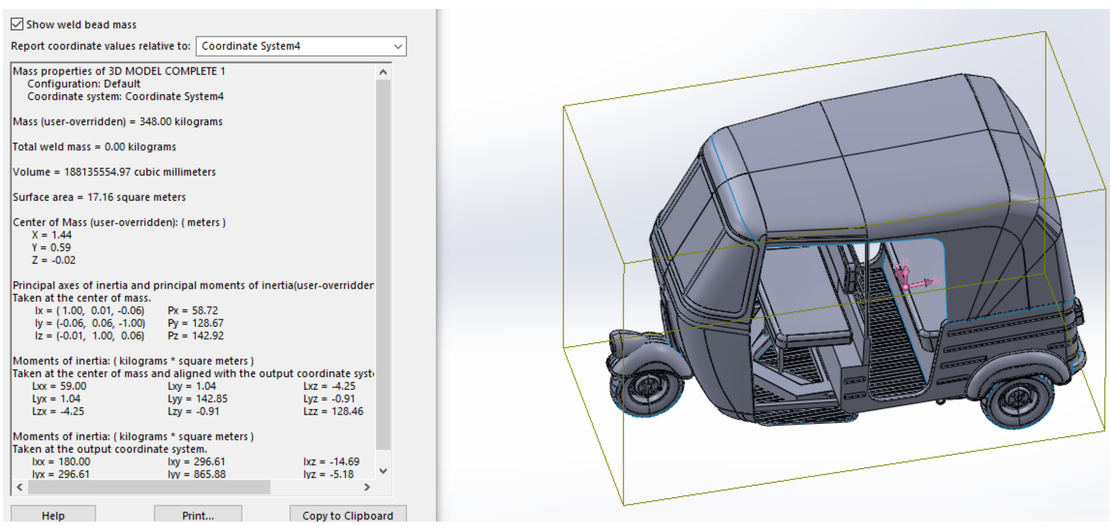


Figure 3.20: The center mass of the three-wheeler vehicle with existing fuel tank

A position relative to an object or set of objects is known as the center of mass. It is the system's average location, weighted by the mass of each component. The centroid is where the center of mass is situated.

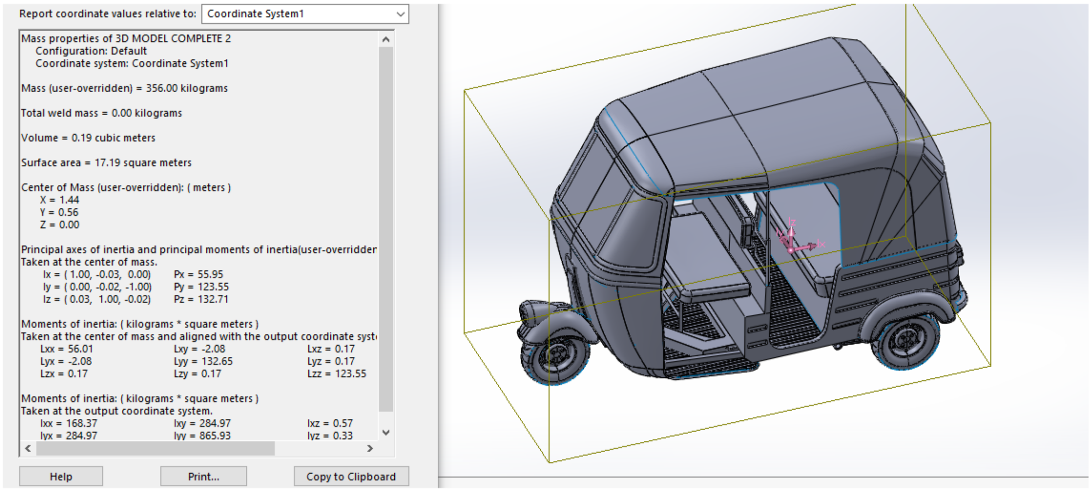


Figure 3.21: The center mass of the three-wheeler vehicle with the new fuel tank

As shown in figure 3.20 and 3.21, the center of mass of the vehicle with the existing fuel tank and new fuel tank is listed in table 3.5.

Table 3.5 Comparison of center of mass of vehicle with existing and new fuel tank

Coordinates	Center of mass of vehicle with existing fuel tank (meters)	Center of mass of vehicle with new fuel tank (meters)
x	1.44	1.44
y	0.59	0.56
z	-0.02	0.00

Therefore, center of gravity height decreased from 590mm to 560mm (i.e. decreased by 30mm to the ground), lateral location of center of gravity w.r.t track width moved from -20 mm to center (i.e. shifted into center by 20mm) and longitudinal location of center of gravity w.r.t. rear axle didn't change the location. As the result the dynamic stability factor as given as in equation 4.43 is calculated.

Dynamic stability factor for vehicle with existing fuel tank is

$$= \frac{WT}{2h}\frac{L1A}{WB} = \frac{1300}{2(590)}\frac{1440}{2000} = 0.793$$

Dynamic stability factor for vehicle with new fuel tank is

$$= \frac{WT}{2h}\frac{L1A}{WB} = \frac{1300}{2(560)}\frac{1440}{2000} = 0.836$$

Therefore, rollover resistance is increased for the vehicle with new fuel tank by improving the fuel tank location or enabling the center of gravity height low.

CHAPTER FOUR

MATHEMATICAL MODELING AND ANALYSIS OF FUEL TANK

4.1 Introduction:

The gasoline tank was modeled using the SOILDWORKS software, and the sloshing study was carried out using the ANSYS-FLUENT software. The system is subjected to numerical analysis and simulation in order to depict the sloshing of fluid flow in the form of mathematical equations known as governing equations. These calculations provide an accurate depiction of the actual event. After the equations are created, the governing equation is solved using CFD techniques.

4.2 Governing Equation: Computational Analysis

Three equations - continuity (mass conservation), Naiver-Stokes (momentum conservation), and energy conservation - are solved numerically to simulate an incompressible fluid flow problem (Arora & Vasudevan, 2017). Because of no exchange of heat energy or it was presumed that the operation was isothermal, the energy equation was turned-off. 2020 (Ahmad et al.).

4.2.1 Continuity Equation

A continuity equation also defined as conservation of mass. It states that mass can neither be created nor be destroyed (Kumar, 2013). A continuity equation describes the transport of conserved quantity. The continuity equation is given by

$$\frac{\partial v_i}{\partial x_i} = 0 \tag{4.1}$$

4.2.2 The Naiver-Stokes Equations

The Naiver-stokes equations called momentum equation. These formulas serve as the fundamental rules for viscous, heat-conducting fluids. By applying Newton's principles of motion to a fluid element, a vector equation was created. It takes fluid viscosity into account because it is typically impossible to ignore the viscous effect (Kumar, 2013).

The Naiver-Stokes equation is given by

$$\rho\frac{\partial (v_i)}{\partial t} + \rho\frac{\partial (v_i v_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \mu\frac{\partial^2 v_i}{\partial x_j \partial x_j} + \rho g_i \tag{4.2}$$

4.2.3 Volume of Fraction

The VOF formula depends on the absence of interpenetrating between two or more phases. The volume fraction of the phase in the computational cell is introduced as a variable for each subsequent phase that can be added to the model (Kumar, 2013). The volume fraction of all phases accumulates to one in each control volume.

Volume fraction equaton is given by

$$\frac{1}{\rho_q}[\frac{\partial}{\partial t}(\alpha_p \rho_q) + \nabla.(\alpha_q \rho_q v_q) = s_{\alpha q} + \sum_{p=1}^{n}(\dot{m}_{pq} - \dot{m}_{qp})] \tag{4.3}$$

Where, $\dot{m}_{pq}$ is mass transfer from phase q to phase p. (Singal et al., 2014)

Two phases (fuel and air) are involved in fuel sloshing. In order to replicate this multiphase flow phenomenon, more models are needed. A phase indicator function is used, which is the fractional amount of fluid (volume fraction) in a certain cell (Ahmad et al., 2020). In a multiphase domain, a cell's volume fraction of the phase is given by

$$\alpha_i = \frac{v_i}{v} \tag{4.4}$$

Where, v_i is the volume of the i^{th} phase in the cell and V is the volume of the cell. In a domain with two phases (Ahmad et al., 2020), the phase indicator function is defined as

- $\alpha_i = 1$ if the cell is filled with phase-1
- $\alpha_i = 0$ if the cell is filled with phase-2
- $0 < \alpha_i < 1$ if the cell contains the interface

The volume fraction equation is solved using the explicit time discretization approach. In a two-phase problem, the density in each cell is determined as follows if the phases are denoted by the subscripts 1 and 2 (Rajamani et al., 2016);

$$\rho = \alpha_2 \rho_2 + (1 - \alpha_2)\rho_1 \tag{4.5}$$

4.2.4 Time Step

The Courant number, which has no dimensions, indicates how long a particle stays in a single mesh cell. It is essential to be less than one, ideally being under 0.7. The particle "skips" the cell if the Courant number is more than one- and the-time step is too great to see the particle in one cell. The particle remains inside the cell for at least two-time steps if it is less than 0.7 (Kumar, 2013). The Courant number is used to determine the time step. Based on the Courant-

Friedrichs-Lewy condition (CFL number), the time step size will be chosen. The time step can be calculated by.

$$c = u\frac{\Delta t}{\Delta x} \tag{4.6}$$

Where C is the Courant number, u the magnitude of the velocity, Δt is the size of the time step, and Δx is the distance between the mesh elements.

4.3 Analytical methods

When uniform acceleration is applied to the rectangular tank, the free surface would initially slop back and forth toward the x-axis, but after sometime this motion would vanish and movement would be uniform. Figure 4.1 depicts the location of the liquid's free surface in a uniformly accelerated tank.

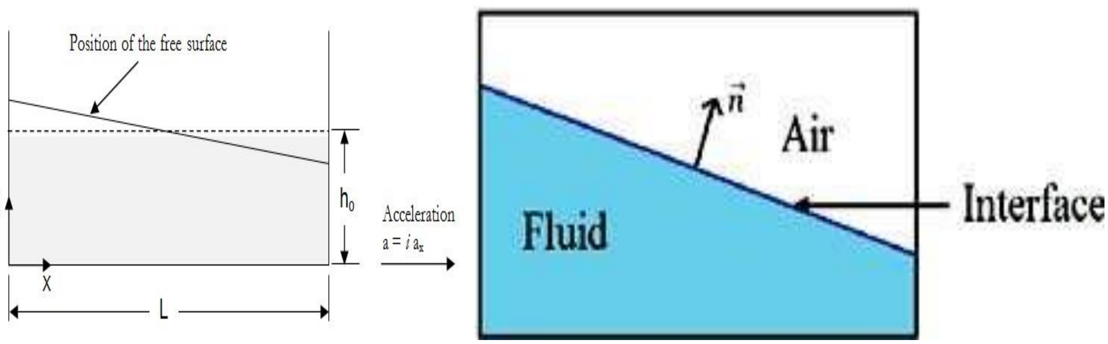


Figure 4.1: Interface between two materials, fluid and air

Through the translation of the liquid cargo's center of mass, the magnitude of the roll moment is connected to the amplitude of lateral acceleration; a greater liquid cargo's center of gravity (cg) translation results in a higher roll moment. 2011 (Dasgupta). On the other hand, the size of cg's translation depends on the free surface gradient, which is represented as;

$$\tan\phi = \frac{\theta - a_y}{(1 + a_y\theta)} \tag{4.7}$$

Where a_y lateral acceleration in g, θ is the mass roll angle in radians and ϕ is the free surface gradient.

Evaluation of sloshing forces, moments, and free liquid surface natural frequencies are all necessary to solve the fundamental issue of liquid sloshing. These forces and moments are connected with vehicle dynamics in partially-filled tanker tankers to demonstrate the directional responsiveness and stability of heavy trucks under external stimulation such as lane change, braking and acceleration as well as road-induced disturbances (Dasgupta, 2011).

The immediate pressure distribution along the tank structure could be used to calculate the transient slosh forces and moments. established User Defined Functions (UDF) to calculate the slosh responses as forces, moments, and load shifts, represented as a function of the liquid cargo's mass center (Alessandro 2011).

4.3.1 Load shift

Volume integrals across the liquid domain within the partially filled tank are used to evaluate the transient load shifts caused by sloshing of liquid cargo (Dasgupta, 2011). The equations are listed below.

$$x_{cg}(t) = \frac{\sum_{c}^{liquid} A_c X_c(t)}{\sum_{c}^{liquid} A_c} \tag{4.8}$$

$$y_{cg}(t) = \frac{\sum_{c}^{liquid} A_c y_c(t)}{\sum_{c}^{liquid} A_c} \tag{4.9}$$

$$z_{cg}(t) = \frac{\sum_{c}^{liquid} A_c z_c(t)}{\sum_{c}^{liquid} A_c} \tag{4.10}$$

Where x_c, y_c and z_c are the instantaneous cg coordinates of the cell $"C"$ with respect to the origin $"O"$, A_C is the cell area in the desired plane and ‘liquid’ defines the integration domain of the liquid cargo.

4.3.2 Sloshing Forces

The pressure distribution along the clean-bore tank's wall is used to determine the forces that occur from sloshing. 2011 (Alessandro). By integrating the result of the instantaneous distributed pressure and the wetted area of the target planes, the forces are calculated, as

$$F_x(t)=\sum_{c}^{A_W} P_c(t)A_c.\vec{i} \quad (4.11)$$

$$F_y(t)=\sum_{c}^{A_W} P_c(t)A_c.\vec{j} \quad (4.12)$$

$$F_z(t)=\sum_{c}^{A_W} P_c(t)A_c.\vec{k} \quad (4.13)$$

Where F_x, F_y and F_z, are the resultant forces acting on the tank, P_C is the pressure of the cell $"C"$ located on the on the tank wall and A_W is the wetted area.

4.3.3 Sloshing Moment

Sloshing moment in addition to the dynamic slosh forces, the moment brought on by changes in the center of gravity coordinate are recognized to be important in determining how the vehicle would respond in terms of directional stability. (Abera, 2015). The roll, pitch, and yaw moment around point "O" at the bottom of the tank just beneath of origin is discovered after integrating the moment corresponding to each cell throughout the wetted surface:

$$\vec{M}=\sum_{c}^{A_W} \vec{r}_c \times F_c \quad (4.14)$$

Where F the force vector is caused by a cell $"C"$ on the boundary, of cell $"C"$ with respect to $"O"$ and $\vec{M}$ is the moment vector about point $"O"$. The coordinate of this point $"O"$ is (0, -r, 0), where R is the tank radius (Abera, 2015).

4.4 Computational Fluid Dynamics Analysis of the Fuel Tank

ANSYS Fluent CFD software consists to represent fluid flow, heat transport, turbulence, and reactions for industrial applications, the software has a wide range of physical modeling features. The software's capabilities have been expanded by the addition of special models that enable it to simulate aeroacoustics, in-cylinder combustion, turbomachinery, and multiphase systems. Unstructured mesh flow issues can be readily overcome thanks to Fluent's mesh flexibility. In 2D problems, Fluent supports triangular and quadrilateral meshes; in 3D problems, it supports tetrahedral, hexahedral, and wedge-shaped meshes. New fuel tank with baffle model in ANSYS is shown in figure 4.2.

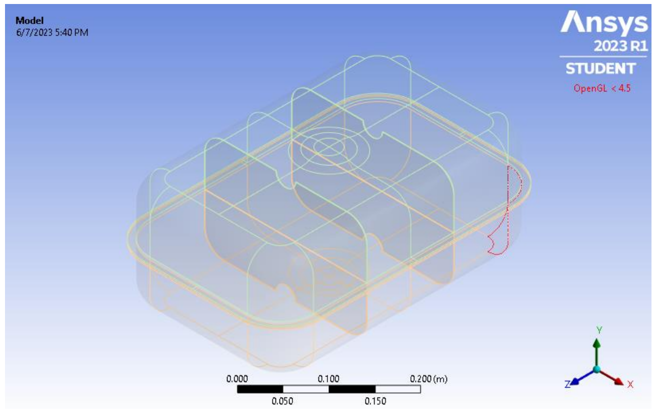


Figure 4.2: New fuel tank with baffle model in ANSYS

4.4.1 Mesh Generation

We must discretize geometry into control volumes after it has been created. We call this procedure meshing. The meshing tool is used for meshing. In this instance, a uniform tetrahedral mesh is produced in every situation. Mesh is generated in 3-D mesh with baffles. In order to keep the stability of the numerical computations and accuracy of the solution of mesh should be good. To check this meshing quality, should be considered the skewness, orthogonal quality based on as it is mentioned in fluent user’s guide. According to this the value of the orthogonal quality can be vary between 0 and 1 and the value of skewness is also less than 0.95. The following figure 4.3 shows the mesh generated on a fuel tank with and without baffles systems.

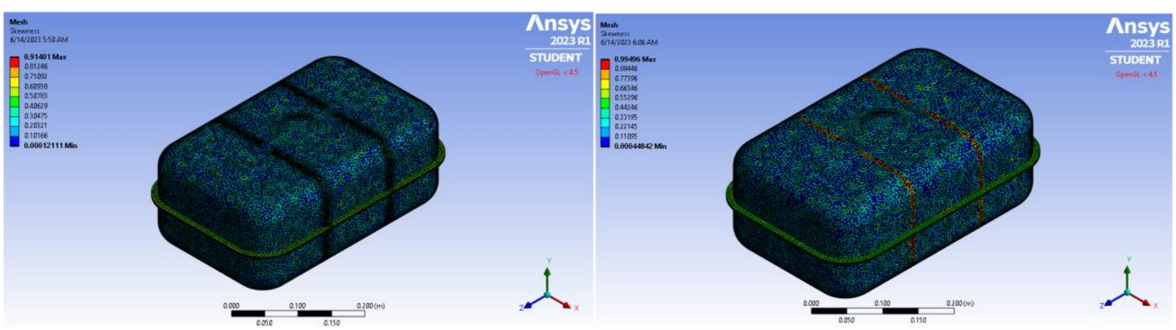


Figure 4.3: Mesh of new proposed fuel tank with and without baffle

4.4.2 Grid Independency test

The grid independence test is a method for determining the best grid condition that uses smallest possible grids while yet producing consistent numerical results. It is based on an analysis of various grid conditions. It is the most influencing factor which determines the computational time, accuracy of the result. So, it is important to choose an optimum mesh size and the results of grid independence test are shown in the table 4.1.

Table 4.1: The new fuel tank nodes and element

	Nodes	Elements
Fuel tank without baffle	66146	326554
Fuel tank with baffle	175259	891065

4.4.3 Fluent Solver Model Development

The mesh file is exported to CFD code FLUENT once meshing is complete. The mesh file is transformed to polyhedral cells for the proposed simulation in order to improve result accuracy. 3D double precision, Pressure-based solver is used for the solution algorithm of the transient conditions and this solver is more accurate for incompressible flows used with multi-phase volume of fluid model. In this case absolute velocity formulation and gravitational acceleration is enabled. A transient analysis is done with the above parameters set.

4.4.4 Volume of Fluid Model

The Volume of Fluid (VOF) formulation in ANSYS FLUENT is generally used to compute a time-dependent solution. VOF free surface model is activated in the multiphase model panel in ANSYS FLUENT and by comparing the fluid volume to the grid volume in the grid element, it is utilized to calculate the free oil liquid surface. The fluid motion is taken into account rather than the movement of particles on the free oil liquid surface. This approach could obtain characteristic parameters throughout the process of strong non-linear sloshing, which provides the basic conditions for further research (Kumar, 2013). The VOF approach is currently the most effective means to monitor the free surface area. In this study, VOF models form the foundation for the numerical results that are presented. The inter-phase between phases is sharp which is used to avoid the interaction between phases. The number of phases in this model is specified as two. Primary phase is stated as air and secondary phase is stated as petrol. After VOF activated, the material properties for each phase are established from the FLUENT database is shown in figure 4.4. The properties are described in the table 4.2 below.

Table 4.2: Properties of fluid material

Fluids	Density (kg/m^3)	Viscosity (kg/m-s)
Petrol	742.9	0.0006
Air	1.225	1.7894e-5

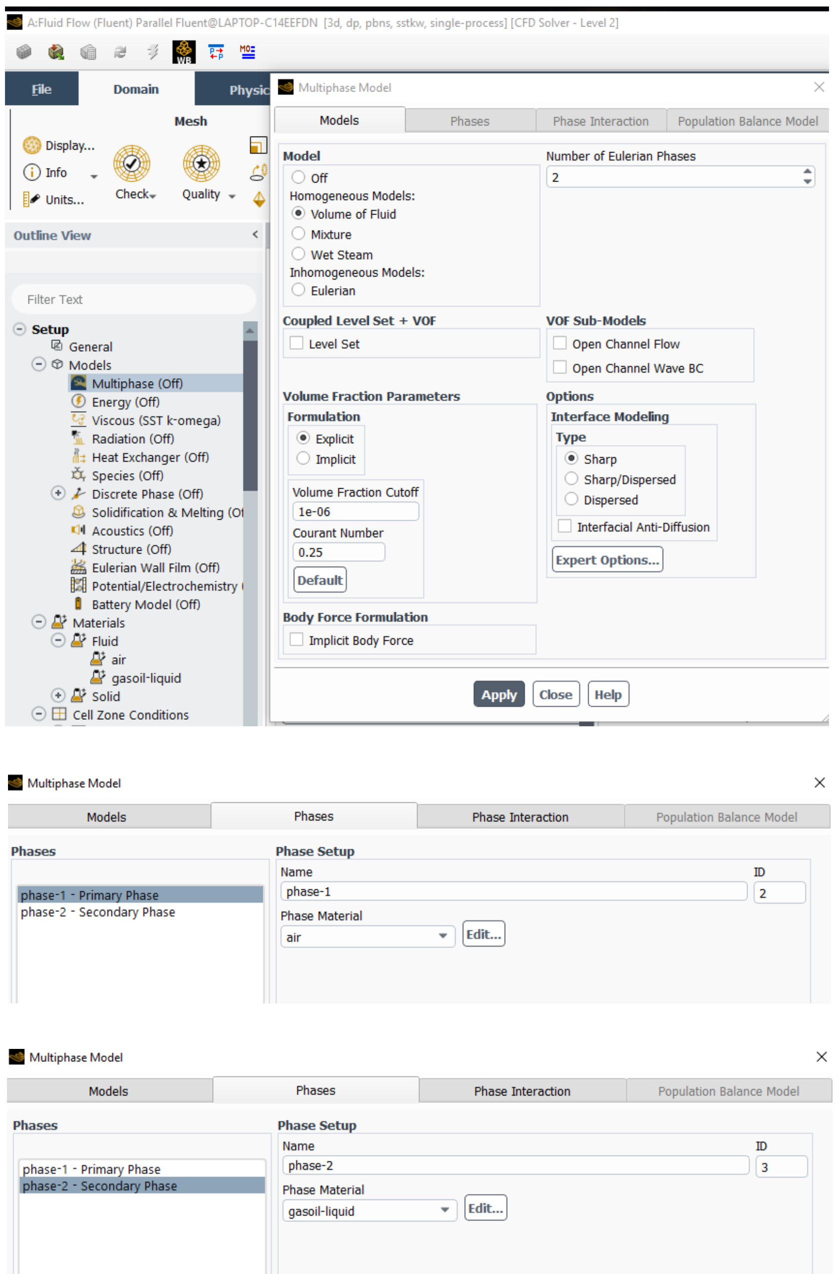


Figure 4.4: Multiphase model panel in fluent

4.4.5 Turbulence Viscosity Modeling

The most popular model used in computational fluid dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions is the k-epsilon (k- ε) turbulence model. It is based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε). It is a semi-empirical model.

- Turbulent kinetic energy (k) is the first transported variable.
- The rate of dissipation of turbulent kinetic energy (ε) is the second transported variable.

In our investigation, the k- ε model has been applied. The viscosity term changes to an effective viscosity eff, which is determined by the sum of a molecular viscosity μ and a turbulent viscosity μt. The momentum equations' structure is left unchanged.

This study utilizes Eddy Viscosity Models to close the Reynold-Averaged Navier Stocks equation. In this study the standard k- ε model that assumes the relation between the Reynolds stress in the fluid and mean velocity gradient. The turbulence viscosity is determined by the following equation.

$$\mu_t = \rho c_\mu \frac{k^2}{\varepsilon} \qquad (4.15)$$

Where k is turbulent kinetic energy, ε is turbulence dissipation rate, c_μ is constant proportionality whose default value is 0.09 in fluent.

4.4.5 Boundary Condition

The boundaries in the computational domain are named as baffles and the fuel tank wall. The boundary type for these considered as a wall while doing the analysis and fluid domain is chosen for the interior of the tank. The table 4.3 shows the boundary condition.

Table 4.3: Boundary Conditions

Condition	Value
Wall Motion	Stationary Wall
Shear Boundary Condition	No Slip

After the boundary condition has been established, the operating condition is established. Assume that the three-wheeler vehicle is accelerated on a curve with a critical radius of 20 m at a speed of 30 km/hr. This constant lateral acceleration simulates a transient state turn curvature acting as the centripetal acceleration given by

$$a = \frac{V^2}{R} \tag{4.16}$$

Accordingly, the centripetal acceleration equation, a fuel tank experiences a constant acceleration of 3 m/s^2.

In the operating conditions panel the following conditions are considered.

- ✓ Operating pressure: - 101325 Pa
- ✓ Gravitational acceleration: - X= 3.5 m/s^2

  Y= -9.81 m/s^2

  Z= 3.5 m/s^2
- ✓ Operating density: - The software package's operating density option is employed, and the operating density is configured to have a minimum density of 1.225 kg/m^3, this represents the density of air's lighter phase. This enhances the precision of momentum balancing by excluding the development of hydrostatic pressure within the lighter phase (Singal et al., 2014). The bottom fuel tank is patched as shown in figure 4.6 with an initial volume proportion of gasoline at 50% of the fill level once the proper boundary conditions have been applied. The following figure 4.5 shows the operating conditions parameters in FLUENT.

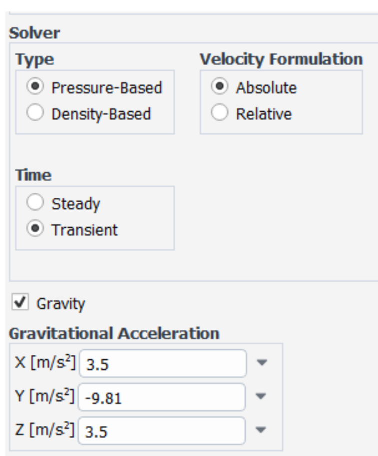


Figure 4.5: The operating conditions panel of FLUENT parameters.

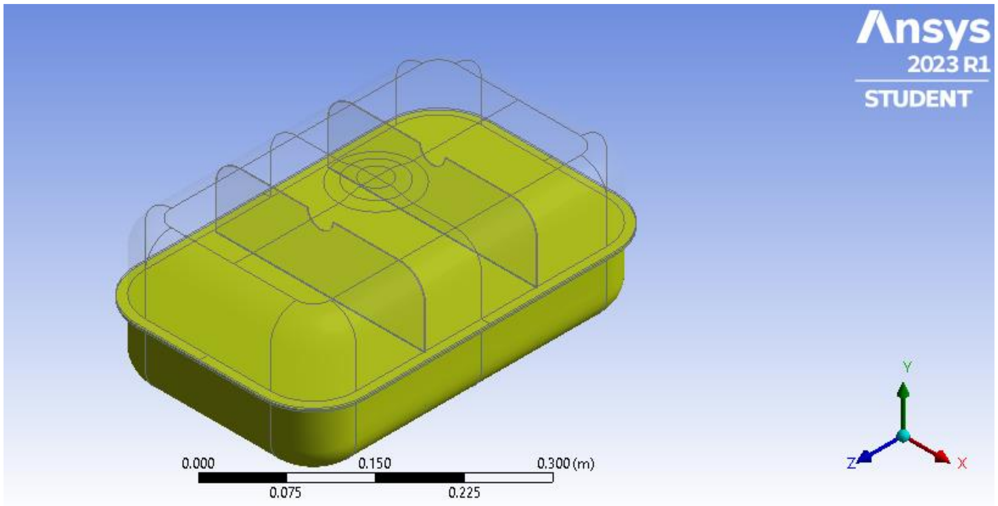


Figure 4.6: The initial volume fraction of petrol patched at 50% fill level

4.4.6 Solution Methods

The VOF solution's accuracy and convergence are being worked on. The bottom center of the tank, where only gasoline is ever present, is where the reference pressure location is established. This is a prerequisite for effortless and quick convergence. When employing the pressure-based solver, the numerical process known as pressure-velocity coupling derives an equation for pressure (or pressure correction) by combining continuity and momentum equations. The fractional step method used as pressure-velocity coupling scheme as the flow is time dependent for transient flow. This method solves the incompressible Navier-Stokes equations with primitive variables. For reduced CPU usage, Non-Iterative Time Advancement is made available for transient formulation. For more precise or computationally costly spatial discretization, the Green-Gauss Node Based technique is utilized; it minimizes incorrect diffusion and is advised for unstructured models. 2010 (ANSYS.Inc.). For the spatial discretization gradient, a second-order upwind technique is used, whereas for the temporal discretization, an implicit scheme is used. Then specify the various VOF parameters in multiphase model panel. This parameter affects how the contact between gasoline and air is predicted. The Geometric-Reconstruction method, which is appropriate for the interface between phases is as sharp and suggested for almost all of VOF computations, is the most accurate interface-tracking technique. As a result, the Geometric-reconstruction approach is used to all the models created for this study. Following figure 4.7 is a list of the parameters used in FLUENT.

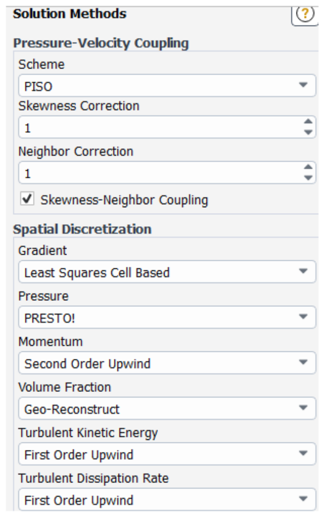


Figure 4.7: Solution method panel in fluent

4.4.7 Solution control

This made it possible to raise all under-relaxation factor values without sacrificing the stability of the solution. To hasten the convergence of the solution, all the under-relaxation factors are set to unity. Reduced the values later if the solution is not converged (Singal et al., 2014). When the solution is not converged, the values were initially put in to one and then reduced to the following components as shown in figure 4.8.

Non-iterative relaxation factor: -

- Pressure: 0.3
- Momentum: 0.7

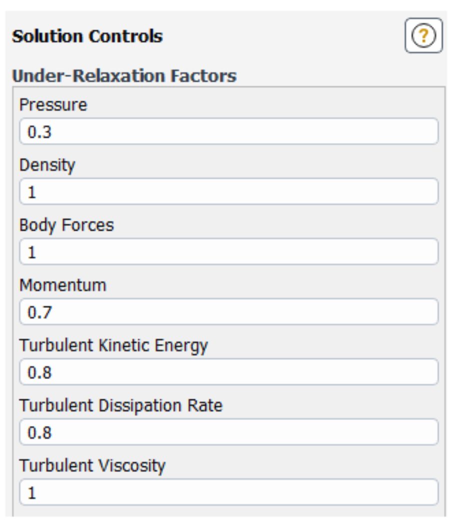


Figure 4.8: Solution controls panel in FLUENT

4.4.8 Time Step Method

The sloshing problem is always transient by its very nature. It is also necessary to discretize the governing equation's time frame derivative. The simulation for the current example has been run at several time steps in order to find the ideal time step without using up too much memory or calculation time. It is required to alter the time step in accordance with the flow velocity in the sloshing case where the liquid flow velocity continuously changes throughout the simulation.

$$L = \frac{1}{2}at^2 \tag{4.17}$$

Where, L is the length of the fuel tank in meter, a is the acceleration (disturbance) in m/s^2 and t is the time step in second.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Results of CFD Analysis and Discussions

This chapter discussed and provided the computational findings for various fuel tanks. In this study, simulations are used to examine how baffle arrangements for modified three-wheeler gasoline tanks affect the magnitudes of slosh forces and moments at partially filled (50%) levels when they are subjected to combined lateral and longitudinal acceleration excitation. The stability of the tank is impacted by the tank's combined acceleration motion, sloshing forces, vertical forces, and roll moment. Therefore, the impact of sloshing forces, vertical forces, and moments is investigated in this study. The proposed new gasoline tank is put through a computational simulation, both with and without baffles systems. The fuel tanks illustrated in figure 5.1 below are used to illustrate the graphs between lateral, longitudinal, and vertical force vs. flow time and moments vs. time in this section.

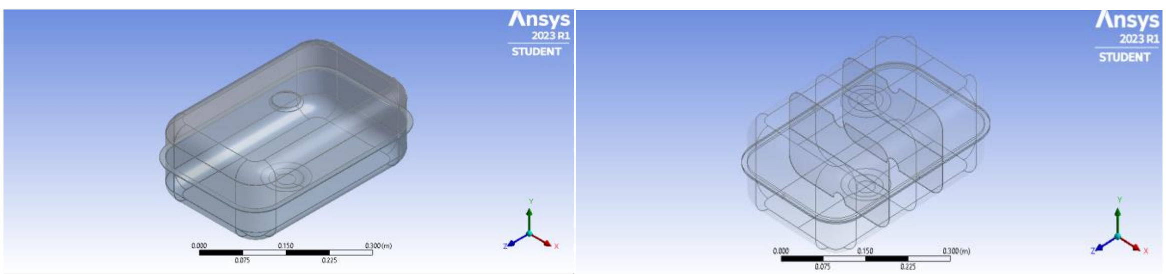
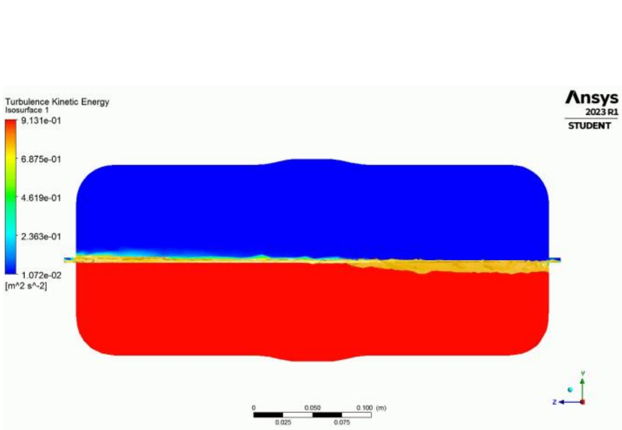


Figure 5.1: The proposed fuel tank with and without baffles modeling in ANSYS

I. The volume fraction of petrol in the fuel tank

The figure below shows the contour plots of the turbulence kinetic energy iso-surface and volume fraction of petrol on the fuel tanker at the initial stage or when the vehicle is not moving. The volume fraction is the fluid's volume to the overall fluid volume as a ratio. The volume fraction measures the phases that are present in the fuel tank. A value of 1 indicates only gasoline, which is represented by the color red, and a value of 0 indicates only air, which is represented by the color blue. The following figure 5.2 and figure 5.3 shows about the volume fraction of fluids at 50% fill levels at initial and moving conditions.



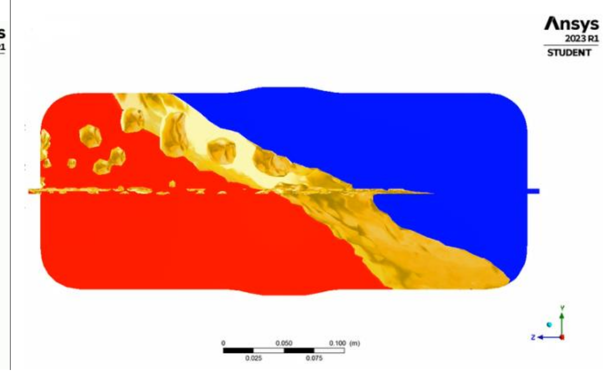


Figure 5.2a: The volume fraction of petrol at 50% fill levels without baffle at initial stage

Figure 5.2b: The volume fraction of petrol at 50% fill levels at t = 0.2 sec without baffle

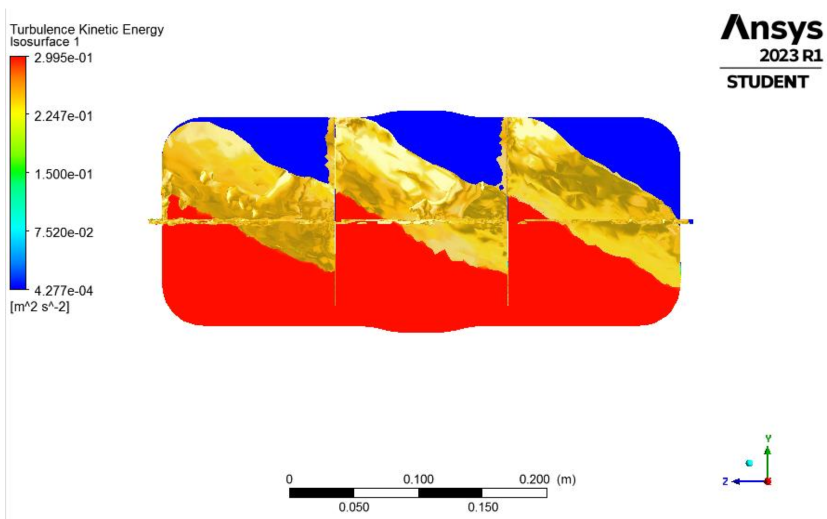


Figure 5.3: The contour plots of the volume fraction of petrol at t = 0.2 sec with baffle

5.2 Results of different forces and moments of existing and new fuel tanks

5.2.1 When the existing fuel tank is subjected to combined acceleration

Figure 5.4, figure 5.5 and figure 5.6 shows the graph between lateral, vertical and longitudinal force Vs. flow time and moments Vs. flow time for the existed fuel tank of 50% fill level at lateral and longitudinal acceleration, a=3.5 m/s^2.

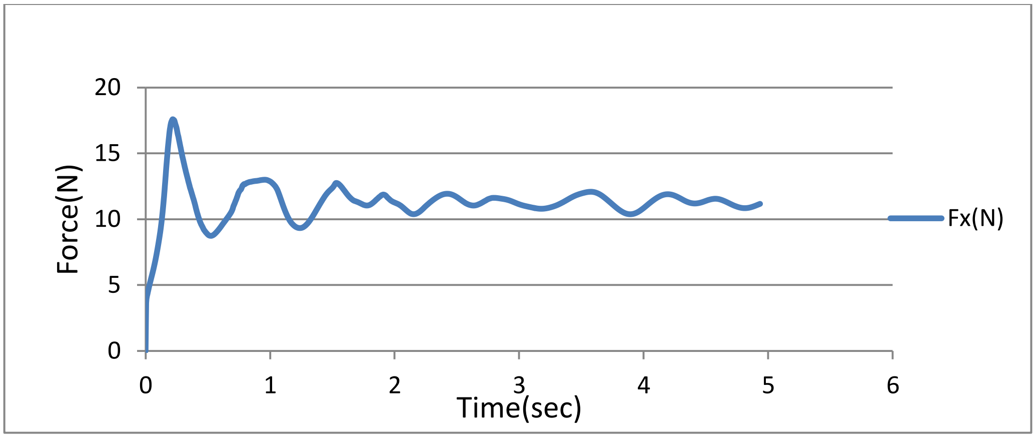


Figure 5.4: Lateral force at 50% fill level

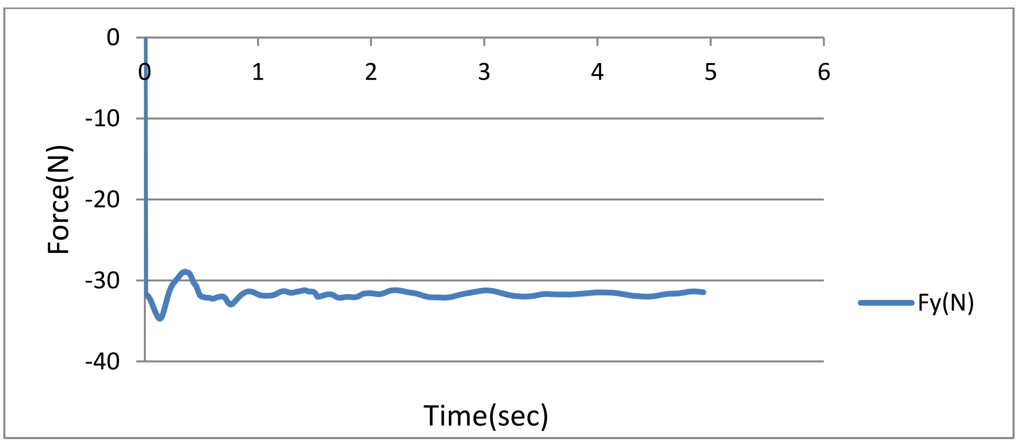


Figure 5.5: Vertical force at 50% fill level

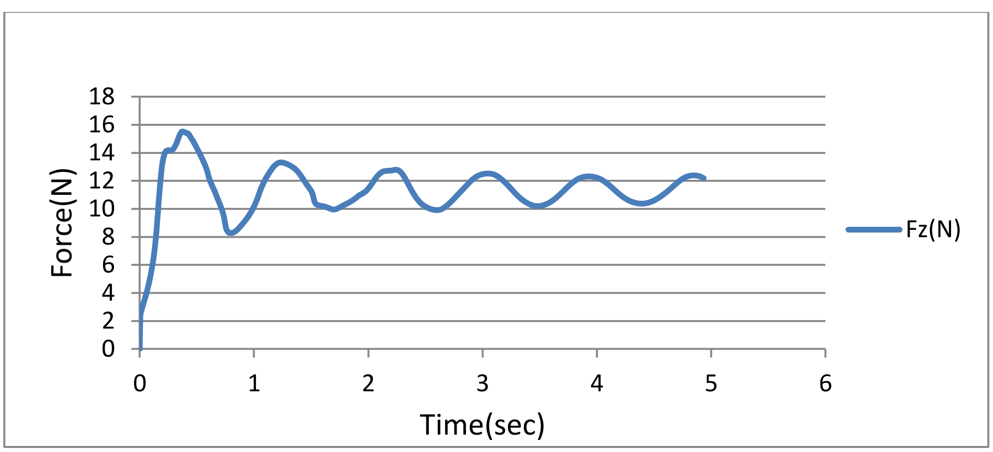


Figure 5.6: Longitudinal force at 50% fill level

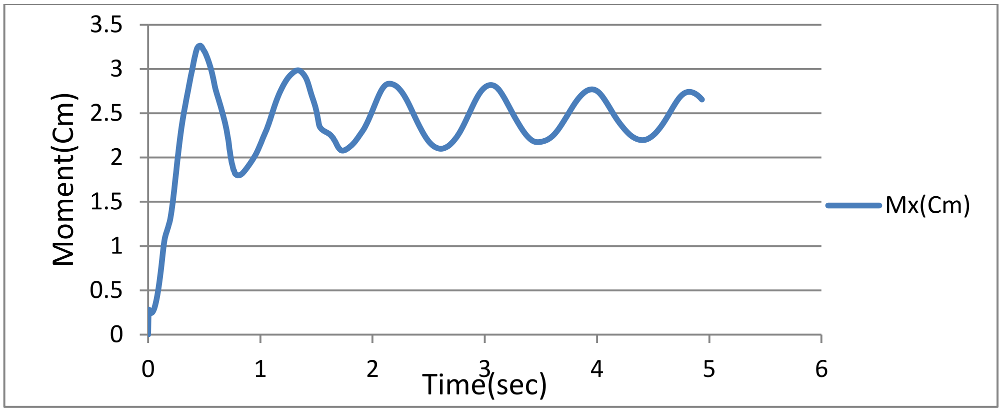


Figure 5.7: Lateral roll moment coefficient at 50% fill level

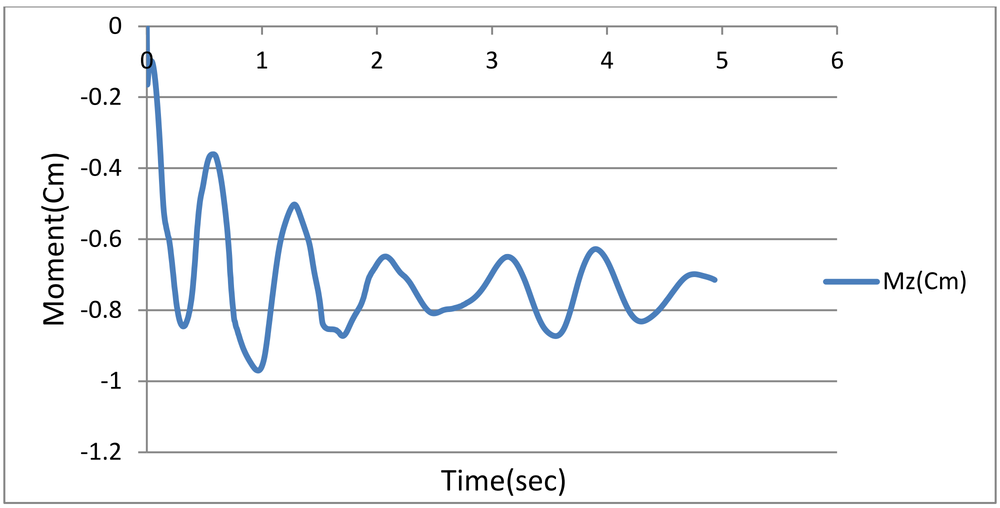


Figure 5.8: Longitudinal roll moment coefficient at 50% fill level

From the above graph, the maximum values for the existing gasoline tank's lateral force, vertical force, longitudinal force, lateral roll moment coefficient, and longitudinal roll moment coefficient are 17.58359N, 34.7241N, 15.5211N, 3.2634Cm, and 0.9701Cm, respectively. As it seen from the graph the fluctuation is very high, it needs more time to dampen the fluctuation. It is because of no baffle system which results no dissipation of energy since its orientation and placement. Therefore, this high lateral force and roll-moment fluctuation makes the vehicle unbalance to affect the roll-over stability of vehicle

5.2.2 When the new fuel tank without baffles is subjected to combined acceleration

Figure 5.9, figure 5.10, figure 5.11, figure 5.12 and figure 5.13 shows the graph between lateral, vertical and longitudinal force Vs. flow time and moments Vs. flow time for the proposed new fuel tank without baffle of 50% fill level at lateral and longitudinal acceleration, a=3.5 m/s^2.

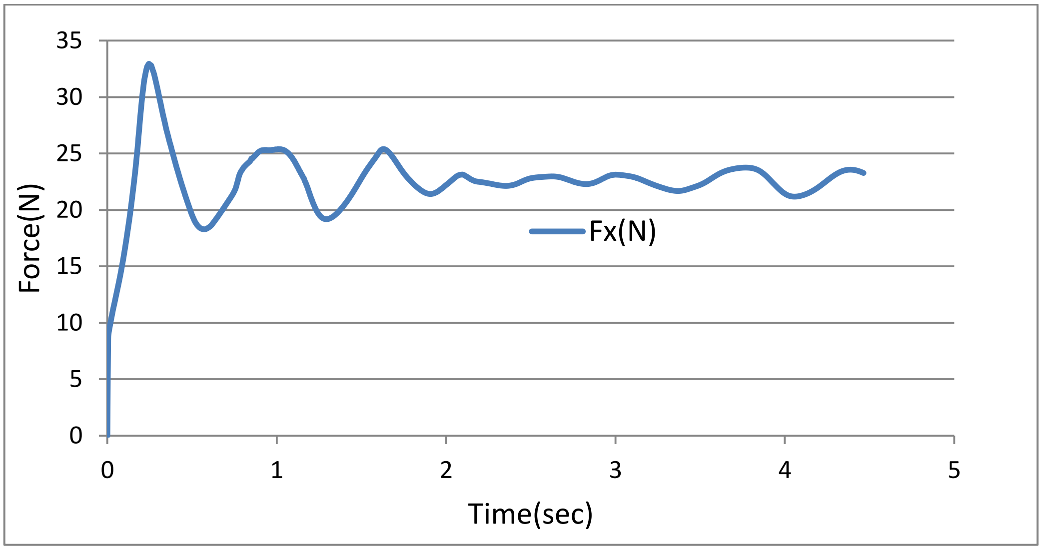


Figure 5.9: Lateral force at 50% fill level without baffles

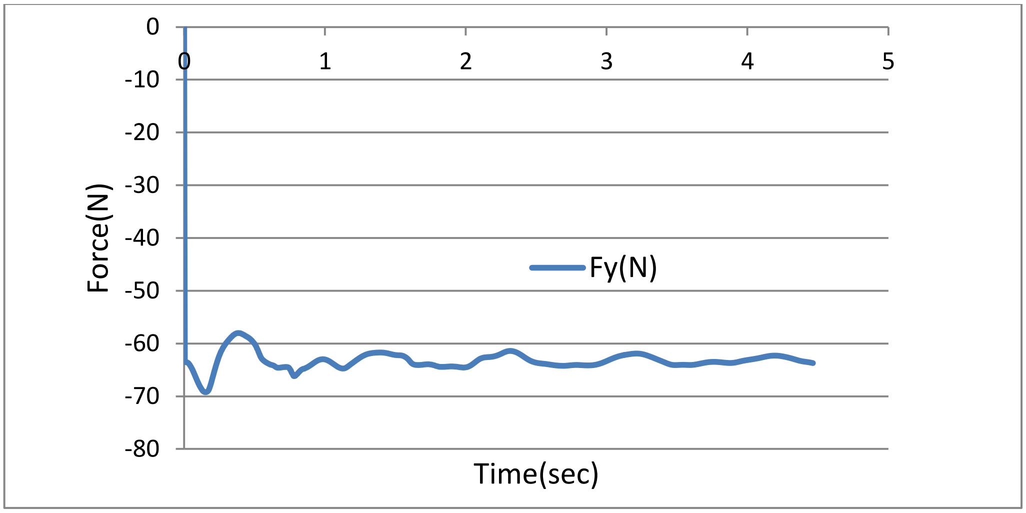


Figure 5.10: Vertical forces at 50% fill level without baffles

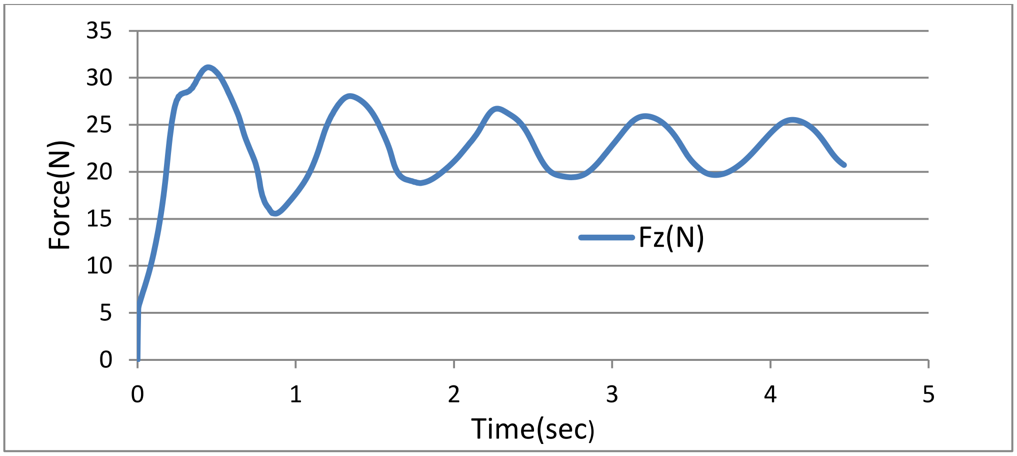


Figure 5.11: Longitudinal forces at 50% fill level without baffles

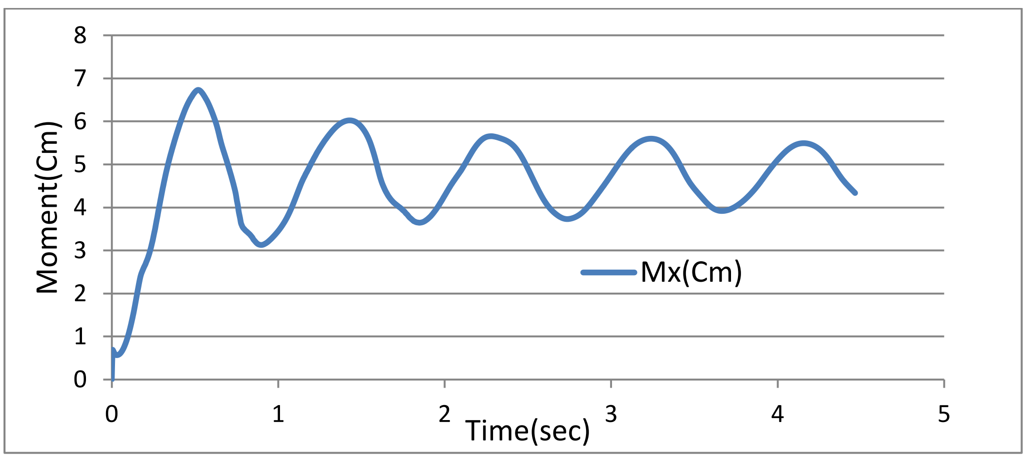


Figure 5.12: Lateral roll moment coefficient at 50% fill level without baffles

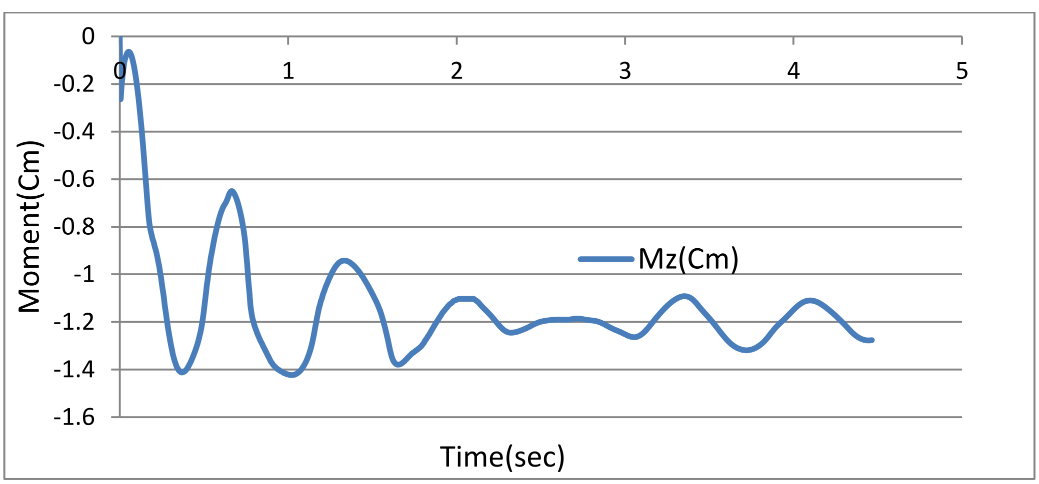


Figure 5.13: Longitudinal roll moment coefficient at 50% fill level without baffles

From the above-mentioned graph, the maximum values of lateral force, vertical force, and roll-moment at a fuel tank without baffles are 32.9401N, 69.2329N, 31.1205N, 6.7315Cm and 1.4235Cm respectively. The fluctuation is very high, as can be seen from the graph; hence additional time is needed to decrease the fluctuation. It is because of no baffle system which results no dissipation of energy since its orientation and placement. Therefore, this high lateral force and roll-moment fluctuation makes the vehicle unbalance to affect the roll-over stability of vehicle.

5.2.3 When the new fuel tank with baffles is subjected to combined acceleration

Figure 5.14, figure 5.15, figure 5.16, figure 5.17 and figure 5.18 shows the graph between lateral, vertical and longitudinal force Vs. flow time and moments Vs. flow time for the proposed new fuel tank with baffle of 50% fill level at lateral and longitudinal acceleration, a=3.5 m/s^2.

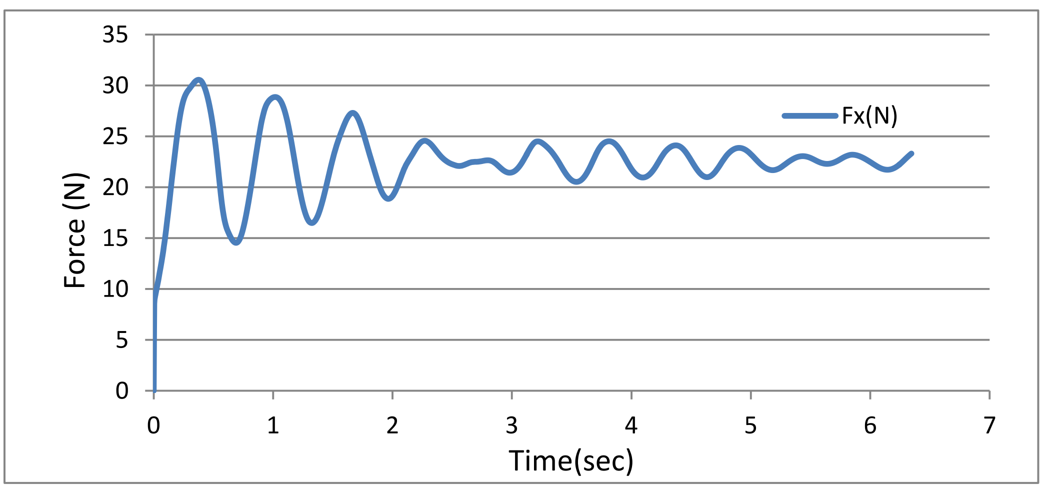


Figure 5.14: Lateral forces at 50% fill level with baffles

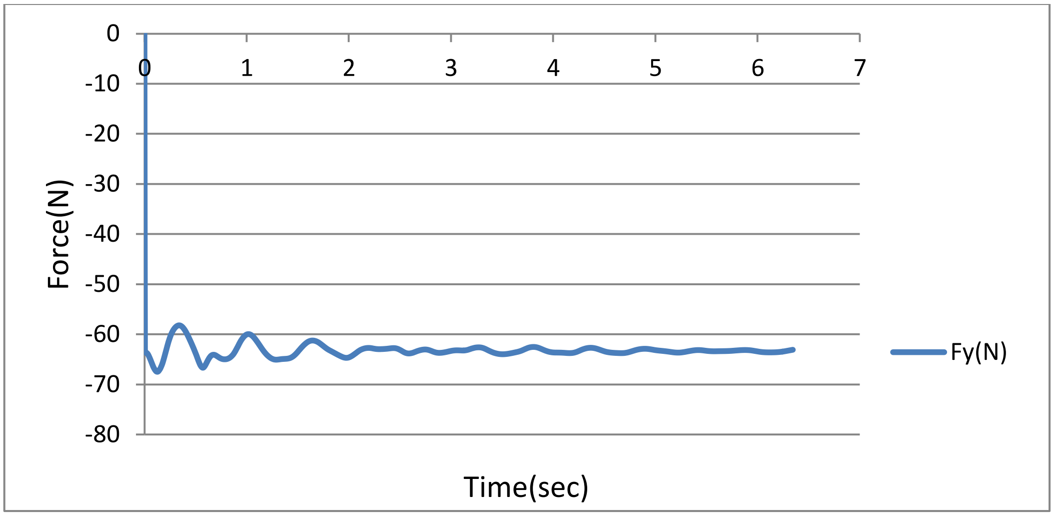


Figure 5.15: Vertical forces at 50% fill level with baffles

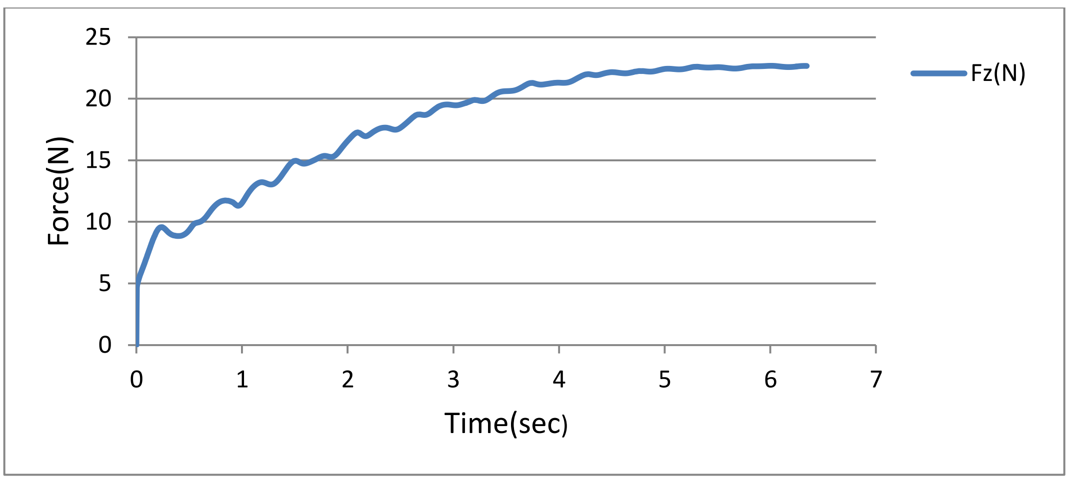


Figure 5.16: Longitudinal forces at 50% fill level with baffles

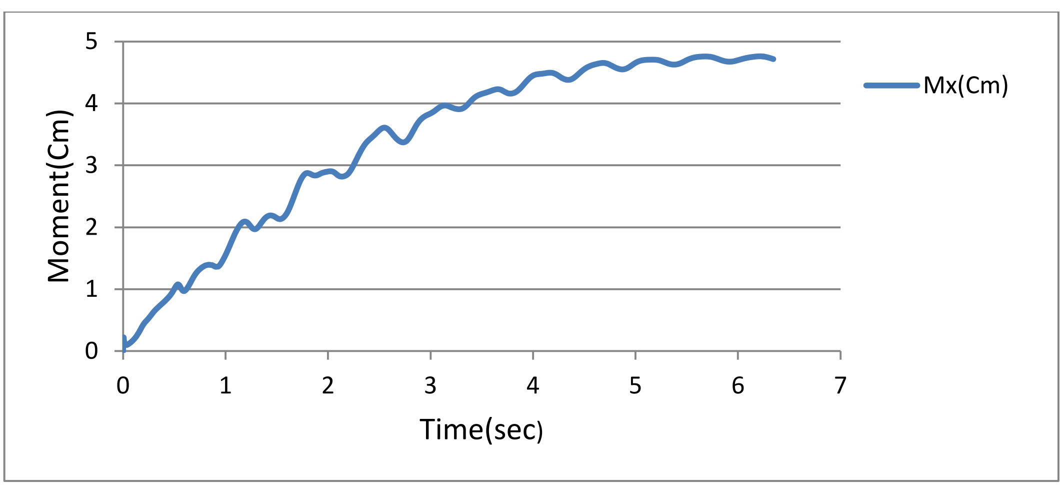


Figure 5.17: Lateral roll moment coefficient at 50% fill level with baffles

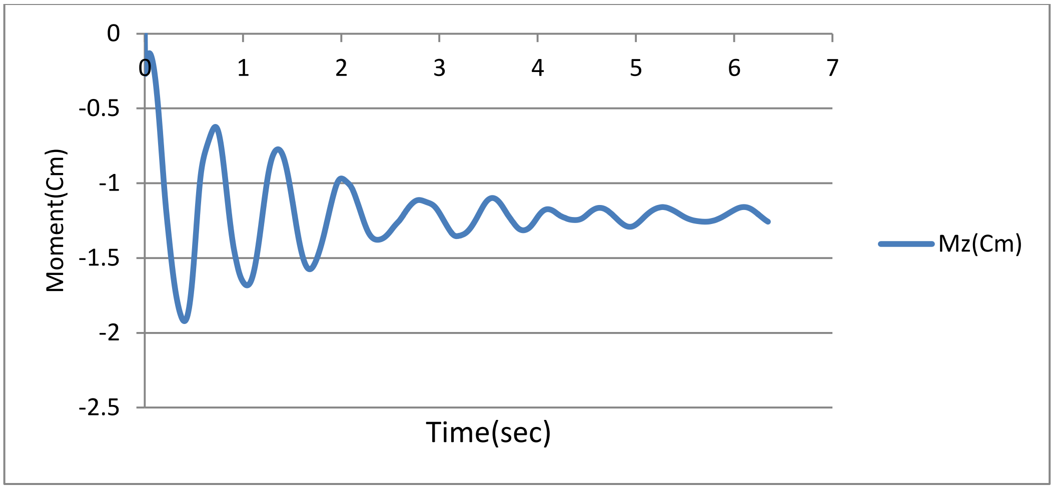


Figure 5.18: Longitudinal roll moment coefficient at 50% fills level with baffles

From the above graph, the maximum values of lateral force, vertical force, and roll-moment of the three wheeler vehicle proposed new fuel tank with baffles are 30.5565N, 67.4775N, 22.6630N, 4.7599Cm and 1.9219Cm respectively. The fluid being split around baffles causes energy to be dissipated, which in turn causes the fluctuation to be very little. The amount of sudden force and moment on the sidewall of the fuel tank is reduced by the baffle system's resistance to the movement of gasoline.

5.3 Comparison between the new fuel tank with and without baffles at 50% fill conditions

Figure 5.19, figure 5.20, figure 5.21, figure 5.22 and figure 5.23 shows the combined graph of lateral, vertical and longitudinal force Vs. flow time and moments Vs. flow time for the proposed new fuel tank with and without baffle of 50% fill level at a=3.5 m/s^2 lateral and longitudinal acceleration.

without baffle with baffle

5.3.1 Lateral forces comparison of new fuel tank with and without baffles

% Lateral force decreases at 50% fill level = $\frac{32.94012-30.55647}{30.55647} \times 100\% = 7.8\ \%$

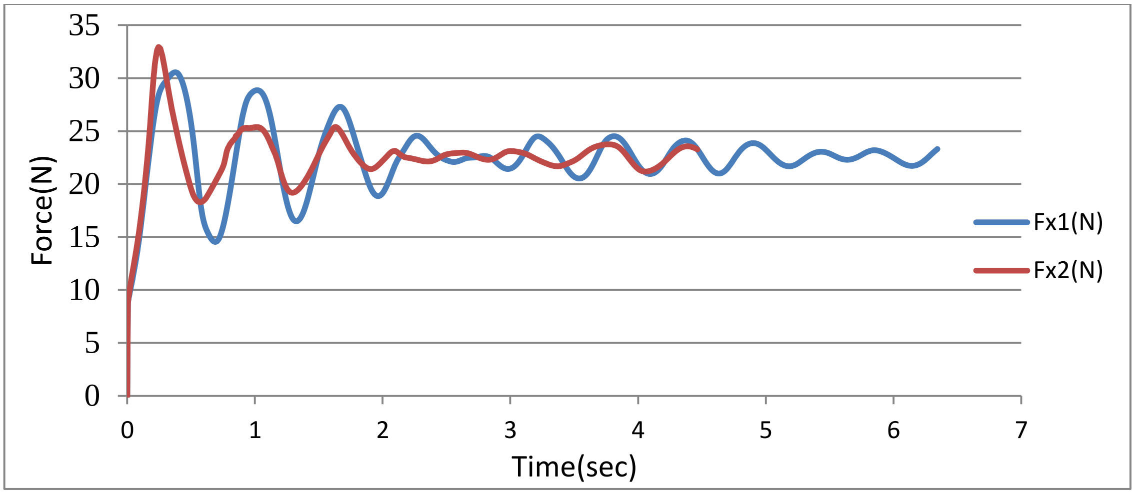


Figure 5.19: Lateral force at 50% fill with and without baffle

As a result, with 50% fill condition, the percentage reduction compared between those fuel tanks is 7.8%. There is no impediment to the lateral motion of fuel in a fuel tank without baffles. The rolling motion of the vehicle is impacted by these lateral forces. The fuel tank with a baffle mechanism achieves the greatest reduction in sloshing forces. As a result of the baffle arrangement's superior ability to disperse energy, the data demonstrate that peak force decreases.

5.3.2 Vertical forces comparison of new fuel tank with and without baffles

% Vertical force decreases at 50% fill level = $\frac{69.2329-67.4775}{67.4775} \times 100\% = 2.6\%$

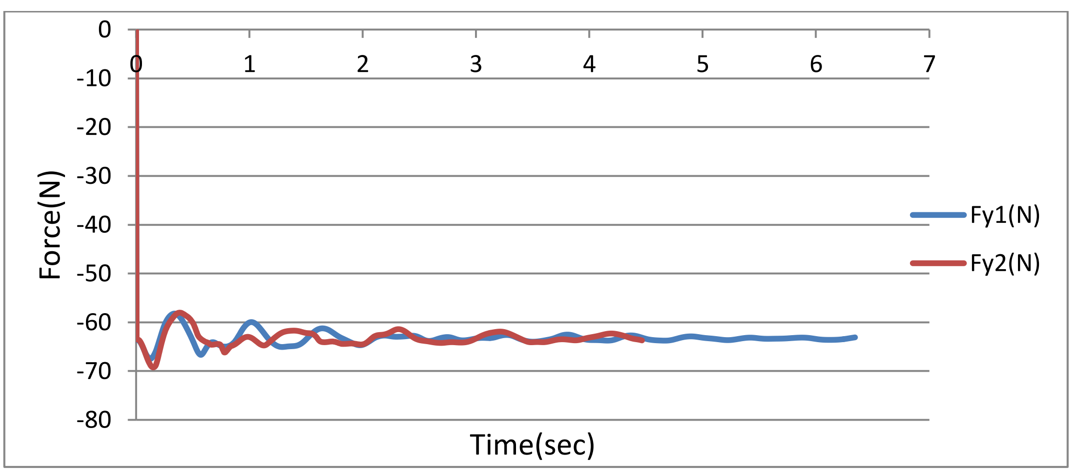


Figure 5.20: Vertical force at 50% fill with different baffle designs

The comparison of vertical forces at 50% fill levels with and without baffles is shown in graph 5.20. The difference between those tanks is reduced by 2.6%. The conclusion is that while adding baffles to vary vertical forces created some fluctuation, it was not excessive. The sloshing effect on vertical forces is therefore minimal.

5.3.3 Longitudinal forces comparison of new fuel tank with and without baffles

% longitudinal force decreases at 50% fill level = $\frac{31.12055-22.66302}{22.66302} \times 100\% = 37.32\ \%$

Therefore, as shown in figure 5.21 below the graph at 50% fill, the percentage reduction between the tanks with baffles and without is 37.32%. There is no impediment to the longitudinal motion of fuel in a fuel tank without baffles. The rolling motion of the vehicle is impacted by these forces. The fuel tank with a baffle mechanism achieves the greatest reduction in sloshing forces. As a result of the baffle arrangement's superior ability to disperse energy, the data demonstrate that peak force rapidly decreases.

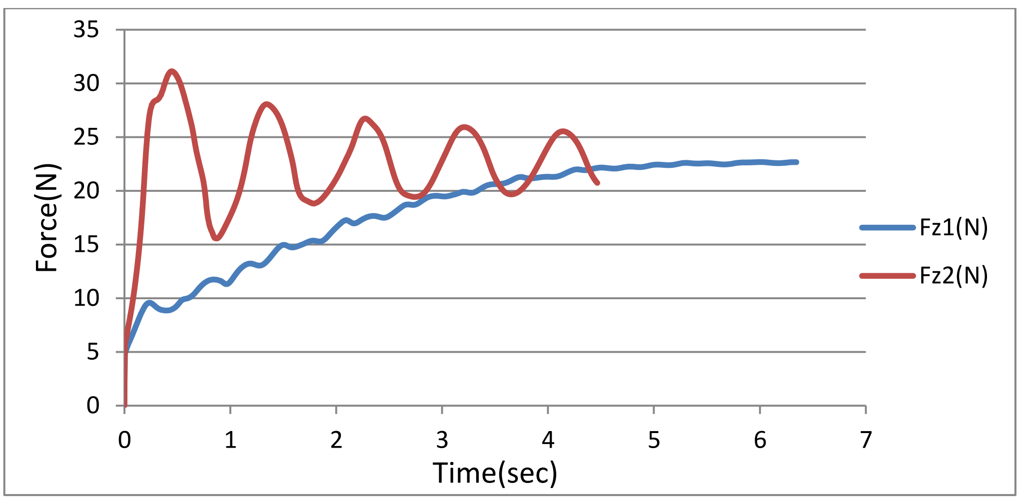


Figure 5.21: Longitudinal force at 50% fill with baffle designs

5.3.4 Lateral roll moment comparison of new fuel tank with and without baffles

% Lateral roll moment coefficient decreases at 50% fill level

$$= \frac{6.731498-4.759893}{4.759893} \times 100\% = 41.42\ \%$$

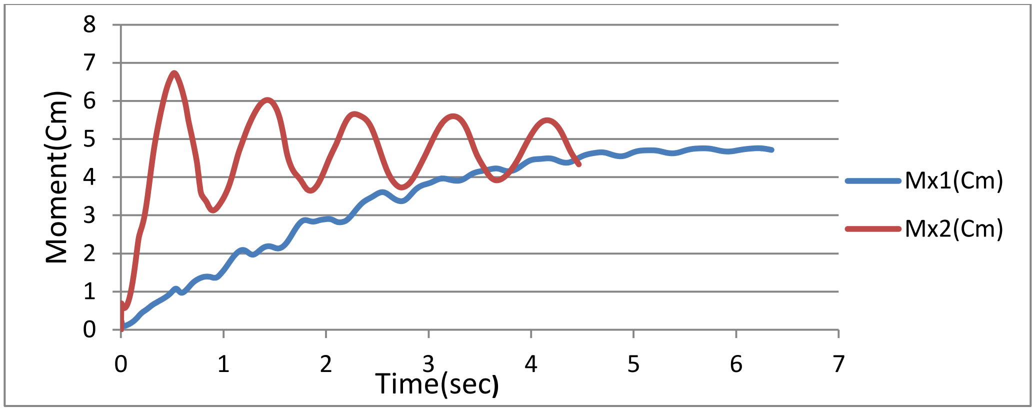


Figure 5.22: Roll moment at 50% fill with different baffle designs

According to the comparison of the lateral roll-moment coefficient, the percentage reduction between the two fuel tanks at 50% fill levels is 41.42%. Therefore, the proposed new fuel tank with baffles offers a significant or high reduction in roll moments as shown in figure 5.22 graph.

5.3.5 Longitudinal roll moment comparison of new fuel tank with and without baffles

As it seen in figure 5.23 below it is shown that the graph comparison of roll-moments when the vehicle is subjected to combined acceleration. The roll-moment coefficient at 50% fill levels at fuel tank with baffles as shown in the graph is increased.

% Longitudinal roll moment coefficient increments at 50% fill level

$$= \frac{1.42352 - 1.92192}{1.92192} \times 100\% = 25.93\ \%$$

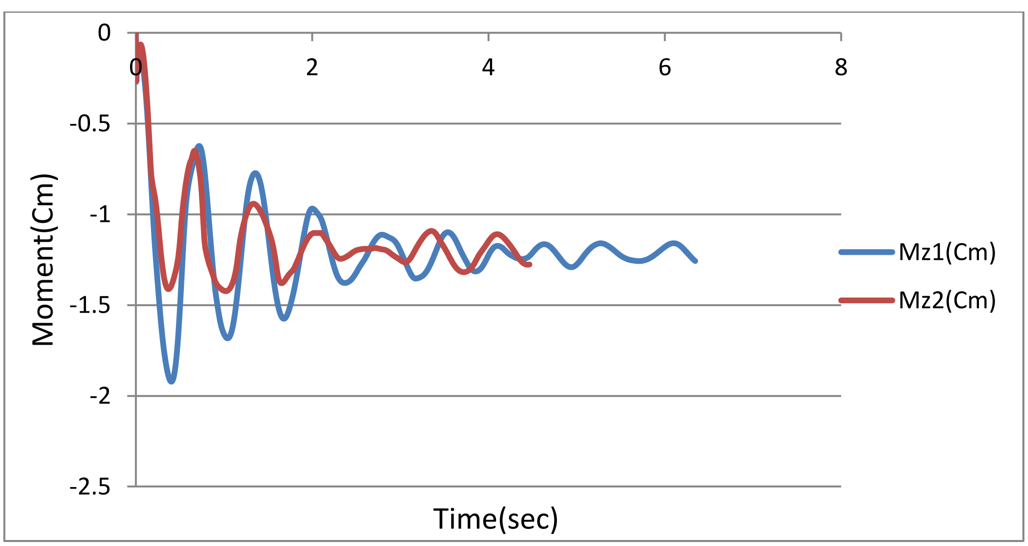


Figure 5.23: Roll moment at 50% fill with different baffle designs

Lateral roll-moment coefficient, the percentage reduction between the two fuel tanks is 41.42% but longitudinal roll-moment coefficient, the percentage increases between the two fuel tanks is 25.93%. Therefore, resultant roll moment about x and z axis for both fuel tank with and without baffles is calculated. Resultant moment coefficients for;

Proposed new fuel tank without baffle is $\sqrt{(6.731498)^2 + (1.42352)^2}$ = 6.88037.

Proposed new fuel tank with baffle is $\sqrt{(4.759893)^2 + (1.92192)^2}$ = 5.13326.

% Roll moment coefficient decrease at 50% fill level = $\frac{6.88037 - 5.13326}{5.13326} \times 100\% = 34.04\ \%$

Therefore, the comparison of roll- moment of proposed new fuel tank with and without baffles offers a significant or high reduction in roll moments.

From the figure 5.19, figure 5.20, figure 5.21, figure 5.22 and figure 5.23 graphs of 50 % fill level, the graph of figure 5.19, figure 5.21 and figure 5.22 gives the best results. Also the graph of figure 5.20 gives less variation. The worst results are obtained with figure 5.23. The comparison results can be summarized in following table 5.1:

Table 5.1 Comparison results between the proposed new fuel tank with and without baffles

Force/Moment	Fill level	Percentage (%)	Effectiveness
Lateral force	50%	7.8	lateral forces reduced at baffled fuel tank.
Vertical force	50%	2.6	baffles has less effect for vertical forces
Longitudinal force	50%	37.32	high reduction in longitudinal forces at baffled fuel tank
Lateral roll moment coefficient	50%	41.42	high reduction in lateral roll moment coefficient at baffled fuel tank
Longitudinal roll moment coefficient	50%	25.93	high increment in longitudinal roll moment coefficient at baffled fuel tank
Resultant roll moment coefficient	50%	34.04	high reduction in resultant roll moment coefficient at baffled fuel tank

5.4 Comparison between the existing and new fuel tank without baffles at 50% fill conditions

Figure 5.24, figure 5.25, figure 5.26, figure 5.27 and figure 5.28 shows the combined graph of lateral, vertical and longitudinal force Vs. flow time and moments Vs. flow time for the existing fuel tank and proposed new fuel tank without baffles of 50% fill level at a=3.5 m/s^2 lateral and longitudinal acceleration.

Existing fuel tank Proposed fuel tank without baffle

5.4.1 Lateral forces comparison of existing and new fuel tank without baffles

$$\text{\% Lateral force increment at 50\% fill level} = \frac{32.94012-17.58359}{32.94012} \times 100\% = 46.62\ \%$$

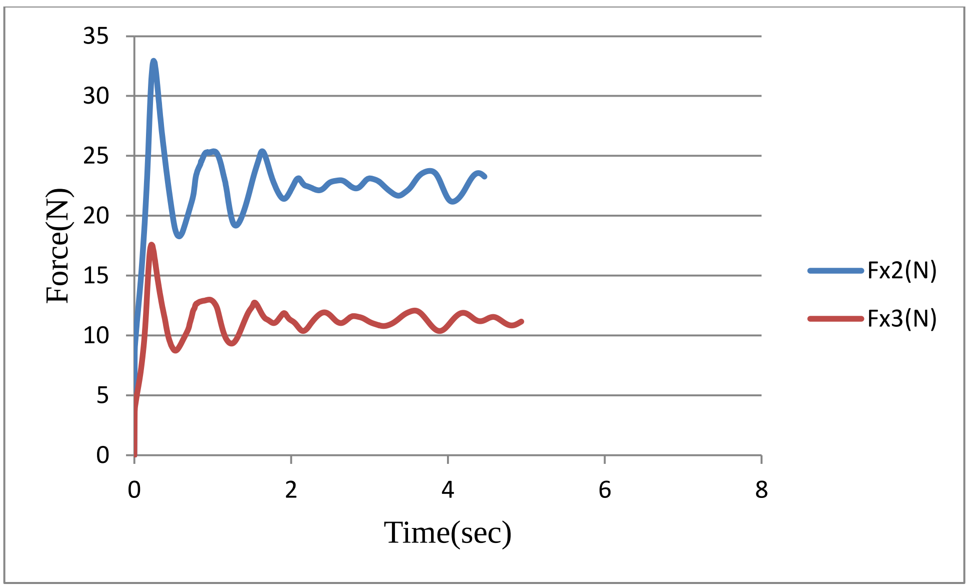


Figure 5.24: Lateral force at 50% fill of existing fuel tank and new fuel tank without baffles

As a result of the increasing 100% fuel volume with 50% fill condition, the percentage increment compared between those fuel tanks is 46.62%.

5.4.2 Vertical forces comparison of existing and new fuel tank without baffles

$$\text{\% Vertical force increment at 50\% fill level} = \frac{69.2329-34.7241}{69.2329} \times 100\% = 49.84\%$$

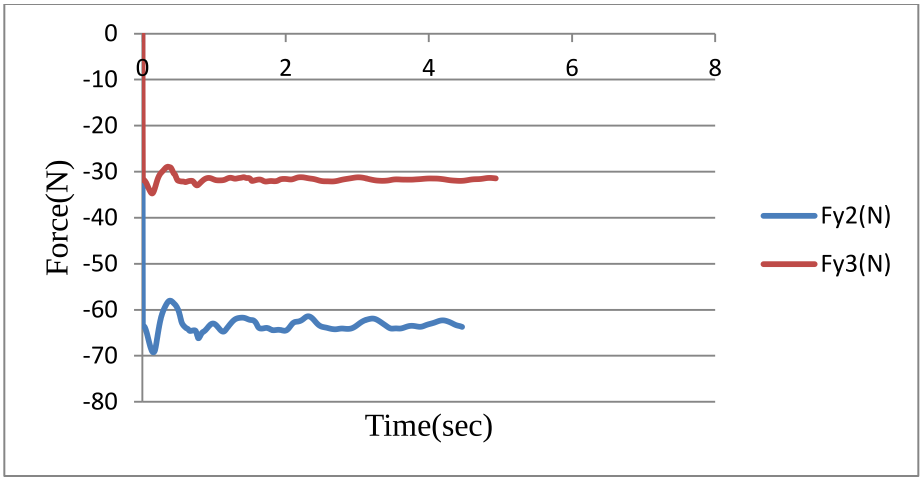


Figure 5.25: Vertical force at 50% fill of existing fuel tank and new fuel tank without baffles

The comparison of vertical forces at 50% fill levels is shown in graph 5.25. The difference between those tanks is increased by 49.84%.

5.4.3 Longitudinal forces comparison of existing and new fuel tank without baffles

% longitudinal force increment at 50% fill level = $\frac{31.12055-15.5211}{31.12055} \times 100\% = 50.13\ \%$

Therefore, as shown in figure 5.26 below the graph as a result of the increasing 100% fuel volume with 50% fill condition, the percentage increment between the tanks of existing and new tank without baffles is 50.13%.

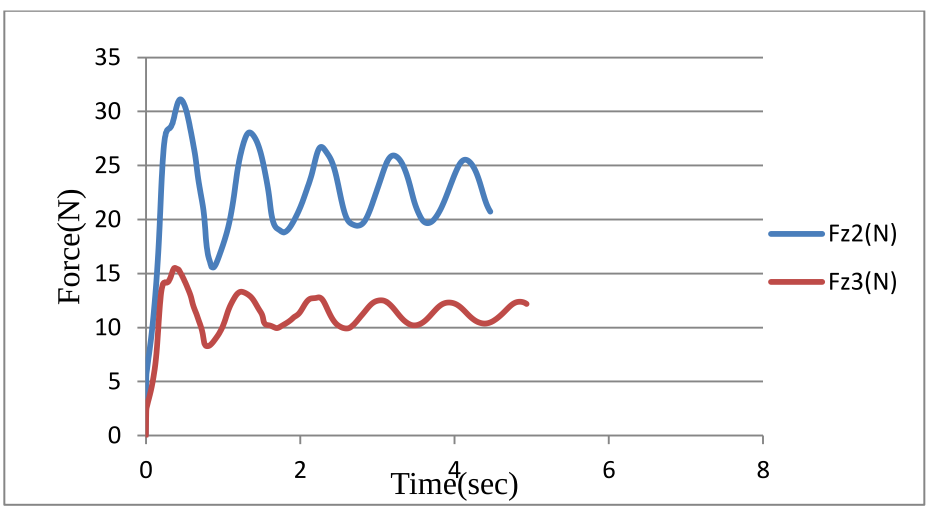


Figure 5.26: Longitudinal force at 50% fill of existing fuel tank and new fuel tank without baffles

5.4.4 Lateral roll moment comparison of existing and new fuel tank without baffles

% Lateral roll moment coefficient increments at 50% fill level

$$= \frac{6.7315 - 3.2634}{6.7315} \times 100\% = 51.52\ \%$$

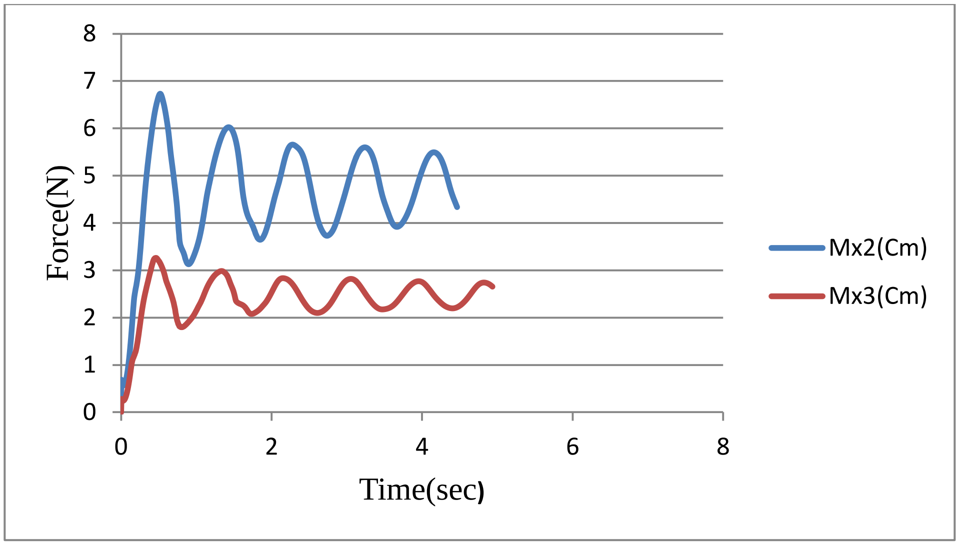


Figure 5.27: Roll moment at 50% fill of existing fuel tank and new fuel tank without baffles

According to the comparison of the lateral roll-moment coefficient, as a result of the increasing 100% fuel volume with 50% fill condition the percentage increment between the two fuel tanks at 50% fill levels is 51.52%.

5.4.5 Longitudinal roll moment comparison of existing and new fuel tank without baffles

% Longitudinal roll moment coefficient increments at 50% fill level

$$= \frac{1.4235 - 0.9701}{1.4235} \times 100\% = 31.85\ \%$$

As it seen in figure 5.28 below it is shown that the graph comparison of roll-moments when the vehicle is subjected to combined acceleration. The longitudinal roll-moment coefficient at 50% fill levels at existing fuel tank and proposed new fuel tank without baffles as shown in the graph is increased by 31.85%.

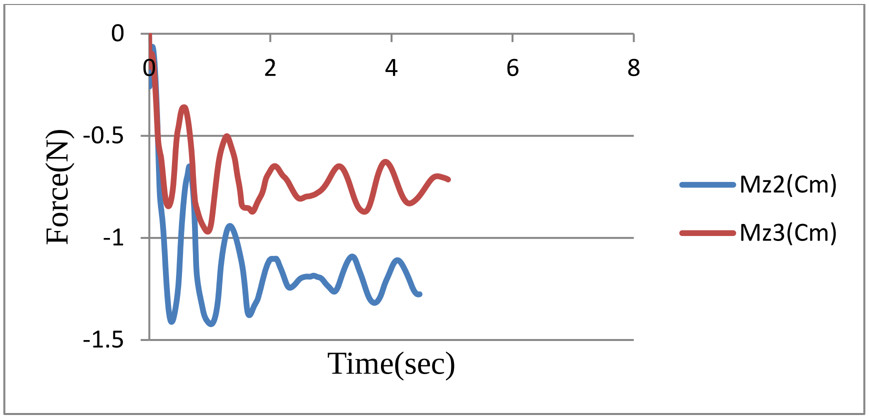


Figure 5.28: Roll moment at 50% fill of existing fuel tank and new fuel tank without baffles

5.5 Comparison between the existing and the new fuel tank with baffles at 50% fill conditions

Figure 5.29, figure 5.30, figure 5.31, figure 5.32 and figure 5.33 shows the combined graph of lateral, vertical and longitudinal force Vs. flow time and moments Vs. flow time for the existing and the proposed new fuel tank with baffles of 50% fill level at a=3.5 m/s^2 lateral and longitudinal acceleration.

Existing fuel tank   Proposed fuel tank with baffles

5.5.1 Lateral forces comparison of the existing and the new fuel tank with baffles

$$\% \text{ Lateral force increment at 50\% fill level} = \frac{30.5565-17.58359}{30.5565} \times 100\% = 42.45\ \%$$

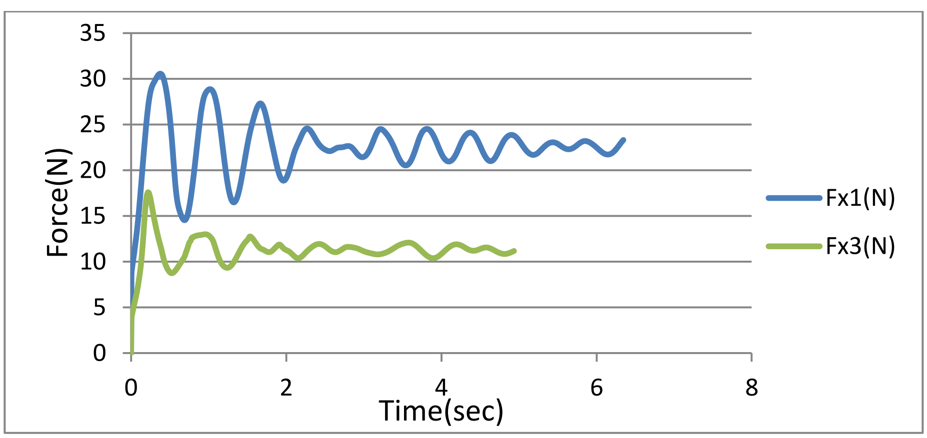


Figure 5.29: Lateral force at 50% fill of existing fuel tank and new fuel tank with baffles

As a result, with 50% fill condition, the percentage increment compared between those fuel tanks is 42.45%.

5.5.2 Vertical forces comparison of the existing and the new fuel tank with baffles

$$\% \text{ Vertical force increment at 50\% fill level} = \frac{67.4775-34.7241}{67.4775} \times 100\% = 48.54\%$$

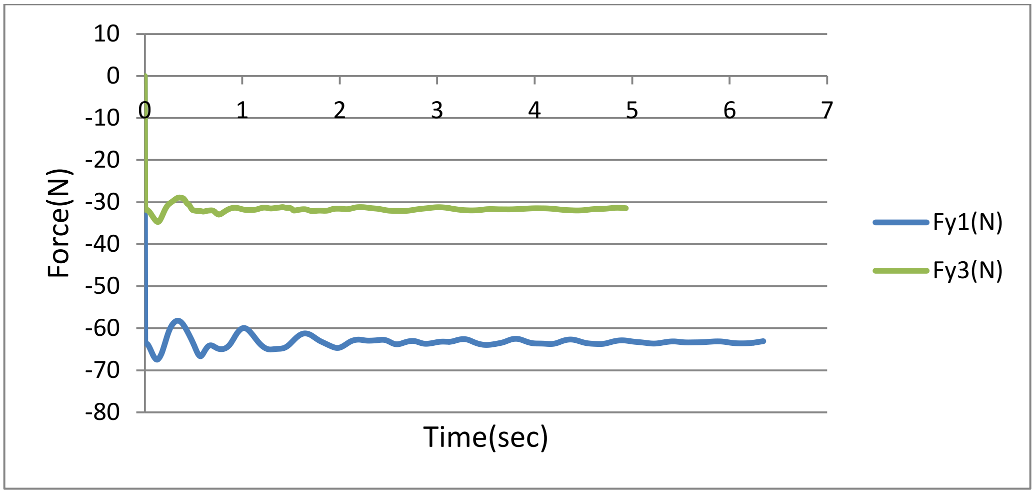


Figure 5.30: Vertical force at 50% fill of existing fuel tank and new fuel tank with baffles

The comparison of vertical forces at 50% fills levels of the existing and the proposed new fuel tank with baffle is shown in graph 5.30. The difference between those tanks is increased by 48.54%.

5.5.3 Longitudinal forces comparison of the existing and the new fuel tank with baffles

$$\% \text{ longitudinal force increment at 50\% fill level} = \frac{22.6630-15.5211}{22.6630} \times 100\% = 31.51\ \%$$

Therefore, as shown in figure 5.31 below the graph at 50% fill, the percentage increment between the existing and the new fuel tank with baffle is 31.51%.

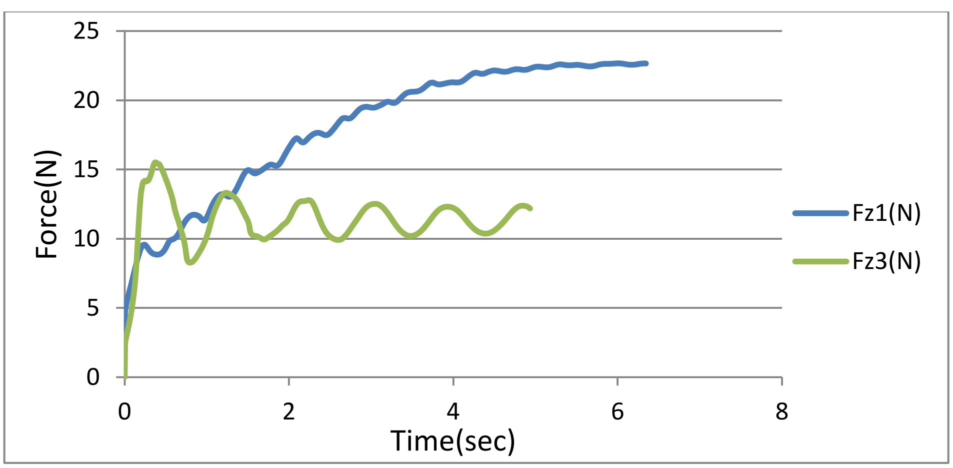


Figure 5.31: Longitudinal force at 50% fill of existing fuel tank and new fuel tank with baffles

5.5.4 Lateral roll moment comparison of the existing and the new fuel tank with baffles

% Lateral roll moment coefficient increments at 50% fill level

$$= \frac{4.7599 - 3.2634}{4.7599} \times 100\% = 31.44\ \%$$

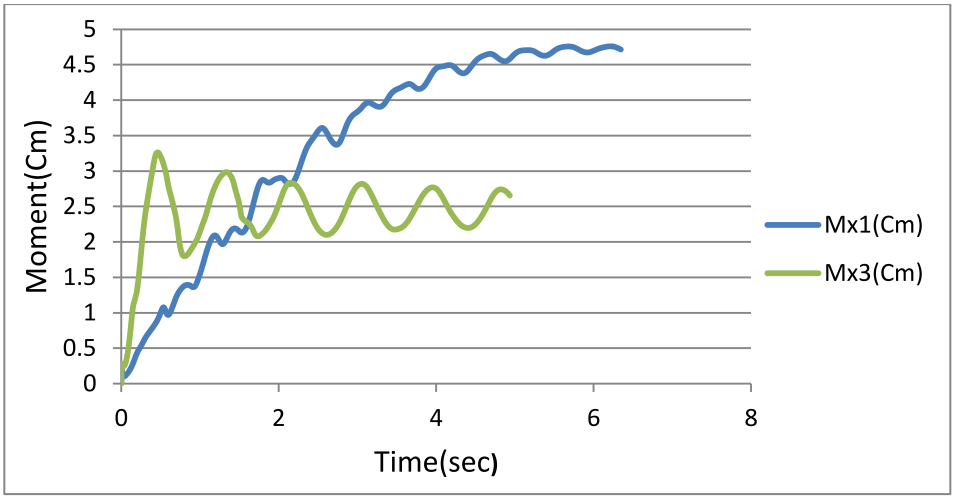


Figure 5.32: Roll moment at 50% fill of existing fuel tank and new fuel tank with baffles

According to the comparison of the lateral roll-moment coefficient, the percentage increment between the two fuel tanks at 50% fill levels is 31.44%.

5.5.5 Longitudinal roll moment comparison of the existing and the new fuel tank with baffles

As it seen in figure 5.33 below, it is shown that the graph comparison of roll-moments when the vehicle is subjected to combined acceleration. The roll-moment coefficient at 50% fill levels at fuel tank with baffles as shown in the graph is increased.

% Longitudinal roll moment coefficient increments at 50% fill level

$$= \frac{1.9219 - 0.9701}{1.9219} \times 100\% = 49.52\ \%$$

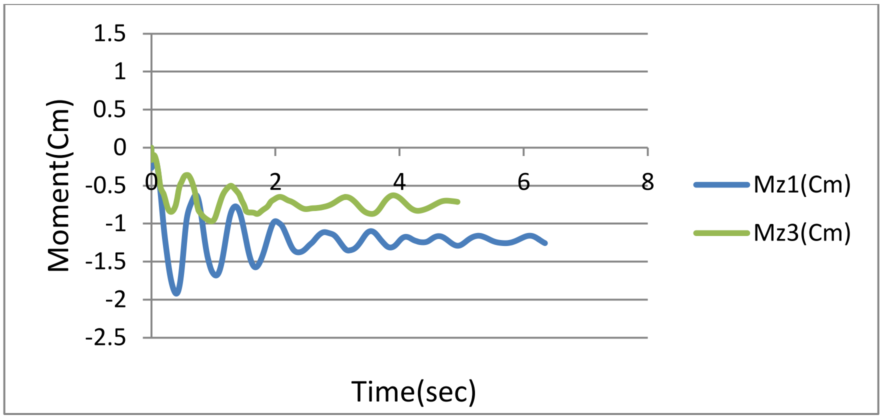


Figure 5.33: Roll moment at 50% fill of existing fuel tank and new fuel tank with baffles

Lateral roll-moment coefficient, the percentage increment between the two fuel tanks is 49.52%.

The comparisons result among the existing and the new fuel tank are shown in table 5.2.

Table 5.2 Comparison results between the existing fuel tank and new fuel tank

Forces and roll moments	Increment b/n existing and new fuel tank without baffles (%)	Increment b/n existing and new fuel tank with baffles (%)	The effect of baffles
Lateral forces	46.62	42.45	Reduced
Vertical forces	49.84	48.54	Reduced
Longitudinal forces	50.13	31.51	Reduced
Lateral roll moment	51.52	31.44	Reduced
Longitudinal roll moment	31.85	49.52	Increased

5.6 CFD Validation

Validation is intended to test the extent to which the model accurately represents reality, to achieve that there are two alternative methods. The primary one is through comparing the results of the CFD with experimental results and another one through cross-checking with preceding CFD studies which undertake validation from experimental findings. Since the aforementioned viscous model is suitable for the fuel tank slosh study, the validation of the CFD model using VOF is accomplished in this way. The VOF in multiphase model is used in baffle analysis and has demonstrated a very strong correlation with the experimental results. Based on Kandasamy, (2010) (Kumar, 2013) (Nema, 2014) (Abera, 2015) (Ahmad et al., 2020) finding, this study is well constructed and verified.

The largest peak moment decrease in a cylindrical tank was 34% when horizontal baffles with a length ratio of 0.75 were used for 50% fill level and 30% when vertical forces with a length ratio of 0.75 were used for 70% fill level, this was done by (Kumar, 2013). The same approach has been used to solve the effect of three wheeler vehicle new fuel tank sloshing using baffles and the results showed closely matched. And (Kandasamy, 2010) was evaluate with different baffle design at different fill level with cylindrical tank geometry the graph of the lateral force and roll-moment were similar with this work. The following figure 5.34 and 5.35shows the force and moment graph was found by Kandasamy.

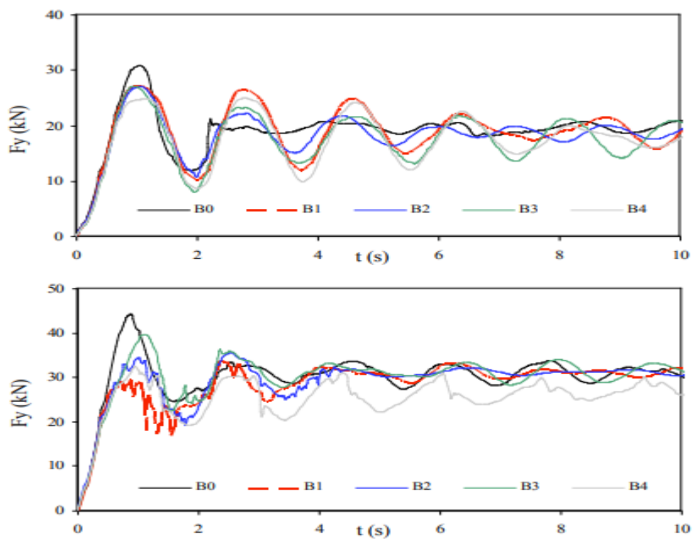


Figure 5.34: Lateral slosh force responses of various baffled tanks subject to gy = 0.25g

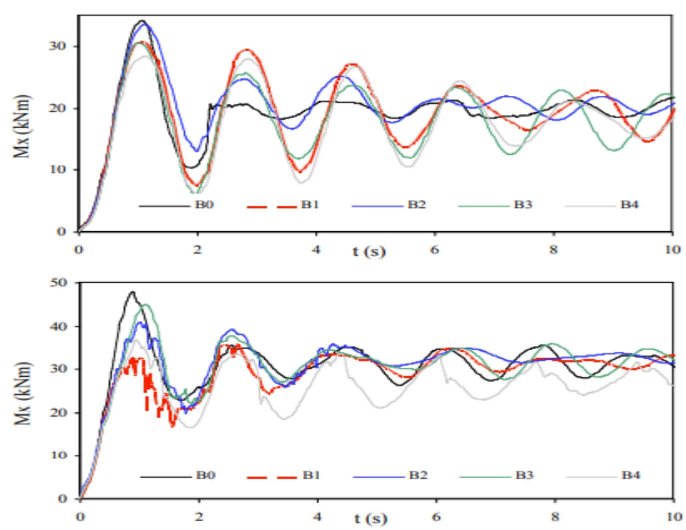


Figure 5.35: Roll moment responses of selected baffled tanks subject to gy = 0.25g

Additionally, a validation scenario has been taken into account to analyze the mobility of the fuel's free surface in a rectangular fuel tank that is only partially filled (Singal et al., 2014).

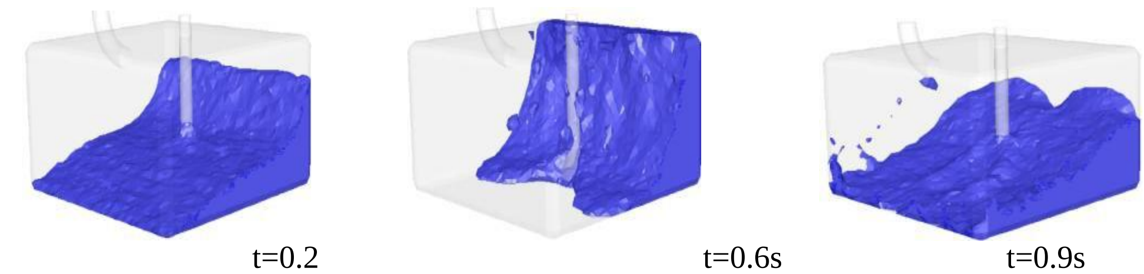


Figure 5.36: Liquid interface at various time steps for Tank without baffles.

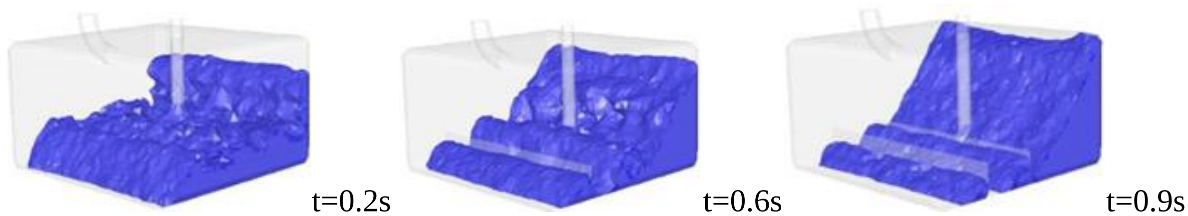
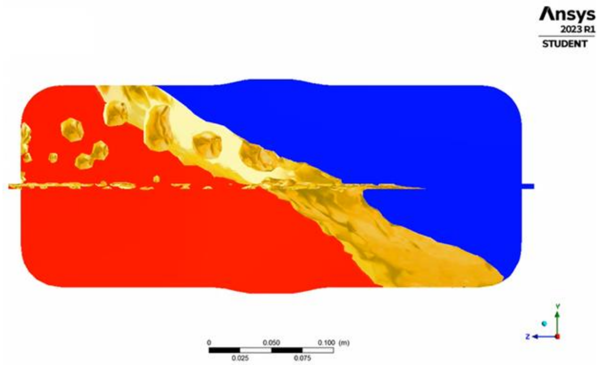


Figure 5.37: Liquid interface at various time steps for Tank with baffles

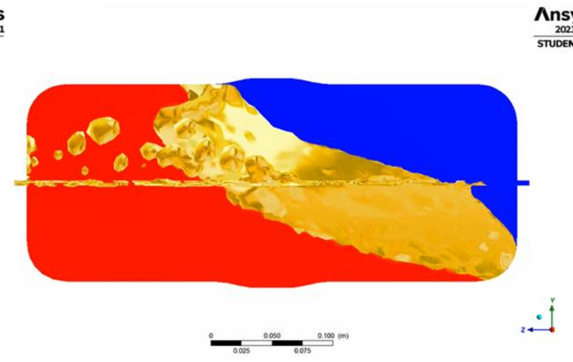
Therefore, the same approach has been used to solve the sloshing effect of the proposed new three wheeler fuel tank. Finally, the outcomes demonstrated motion that was comparable to this real simulation. The findings of the motion of the free surface of gasoline are displayed in the next section for verification.

5.7 Liquid surface interface of the new fuel tank for 50% fill levels at different time steps

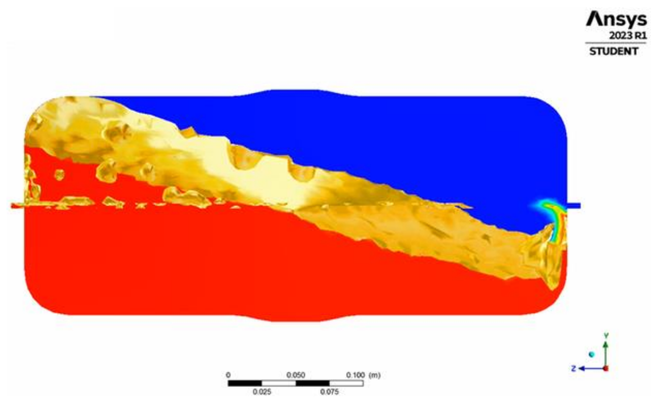
The movement of gasoline in the fuel tank without baffles at various times is depicted below in Figure 5.38. It has been discovered that as a vehicle is cornering, the fuel strikes the tank's side wall, increasing the cornering moment since the fuel is moving toward the sidewall. Since the roll moment is increasing and not decreasing quickly, that suggests the car may roll over as a result of fuel fluctuations.



t=0.2sec



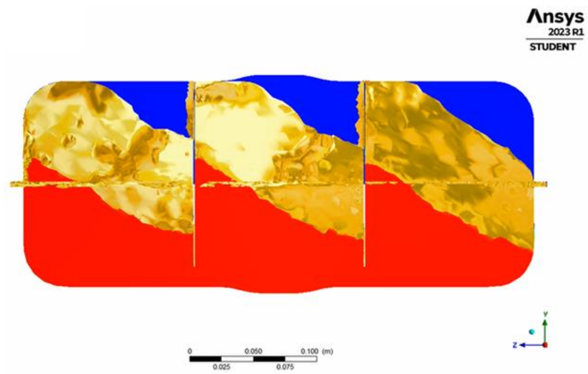
t=0.6sec



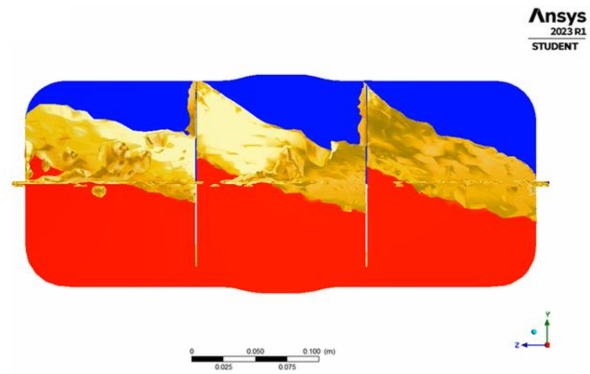
t=0.9sec

Figure 5.38: Liquid surface in the new tank without baffles of 50% fill at t=0.2, 0.6 and 0.9sec.

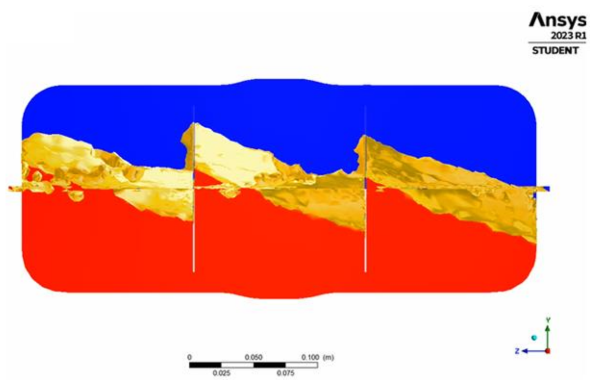
Figure 5.39, which represents the motion of gasoline inside a fuel tank with baffles, is below. This baffle further decreased the vehicle's lateral forces, longitudinal forces, and moments to a safe level. Using both the graphs above and below, it is easy to understand how the fuel's motion differs from one another. The graph below illustrates how quickly fuel can return to a stable state. For instance, up until 0.6 sec, motion increases, then decreases, and then at 0.9sec, fuel returns to a stable state in contrast to the graph before. As a result, baffles significantly minimize fuel motion while cornering.



t=0.2sec



t=0.6sec



t=0.9sec

Figure 5.39: Liquid surface in the new tank with baffles of 50% fill at t=0.2, 0.6 and 0.9sec.

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Summery

This chapter concludes the results of computational analysis of fuel tank to examine the effect of baffle for modified three wheeler fuel tank at 50% filled levels and at the combined lateral and longitudinal acceleration of 3.5 m/s^2. Due to the combined acceleration motion, parameters defining stability of the tank as well as the vehicle such as sloshing forces, vertical forces and roll moments computational simulation are carried out at the existing fuel tank, a proposed new fuel tank with and without baffles systems. A baffle of a fuel tank presented the largest benefit in reducing the sloshing impact. Mounting new designed part is carried out at the bottom of the vehicle in which the height of center of mass of the vehicle is reduced. Therefore, center of gravity height decreased from 590mm to 560mm (i.e. decreased by 30mm to the ground), lateral location of center of gravity w.r.t track width moved from -20 mm to center (i.e. shifted into center by 20mm) and longitudinal location of center of gravity w.r.t. rear axle didn't change the location. As the result the dynamic stability factor as given as in equation 4.43 is calculated as follows;

Dynamic stability factor for vehicle with existing fuel tank is

$$= \frac{WT}{2h}\frac{L1A}{WB} = \frac{1300}{2(590)}\frac{1440}{2000} = 0.793$$

Dynamic stability factor for vehicle with existing fuel tank is

$$= \frac{WT}{2h}\frac{L1A}{WB} = \frac{1300}{2(570)}\frac{1440}{2000} = 0.821$$

Therefore, rollover resistance is increased for the vehicle with new fuel tank by optimizing the fuel tank location or enabling the center of gravity height low.

Finally after analysis performed, mileages of fully filled existing fuel tank and new fuel tank are about 136 km and 272 km respectively. To fill once the driver waits for average of 5 hours and works for about 2 days for the existing fuel tank and 4 days for the new fuel tank.

6.2 Conclusions

Therefore, the thesis work conducted a new design of most secure and safe fuel tank for three-wheeler vehicles in which its capacity increased twice the amount of the existing and with optimized location and mounting techniques. The vehicles rollover resistance is increased with new location of new fuel tank enabling the center of gravity height lower. A mileage of the vehicle with new fuel tank is increased twice from existing fuel tank once the tank is fully filled.

The following is a summary of the key findings:

- ✓ The percentage reduction of lateral force at 50% filled level in those fuel tanks with and without baffle is 7.8%. There is no impediment to the lateral motion of fuel in a fuel tank without baffles. The rolling motion of the vehicle is impacted by these lateral forces. The fuel tank with a baffle mechanism achieves the greatest reduction in sloshing forces. As a result of the baffle arrangement's superior ability to disperse energy, the data demonstrate that peak force decreases.
- ✓ The comparison of vertical forces at 50% fill levels with and without baffles in those tanks is only reduced by 2.6%. Adding baffles vary vertical forces some fluctuation, it was not excessive. The sloshing effect on vertical forces is therefore minimal.
- ✓ The fuel tank with a baffle mechanism achieves the greatest reduction in longitudinal sloshing forces at 50% fill, the percentage reduction between the tanks with baffles and without is 37.32%. As a result of the baffle arrangement's superior ability to disperse energy, the data demonstrate that peak force rapidly decreases. The rolling motion of the vehicle is impacted by these forces when there is no impediment to the longitudinal motion of fuel in a fuel tank without baffles.
- ✓ Lateral roll-moment coefficient, the percentage reduction between the two fuel tanks is 41.42% but longitudinal roll-moment coefficient, the percentage increases by 25.93% at the fuel tank with baffles. Therefore, resultant roll moment about x and z axis for both fuel tank with and without baffles is calculated. Therefore, the reduction comparison of roll- moment at a proposed new fuel tank with offers a significant or high reduction in roll moments of 34.04%.
- ✓ Center of gravity height decreased from 590mm to 560mm (i.e. decreased by 30mm to the ground), lateral location of center of gravity w.r.t track width moved from -20 mm to center (i.e. shifted into center by 20mm)
- ✓ Mileages of fully filled existing fuel tank and new fuel tank are about 136 km and 272 km respectively. To fill once the driver may wait for average of about 5 hours and works for about 2 days for the existing fuel tank and 4 days for the new fuel tank.

- ✓ Table 6.1 Comparison results summery at 50% filled level is as follows;

Table 6.1 Comparison results summery at 50% filled level

Force/Moment	Percentage (%)	Effectiveness
Lateral force	7.8	lateral forces reduced at baffled fuel tank
Vertical force	2.6	baffles has less effect for vertical forces
Longitudinal force	37.32	high reduction in longitudinal forces at baffled fuel tank
Lateral roll moment coefficient	41.42	high reduction in lateral roll moment coefficient at baffled fuel tank
Longitudinal roll moment coefficient	25.93	high increment in longitudinal roll moment coefficient at baffled fuel tank
Resultant roll moment coefficient	34.04	high reduction in resultant roll moment coefficient at baffled fuel tank

6.3 Recommendation for future work

- ✓ This thesis work is only carried out on lateral baffles configuration. Therefore, it is recommended to further study on the effect of longitudinal baffles configurations by considering different shapes and number of baffles as well as examining the of the fluid sloshing forces and moments at different filled level tank.
- ✓ The vehicles rollover stability and fuel sloshing effect is interrelated strongly when turning/cornering. So, study of the rollover stability of the three wheeler vehicle needs at different fuel tank location.
- ✓ The existing and the modified fuel tank are made of sheet metal but it is recommended to made at the material of the plastic fuel tank (HDPE) which is lightweight and less expensive.

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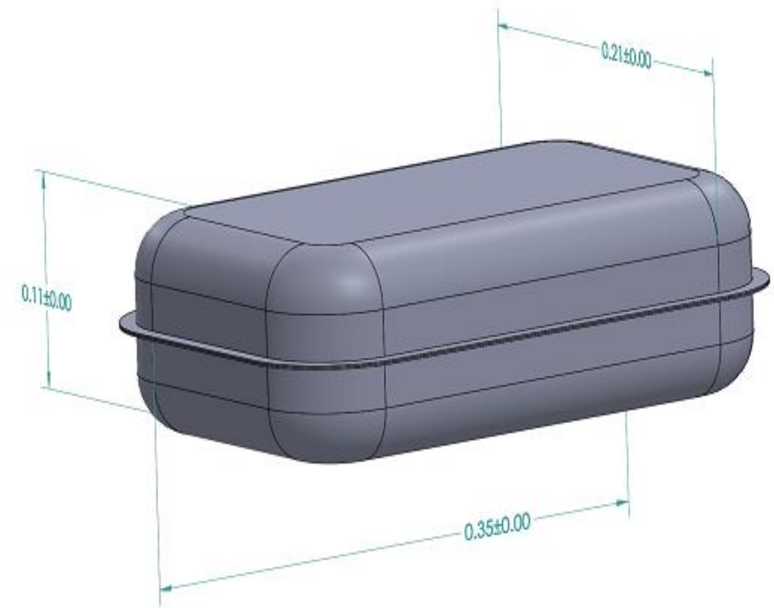
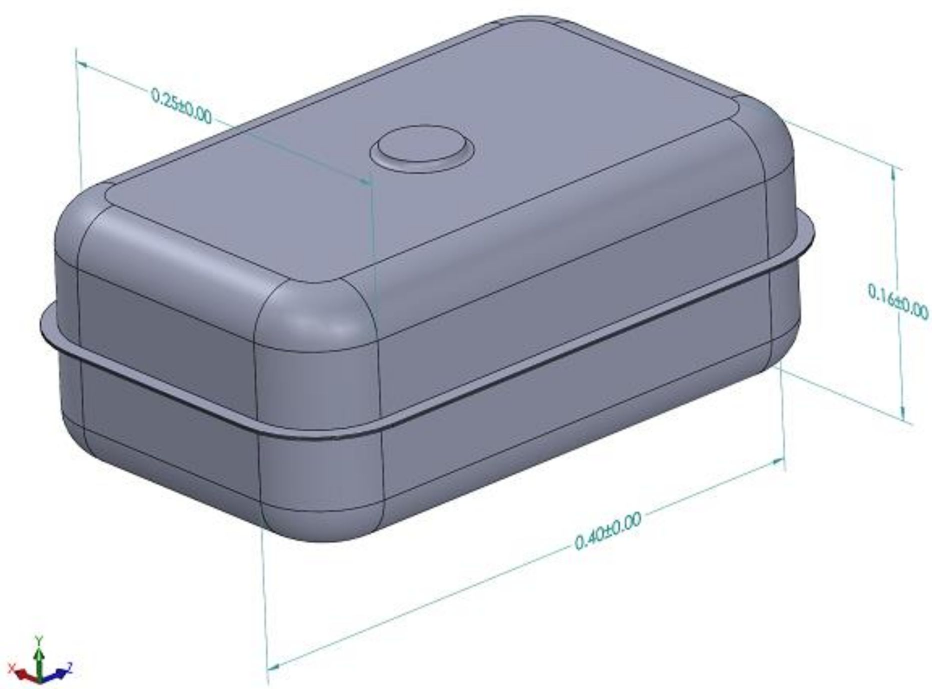
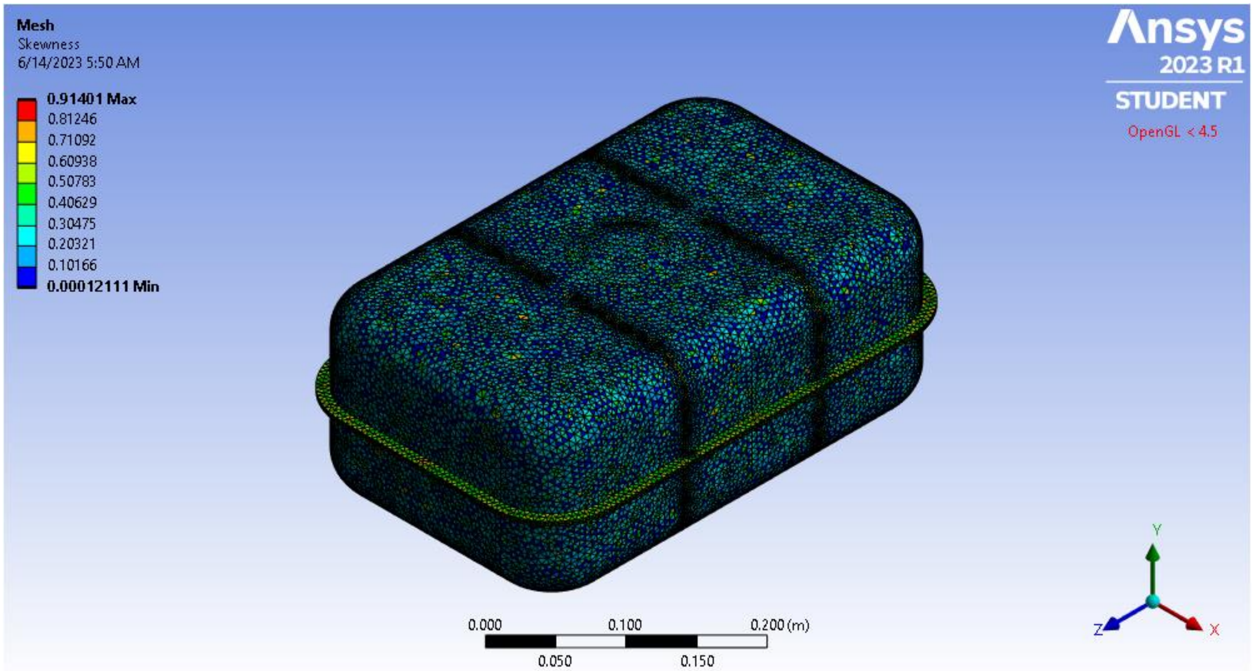
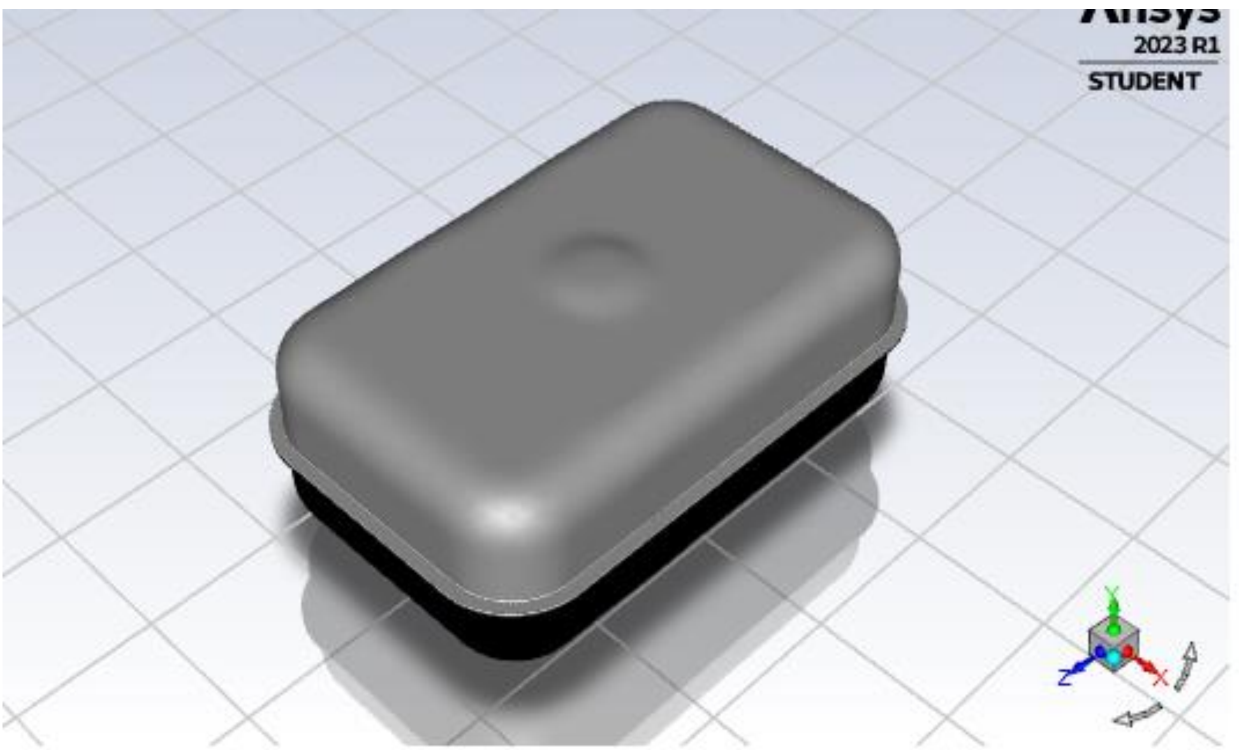
APPENDIX A
Existing and New Fuel Tank Dimensions (m)

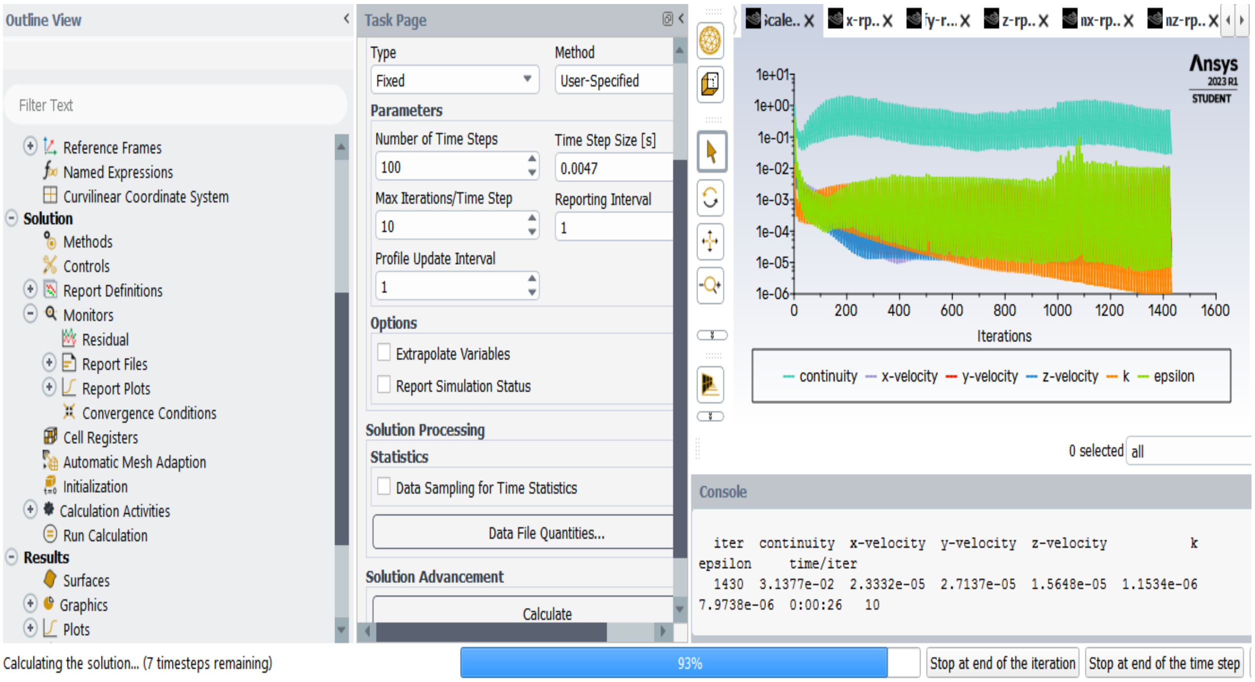




APPENDIX B
ANSYS Simulation






Outline View
Filter Text
Reference Frames
Named Expressions
Curvilinear Coordinate System
Solution
Methods
Controls
Report Definitions
Monitors
Residual
Report Files
Report Plots
Convergence Conditions
Cell Registers
Automatic Mesh Adaption
Initialization
Calculation Activities
Run Calculation
Results
Surfaces
Graphics
Plots
Task Page
Type
Fixed
Method
User-Specified
Parameters
Number of Time Steps
100
Time Step Size [s]
0.0047
Max Iterations/Time Step
10
Reporting Interval
1
Profile Update Interval
1
Options
Extrapolate Variables
Report Simulation Status
Solution Processing
Statistics
Data Sampling for Time Statistics
Data File Quantities...
Solution Advancement
Calculate
Ansys
2023 R1
STUDENT
Iterations
continuity
x-velocity
y-velocity
z-velocity
k
epsilon
0 selected
all
Console
iter continuity x-velocity y-velocity z-velocity k
epsilon time/iter
1430 3.1377e-02 2.3332e-05 2.7137e-05 1.5648e-05 1.1534e-06
7.9738e-06 0:00:26 10
Calculating the solution... (7 timesteps remaining)
93%
Stop at end of the iteration
Stop at end of the time step

APPENDIX C
Interview Questions



<u>በባለ ሦሰት እግር ተሽከርካሪ ዙሪያ የሚሞላ ለተጠቃሚ ደንበኞች የቀረበ ቃለ መጠይቅ</u>

ቀን : ___________ በታ : ___________

1) ባለ ሦስት እግር ተሽከርካሪ ላይ ያልዎት ድርሻ:

2) ተሽከርካሪዋ የሙቼ ስሪት ወይንም ሞዴል ናት? _________

3) የተሽከርካሪዋ ነዳጅ የመያዝ አቅሞ ስንት ሊትር ነው? _______________

4) በአንድ ሊትር ምን ያህል ኪሎ ሚትር ትጓዛለች/ትሰራለች? ______________

5) በቀን ዉስጥ ምን ያህል ሰዓት በስራ ታሳልፋለህ? ____________

6) አንዴ ከሞሉ ለምን ያህል ጊዜ ተጨማሪ መሙላት ሳያስፈልግ ይሰራሉ?

7) ነዳጅ ለመሙላት ይቸገራሉ?

8) ነዳጅ ማደያ ሄደው ለመሙላት የሚያሳልፉት ጊዜ ምን ያህል ነው? ______________

9) የነዳጅ ማጠራቀሚያ ታንከር ተጨማሪ ነዳጅ መያዝ ቢችል ይመርጣሉ, ያስፈልጋል ብለው ያምናሉ ? አያስፈልግም ካሉ ለምን?__________________________

መልስዎ አዎ ከሆነ, ታንከሩ አሁን ካለበት ሌላ ምን ያህል ሊትር ቢይዝ ይፈልጋሉ? ______________

10) ተጨማሪ ነዳጅ ተሽከርካሪዋ ላይ ክብደት መጨመሩ የነዳጅ ፍጆታ አይጨምርም?

ቢያስረዱኝ፡-____

11) የነዳጅ ሰልፍ ላለመሰለፍ ምን አማራጭ መፍትሔ ይወስዳሉ?

12) ስለ ነዳጅ ማጠራቀሚያዉ ማነስ ቅሬታ ወይንም ሀሳብ ያቀረባችሁለት አካል አለ? __________

መልስዎ አዎ ከሆነ ቢገልፁልን፡-______________________________________

13) ተሽከርካሪዎ ላይ ሌላ ምን አይነት ችግር አጋጥሞት ያውቃል ወይንም ይህ ቢስተካከል ሚሉት ነገር ይኖራል? __________________________

ATUL

VAYO
AUTOMOBILES

Date: - 22 June 2023

Ref No፡-VAYO/578/2023

To Adama Science and Technology University

Adama

Subject: - Support Letter

Our employee, Haileyesus Aderaw, has requested us a letter that supports his research entitled "Designing of Fuel Tank with Increased Capacity and Optimizing Its Location for Better Stability of Three Wheeled Vehicles".

To this effect we would like to express our appreciation for timely initiating this problem solving study that may improve the livelihood of three-wheeled vehicle users in particular to those in rural areas. As one of the manufactures of three-wheel vehicles in the country, we attest that the investigation is in our interest and full view support.

Yours Sincerely

Nigussie Kassa

Factory Administrator

VAYO AUTOMOBILES MANUFACTURE PRIVATE LIMITED COMPANY
Bole Sub City, Woreda 02, House No. New, Addis Ababa, Ethiopia
+251 11 8688991 | info@vayo.group | www.vayo.group

We Make A Difference...