Aerodynamics Design of a Motor Tricycle

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Abstract

This work is on the aerodynamics design of the body and frame of a motor tricycle using SolidWorks 2011 modeling system. Its Computational Fluid Dynamics (CFD) feature was used to run simulation tests at a target speed of 150 km/h to evaluate the aerodynamic performance of the tricycle. Simulation results presented shows that lift and drag forces are diminished considerably and that 170 km/h is the maximum speed to be travelled by the tricycle for a smooth and stable ride. Also, the design reduced drastically the effects of lift and drag forces, increased the tricycle's stability, traction and performance as well as minimized the weight of the tricycle as a result of the use of high performance to mass ratio materials such as carbon fiber for the body and alloy steel for the frame and rims.

***Keywords**: Lift, form drag, ground clearance, skin friction, streamline, velocity, pressure, carbon fiber, coefficient of drag.*

1. Introduction

In the design of any machine, safety as well as good function-ability is considered to constitute the overall aims of the conceived idea. Over many decades the principles of aerodynamics have been applied in this direction to various transport mediums either as a working principle for airplanes, or in automobiles, as a means for reducing wind noise, enhancing the vehicle's air penetration capability, and preventing undesired lift forces as well as other causes of instability at high speeds. In the design of airplanes, the application of the principles of aerodynamics cannot be overemphasized. Ranging from its lift, thrust, drag and weight, to its maneuvering in the air, aerodynamics expounds the recondite concept. Recent technological developments in the automobile industry have incorporated aerodynamics in the manufacture of vehicles, through creating more streamlined and sleek designs so as to attain improved efficiency.

The new generations are now sorting cheaper means of transportation especially for short distances, this has led to the enormous manufacture of motor tricycles and motorcycles that operate on two-stroke engines, hence consume less fuel when compared to motor vehicles that operate on four-stroke – four or more cylinder engines. However, aerodynamic enhancements seem to be underutilized, hence this work aims to create an efficient tricycle applying the principles of aerodynamics in its frame and body design with the aid of SolidWorks (2011), a three-dimensional (3D) mechanical computer-aided design (CAD) software package.

2. Design Considerations

Internal features and side mirrors were neglected in the design because of their little significance to the aerodynamics performance of the tricycle.

2.1 Form Drag

Form drag, profile drag, or pressure drag, may arise because of the form of a motor tricycle. The general size and shape of the body is the most important factor in forming drag, bodies with a larger apparent cross-section will have a higher drag than thinner bodies. Sleek designs, or designs that are streamlined and change cross-sectional area gradually are also critical for achieving minimum form drag. Form drag follows the drag equation, meaning that it rises with the square of speed as given in the following relation (Katz 1995):

$$F_{drag} = \rho V^2 A_S C_D/2, \quad (1)$$

where:
F_{drag} = drag force, defines the force component in the direction of the flow velocity (N);
A_S = cross section area (mm^2);
V = speed of the motor tricycle relative to the wind (m/s or km/h);
C_D = coefficient of drag; and
ρ = mass density of the air stream (g/mm^3 or kg/m^3).

From Eq. (1), it could be deduced that for any increase in the speed of the motor tricycle, there would be a corresponding four times increase in the form drag.

2.2 Skin Friction

Viscous drag or Skin friction arises from the friction of the fluid against the "skin" of the tricycle that is moving through it. As with other components of parasitic drag, skin friction follows the drag equation and rises with the square of the velocity (Katz 1995).

The skin friction coefficient, C_f is hereby defined as:

$$C_f \equiv \tau_\omega / (\rho U_\infty^2/2), \quad (2)$$

where:
τ_ω = is the local wall shear stress (N/m^2 = Pascal, or N/mm^2);
ρ = is the fluid density (g/mm^3 or kg/m^3); and
U_∞ = free-stream velocity (usually taken outside of the boundary layer or at the inlet (m/s or km/h).

Skin friction is caused by viscous drag in the boundary layer around the tricycle. The boundary layer at the front of it is usually laminar and relatively thin, but becomes turbulent and thicker towards the rear. The position of the transition point depends on the shape of the tricycle. There are two ways to decrease friction drag: the first is to streamline the body so that laminar flow is possible, like an airfoil. The second method is to decrease the length and cross-section of the tricycle as much as is practicable. To do so, a fineness ratio which is the length of the motor tricycle divided by its width at the widest point (L/D) is considered (Katz 1995).

2.3 Lift

Lift is a component of force that is perpendicular to the direction of flow of the air stream. In automobile design lift is an undesirable phenomenon as it reduces traction, resulting to an unbalanced design, as sliding of the tires may occur. To address lift, the base of the *trike* is designed to tilt upwards slightly at a very small angle from front to rear, preventing the oncoming air stream from lifting it. The lift offered by the oncoming air stream to the motor tricycle is defined by (Katz 1995):

$$L = \rho V^2 A C_L/2, \quad (3)$$

where:
L = lift force (Newton);
ρ = air density (g/mm^3 or kg/m^3);
V = speed of the motor tricycle relative to the wind (m/s or km/h);
A = platform area (mm^2); and
C_L = the lift coefficient at the desired angle of attack.

Streamlining

Streamlining is a way of shaping the body of an object to provide less resistance to air. This concept involves the rounding and steepening of vertical surfaces to direct the flow of air over the body of an object as well as reduce the area of direct contact between the surface of the object and the boundary layer of the air, hence reducing drag. The tricycle has been streamlined and will be discussed in details in subsequent sections of this report (Zdravkovich 2003).

3. Design Analysis

3.1 Body Shape

The shape of this design may be described generally as a streamlined half-body. Its top streamlined and base made flat, designed to minimize the wetted surface area at the top, thus reducing the extent to which boundary layer is formed on the top surface and preventing lift at the bottom of the *trike*.

The body is also designed to incorporate fins at both sides of the tricycle just before the entrance openings so as to create a jump of the air stream over the openings. The design chosen for the tricycle body is shown in Figs. 1-4.

3.2 Frontal Area

The frontal area is designed as a bonnet to begin the shape as small as posible and made to widen gradually towards the main body of the vehicle. The front windshield and fins were designed to steep as much as necessary to form a gradual increase in the area such as is suitable for aerodynamics purpose, and the bonnet was made to incorporate as many irregular surfaces as possible to scatter the air stream preventing it from staying on one surface for long so as to reduce skin friction. From Fig. 3, it would be seen that the bonnet is made to curve upwards slightly. This is to create a jump of the wind after rubbing a small surface area of the bonnet to interfere with the oncomming direct stream, reducing its impact on the front windshield, hence reducing the form drag on the windshield.

3.3 Ground Clearance

Ride height (Ground clearance) is a critical factor in several important characteristics of a vehicle, and variations in clearance represent a trade-off between handling and practicality. A higher ground clearance means that the center of mass of the *trike* is higher, therefore handling is low and the tendency for somersaulting is high. However, a high ground clearance also means that the vehicle is more capable of being driven on roads that are not level, without scraping against the road and likely damaging the chassis and underbody (George 1981). Higher ride heights will typically adversely affect aerodynamic properties of the *trike*, hence, a moderate ride height will be considered to both allow for handling and also capability to be used on rough roads given the condition of the Nigerian roads. The wheel diameters are set at 32 cm (front) and 34 cm (rear) to allow for a reasonable ground clearance of atleast 25 cm. This is made so to improve traction, minimize lift force considerably, enable cooling of the engine by the controlled amount of air flowing through the underneath, as well as increase its capability to be driven on rough roads. The placement of a step board and a slightly smaller front wheel (relative to the rear wheel) also allows the tricycle to tilt slightly upwards towards the rear so as to improve traction and reduce lift as shown in Fig. 4.

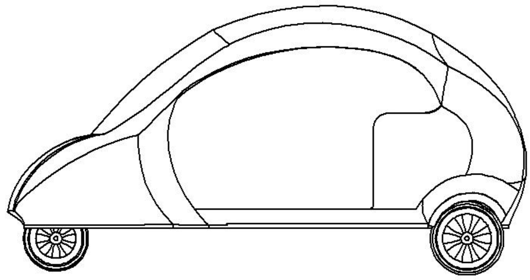

Fig. 1. Side view of tricycle showing the streamlined shape.

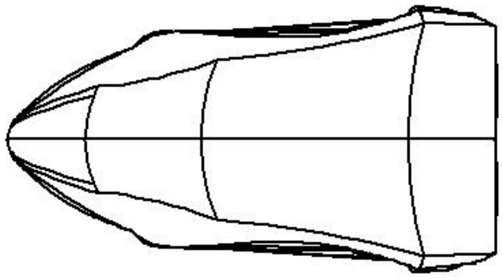

Fig. 2. Plan of tricycle.

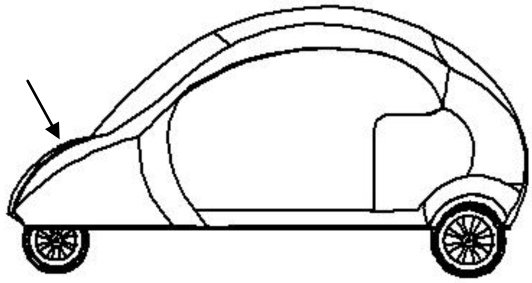

Fig. 3. Frontal surface air jump.

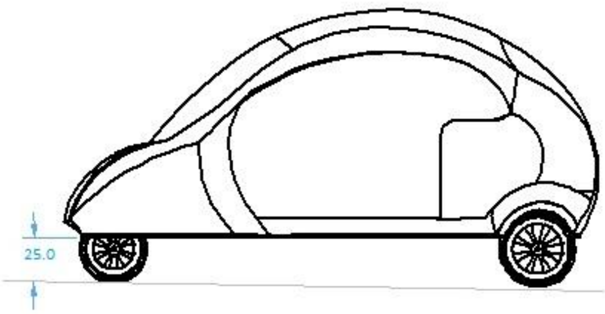

Fig. 4. Ride height (ground clearance).

3.4 Rear Vent

Due to the side openings, wind let into the vehicle becomes trapped constituting internal pressure drag. In order to solve this problem, a vent is created in place of the rear wind shield. It comprises a handle to allow for adjustment i.e. opening and closing, and has been made as wide as 80 × 40 cm, adequate for the out flow of air from the inner compartment. Thus enhancing the comfort of the passengers and driver, and as well reduce internal pressure drag when on motion.

3.5 Internal Compartment

One of the main aims achieved in this design is the creation of a wider inner compartment to accommodate more passengers. The rear width is set to 150 cm to allow four passengers (17-25 cm per passenger) sit in a row at the rear seat. Unlike the old conventional designs with width ranging from 117-128 cm, giving room for three passengers at the rear seat, this new design puts economy into consideration by increasing the income earned by the driver in one trip by 33% and maintaining a good aerodynamics as well, which in turn helps in fuel economy by reducing the minimum power to be generated by the engine for movement of the automobile.

3.6 Efficiency of Design

The efficiency of the tricycle is the percentage ratio of the net power utilized directly for propelling the tricycle to the gross power generated by the two-stroke engine of the tricycle. It is defined by (Hucho 1998):

$$E = (Propelling\,Power/Generated\,Power)\times 100. \quad (4)$$

4. Material Selection

In selecting the materials used in this design, factors such as rigidity, stiffness, shear strength, flexibility, high temperature tolerance, low thermal expansion, toughness, tensile strength and low weight were set as goals while considering cost economy. The following materials were selected.

4.1 Frame (SAE 1020)

The frame is the main structure of the chassis of the tricycle, all other components are fastened to it, a term for this in design is body-on-frame construction. In designing the frame of the motor tricycle, the preferred material used was mild steel (0.18-0.23% carbon) alloyed with nickel for strength and toughness, chromium for hardness and rigidity alongside other alloying elements for improved mechanical properties. The composition of alloying materials in the steel is set as required to improve the steel's ability to withstand shock in case of an accident, prevent squeezing of the vehicle so as to protect the passengers and driver, and also, tough enough to carry the load exerted by the tricycle body and passengers. For details on the composition of alloy steel used (SAE 1020), see Table 1.

Table 1. Composition and mechanical properties of SAE 1020 (AMS5032G 2005).

SAE 1020		
Chemical composition: C=0.20%, Ni=0.3% max, Cr=0.3% max, Mn=0.45%, P=0.04% max, S=0.05% max		
Property	Value in metric unit	
Density	7.872×10^3	kg/m³
Modulus of elasticity	200	GPa
Thermal expansion (20 ºC)	11.9×10^{-6}	ºC⁻¹
Specific heat capacity	486	J/(kg*K)
Thermal conductivity	51.9	W/(m*K)
Electric resistivity	1.59×10^{-7}	Ohm*m
Tensile strength (hot rolled)	380	MPa
Yield strength (hot rolled)	165	MPa
Elongation (hot rolled)	25	%
Hardness (hot rolled)	66	RB

4.2 Body (Carbon Fiber)

According to a general description about the use of carbon fiber in cars (MarketResearch.com 2010): "Carbon fiber, alternatively graphite fiber, carbon graphite or CF, is a material consisting of extremely thin fibers about 0.005-0.010 mm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber very strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric."

The properties of carbon fibers such as high flexibility, high tensile strength, low weight, high temperature tolerance and low thermal expansion make them very suitable for automobile body, hence, for most parts of the motor tricycle body carbon fiber sheets was selected. However, they are relatively expensive when compared to similar fibers for example glass fibers or plastic fibers.

4.3 Wheels (Bainitic J1392 or Dual-phase Steel)

Material selected for the rim is either Bainitic steel or dual-phase steel developed in 1994. These alloy steels have been developed over the years to posses the suitable mechanical properties for vehicle rim application. With chromium for hardness and strength, nickel for toughness and more strength alongside other alloying elements, the application of these materials as the rim of the tricycle will improve its ability to carry the entire weight of the tricycle and passengers.

4.4 Front Windshield (Laminated Glass)

The windshield or windscreen of the motor tricycle is the front window. Modern technology suggests that the windshield is made of laminated safety glass, a type of treated glass, which consists of two (typically) curved sheets of glass with a plastic layer laminated between them for safety, and glued into the window frame.

5. Results and Discussion

5.1 Testing

Testing the tricycle was done using SolidWorks analysis/simulation. SolidWorks analysis/simulation creates a virtual domain to analyze a model according to set goals. For this tricycle, component of drag force, lift force and resultant velocity were computed at a set air stream speed of 150 km/h, the centre of gravity, mass and mass properties of the tricycle were also computed, and a graph indicating the magnitude of drag force contributed by individual surfaces of the motor tricycle was generated as well

5.2 Goals

Table 2 shows the lift and drag forces acting on the tricycle in motion and Table 3 shows the maximum and minimum values of parameters at 150 km/h obtained from the computational fluid dynamics analysis as generated by SolidWorks simulation.

Table 2. Analysis result of lift and drag at air stream speed of 150 km/hr.

Force direction	Name	Unit	Value	Progress
X	Drag force	N	-686.462	100
Y	Lift force	N	90.112	100

Table 3. Maximum and minimum values of parameters at air stream speed of 150 km/hr.

Name	Minimum	Maximum
Pressure [Pa]	96,534.90	111,154.11
Temperature [K]	292.87	294.07
Velocity [km/h]	0	170.002
Z - Component of Velocity [km/h]	-95.637	112.366
Y - Component of Velocity [km/h]	-93.001	93.588
X - Component of Velocity [km/h]	-169.231	83.355
Density [kg/m^3]	1.14	1.32

6. Discussion

The results obtained from the analysis show good aerodynamic properties and comply with the current trend of automobile requirements which is achieving good rigidity and minimizing the weight of the automobile. These results are shown in Tables 4-5 and Figs. 5-9.

Table 4. Mass properties of the tricycle.

Mass (grams)	Volume (cm^3)	Surface Area (mm^2)
238,305.42	155.444×10^6	25.028×10^6

Table 5. Principal axes of inertia and principal moments of inertia at center of mass (g mm^2).

I_x = (-0.02, -0.04, 1.00)	$P_x = 63.865 \times 10^9$
I_y = (0.97, 0.22, 0.03)	$P_y = 167.628 \times 10^9$
I_z = (-0.22, 0.97, 0.03)	$P_z = 170.671 \times 10^9$

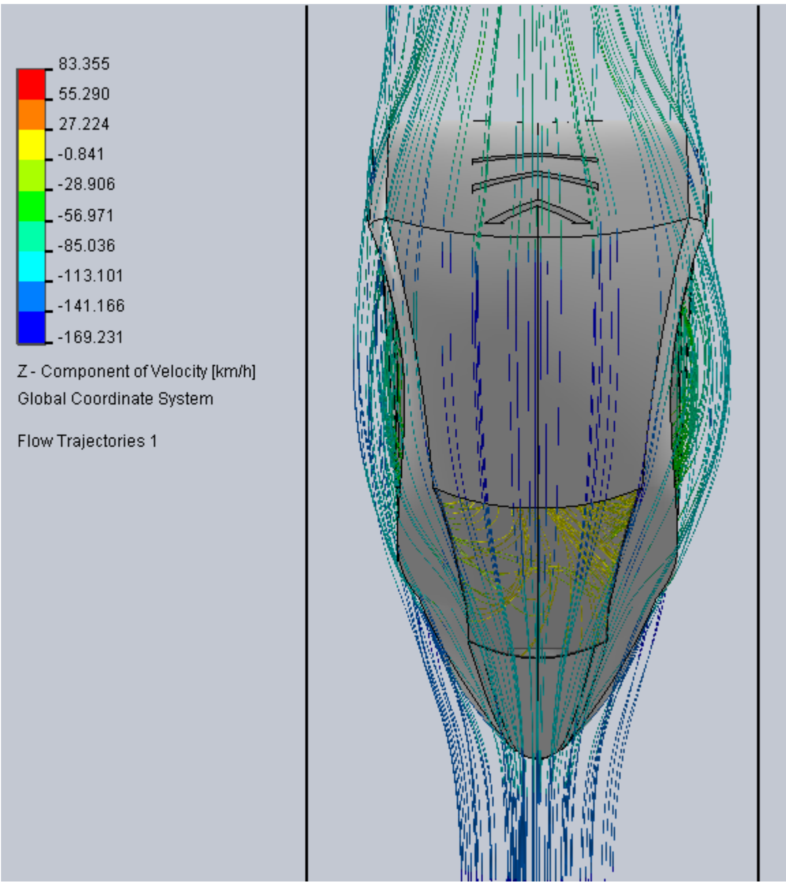

Fig. 5. Component of velocity.

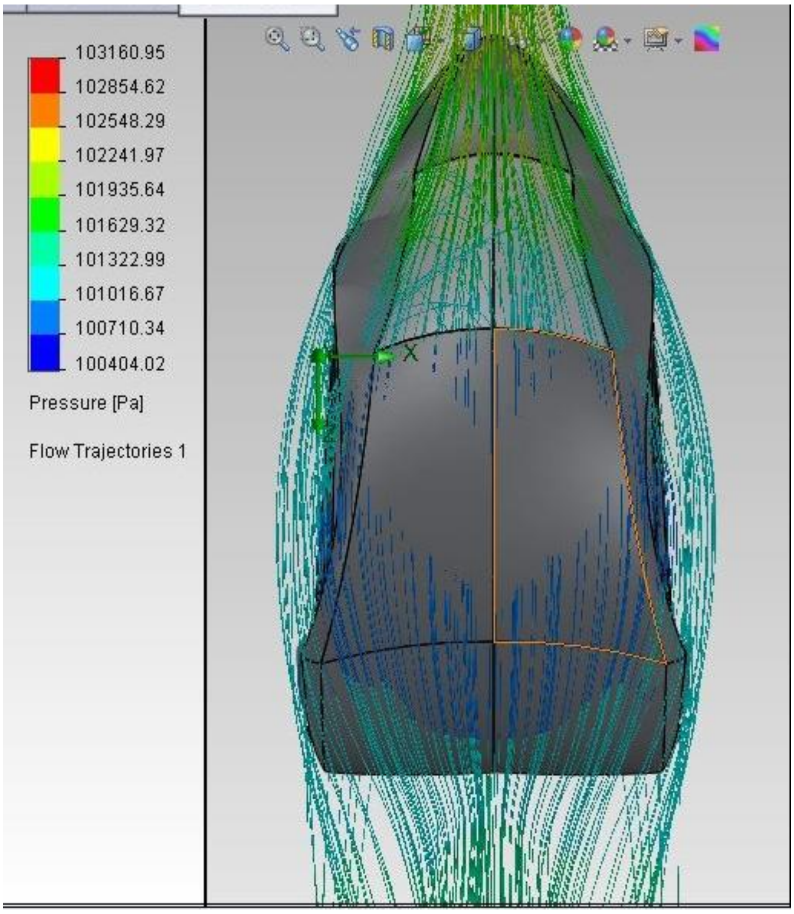

Fig. 6. Component of pressure.

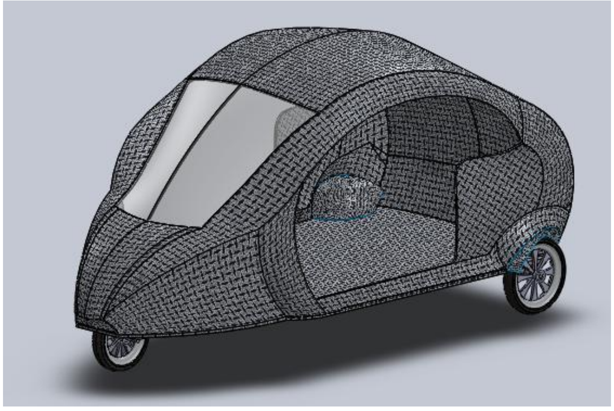

Fig. 7. Isometric view of assembly.

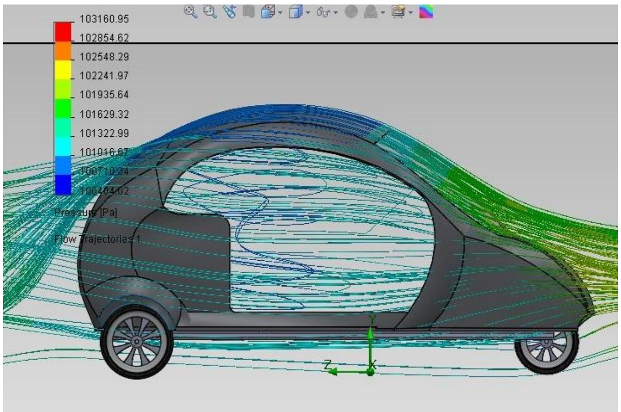

Fig. 8. Side view of pressure analysis.

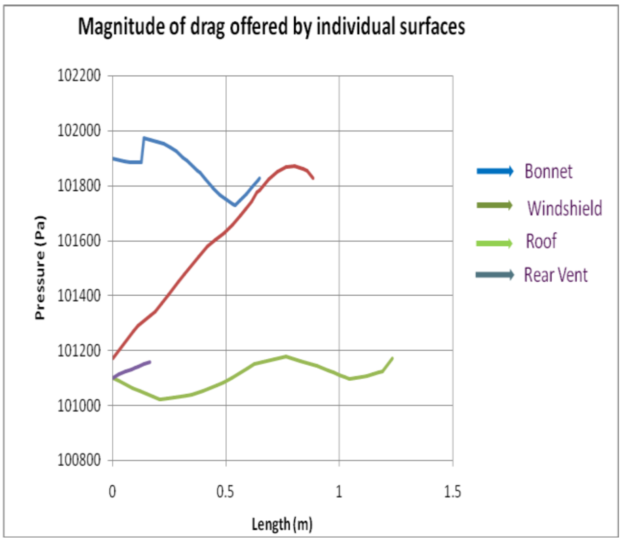

Fig. 9. Graph of pressure against length.

6.1 Goals

In this design, the main goals are to minimize drag and lift forces. From the results obtained (Table 2), the magnitude of drag was calculated to be -686.462 N. The drag value (686.462 N) indicates that the air stream exerts a force of this magnitude to obstruct the movement of the tricycle, and the negative sign (-) shows that this force (686.462 N) is acting in a direction opposite to that travelled by the tricycle. This resistance is small when compared to the force at which the tricycle is moving at a speed of 150 km/h, hence, the design is effective in drag reduction.

On the other hand, at 150 km/h, the air stream will offer a lift force of 90.112 N which is relatively insignificant when considering the mass of the tricycle (approximately 238 kg not including the mass of internal fittings, driver and passengers), thus it can be said as well that the design is effective in counteracting lift forces.

6.2 Performance Parameters

From Table 3, the maximum velocity that can be attained by the tricycle while maintaining stability and smoothness of the ride is computed as 170 km/h.

6.3 Pressure Drag on Individual Surfaces

Studying the chart in Fig. 9, long surfaces such as the wind shield and roof of the tricycle are subjected to a pressure drag of magnitude ranging between 101,100 Pa and 101,200 Pa from the resisting wind, this is low compared to the pressure exerted on the bonnet by the obstructing air stream which is about 101,900 Pa and is attributed to the streamlining of the tricycle, indicating that air is prevented from staying on one surface for long, hence, skin friction is minimized as well.

6.4 Physical Properties of the Tricycle

The values obtained for mass, volume, and surface area (Table 3) and mass properties at center of mass such as principal axes of inertia and principal moments of inertia (Table 4) suggest that the design achieves balance and stability while minimizing weight, thus it can be said that it complies with modern automobile manufacturing technology trends as well as economy in material selection and cost of manufacture.

7. Conclusion

The main parts of the tricycle such as body, frame and wheels were designed and tested using SolidWorks, parametric design software with good accuracy for modeling and simulating mechanical parts and bodies.

The design is mainly concerned with the features necessary to improve the aerodynamics of the motor tricycle.

Other parts, such as side mirrors, seats, steering and other internal fittings are neglected in the design because of their little significance to the aerodynamics of the tricycle, which is the major aim of this design work.

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