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Research Paper

Optimized Cost Effective Load-Bearing Tricycle: Design and Fabrication

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Abstract
The need for quick and efficient cost-effective transportation of goods like farm products safely to their desired locations formed the basis for this research. Solidworks simulation and finite element analysis software tools which enabled the ideal virtual testing environment for the design evaluation, and also aided in making of right choices for enhanced quality improvement were employed in the early stage of the tricycle design. After considering material selection, available technology, stability and effect of loads, as well as aerodynamics and ergonomics, the unitary or frameless chassis construction which is strengthened by cross members that are welded together was adopted for the chassis fabrication. Factor of Safety (FoS) which describes the load carrying capacity of the tricycle beyond the expected or actual loads, as well as the ratio of the ultimate strength of a member to the actual working stress or maximum permissible strength when in use was selected as 2.6 and 7 for minimum and maximum respectively. Cold rolled steel with yield strength of 350MPa was used for the chassis frame, while the point of maximum stress is 132.391MPa thereby leading to a factor of safety of 2.6 which is within a safe range. A twin spark 4 stroke engine that leads to better pickup, drive ability, and load bearing capacity was mounted at the rear wheel drive layout with the rear wheels linked to the engine with the support of shafts. The shafts connected to the engine crankshaft generate motion to the back wheels which in turn provides motion to the front wheel. When climbing a steep slope, a fragmentary weight transfer to the rear wheels takes place thereby boosting tyre-to-road grip. The SAE standard for seat design was adopted for the tricycle which greatly enhanced the ergonomics suitability of the driver's seat. Also, the weight of loads to be conveyed at a time by the tricycle was optimized from 500kilograms to 1000kilograms.
Keywords: *tricycle, auto rickshaw, design, fabrication, transportation, factor of safety, vehicle, engine*

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I. Introduction

The need for mobility in various parts of the world grows at a very rapid rate. It is an important and urgent aspect of life as information, foodstuffs, materials, etc. are moved across to people through this need. Fadare, and Salami (2004), noted that the growing transport demand is borne out of the necessity for people to meet social and economic needs. Due to increase in industrialization, urbanization, and population, public transport demand is becoming unavoidably high.

Transportation is defined as the public conveyance of passengers or goods especially as a commercial enterprise. In other words, transportation can be said to be the movement of people and goods from one location to another. Transportation serves as a link between manufacturers, farmers or producers and consumers. It is of utmost importance to them.

A vehicle is a non-living device that is used to move people and goods from one place to another. Unlike the infrastructure, the vehicle moves along with the cargo and riders. Except when being pulled or pushed by a cable or muscle-power, vehicles often provide their own propulsion; this is most commonly done through a steam engine, combustion engine, electric motor, a jet engine or a rocket, although other means of propulsion also exist. Vehicles also need a system of converting the energy into movement; this is most commonly done through wheels, propellers and pressure.

Transportation is pertinent as it promotes trade between people, and this is important for civilization. According to Ipingbemi and Adebayo (2016), Informal Public Transport (IPT) is a widespread means of moving people particularly in developing countries; globally, one of the most visible modes of IPT is the tricycle or three wheeler vehicles. A tricycle is a vehicle with three wheels. Adam (2011), and Michelle and Mitter (2010), also defined a tricycle as a human-powered (or gravity-powered) three-wheeled vehicle. The origin of this three-wheeled vehicle used in transportation, was based more on standard carriages, only that the scale was being reduced and then enhanced with additional mechanisms that allowed it to have easier propulsion.

In Nigeria, tricycles are becoming common as a means of transportation especially for low-income earners in the urban area and those living in rural areas. They are also rapidly replacing motorcycles in some certain parts of Nigeria such as in Enugu State, due to its better safety level as compared to the motorcycles. The three-wheeler is known by different names in different countries e.g. in India it is called auto-rickshaws, keke NAPEP in Nigeria, trishaws in Sri Lanka, etc.

Motorized tricycles are three-wheeled vehicles which are powered by scooter engines, electric motors, motorcycles or car engines. It is founded on the same technology as bicycles and/or motorcycles. The tricycle can be arranged in either the delta configuration or the tadpole.

The motorized tricycles are a common means of public transportation in many countries. They also serve as a form of transportation for private purposes, refuse disposal, transportation of goods, etc. With the growing population in Nigeria, the need for effective transportation is becoming extremely high, as many have sought different ways to move themselves and their goods from one location to another in an easy, cheap, and swift manner, and still be ensured of their safety. In terms of quick movement, affordability and moving through bad roads, motorcycles tend to be the choice of passengers. However, due to the increase in crime rate as a result of fast escape of criminals with the use of these motorcycles, different states in the country were forced to ban them. Mgbemena (2013) opined that this led to the proliferation of tricycles in Nigeria as a means of commercial transportation in several cities in Nigeria, especially in most of the cities in the South Eastern states such as Aba and Umuahia in Abia State, Owerri in Imo State, Uyo in Akwa Ibom State, Port Harcourt in Rivers State, among others.

A critical step in this research is the identification of its objectives which is aimed at designing and fabricating an optimized cost effective cargo-bearing tricycle with high percentage locally sourced materials.

1. Design and Analysis

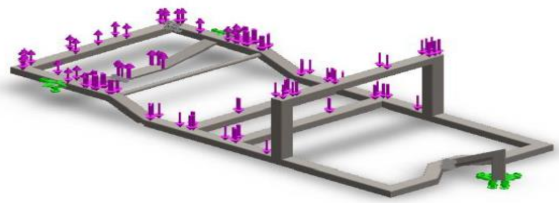
The frameless or unitary construction chassis was adopted for the design of the cargo-bearing tricycle. According to Shukla et al. (2001), frameless or unitary construction is a type of chassis construction in which the heavy side members are eliminated, the floor is strengthened by cross-members and the body is welded together.

More so, the availability and affordability of materials, and the technological-know-how also affected the choices that were made in the design. The stability of the tricycle, effect of loads, aerodynamics, as well as ergonomics were put into consideration in the design. To this end, computed aided design software – Solidworks were employed to aid in the design. Various analysis tests were done by employing solidworks simulation and finite element analysis software tools. The analysis tests carried out includes stress analysis test, displacement analysis test, deformation analysis test, factor of safety, etc.

Solidworks simulation provides the ideal virtual testing environment to evaluate one's designs and also enables one to make the right decisions for overall quality improvement. Okpala et al. (2017), explained that solidworks simulation is a computer aided design software that helps engineers to determine the stresses, among other quantities, acting on a body based on the applied load. This offers a better alternative than the traditional method of calculation which is done manually, as time is being saved, errors in calculations due to human imperfections are also being reduced, and the work or calculation was made less tedious.

Finite Element Software (FES) divides the entire element into smaller parts called elements and analyses each of the elements individually for whatever intent. The model information of the chassis is depicted in table 1.

Model Information



Model name: chasis
Current Configuration: Default<As Machined>

Solid Bodies

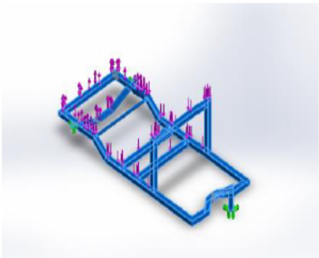
Document Name and Reference	Treated As	Volumetric Properties	Force
	Solid and homogeneous Body	Mass:78.1525 kg Volume:0.00993043 m^3 Density:7870 kg/m^3 Weight:765.895 N	The forces were assumed to be Static and uniformly distributed

Figure 1: The model information of the chassis

In the selection of materials, various materials were being compared and the conclusion being made due to strength, cost-effectiveness, ductility and rigidity. Hence, the selection of AISI 1020 Steel and Cold rolled steel which were locally sourced. The components as shown in Table 1 are of rectangular and square pipe profile.

Table 1: The Material Properties and Components of the Chassis

Material Properties

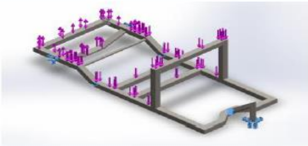
Model Reference	Properties	Components
	Name: AISI 1020 Steel, Cold Rolled Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 350 N/mm^2 Tensile strength: 420 N/mm^2	Rectangular and square pipe profile

Loads

Loads are forces or weights that are being applied to a structure or component. It causes stresses, displacements and deformations in structures. Assessment of their effects is carried out by the methods of stress or structural analysis. Excess load or overloading can lead to failure of the mechanical component. Loads are basically of two types: dynamic and static loads. Loads such as cyclic loads may cause fatigue.

Figure 2 gives the details of the various loads that will act on the chassis and the fixtures involved. It entails both the image, the type of load, phase angle and magnitude of the load.

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Front wheel joint		Entities: 5 face(s) Type: Fixed Geometry

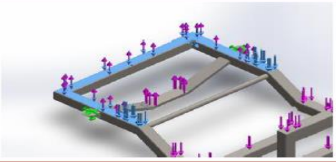
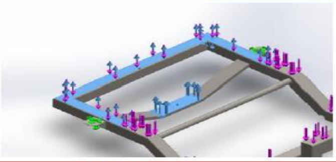
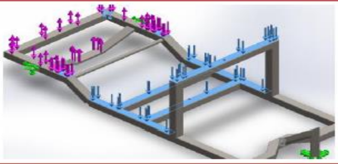
Load name	Load Image	Load Details
major load		Entities: 5 face(s) Type: Apply normal force Value: 4500 N Phase Angle: 0 Units: deg
minor laod		Entities: 2 face(s) Type: Apply normal force Value: -1000 N Phase Angle: 0 Units: deg
Force-3		Entities: 4 face(s) Type: Apply normal force Value: 500 N Phase Angle: 0 Units: deg

Figure 2: Loads and fixtures that is expected to act on the chassis frame

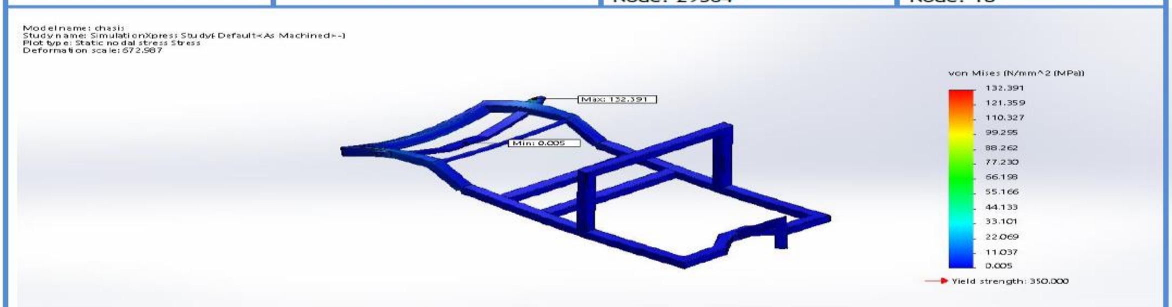
Factor of Safety (FOS)
Factor of safety is a term that describes the load carrying capacity of a system beyond the expected or actual loads. It shows how much stronger a system is than it usually needs to be for an intended load. It is the ratio of the ultimate strength of a member to the actual working stress or maximum permissible strength when in use.

It is of necessity that the value of the FOS should be of a reasonable high value. To this regard, a minimum FOS value of 2.6 and maximum FOS of 7 was adopted for the work.

Solidworks Simulations
The use of the Solidworks simulation tool led to fast and efficient design which will ultimately validate the quality, performance, and safety of the tricycle. It was employed for various analysis such as the stress analysis, displacement, etc.

Figures 3 to 5 depict the various analysis that were carried out in the process of the design.

Name	Type	Min	Max
Stress	VON: von Mises Stress	0.00456058 N/mm^2 (MPa) Node: 29564	132.391 N/mm^2 (MPa) Node: 18



chasis-SimulationXpress Study-Stress-Stress

Figure 3: Chassis frame maximum and minimum stresses

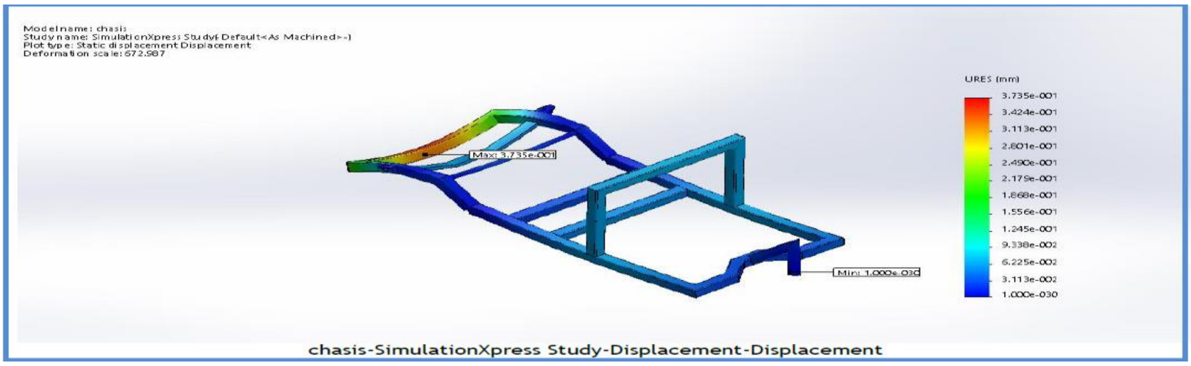


Figure 4: Chassis frame static displacement

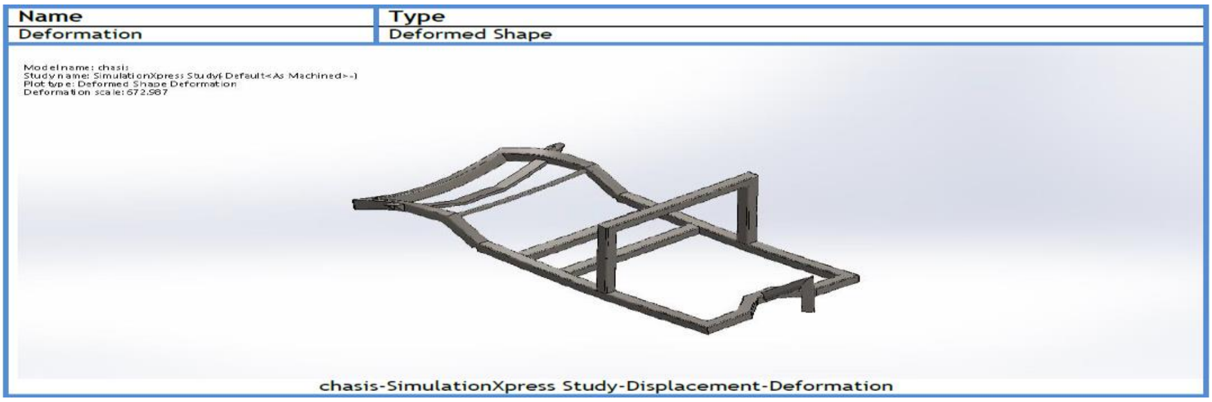


Figure 5: Chassis frame static deformation

From the result obtained from Figure 4, the chassis would undergo a maximum deflection of 3.735mm. Figure 3 shows the stresses acting on the chassis. The stresses here range from 0.005MPa to 132.391MPa. The material used for the chassis frame (cold rolled steel) has yield strength of 350MPa. The point of maximum stress as shown in the figure is 132.391MPa leading to a factor of safety of 2.6 which is within a safe range.

Shell/Body

This part provides the visual character of the vehicle with its shape, colour, and decals. Included in this group are parts that are attached to the shell such as the head lights, signal lights, interior lights, seat and upholstery, rain cover, side and rear mirrors, handle bars, roof, the dash board with the speedometer, odometer, and other indicators.

Mechanical Drive

This is the group of components that provide locomotion to the tricycle. It is composed of the motor i.e. the engine with gear box, controller (with regenerative breaking option), throttle, shafts, key switch, forward/reverse switch, signal wand, wind shield wiper, etc.

Power Steering

Tilakiswaran (2007), observed that the main components of an integral power steering system consist of a hydraulic pump assembly connected with hoses. A rotary valve power steering gear for the integral system using recirculating ball type worm and wheel steering gear as shown in figure 6 was selected for the work.

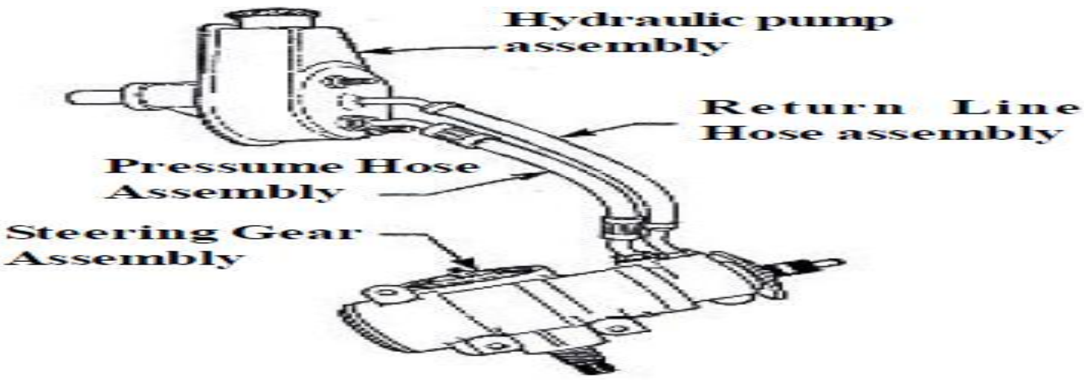


Figure 6: Power Steering Gear

Steering geometry refers to the positioning of the front wheels and steering mechanism that gives the vehicle directional stability, promotes ease of steering, and reduces tyre wear to a minimum. It also refers to the angular relationship between the front wheels and parts attached to the front wheel, frame of the vehicle. It depends upon the following terms: the caster angle, camber angle, king-pin inclination, and toe-in toe-Out on turn.

The steering radius is an important aspect when it comes to low speed performance, especially when turning around the vehicle or during parking. The radius is determined by the wheel base and the wheels turning angle. For the tricycle, the wheel base is the distance between the front wheel and the centre of the rear wheels. The steering radius can be derived by drawing a perpendicular line from the rear wheels and the front wheel. Where the lines meet is the middle point of the turning circle i.e. the distance will be the steering radius.

Mathematically, it can be calculated with the following equation:

$$r = \frac{w}{\delta \cos(\emptyset)}$$

Where r = approximate radius
w = wheelbase
δ = steer angle
$\emptyset$ = caster angle of the steering axis

The Braking System
In Automobile brakes play important role in slowing down and stopping of a vehicle by the driver. Fundamentally the brakes are of two types; Internal expanding and External contracting types. According to application, brakes are of different types - mechanical, hydraulic air, vacuum, as well as air assisted hydraulic.

Suspension System
Jazar (2008), defined suspension as the system of tyres, tyre air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. It is pertinent that the suspension keeps the road wheel in contact with the road surface as much as possible; this is because all ground forces acting on the tricycle do so through the contact patches of the tyres. The job of a tricycle suspension is to maximize the friction between the tyres and the road surface, to provide steering stability with good handling and to ensure the comfort of the passengers.

According to Smith (2002), the following are the objectives of a suspension system: to provide good ride and handling performance, to ensure that steering control is maintained during maneuvering, to ensure that the vehicle responds favourably to control forces produced by the tires during longitudinal braking, accelerating forces, lateral cornering forces and braking and accelerating torques, and to provide isolation from high frequency vibration from tire.

Force Analysis: Spring and Wheel Rates
According to Smith (2002), the relationship between spring deflections and wheel displacements in suspensions is non-linear. The desired wheel-rate (related to suspension natural frequency) has to be interpreted into a spring-rate.
W and S are the wheel and spring forces respectively
v and u are the corresponding deflections

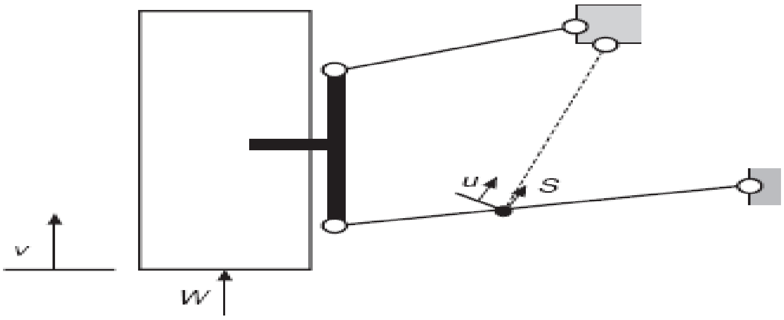


Figure 7: Notation for analyzing spring and wheel rates in a double wishbone suspension

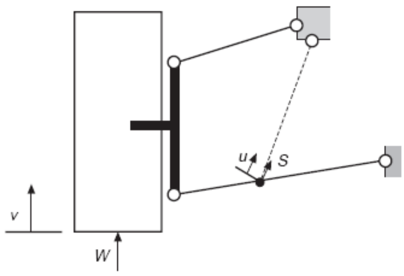
Suspension ratio can be defined as: $R = \frac{S}{W}$

Spring stiffness, K_s: $k_s = \frac{dS}{du} = d(RW) = R\frac{dW}{dv}\frac{dv}{du} + W\frac{dR}{dv}\frac{dv}{du}$

From principle of virtual work: $S\,du = W\,dv$

$$R = \frac{S}{W} = \frac{dv}{du}$$

Wheel rate: $k_w = \frac{dW}{dv}$



Combined equation: $k_s = k_w R^2 + S\frac{dR}{dv}$

The Transmission System

The mechanism that transmits the power developed by the engine of an automobile to the driving wheels is called the Transmission System (or Power Train). It is composed of:

- Clutch
- The gear box
- Propeller shaft
- Universal joints
- Rear axle
- Wheel
- Tyres

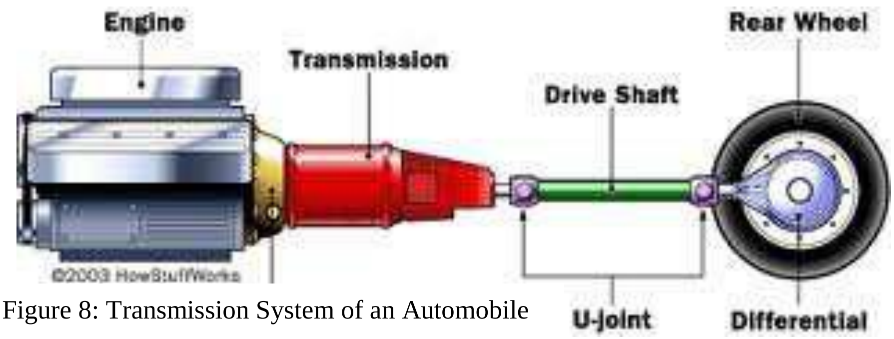


Figure 8: Transmission System of an Automobile

Manual Transmission System

In this transmission system, the driver has to manually select and engage the gear ratios. This type of transmission system which is distinct from automatic transformation system was adopted for the work.

The Clutch
A clutch is a mechanism which enables the rotary motion of one shaft to be transmitted at will to second shaft, whose axis is coincident with that of first. Clutch is located between engine and gear box. When the clutch is engaged, the power flows from the engine to the rear wheels through the transmission system and the vehicle moves. When the clutch is disengaged, the power is not transmitted to the rear wheels and the vehicle stops, while the engine is still running.

As shown in figure 9, the clutch used in the work is a wet multi disc type where it is used to connect the engine and the gear box. Here, the clutch helps to crank and start the engine, disengage the transmission, and also change the gear to alter the torque on the wheels.

Figure 9: The selected clutch

The Engine
An engine is a machine or a mechanical device which converts energy into useful motion or physical effects. It can also be described as a part of a vehicle which provides the force for motion. The power requirement of every vehicle is always provided by the engine. In the design of the tricycle, the engine used is a twin spark 4 stroke engine which leads to better pickup, enhanced driving and load bearing capacity.

A four-stroke cycle engine is an internal combustion engine that utilizes four distinct piston strokes (intake, compression, power, and exhaust) to complete one operating cycle. The piston makes two complete passes in the cylinder to complete one operating cycle. Aisyah et al. (2016), defined the twin spark ignition engine as an engine that has two spark plugs located in the very end of the combustion chamber which produces fast and efficient combustion. The advantages of efficient combustion process are better fuel efficiency and low emission. Ignition of twin spark plugs is an alternative solution to slow combustion process on single spark plug usage.

Engine Capacity Design
Engine displacement is the swept volume of all the pistons inside the cylinders of a reciprocating engine in a single movement from Top Dead Centre (TDC), to Bottom Dead Centre (BDC). It is commonly specified in cubic centimetres (cc or cm^3), or litres (l).
Engine displacement can be calculated with the following equation:

$$V_{sv} = n\frac{\pi}{4}{d_{bo}}^2 L_{st} \text{ (cc or cm}^3\text{)}$$

Where;

V_{sv} = engine displacement or swept volume
d_{bo} = engine bore = 5 cm
L_{st} = engine stroke = 10.129 cm
n = number of cylinders = 1

$$V_{sv} = 198.88 \text{ cc}$$

If the exhaust port closes some distance called the trapped stroke, before the top dead centre, the trapped swept volume of any cylinder is given by

$$V_{ts} = n\frac{\pi}{4}{d_{bo}}^2 L_{ts} \text{ (cc or cm}^3\text{)}$$

Where;
V_{ts} = trapped swept volume of any cylinder

L_{ts} = trapped stroke before top dead center

Required Acceleration of the Tricycle
To obtain the acceleration of the tricycle, consideration is taken from a condition of rest (0 km/h), to the time (say 20 seconds) when the vehicle attains a velocity of 30km/h (for most tricycles).
Acceleration, a_m:

$a_m = \frac{v_2 - v_1}{t}$

$a_m = \frac{30-0}{20} \times \frac{1000}{3600}$ = 0.417 m/s^2

Thrust Force (Tractive Effort) Required for Motion, F_T
The thrust force represents the force needed for the tricycle to be in motion. It is the sum of the force due to acceleration and the force due to road resistance. The road resistance to vehicle movement is given in tractive resistance (KN). The tractive effort (KN) provides the propelling thrust at the tire to road boundary needed to overcome the tractive resistance.
Thrust force, F_T, is given by the relation:

$F_T = f_{aero} + f_{roll} + f_{grad} + f_{acc}$

$F_T = C_d A V^2 + C_{rr} mg + \%slope.mg + ma$

$F_T = \frac{\rho}{2} C_d A V^2 + mg\left(C_{rr} + \%slope + \frac{a}{g}\right)$

Where ρ = air density = 1.2kg/m^3
A = frontal area, m^2= 1.75 m^2
C_d = aerodynamic drag coefficient (0.44)
V = air velocity, m/s = 6.5 m/s
C_{rr} = rolling resistance co-efficient (approximately 0.015)
% slope is rise/run (tan θ, $\theta = 15^0$)
a_m; required acceleration of tricycle = 0.417m/s^2
m; mass of tricycle = 771.5 Kg

$$F_T = 2482.71N$$

Torque required to accelerate the Tricycle, T
The torque required to accelerate the tricycle is derived from multiplying the tractive effort by the radius of the tire used.

$T = F \times R_{tyre}$

Force required at the two back tires to move the car is

$$F = 2482.71N$$

Force required at each tire is

$$\frac{F}{2} = \frac{2482.71}{2} = 1241.36N$$

The tire is a radial tire with size chosen as 4.00-8 6 PR with the following specifications:

- Wideness – 4 inches (101.6 mm)
- Sidewall Height – 4 inches (101.6 mm)
- Rim Diameter – 8 inches (203.2 mm)
- Wheel Base – 2000 mm

The choice for the tire selection size was due to market availability and width consideration to give the tricycle more dynamic balance.
Total height of each tire, H_T is

$H_T = (203.2 + (101.6 \times 2)) = 406.4$ mm

Radius of each tire is 406.4/2 = R = 203.2 mm = 0.2032m
Torque required at each wheel, T

$$T = \frac{F}{2} \times R = 1241.36 \times 0.2032 = 252.24Nm$$

Torque required at both back wheels, T_b

$T_b = 2T = 2 \times 252.24$

$$T_b = 504.49Nm$$

For this project, it has been determined that the combined torque available at the rear wheels is 504.49Nm. This implies that any engine that must be selected for this tricycle must possess a maximum torque of more than 504.49Nm.

There is another factor important in engine section apart from the approach seen above; that is the brake torque, T_b (this is the torque at the tires due to the transmission system). This is given by the relation below:
$T_b = T_c \times D_G \times D_C \times D_D$
Where,
T_T = torque from the engine available to the tires
T_C = torque on the crank shaft
D_G = primary drive ratio of the gearbox
D_S = drive ratio of the shaft
D_D = drive ratio of differential.

The Engine Specification:

- Model: Bajaj RE 4S
- Type: Single cylinder, Twin spark 4-stroke engine
- Weight: 31.5 kg
- Displacement: 198.88 cc

- Max. power: 7.00 HP, 5.15 KW at 5000 rpm
- Transmission: 4 forward and 1 reverse
- Cooling Medium: Air
- Fuel: Petrol
- Fuel consumption: 18 to 20 km/litre

Note: 'cc' is cubic centimetres which is a measure of volume. It is a parameter for describing the total volume of the engines' cylinders which is filled with a mixture of air and fuel. It is often referred to as the displacement volume that suggests the power produced by an engine.
To determine if the selected engine is suitable for the design, it is calculated thus:
T_b = 504.49Nm
T_C = ?
D_G = 4.5
D_S = 3.75
D_D = 5
$T_C = \frac{T_b}{D_G \times D_{S\times} \times D_D}$

$$T_C = \frac{504.49}{4.5 \times 3.75 \times 5}$$
$$T_C = 5.98\text{Nm}$$

The calculated T_C values of 5.98Nm justifies the choice of the engine, as the engine's rated maximum torque of 18Nm is greater than the calculated value of 5.98Nm.

Ergonomics

According to Kroemer et al. (2001), ergonomics also called human factor engineering is the study of human characteristics for the appropriate design of the living and work environment. Its fundamental aim is that all human-made tools, devices, equipment, machines, and environment should advance, directly and indirectly, the safety, well-being, and performance of human beings. This includes anthropometry, an applied discipline which is one of the cores of ergonomics. Godoy (2015) explained that anthropometry commands ergonomic analysis which intends to design things to "fit" the human body, and therefore achieve its ultimate goal of generating "optimal" conditions which are so well adapted to human characteristics, capabilities, and desires, to ensure that physical, mental, and social well-being are achieved.

Human Factors Engineering or Ergonomics is applied in various industrial areas which includes transportation. Anthropometric measurements obtained as depicted in figure 10 are the popliteal height, buttock-to-popliteal length, sitting shoulder height, shoulder breadth, and sitting height.
Novabos (2010), indicated that these measurements are used as basis in the ergonomic intervention on the existing tricycle side car seat design.

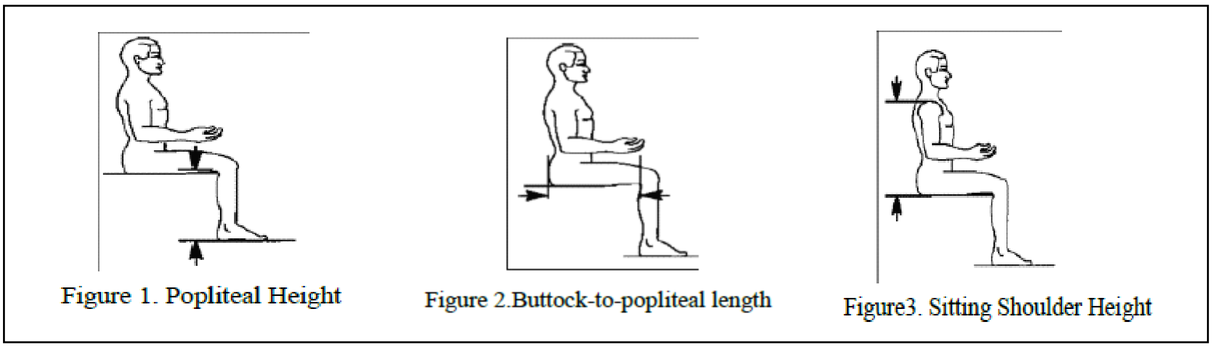


Figure 10: Various Anthropometric Measurements for Seats of a Tricycle. Source: Godoy (2015)

The existing measurements of the design of tricycle's rider's seat were done with respect to the backrest width, backrest angle, seat pan depth, seat height, sidecars' vertical clearance (sitting height), and horizontal clearance from the seat edge to the sidecar front edge. The mean *m* and the standard deviation were computed to come up with a design that will fit the commuters. A normally distributed set of *n* data is described by two simple statistics: The 50th percentile is, by definition, the same as the mean m.

$$m = \frac{\Sigma \mathrm{x}}{\mathrm{n!}}$$

Where: Σx is the sum of the individual measurements.
The standard deviation *SD* describes the distribution of the data:

$$\mathrm{SD} = \sqrt{\frac{\Sigma(x-\overline{x})^2}{(n-1)}}$$

To calculate a percentile value *p* of a normal distribution, the standard deviation is multiplied by a factor *k* selected from the Probability Distribution and Percentile Table from Mean and Standard Deviation. Then the product is subtracted from the mean if *p* is below the average value:

p = m – kSD

If *p* is above the average, add the product to the mean:

p = m + kSD

2. Fabrication

The motorized tricycle is made of various parts which can be classified into three groups: the chassis, shell (body frame) and mechanical drive system.

The chassis forms the base frame and the platform where all the other components are mounted. It consists of an internal vehicle frame that supports an artificial object in its construction and use, and can also provide protection for some internal parts. An example of a chassis is the under part of a motor vehicle, consisting of the frame on which the body of the vehicle is mounted. This chassis includes the suspension part such as the wheels, axles, shock absorbers, leaf springs and braking system and can be standardized for mass production. The designed chassis frame of the tricycle is depicted in figure 11.

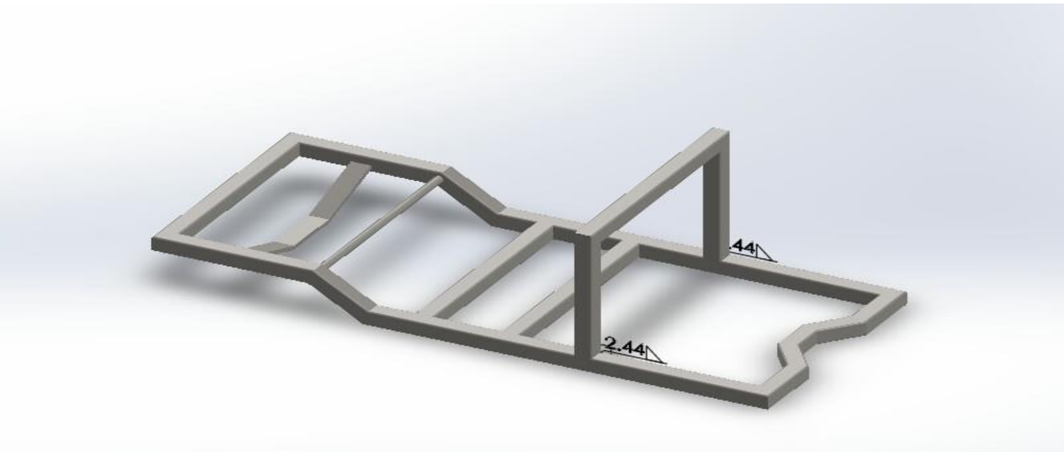


Figure 11: Chassis frame of the tricycle

During the fabrication, the body of the tricycle was flexibly moulded according to the structure of the chassis.

Radiator
This is a device used to re-cool the hot engine cooling water for recirculation purpose. During the fabrication, the radiator was connected by rubber hoses to the engine, in order to allow the cooling system water to circulate between them. Other parts of the cooling system are fan, fan belt, and water circulating pump.

Gearbox
The gear box was properly mounted to provide the torque of the required amount at the driving road wheels. Whenever the resistance to be overcome by the vehicle alters, the gear ratio of the power train is to be changed. The gearbox also helps to reverse the vehicle.

Other components
The remaining parts of the tricycle which include the braking system, battery, seat, propeller, steering, rims, cargo carrier, lightings etc. were either fabricated or procured before being properly mounted in the tricycle.

II. Results and Analysis

Analysis of the Tricycle Performance
The use of integral construction for the tricycle made it stronger, rigid and of light weight. The chassis strength and structure enables the tricycle to withstand different loadings, that is, the static and dynamic loads. The chassis was made of 45mm square mild steel pipe (3mm thickness) and the engine seating is constructed with U-channel steel. This U-channel steel was selected due to its high strength, rigidity and durability. The flooring which was done with 18 guage 1.2mm mild steel sheet helps to withstand sagging effect that occurs due to the weight of goods in the tricycle.

Moreover, the body of the tricycle has a wider back and a slim front thus making it streamlined. This streamlining reduces aerodynamic drag. The body also has the ability to resist different stresses that act on the frame, both at rest and during motion. The shell was also formed with the 18 guage 1.2mm sheet metal (mild steel). This was used because it offers excellent body finishing advantages. The body dimensions of the tricycle made with Computer Aided Design and the work in progress at the faculty of engineering workshop are depicted in figure 12.

Figure 12: Body dimensions of the tricycle and work in progress

The engine mounted at the rear and rear wheel drive layout is such that the rear wheels are linked to the engine with the support of shafts. The shafts are connected to the engine crankshaft and generate motion to the back wheels which in turn provides motion to the front wheel. When climbing a steep slope, a fragmentary weight transfer to the rear wheels takes place thereby boosting tyre-to-road grip.

The starter is placed in a horizontal position next to the engine crank case so that the drive pinion is in a position to mesh with the flywheel or drive plate ring gear. The starter is a manual starter which when pulled up by the driver, starts the engine. The control linkages from the clutch, gearbox and engine to the driver's cabin are made simple and direct. The rear mounted engine is easily accessible for routine maintenance and repairs.

The driver seat frame is welded to the frame between the driver and passenger. Also, the passengers' seat frame is also welded to the skeleton of the body and reinforced by welding angle irons from the seat frame to the floor of the tricycle. Testing shows that the seats are comfortable and accommodates different body sizes.

The rear wheels were mounted on a spring suspended axle while the front wheel is mounted on a suspended trailing link. The chassis is supported on the axle through springs. Thus the movement of the two rear wheels is interdependent so that when one of them passes over road obstacles, both experience exactly the same magnitude of the angular movements in the vertical plane. The suspension is capable of executing parallel up and down motion (or nearly so), without any change in the plane of rotation of the wheels which greatly diminishes the gyroscopic effect and hence offers a satisfactory solution for the wheel wobble. A shock absorber is incorporated with each suspension to rapidly dampen and stop spring oscillation.

Testings

When a starter is pulled, and there is an observation of engine resistance, this implies that the starter system is faulty and needs repair. The starter performs competently without an occurrence of this engine resistance.

The tyre made contact with the ground squarely and rolled without any sidewise thrust or force in the absence conditions such as acceleration, braking, road irregularities, wind gust, etc. The front trailing link carries the weight of the front part of the vehicle as well as facilitates steering and absorbs shocks due to road surface variations. The steering system effectively converts the rotary motion of the driver's steering handle into the angular turning of the front wheel as well as multiplies the driver's effort with mechanical advantage for turning the wheels. The steering is light and stable with a certain degree of self-adjusting ability.

Cost

The total cost of designing and fabricating the tricycle is approximately one million four hundred and eighty thousand Naira (₦1,480,000.00), which is equivalent to one thousand nine hundred and seventy three Dollars ($1,973.00). As close to two third of the stated amount were spent on research, equipment, and software procurement, as well as textbooks and journal articles, the cost for subsequent fabrication of the tricycle will not exceed six hundred thousand Naira (N600,000) or eight hundred Dollars ($800).

III. Conclusion

The body of the tricycle was designed with the aid of Solidworks software and is composed of about 60% locally sourced material. After the performance study, it was realized that the maximum speed of the tricycle is 65km/hr. The ergonomics suitability of the driver's seat was enhanced due to the research and calculations carried out; also the adoption of SAE standard for seat design added to this. The ground clearance of the tricycle was 200mm. In addition, the weight of loads to be conveyed at a certain time was optimized from 0.5 tonne (500kg) to 1 tonne (1000kg).

The following results were achieved after the completion of the tricycle: optimized carrying capacity of goods, cost-effective tricycle, low maintenance cost, optimized ergonomic suitability of the driver's seat, as well as enhanced aesthetics and good body finishing.

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