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# Vehicle Body Shape Analysis of Tricycles for Reduction in Fuel Consumption

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## Abstract

Growing concern about environmental protection and energy conservation has led a number of studies to increase fuel economy and reduction in emissions. From theoretical studies one of the major factors influencing fuel consumption is air resistance and developing ways to reduce this influencing factor could be achieved by designing vehicle body shape to have a low coefficient of air resistance. This paper focuses on the comparative analysis of fuel consumption of one of an existing tricycles and NASENI TP1 with reference to their body shapes. Solid models for these two different tricycles were done and simulated using Solidworks flowxpress. Mathematical models were applied to compare the rate of fuel consumption between the simulated models. The result of simulation shows that there is a 2% reduction in coefficient of drag ($C_d$) and 17.34% reduction in fuel consumption for NASENI TP1 as compared to the referenced tricycle.

## 1.0 Introduction

Reducing the transportation sector energy consumption is an important part of reducing overall energy consumption. It requires development of new more fuel efficient vehicle models and more efficient operating of existing vehicles. This makes the development of fuel efficient vehicles a paramount issue [1].

In 2004, on the average cars in the United States of America have 8.7L/100km as its fuel consumption rate and in 2012 cars in the European countries have 5L/100km on the average [2]. Likewise for motorcycles the fuel consumption ranges from 1.5L/100km to about 2.8L/100km. this shows a remarkable decrease when compared to that of cars because of the specifications of the engine [3]. The fuel consumption from different samples of tricycles ranges from 2.8L/100km to 4L/100km. This range in fuel consumption also depends on the specification/type of the engine and also varies between manufacturers. A larger engine type consumes more fuel [4].

In some developing countries like Nigeria, tricycles are being used in urban cities for transportation. This contributes to increase in fuel consumption in the transportation sector, thus causing an increase in gas emissions that are potentially dangerous to human health. Minimizing the use of fuel in order to reduce emissions is an important short-term and long-term goal. In order to reduce the amount of fuel consumption, more fuel efficient tricycle models should be produced as well as operating exiting ones efficiently. The most simple and conveniently implemented method used in the estimation of fuel consumption is based on utilization of mathematical models. Evaluating fuel efficiency is an important factor to consider while designing vehicles. Based on this, evaluation is usually performed via mathematical modeling and simulation, the main constructive parameters of the vehicle may be determined at the design stage and steps to reduce fuel consumption may be taken [5]. Several mathematical models for estimating fuel efficiency are described in literature. Generally, analytical mathematical models used in computation of fuel consumption in vehicles can be applied to tricycles.

This paper focuses on the comparative analysis of fuel consumption of two models of tricycles with reference to their body shapes. The referenced model (RFM1) is the common shape of tricycles in use in most urban cities in Nigeria while the second model (NASENI TP1) is the tricycle designed and constructed by National Engineering Design and Development Institute (NEDDI) Nnewi, an institute under National Agency for Science and Engineering Infrastructure (NASENI). The tricycles are modeled and simulated using Computational Fluid Dynamics (CFD) capability of Solidworks flowxpress software and the necessary data needed for analysis were generated. The use of the software and mathematical models reduces the need for costly physical testing and prototyping.

## 2.0 Review of Mathematical Models

At present the most widely used methods of fuel consumption estimation are simulations and road tests. Utilizing simulations and mathematical models are simple and more readily available [6].

Silva et al, 2009 proposed a mathematical model for evaluating fuel consumption. The proposed model evaluates fuel consumption $Q_s$ measured in liters per 100 km, on the basis of hourly fuel consumption and engine power via the following relation [7].

$Q_s = \frac{g_e \cdot (P_{rl} + P_W + P_a)}{10.V_a \cdot \eta_T \rho_f}$--------------------------------------------------------------------------------1

Where
$g_e$ is the specific fuel consumption, g ·kWh-1,

$P_{rl}$ is the power required to overcome the rolling resistance of the road, kW,

$P_w$ is the power required to overcome the resistance of the air, kW,

$P_a$ is the power required to overcome the resistance of the inertial acceleration, kW,

$\eta_T$ is the efficiency of the transmission,

$\rho_f$ is the fuel density, kg/l,

$V_a$ is the average speed of the vehicle, km/h.

The above equation assumes that the vehicle constantly operates in acceleration mode, Specific fuel consumption is assumed to be constant and at optimal and the engine power is determined according to this assumption.

Another mathematical model of interest was produced by L.Guzzeella and A. Sciarretta [8]. From their study, the fuel consumption of vehicles for the European Driving Cycle Motor Vehicle Emission Group-95 (MVEG-95) was determined on the basis of energy expenditure during the movement of the vehicle. The authors proposed relation assumes that the vehicle constantly operates in acceleration mode and the efficiency is constant and optimal. The relation is as follows:

$E_{MVEG-95} \approx (A_f C_D \times 1.9 \times 10^4) + (M_v F_r \times 8.4 \times 10^2) + (M_v \times 10) [\frac{KJ}{100km}]$------------2

Where
$M_v$ is car mass (kg),

$F_r$ is the rolling resistance coefficient,

$C_D$ is the coefficient of aerodynamic resistance of the car,

$A_f$ is the characteristic area of the car, $m^2$,

In the equation, the first term in the right-hand side is the energy required for overcoming the resistance of the air, the second term is the energy required for overcoming the resistance of the road, whereas the third term is the energy required for overcoming the inertial acceleration.

Michael Ben Chaim et al took into consideration the mode of motion and the need to use instantaneous specific fuel consumption in the analysis instead of assuming it to be constant. In the determination of the fuel consumption, they assumed that the car consumes fuel only to cover 100 km at a constant speed of the cycle and to increase the kinetic energy during accelerations. They proposed a mathematical model based on the assumptions as stated above.

$E_s = E_1 + E_2$.-----------------------------------------------------------------------------------------------------3

Where

$E_S$ is the total energy expenditure

$E_1$ is the energy required to overcome the forces of resistance at average speed on the 100 km interval,

Thus

$E_1 = \frac{1}{\eta_T \eta_{P,n}} \left[ M_a \times g \times C_r + \frac{\rho}{2} \times C_D \times A_f \times V_a^2 \right] \times S$------------------------------------------4

Where

$\eta_T$ is the efficiency of the transmission

$V_a$ is the average speed of the vehicle, m/sec

$M_a$ is car mass, kg.

$C_r$ is the rolling resistance coefficient

$C_D$ is the coefficient of aerodynamic resistance of the car,

$A_f$ is the characteristic area of the car, $m^2$.

$\eta_{P,n}$ is the efficiency of the engine, which depends on the degree of power utilization and the engine speed mode in the following way:

$$\eta_{P,n} = \eta_e \mu_p \mu_n$$

$\eta_e$ is the engines peak efficiency

$\mu_p$ is the coefficient through which the influence of the degree of power utilization on the peak efficiency of the engine is expressed

$\mu_n$ is the coefficient through which the influence of engine speed mode on the peak efficiency of the engine is expressed.

$E_2$ is the kinetic energy required for non-uniform accelerations on the 100 km interval, J thus;

$E_2 = \frac{q m_a}{\eta_T \eta_e} \sum_{i=1}^{k} \frac{a_i \times \gamma_{mi} \times S_i}{\mu_{p_i} \times \mu_{n_i}}$-------------------------------------------------------------------------------5

Where
$\gamma_{mi}$ is the mass factor of the vehicle

$a_i$ is the acceleration of the vehicle , $m/s^2$

$S_i$ is the acceleration distance of the vehicle, m

K is the number of acceleration intervals,

q is the number of accelerations in each interval

$\eta_e$ is the engines peak efficiency

$m_a$ is the mass of the vehicle

$\mu_{p_i}$ is the coefficient through which the influence of the degree of power utilization (the part-load) on the peak efficiency of the engine is expressed in each acceleration interval

$\mu_{n_i}$ is the coefficient through which the influence of engine speed mode on the peak efficiency of the engine is expressed in each acceleration interval.

Fuel consumption per 100 kilometers has the form:

$Q_{S(e)} = \frac{E_S}{H_L}$----------------------------------------------------------------------------------------------------6

Where
$H_L$ is the calorific value of one litre of fuel

The efficiencies, coefficients and other necessary parameters can be obtained from empirical equations and charts. However, so many factors affect the fuel mileage of a vehicle and this can be classified as internal factors and external factors. The internal factors depend on the engine and other mechanical components while the biggest factor of the external factor is the air resistance [9].

This is same for tricycles. In as much as some mathematical models take into account both external factors and internal factors, but for the sake of comparison the internal factors will be assumed to be the same.

Air resistance or the drag force is the external force that opposed the direction of thrust of a vehicle and it is expressed as:

$D=1/2C_d\rho AV^2$---------------------------------------------------------------------------------------------------**7**
Drag force is a function of the perpendicular area of the vehicle A, the density of the air ρ, the coefficient of drag of the tricycle $C_d$, and the tricycle speed squared $V^2$. Drag force is a major contributor at the rate in which tricycle consumes fuel at high speed and reduction of drag force reduces the amount of fuel consumed and also reduces the amount of exhaust gases emitted to the atmosphere. In order to reduce drag force acting on the tricycle, drag coefficient needs to be reduced and this is achieved by modifying the shape of the body to have a more aerodynamic shape.

Nevertheless for a tricycle in motion, traction power is needed to overcome the resistive forces opposing its movement and for this to be achieved the engine needs to burn a certain amount of fuel. Thus, the total Traction Power P, needed to drive a tricycle is given as

$P=F_T \times V$---------------------------------------------------------------------------------------------------------8
Where $F_T$ = the total traction force

V = the tricycle velocity

If the tricycle is in motion the total traction force can be calculated as follows

$F_T=F_D+F_R+F_G+F\alpha$----------------------------------------------------------------------------------------------9

$F_D$ is aerodynamic drag or drag force and is expressed as, $F_D = 0.5\rho V^2 C_d A$ as previously discussed.

$F_R$ is rolling resistance ($F_R=F_r mg$; where Fr is the coefficient of rolling resistance and mg is the weight)

$F_G$ is climbing resistance ($F_G = mg\sin\alpha$, where mg is the weight and $\alpha$ is the climbing angle);

$F\alpha$ is acceleration resistance ($F\alpha = m\frac{dv}{dt}$; where m is mass of tricycle, v is velocity and t is time)

For tricycles/vehicles travelling at 70miles/hr which is approximately 113km/hr, it has been noted that about 65% of the power generated is used in overcoming the aerodynamic drag [7]. Thus the total power can be simplified by taking aerodynamic drag force into consideration as shown;

Power= $\frac{F_D.V}{0.65} = \frac{C_d A\rho V^3}{1.3}$-------------------------------------------------------------------------------10

There is a relationship between the approximated power as stated above and fuel consumption and it is known as the Fuel economy [10]. This relation shows how many kilometers or miles the tricycle will complete with just one litre of fuel. It is measured in kilometer per litre (Km/L) or miles per gallon (MPG) and the more the value obtained the more economical the tricycle is. The relation is as stated below

Rate of fuel consumption = $\frac{1.3}{(bsfc.C_d A\rho V^2)}$ ------------------------------------------------------------11

Where bsfc is the brake specific fuel consumption and other variables remains as defined before.

A more realistic estimate of the decrease in fuel consumption due to a decrease in drag can be estimated. Study has shown that all other factors remaining constant or equal, fuel consumption is directly proportional to the drag coefficient. Therefore any decrease in drag coefficient brings about almost the same decrease in fuel consumption. Hence for a gasoline /petrol engine, the following expression holds;

$\frac{\Delta B}{B_o} = 0.40\ \frac{\Delta C_d}{C_{do}}$-------------------------------------------------------------------------------------12

Where

$\frac{\Delta B}{B_o}$ is the change in fuel consumed

$\frac{\Delta C_d}{C_{do}}$ is the change in the coefficient of drag

Performing physical experiments seems very tedious and might be impossible or impractical in some cases. This might be due to the reasons of safety or unavailability of necessary instruments or devices required. Computer Aided Simulation approach is used to solve this complex engineering problems [11-15].

### 3.0 Methodology

Computational Fluid Dynamics (CFD) simulations were carried out for the two tricycle models. Lift and drag force were generated for the two models at different speed of 40km/h, 50km/h, 60km/h, 70km/h, 80km/h and 90km/h. Parameters considered in the simulation are drag force, air density, coefficient of drag and frontal area, all are shown in table 1 and 2

Figure 4 and 5 shows the simulation and pressure result of RFM1 and NASENI TP1 respectively. The flow trajectory shows the movement of air molecules around the tricycles in the computational domain.

Fig 1: RFM1

Fig 2: NASENI TP1

Equation 10 was used to calculate the power required to overcome drag force for the two models and equation 1 was used to evaluate the fuel consumption for the two models. In this work, we have made some necessary assumptions. These assumptions includes that the efficiency of transmission will be constant and therefore can be taken to be 0.95, the engine operates constantly in an acceleration mode, the specific fuel consumption of the engine is 800g/KWh and the density of fuel is 0.77Kg/L. Since we are comparing the fuel consumption for the two models of the tricycle, the assumptions will be the same for the two cases.

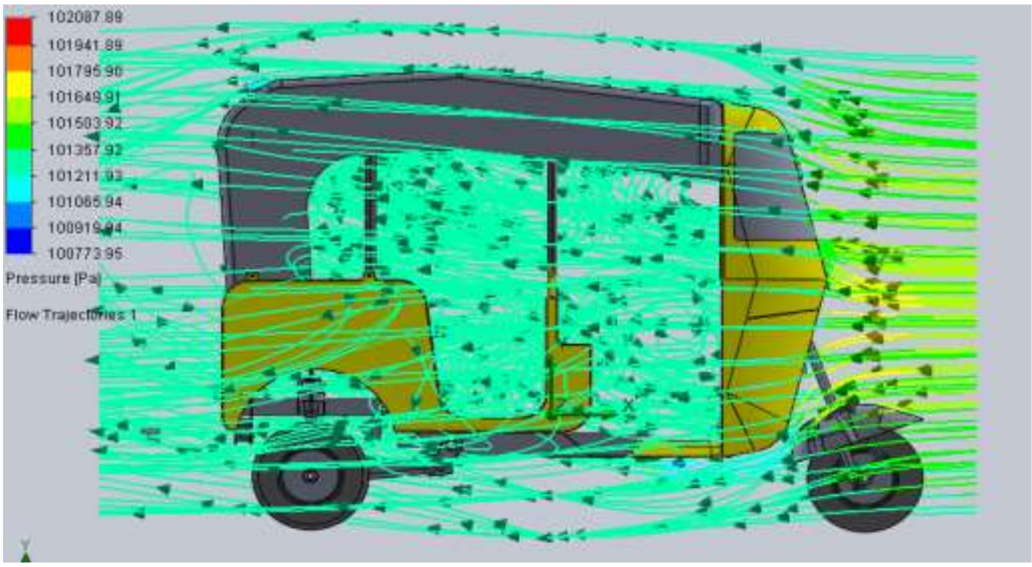

Figure 3: distribution of pressure around RFM1

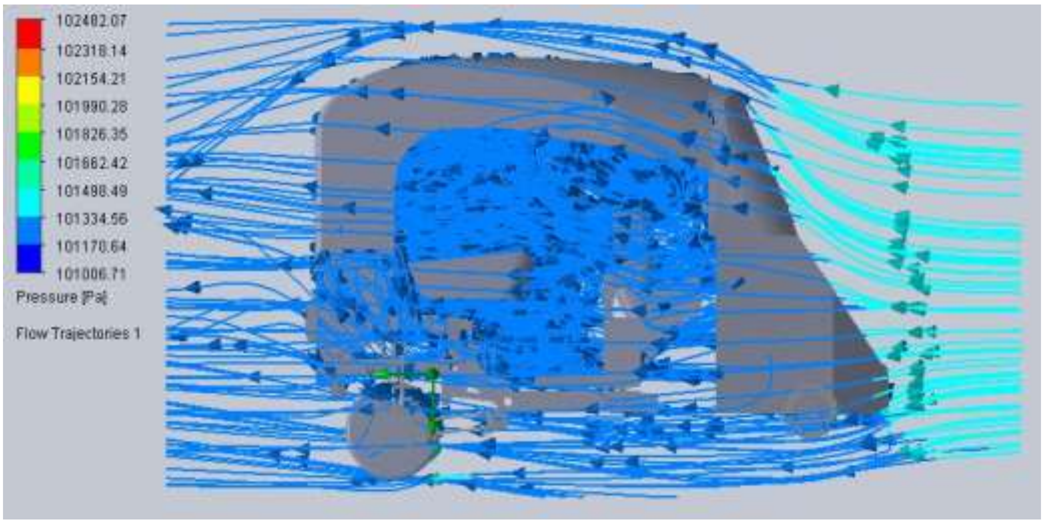

Figure 4: Distribution of pressure around NASENI TP1

## 4.0 Result and Discussion

Table 1 and Table 2 show the simulation result of RFM1 and NASENI TP1 respectively**.**

Table 1: Aerodynamics analysis result of RFM1

| Velocity | | Drag force (N) | Air density (Kg/m$^3$) | Frontal area (m$^2$) | $C_{d1}$ |
|---|---|---|---|---|---|
| km/h | m/s | | | | |
| 40 | 11.11 | 12.67913 | 1.165 | 2.901 | 0.34 |
| 50 | 13.89 | 19.81114 | 1.165 | 2.901 | 0.34 |
| 60 | 16.67 | 28.52804 | 1.165 | 2.901 | 0.34 |
| 70 | 19.44 | 38.82983 | 1.165 | 2.901 | 0.34 |
| 80 | 22.22 | 50.71651 | 1.165 | 2.901 | 0.34 |
| 90 | 25.00 | 64.18809 | 1.165 | 2.901 | 0.34 |

Table 2: Aerodynamic analysis results for NASENI TP1

| Velocity | | Drag force (N) | Air density (Kg/m$^3$) | Frontal area (m$^2$) | $C_{d2}$ |
|---|---|---|---|---|---|
| (km/h) | (m/s) | | | | |
| 40 | 11.11 | 10.4801 | 1.165 | 3.309 | 0.32 |
| 50 | 13.89 | 16.37515 | 1.165 | 3.309 | 0.32 |
| 60 | 16.67 | 23.58022 | 1.165 | 3.309 | 0.32 |
| 70 | 19.44 | 32.09529 | 1.165 | 3.309 | 0.32 |
| 80 | 22.22 | 41.92038 | 1.165 | 3.309 | 0.32 |
| 90 | 25.00 | 53.05549 | 1.165 | 3.309 | 0.32 |

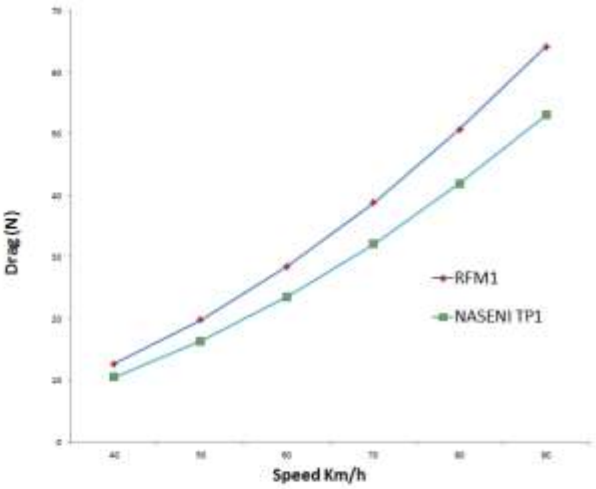

Figure 5: Drag vs. Speed

From the above tables, the coefficient of drag for RFM1 is 0.34 while that of NASENI TP1 is 0.32. The percentage difference in the coefficient of drag $C_d$ is 2%. From equation 12, the change in $C_d$ will result to a change of about 0.8% reduction in the fuel consumed by the tricycle when NASENI TP1 is used.

Table 3: Result of fuel consumption based on power

| Velocity (m/s) | Power (Kw) | | Fuel Consumption (L/100km) | |
|---|---|---|---|---|
| | RFM1 | NASENI TP1 | RFM1 | NASENI TP1 |
| 40 | 0.21671559 | 0.17912909 | 0.592523831 | 0.489758288 |
| 50 | 0.42334882 | 0.34992436 | 0.925985121 | 0.765384791 |
| 60 | 0.73163450 | 0.60474195 | 1.333578497 | 1.102286534 |
| 70 | 1.16131061 | 0.95989606 | 1.814370640 | 1.499691136 |
| 80 | 1.73372439 | 1.43303207 | 2.370094857 | 1.959032217 |
| 90 | 2.46877269 | 2.04059577 | 2.999951627 | 2.479648539 |

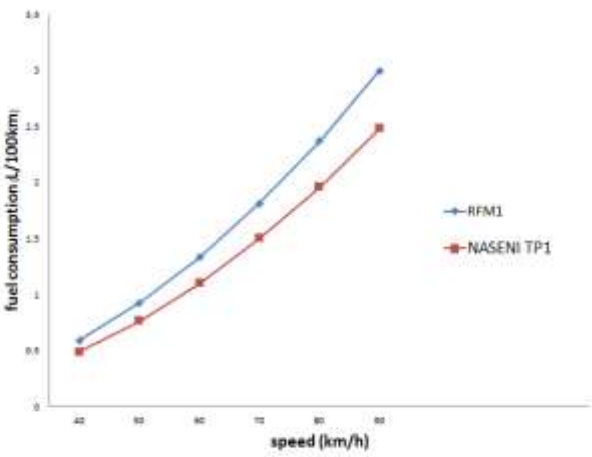

Figure 6: Fuel Consumption vs. Speed

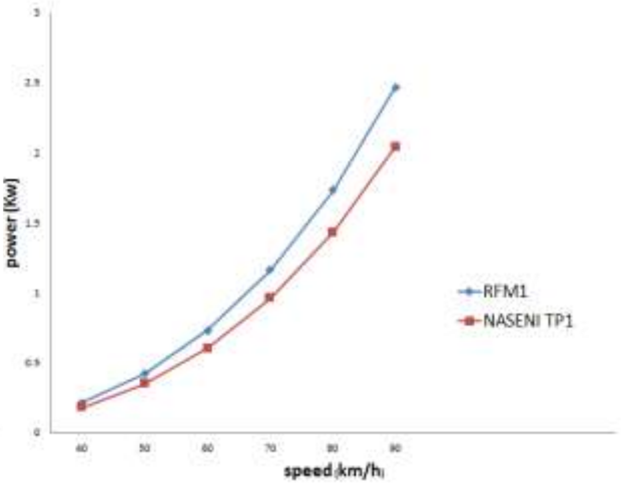

Figure 7 : Power vs. Speed

From figure 5, it can be seen that drag force increases with speed and also the drag force of RFM1 is always greater than the drag force of NASENI TP1. Secondly, at the speed of 90km/h the reduction percentage difference in drag force is approximately 17.34%. This reduction in drag force saves fuel, money and also reduces the amount of $CO_2$ emitted to the environment in the end.

Figure 6 and 7 shows the fuel consumption and power plots against speed. Analysis on the power and fuel consumption for the tricycle models show that NASENI TP1 uses less power to overcome drag force when compared to RFM1. Therefore, RFM1 will use more fuel than NASENI TP1. At the speed of 90km/h the percentage reduction in fuel consumption is approximately 17.34%.

## 5.0 Conclusion

We have studied and carried out comparative analysis of fuel consumption of two models of tricycles with reference to their body shapes. The Two tricycles were modeled, simulated for aerodynamics effect, and fuel consumption was calculated. The Simulations shows that NASENI TP1 consumes 2.48L/100km, and RFM1 consumes 3L/100km. The result of the simulation shows that NASENI TP1 is more fuel efficient when compared to RFM1. It saves fuel, money and reduces the amount of $CO_2$ emitted to the environment in the end. In addition, it would serve in the national strategic interest in reducing, the energy consumption in the transportation sector.

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