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Research article

Modelling and simulation of fuel tank with increased capacity and improving its location for better stability of three wheeled vehicle

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ABSTRACT

In the automotive industry, the fuel tank is an essential component of the vehicle. It is; designed as an integral part of the fuel system to transport the fuel and deliver it to the engine via the fuel filter and fuel pump. In Ethiopia, it is observed that due to the smaller fuel tank of three-wheeled vehicles, more frequent visits to fuel stations result in a lot of time being wasted waiting in long queues at fuel stations. In addition, the current location of the fuel tank causes some stability problems. Subsequently, the method, location, installation techniques and stability analysis of the three-wheeled vehicle are carried out. This study includes a new design of fuel tanks for three-wheeled vehicles in which the capacity is doubled and the rollover stability; of the vehicle is maintained. The SOLIDWORKS software and the CFD software ANSYS FLUENT for the sloshing analysis were used for the modeling of this work. The CFD results of the comparative sloshing analysis of partially filled (50% level) fuel tanks with and without baffles are performed; and conclusions are drawn. It is concluded that a baffle plate for the fuel tank offers the greatest advantage in reducing the effects of sloshing. The newly developed part is mounted on the underside of the passenger seat. A bottom-mounted fuel tank optimizes the vehicle's center of gravity, as the height of the vehicle's center of gravity is lowered by 30 mm. This increases the rollover safety of the vehicle. According to the analysis, the mileage of the filled existing and new tanks is 136 km and 272 km respectively. To refuel once, the driver waits an average of 5 h and works about two days for the existing tank and four days for the new tank.

1. Introduction

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 USA and Europe while increasing in India, Japan and China.

The three-wheeler and motorcycles 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

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Fig. 1. Long queue of three-wheeler vehicles near fuel station. Photographer: Yasuyoshi Chiba/AFP/Getty Images.

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 [1].

Bajaj company from India started selling three wheelers built by using the parts produced by Italian Piaggio scooters (three-wheelers known as "scooters" had previously been used in Italy as economical freight vehicles). This act fuelled the use of three-wheelers for transportation services. The three-wheeled Bajaj scooter gained appeal as a low-cost, point-to-point urban taxi since it could hold two or three passengers in its rear seat. They began to replace bicycle rickshaws, and their name was changed to "auto-rickshaws". German Tempo freight three-wheeler was also transformed by Bajaj into a bigger car with two rear seats that could hold six passengers in order to make it more appropriate for route-based transport service operations. The largest three-wheeler manufacturer in the world, Bajaj, soon surpassed rivals. A third of the three-wheelers produced in India each year by 2018 were exported, primarily to an excessive number of African countries [2].

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 [3].

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 Fig. 1.

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 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 Steven F. Aulph [4], 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.

1.1. Sloshing analysis

Liquid free surface motion caused by external excitation in a partially filled container is called sloshing. The motion type, strength and simulation frequency, 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 [5].

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 [6].

Wang et al. [7] 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.

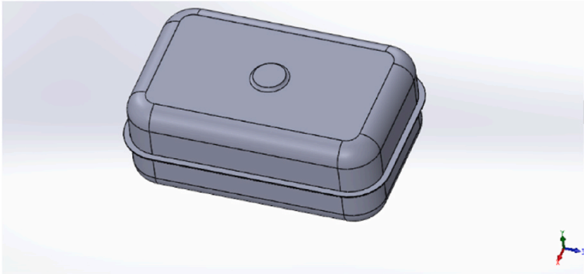


Fig. 2. New fuel tank with no baffles.

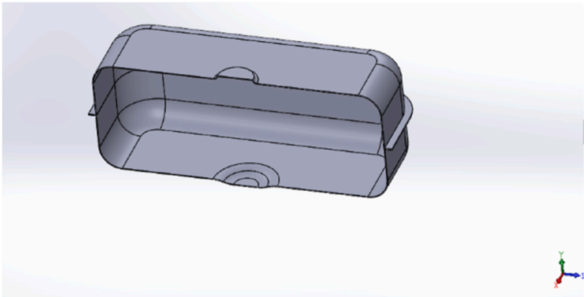


Fig. 3. Cross-sectional view of new fuel tank with no baffles.

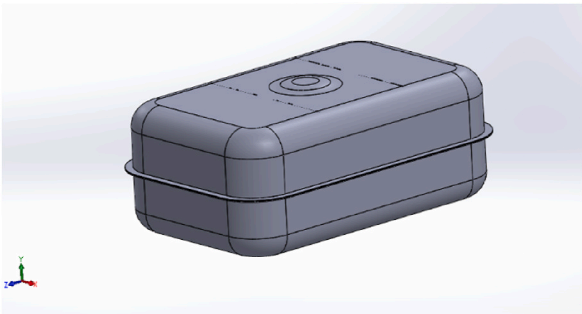


Fig. 4. New fuel tank with baffles.

The main focus of Xue et al. [8] 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.

1.2. Causes for the occurrence of sloshing in a tank

According to Reddy [9], 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.

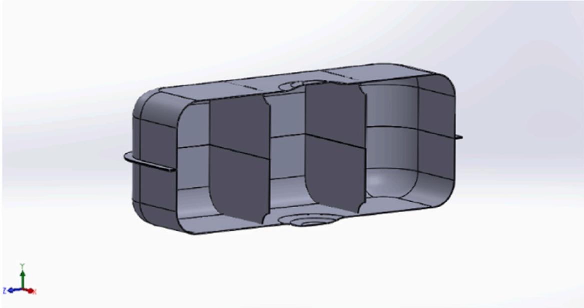


Fig. 5. Cross-sectional view of new fuel tank with baffles.

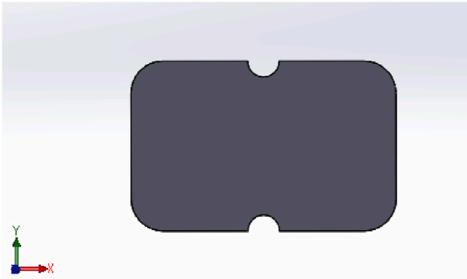


Fig. 6. Baffles of new fuel tank.

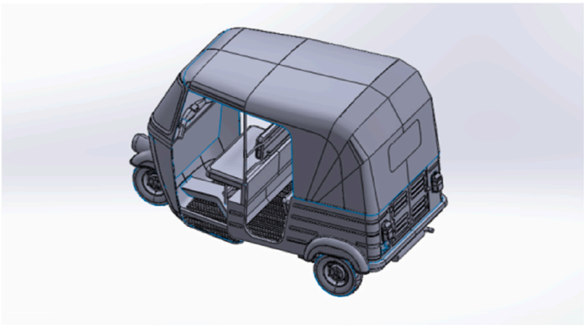


Fig. 7. 3D Model of three-wheeler vehicle.

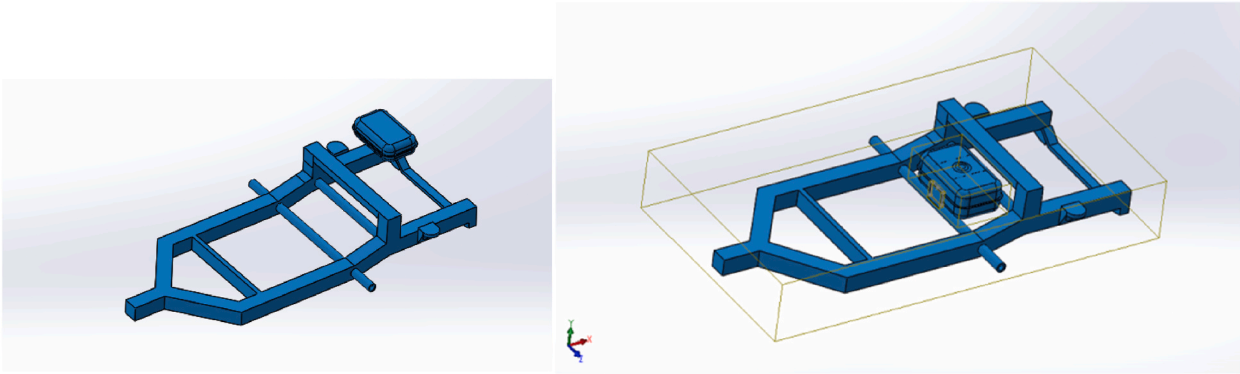
1.3. Factors which influence the intensity of sloshing

According to Reddy [9], 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. SOLIDWORKS modeling

The 3-D object is modeled in SOLIDWORKS software as shown in Figs. 2–7 below. The geometry of new fuel tank without baffles is modeled to study simulation to investigate baffle configuration. 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. The three-wheeler vehicle model is for center of mass purpose.



(a) (b)

Fig. 8a). Location of existing fuel tank
b): Location and mounting of new fuel tank with chassis.

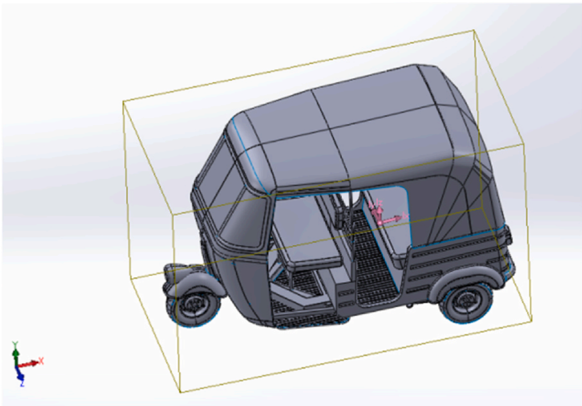


Fig. 9. The center mass of the three-wheeler vehicle with the new fuel tank.

Table 1
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

3. Location and mounting of the new fuel tank

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. Locations of the existing and new fuel tank are shown in figure 8a and figure 8b.

3.1. The effect of fuel tank on rollover stability of the vehicle

Due to dynamic reactions to acceleration and deceleration [10], due to aerodynamic reactions to drag force [11,12], Coriolis force and couple caused by gyroscopic effect are some dynamic reactions that might be integrated in the fundamental equation (1).

$$\frac{a}{g} = \frac{WT}{2h}\frac{L1A}{WB} \tag{1}$$

The center mass of the three-wheeler vehicle with the new fuel tank is shown below figure (9). The comparison of center of mass of vehicle between existing and new fuel tank is shown in Table 1.

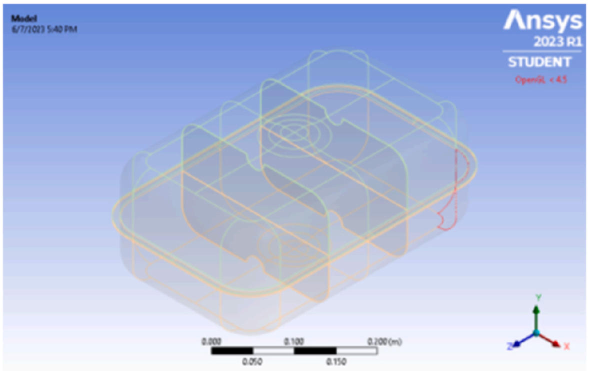


Fig. 10. New fuel tank with baffle model in ANSYS.

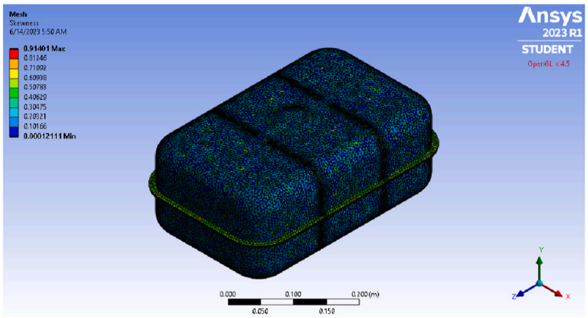


Fig. 11. Mesh of new proposed fuel tank with baffle.

Table 2
The new fuel tank nodes and element.

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

$$\text{Dynamic stability factor for vehicle with existing fuel tank is} = \frac{WT}{2h}\frac{L1A}{WB} = \frac{1300}{2(590)}\frac{1440}{2000} = 0.793$$

$$\text{Dynamic stability factor for vehicle with new fuel tank is} = \frac{WT}{2h}\frac{L1A}{WB} = \frac{1300}{2(560)}\frac{1440}{2000} = 0.836$$

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.

4. Computational fluid dynamics analysis of the fuel tank

ANSYS Fluent CFD software consists to represent fluid flow, turbulence, heat transport, turbulence, and reactions for industrial applications; the software has a wide range of physical modeling features. New fuel tank with baffle model in ANSYS is shown in Fig. 10.

4.1. Mesh generation

The geometry must discretize into control volumes after it has been created, this procedure is known as meshing. The following Fig. 11 shows the mesh generated on a fuel tank with baffles systems.

Table 3
Properties of fluid material.

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

Table 4
Boundary conditions.

Condition	Value
Wall Motion	Stationary Wall
Shear Boundary Condition	No Slip

4.2. Grid independency test

A technique for selecting the ideal grid condition is the grid independence test that uses smallest possible grids while yet producing consistent numerical results. It is the most influencing factor which determines the computational time, accuracy of the result. The nodes and elements of new fuel tank with and without baffles are shown in Table 2.

5. 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.

5.1. Volume of fluid model

To get a time-dependent solution, the Volume of Fluid (VOF) formulation in ANSYS FLUENT is typically utilized. The VOF free surface model is activated in the multiphase model panel of ANSYS FLUENT, and it is used to find liquid surface of the free oil by comparing fluid volume to the grid element grid volume. Rather than considering the movement of particles on the free oil liquid surface, the fluid motion is taken into account. Strong non-linear sloshing may be obtained using this method, and the resulting characteristic parameters offer the fundamental framework for further study [13]. Currently, the VOF method is the best way to keep track of the free surface area. The numerical results that are provided in this work are built using VOF models. In order to prevent contact between phases, there is a sharp inter-phase between each phase. This model contains two phases, according to the specification. Air and gasoline are used to denote the primary and secondary phases, respectively. Each phase material properties are determined from the database of FLUENT after the VOF is triggered, and the properties are described in Table 3.

5.2. Turbulence viscosity modeling

The mean flow characteristics are mostly found using k-epsilon (k- $\boldsymbol{\varepsilon}$) turbulence model in situations of turbulent flow in computational fluid dynamics. Turbulence kinetic energy (k) and its rate of dissipation ($\boldsymbol{\varepsilon}$) is based on model transport equations.

The turbulence viscosity is determined as follows using equation (2).

$$\mu_t = \rho c_\mu \frac{k^2}{\varepsilon} \tag{2}$$

Where ε is turbulence dissipation rate, k is turbulent kinetic energy, c_μ is constant proportionality (default value is 0.09).

5.3. Boundary condition

Baffles and the fuel tank wall are the names of the boundaries in the computational domain. When performing the analysis, the fluid domain is chosen, and the boundary type for these is believed to be a wall. Table 4 shows the boundary condition.

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/h. This constant lateral acceleration simulates the centripetal acceleration functioning as a transient state turn curvature given in equation (3).

$$a = \frac{V^2}{R} \tag{3}$$

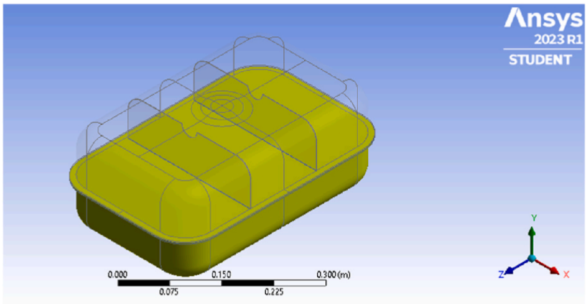


Fig. 12. Initial volume fraction of petrol patched at 50% fill level.

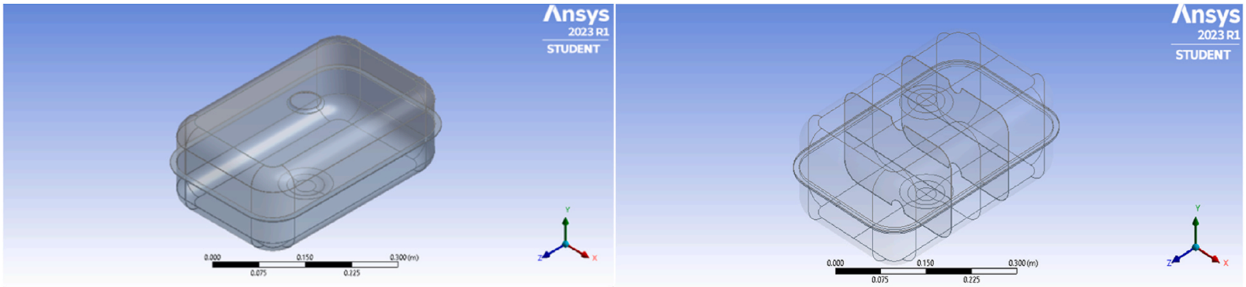


Fig. 13. The proposed fuel tank with and without baffles modeling in ANSYS.

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 operational density option of the software program is used, and the operating density is set to have a minimum density of 1.225 kg/m3, which corresponds to the lighter phase air density. By preventing the formation of hydrostatic pressure in the lighter phase, this improves the precision of momentum balancing [14]. Once the appropriate boundary conditions have been applied, the bottom fuel tank is patched as depicted in Fig. 12 with an initial volume proportion of gasoline at 50% of the fill level.

5.4. Time step method

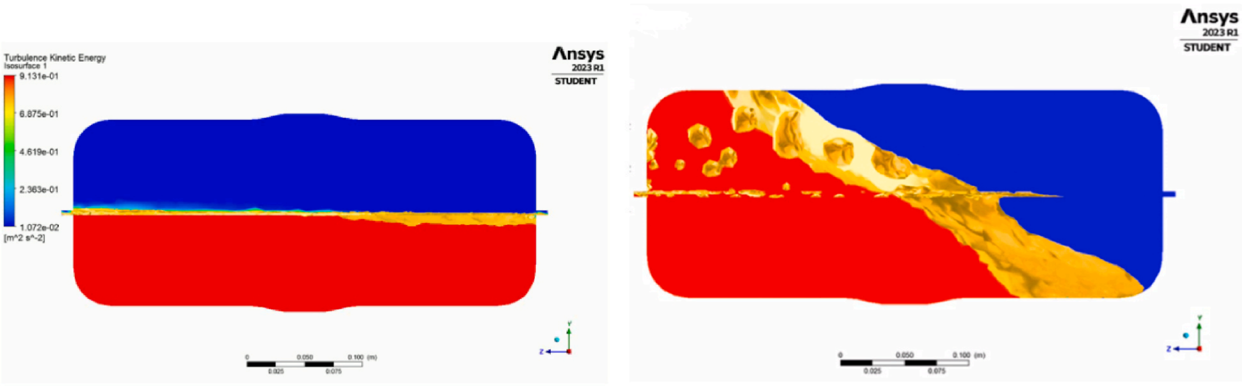
The sloshing problem is always transient by its very nature. It is also necessary to discretize the governing equation's time frame derivative. The simulation for the current example has been run at several time steps in order to find the ideal time step without using up too much memory or calculation 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. equation (4) shows the time step as follows.

$$L = \frac{1}{2}at^2 \tag{4}$$

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.

6. Results of CFD analysis and discussions

These results 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



(a) (b)

Fig. 14. 50% fill level volume fraction of petrol without baffle (a) initial stage at t = 0 s, (b) at t = 0.2 s..

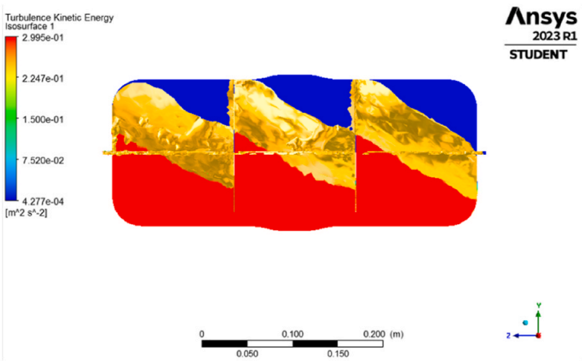


Fig. 15. Volume fraction contour plots of petrol at t = 0.2 s with baffle.

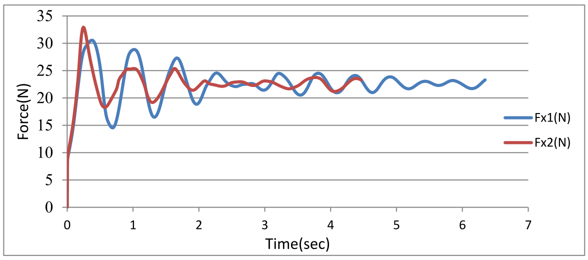


Fig. 16. Lateral force at 50% fill with and without baffle.

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 Fig. 13 below are used to illustrate the graphs between lateral, longitudinal, and vertical force vs. flow time and moments vs. time in this section.

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 ratio of fluid's volume to the overall fluid volume is known as volume fraction. 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 Fig. 14a shows 50% fill level volume fraction of petrol without baffle at initial stage and Fig. 14b shows 50% fill level volume fraction of petrol at t = 0.2 s without baffle. Fig. 15 shows volume fraction at baffle.

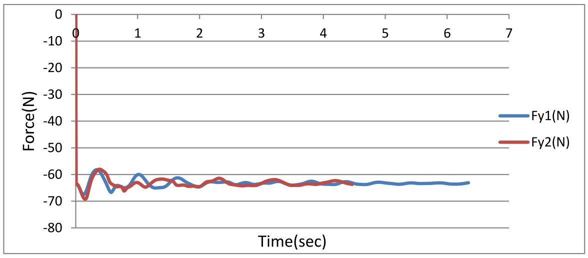


Fig. 17. Vertical force with different baffle designs (50% fill).

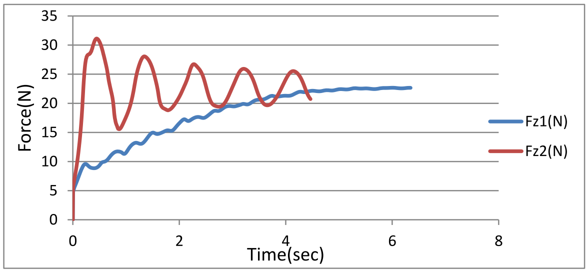


Fig. 18. Longitudinal force at 50% fill with baffle designs.

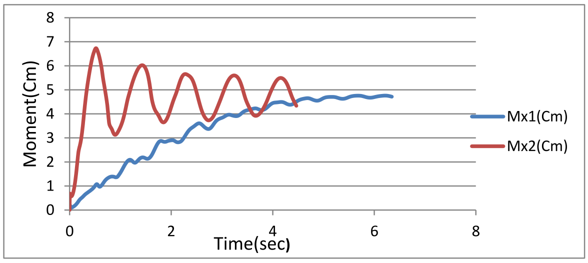


Fig. 19. Roll moment with different baffle designs (50% fill).

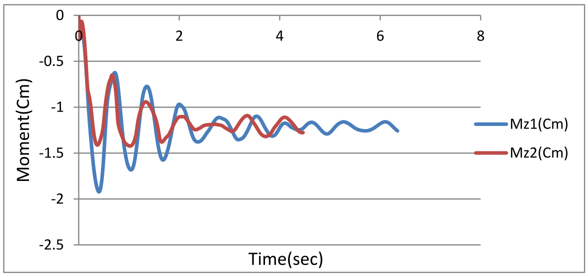


Fig. 20. Roll moment caused by different baffle (50% fill).

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

Figs 16–20 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.

Lateral forces comparison of new fuel tank with and without baffles

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

Table 5
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

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.

6.2. Vertical forces comparison of new fuel tank with and without baffles

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

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.

6.3. Longitudinal forces comparison of new fuel tank with and without baffles

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

Therefore, as shown in Fig. 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.

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

$$\%\ \text{Lateral roll moment coefficient decreases at 50\% fill level} = \frac{6.731498 - 4.759893}{4.759893} \times 100\% = 41.42\ \%$$

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 Fig. 19 graph.

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

Comparison of roll moment is shown in Fig. 20 when the vehicle is subjected to combined acceleration. It is observed that 50% fill level roll moment is increased.

$$\%\ \text{Longitudinal roll moment coefficient increments at 50\% fill level} = \frac{1.42352 - 1.92192}{1.92192} \times 100\% = 25.93\ \%$$

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;

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

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

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

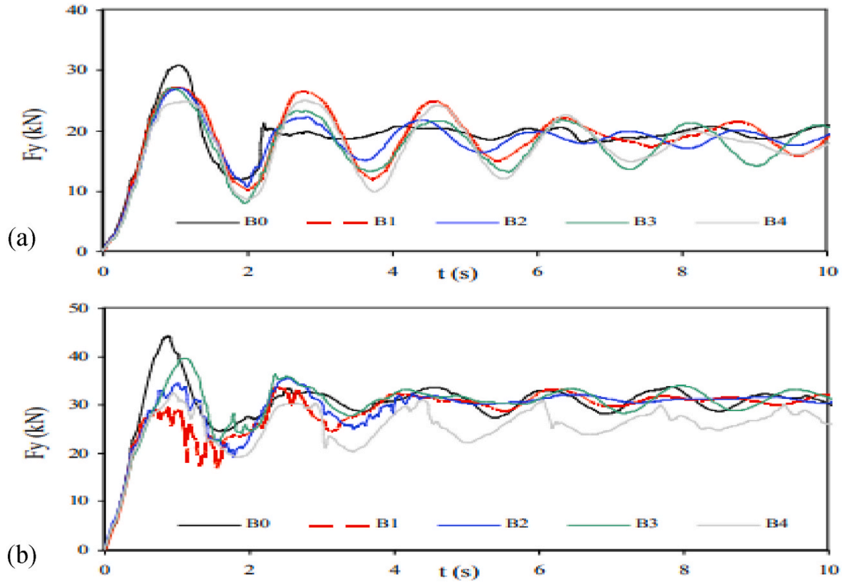


Fig. 21. Responses of various baffled tanks to lateral slosh forces at gy = 0.25 g, (a) at 50% fill level, (b) at 70 % fill level.

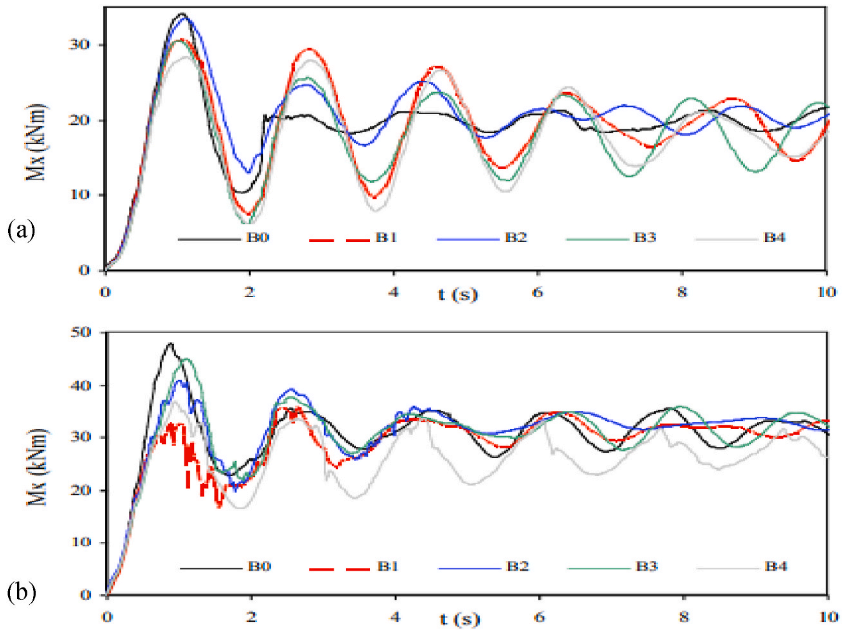


Fig. 22. Chosen baffled tanks' roll moment responses when gy = 0.25 g, (a) at 50% fill level, (b) at 70 % fill level.

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 Figs. 16, figure 17, figure 18, Figs. 19 and Fig. 20 graphs of 50 % fill level, the graph of Figs. 16, Figs. 18 and Fig. 19 gives the best results. Also the graph of Fig. 17 gives less variation. The worst results are obtained with Fig. 20. Table 5 summarizes the comparison results.

6.6. 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 CFD results 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

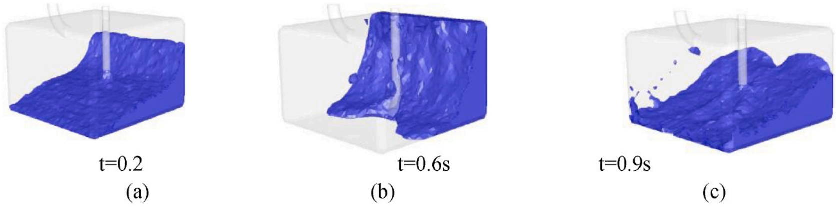


Fig. 23. At various time steps, a liquid interface for the Tank without baffle, (a) at t = 0.2 s, (b) at t = 0.6 s and (c) at t = 0.9 s..

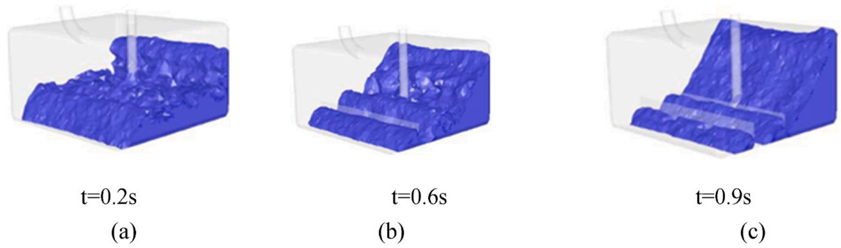


Fig. 24. Liquid interface for the Tank with baffles at various time steps, (a) at t = 0.2 s, (b) at t = 0.6 s and (c) at t = 0.9 s..

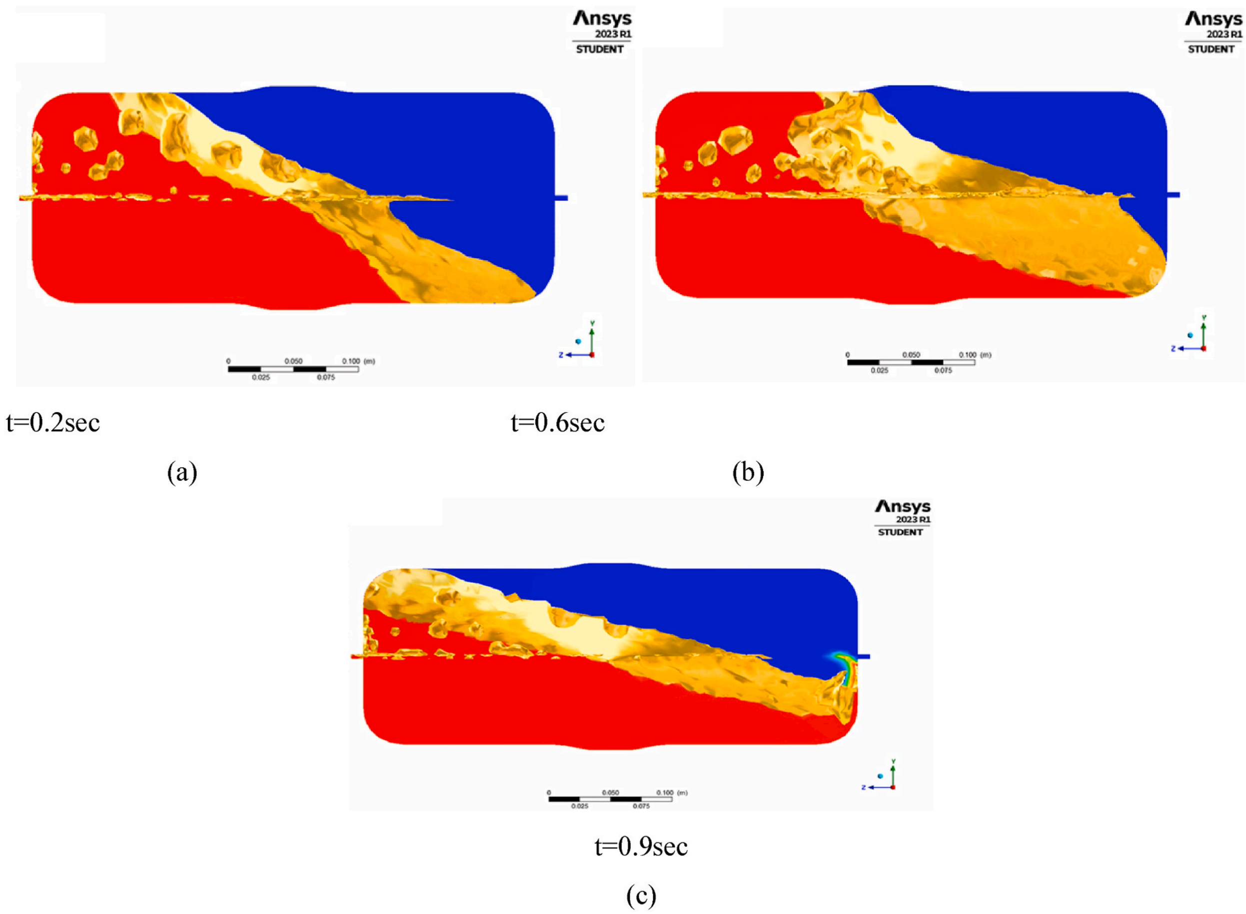
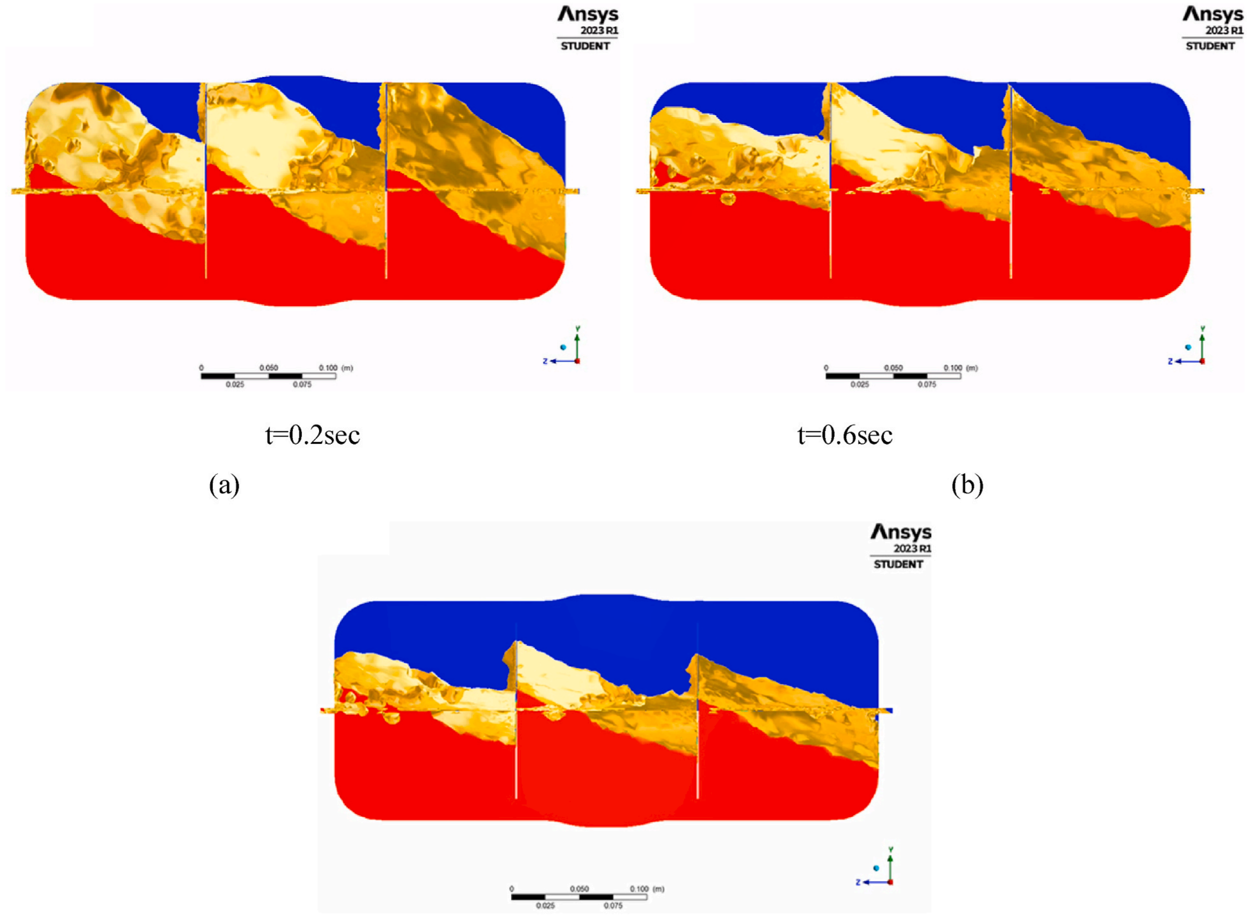


Fig. 25. Liquid surface in the new tank without baffles of 50% fill, (a) at t = 0.2 s, (b) at t = 0.6 s and (c) at t = 0.9sec.



t=0.2sec (a) t=0.6sec (b)

t=0.9sec (c)

Fig. 26. Liquid surface in the new tank with baffles of 50% fill, (a) at t = 0.2 s, (b) at t = 0.6 s and (c) at t = 0.9sec.

suitable for the fuel tank slosh study, using VOF the validation of the CFD model is accomplished in this way. Multiphase model VOF is used in baffle analysis and has demonstrated a very strong correlation with the experimental results. Based on Kandasamy [13,15] (Nema, 2014) [16,17] finding, this study is well constructed and verified [18].

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 Ref. [13]. The effect of a three-wheeler vehicle's new fuel tank sloshing has been addressed using a similar strategy, and the outcomes were very similar. The graphs of the lateral force and roll-moment in Ref. [15] was evaluate with clean-bore tank (B0) conventional baffles with a large central orifice (B1), obliquely placed conventional baffles (B2), partial baffles in an alternating pattern without an equalizer (B3) and semi-circular orifice baffles of identical opening area (B4) at different fill level with cylindrical tank geometry the graph of the lateral force and roll-moment were similar with this work. The following Fig. 21a and b and Fig. 22a and b of 50 % and 70% fill level shown are the force and moment graph was found by Kandasamy.

A validation scenario has also been considered in order to examine the mobility of the fuel's free surface in a partially full rectangular fuel tank [14]. Liquid interface for the Tank with and without baffles at various time steps are shown in Fig. 23a and b 23c and Fig. 24a,b,24c are shown below.

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 gasoline free surface motion are displayed in the next section for verification.

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

Movement of gasoline in the fuel tank without baffles at various times is depicted below in Fig. 25a, b and 25c. 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.

Fig. 26a, b and 26c, which represents the motion of gasoline inside a fuel tank with baffles at various time intervals, are 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 s, 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.

7. 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 better location. 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 main conclusions are listed below:

✓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 longitudinal sloshing forces achieves the greatest percentage reduction between the two tanks is 37.32%. And the reduction comparison of roll-moment at a proposed new fuel tank offers a significant or high reduction in roll moments of 34.04%.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Haileyesus Aderaw: Software, Methodology, Investigation, Conceptualization. **Ramesh Babu Nallamothu:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] P. Starkey, The benefits and challenges of increasing motorcycle use for rural access, in: Proceedings of International Conference on Transport and Road Research (iTRARR) Held Mombasa, 2016. March 2016. 17pp.
[2] SIAM, Automobile Domestic Sales Trends, Society of Indian Automobile Manufactures (SIAM), 2019. http://www.siamindia.com/statistics.aspx?mpgid=8&pgidtrail=14. (Accessed 1 March 2019).
[3] Mohd Arif Shaikh, Pagadala Sugandha Devi, Dr U. Devi Prasad, Dr Asefa Abahumna woldetsadik, "Demographics and passenger Satisfaction in case of three-wheeler auto Rick shaw passengers"- A case of Asella city, Ethiopia 8 (Issue 09) (Sep 2019).
[4] Steven F. Aulph, Mich Flint, Steven G. Kensinger, Minn Burnsville, Fuel Tank Assembly" United States Provisional Patent Application Ser, vol. 8, 1999. No. 60/138,252, filed Jun.
[5] M.S. Celebi, H. Akyildiz, Nonlinear modeling of liquid sloshing in a moving rectangular tank, Ocean Eng 29 (12) (2002) 1527–1553.
[6] Ganesh Sriraam Anirudh, Manav Badamwala, Sagnik Deb, Bibin John "Computational Simulation of Fuel Tank Sloshing for a FSAE Car Using CFD Techniques" Volume-8 Issue- 3, 2019.
[7] W. Wang, Y. Peng, Z. Wei, Z. Guo, Y. Jiang, High performance analysis of liquid sloshing in horizontal circular tanks with internal body by using IGA-SBFEM, Eng. Anal. Bound. Elements 101 (2019) 1–16.
[8] M.-A. Xue, Y. Chen, J. Zheng, L. Qian, X. Yuan, Fluid dynamics analysis of sloshing pressure distribution in storage vessels of different shapes, Ocean Eng 192 (2019) 106582.
[9] V.T. Reddy, CFD analysis of sloshing within a tank with porous baffles, Int. J. Sci. Res. 6 (12) (2017) 172–177.
[10] J.C. Huston, B.J. Graves, D.B. Johnson, Three wheeled vehicle dynamics, in: SAE, Technical Series Paper No, vol. 820139, 1982. . 820139.
[11] R.C. Sachdeva, O. Kamiyo, Fundamentals of Engineering Heat and Mass Transfer, New Age International Publishers., New Delhi, 2015, pp. 291–292.
[12] R. Rajamani, Vehicle Dynamics and Control, Springer Science+Business Media., NewYork, 2012, p. 89.
[13] N. Kumar, Study of Sloshing Effects in a Cylindrical Tank with and without Baffles under Linear Acceleration, department of mechanical and aerospace engineering, 2013 msc, thesis.

[14] V. Singal, J. Bajaj, N. Awalgaonkar, S. Tibdewal, CFD analysis of a kerosene fuel tank to reduce liquid sloshing, Procedia Eng. 69 (2014) 1365–1371.
[15] Thanqaraj Kandasamy, An Analysis of Baffles Designs for Limiting Fluid Slosh in Partly Filled Tank Trucks, Jan 2010.
[16] S. Abera, T. Daniel, Dynamic Simulation of Sloshing Effect on Fluid Transporting Freight-Wagon, Addis Ababa Institute of Technology Department of Mechanical and Industrial Engineering, 2015. Msc, thesis. department of mechanical and(railways engine).
[17] N. Ahmad, M. Varshney, M.H. Farooqi, Design and CFD analysis of baffles of fuel tanker trucks for normal and grade highway conditions, International Journal of Forensic Engineering and Management 1 (1) (2020) 76.
[18] Woinshet Siraye, Alemayehu Wakjira, Ramesh Babu Nallamothu, An analysis of fuel oil sloshing in partially filled cargo tanker trucks under cornering conditions using various baffle systems, J. Eng. 2023 (2023), https://doi.org/10.1155/2023/9941864. Article ID 9941864, 17 pages.