ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE, September 2019. Vol. 15(3) 628-637
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

EFFECT OF NUMBER OF PASSENGERS [LOADING] ON CENTRE OF GRAVITY OF A THREE WHEELED VEHICLE [KEKE-NAPEP]

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ARTICLE INFORMATION

Submitted 22 November, 2018
Revised 7 March, 2019
Accepted 10 March, 2019

Keywords:
CG Analysis
CG of Four Wheeled Vehicle
CG of Three wheeled Vehicle
Effects of Loading on CG
Static Stability Factor

ABSTRACT
In order to combat insecurity and to reduce the rate of accidents caused by commercial motorcyclist; many States Government in Northern Nigeria have substituted the use of motor cycles commonly known as Okada, with the use of three wheeled vehicle commonly known as keke-napep. The Static and dynamic characteristics of these vehicles are not as those of the usual vehicles. Therefore, the need to know more about the effects loading on these vehicles is highly needed by Nigerians in order to ensure good road and passengers' safety. This paper uses simple approach to highlight the effects of number of passengers (loading) on the position of Centre of Gravity (CG) of the three wheeled vehicles. It will serve as a measure for ensuring safe riding and reducing road clashes. As the load on the three wheeled vehicle increases from 3505N to 5410N, the Static Stability Factor decreases. This reduces the safety margin against rollover of the three wheeled vehicles compared to those of the four wheeled vehicles. The keke-napep is a rear wheel drive vehicle with rear engine and rear passenger arrangement. It subjects the vehicle to high weight transfer during braking. This causes the change in position of Centre of Gravity and the instability of the three wheeled vehicles. Therefore, it is hereby recommended that the wheelbase, track length, loading space and the Centre of Gravity position should be given a critical consideration during chassis design in order to improve the static and dynamic stability of these vehicles. Also, Components such as the engine and transmission system should be rearranged to obtain a more reliable position of the Centre of Gravity.

1.0 Introduction

Three wheeled vehicles are automobiles with three wheels; having one or two wheels at the front for steering while the other one(s) for power transmission (Saeedi and Kazemi, 2013). These vehicles are commonly known as: Tuk-tuk in Kenya, Bajaj in Somalia, Tok-tok in Egypt, Rasha in Sudan, Baby Taxi in Bangladesh and Keke-napep in Nigeria. Having one wheel at the front and two at the rear the vehicle is known as the delta configuration. The second type of three wheeled vehicles is called the tadpole or reverse trike which is the opposite of the delta type (Palash et al., 2014). Figure 1 shows the Delta type of three wheeled vehicle commonly use in Nigeria for commercial transportation. The vehicle has many advantages over two wheeled vehicles. They offer, more comfort, more luggage space, more distance between fill-ups and an increased safety. Having three wheels on the ground, they are naturally more stable than two wheeled vehicles. They combine the comfort and safety of a four wheeled vehicle (car) (Berote et al., 2008). It has the disadvantage of instability compared to four wheeled vehicles. The presence of three wheels indicates that the vehicles would have different static and dynamic characteristics compared to those of other vehicles. This paper shows how the number of passengers (loading) effects the position of Centre of Gravity (CG) of the three wheeled vehicles, thereby affecting its static and dynamic characteristics.

One of the crucial vehicle properties is the location of its position of Center of Gravity and if it is properly located, the vehicle would be stable (Starr, 2006)). The Centre of Gravity position of the three wheeled vehicle changes with inclusion of more passengers (Mukherejee, 2007). This happens as the result of loading on the vehicle. Overloading is a safety hazard that has leads to loss of lives, properties and deterioration of our roads which results in increase of maintenance and transportation cost. In the fight against road accident; the Federal Road Safety Commission incorporate campaigns against overloading. This fight can only be successful if the riders and public knows the impact and effects of overloading on the vehicles. This paper tends to highlight the effects of passengers (loading) on the position of Centre of Gravity of the three wheeled vehicles. The concept of this paper would help to educate the riders and the general public on effects of loading on the stability of these vehicles. This would help to monitor the static and dynamic characteristics of these vehicles thereby improving its service life and to ensure good road and passengers' safety.

Figure 1: A Delta Type of Three Wheeled Vehicle Commonly use in Nigeria

2.0 Materials and Method

The materials used in this paper are: three wheeled vehicle technical specifications, literatures, Microsoft excel (2007) and AutoCAD (2010) engineering drawing software. Data obtained from the three wheeled specification and literatures were utilized using equations to calculate the position of Centre of Gravity (CG) from; the rear wheel, front wheel and from the roll over lines. The data were also used to calculate the height of the Centre of Gravity from the road surface and Static Stability Factor (SSF) of the three wheeled vehicles under different loading conditions. This was done in order to investigate the effect of number of passengers (loading) on the Centre of Gravity of the three wheeled vehicles. All the calculated results were presented inform of graphs using Microsoft excel (2007) and the results were discussed. The AutoCAD (2010) engineering drawing software was used for drawing purpose to illustrate the position of Centre of Gravity on the three wheeled vehicles.

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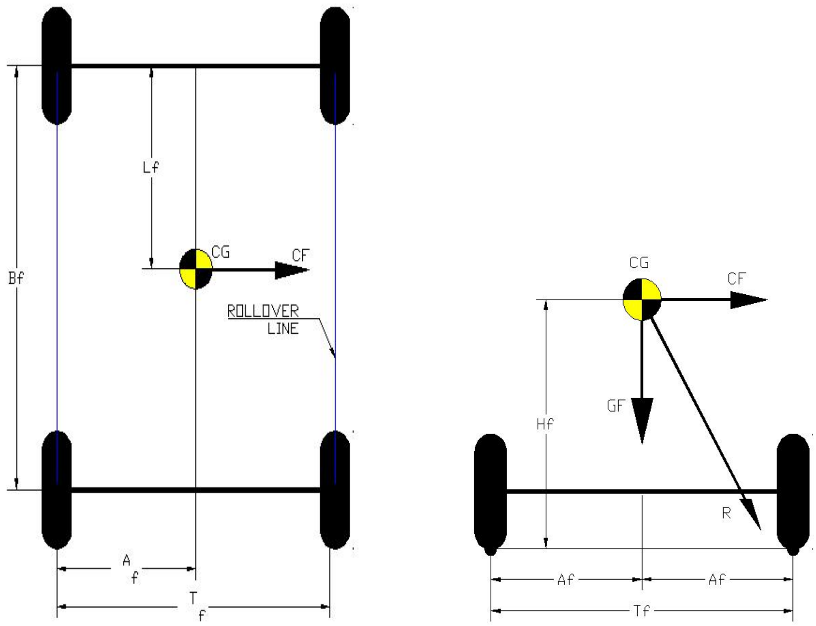
3.0 Centre of Gravity (CG) Analysis

It was noted in Raipput (1991) and Abbott (1984) that the weight of all parts of a body are directed toward the centre of the earth and the point through which all the weights act is called the Centre of Gravity (CG). Palash et al. (2014) and Abbott (1984), also noted that the centrifugal force (CF) is exerted at the Centre of Gravity (CG) and is directed toward the centre (turning point) in order to keep a body moving in a circular path.

3.1 Centre of Gravity Analysis for Four Wheeled Vehicle

Consider a four wheeled vehicle as shown in Figure 2 (a). If the vehicle is in a curve towards the left, the Centrifugal Force (CF) tends to roll the vehicle over towards the right, around an imaginary point (black spot under the right tyre in Figure 2 (b)), while the Gravitational Force (GF) holds the vehicle back to avoid rollover. It's as though the Centrifugal Force and the Gravitational Force combined together into a resulting force exerted on the Center of Gravity to turn it around this imaginary point (Palash et al., 2014).

Mukhejee (2007), states that the ratio of half-track width (half the distance of the centre of the two rear tyres) to the height of Centre of Gravity (h) is called the State Stability Factor (SSF), and this plays a crucial role in determining the stability against rollover of a four wheeled vehicle.

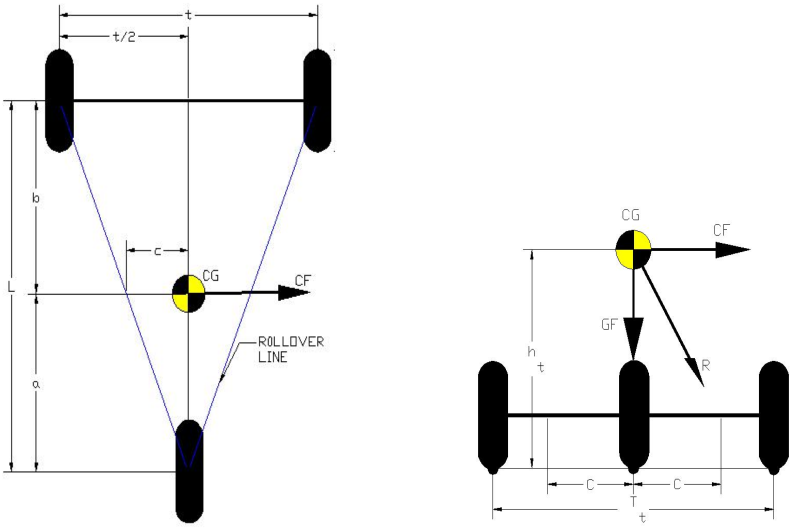


(a) (b)

Figure 2: Position of Centre of Gravity (Developed from; (Palash et al. 2014). (a) Top view of Four Wheeled Vehicle. (b) Rear view of Four wheeled Vehicle.

3.2 Centre Gravity Analysis for Three Wheeled Vehicles

In the case of three wheeled vehicles, another factor comes into play; unlike the four wheeled vehicles, their structures are triangular in design. The slant sides from the front wheel to the rear wheel are called the rollover lines. It is observed that the distance between the Center of Gravity and the rollover line (Figure 3 (a)) is shorter than in the case of the four wheeled vehicles, even though the Center of Gravity height (h), the base length (L) and the track (t) of the three wheeled vehicle are the same as those of the four wheeled vehicles. The Center of Gravity height (h) is therefore proportionately greater, which reduces its safety margin against rollover of the three wheeled vehicles in curves. As it was shown for the four wheeled vehicles; they roll over around the rollover line corresponding to the imaginary point. But in the case of a three wheeled vehicle, it rather rolls over around the rollover line going from the single front wheel to one of the two symmetrical rear wheels.

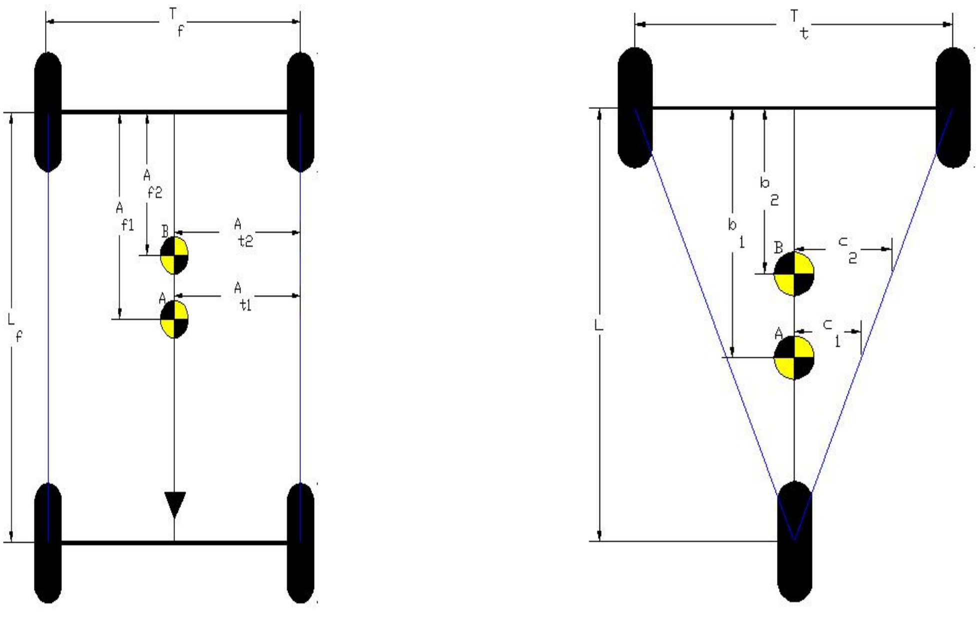


(a) (b)

Figure 3: Position of Centre of Gravity (Developed from Palash et al., 2014). (a) Top view of Three Wheeled Vehicle. (b). Rear View of Three Wheeled Vehicle.

3.3 Effects Loading on Centre of Gravity (CG)

Kenneth et al., (1996) noted that the Centre of Gravity (CG) of a loaded vehicle ''A'' would shift rearward to point ''B'' as shown in Figure 4 (a). As the Center of Gravity (CG) of the four wheeled vehicles shift from 'A' to 'B' the distance At_1 and At_2 remains constant ($At_1=At_2$). While for the three wheeled vehicles; distance increases (C1<C2) as shown in Figure 4 (b). The loading of the four wheeled vehicles in this analysis leads no change in static stability. The loading of the three wheeled vehicles did improve its static stability when change in CG height is neglected (Kenneth et al., 1996).



(a) (b)

Figure 4: The Effects of Loading. (a). Four Wheeled Vehicle, (b) Three Wheeled Vehicle. (Adapted from; Kenneth et al. 1996)

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3.4 Effects of Loading on Centre of Gravity Position

From the technical specifications of three wheeled vehicles by Bajaj (2014); It was noted that the three wheeled vehicles have a wheel base (L) of 2m and wheel track (t) of 1.3m. Mukherejee (2007) shows that. The Centre of Gravity position, mass and moment of inertia changes with the inclusion of more passengers (loads) on the Bajaj three wheeled vehicle. In order to calculate the distance of the rollover line parallel to the Centre of Gravity (c′′) at various (number of passengers) loading condition, the 'x' axis was rotated parallel to the roll over axis, as shown in Figure 5.

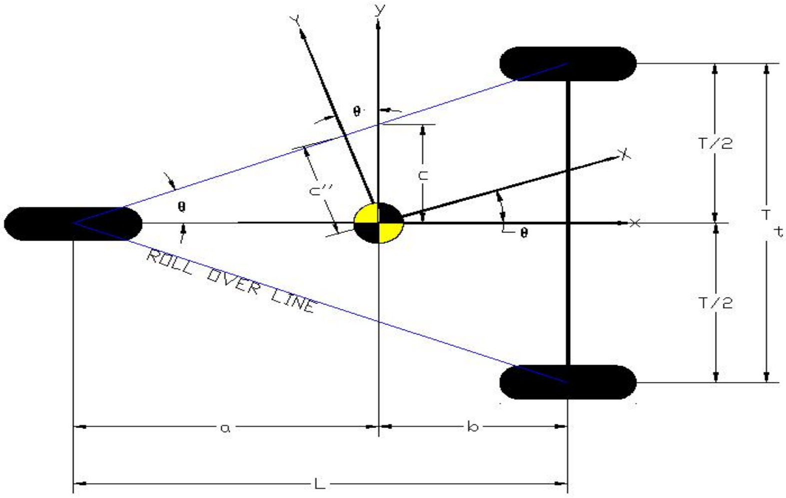

Figure 5: Lateral distance from CG to rollover axis (Adapted from Azadeh, 2014)

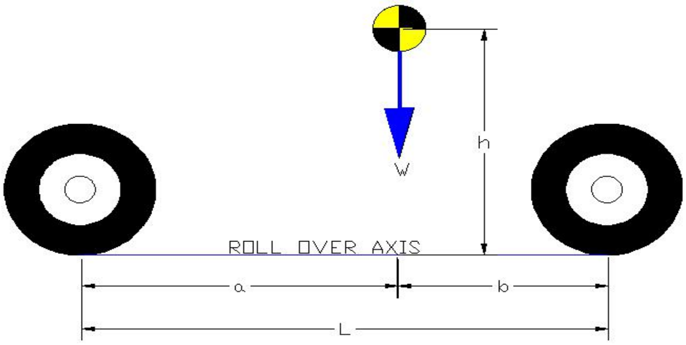

Figure 6: Side-view of the vehicle showing the vertical force (weight).

According to Figure 5, θ can be determined from equation (1),

$$\theta = \tan^{-1}\frac{t}{2L} \qquad (1)$$

To calculate the distance of Centre of Gravity (CG) from the Rollover line (c) from Figure 3 (a) and Figure 5 (Azadeh, 2014);

$$\frac{c}{T/2} = \frac{a}{L} \quad \rightarrow \quad c = \frac{T \times a}{2L} \qquad (2)$$

While,

$$c'' = c\cos\theta \qquad (3)$$

By substituting Equation (2) into Equation (3)

$$c'' = \frac{T \times a}{2L} c\cos\theta \qquad (4)$$

Equation (4) above is used to determine the position of Centre of Gravity from the roll over line

The Static Stability Factor (SSF) is defined as one half the track width (wheel track) divided by the height of the Centre of Gravity (Narang, 2004). This is determine using equation (5) below;

$$SSF = \frac{t}{2h} \qquad (5)$$

According to Thomas (1992), when a vehicle sits statistically on a level ground, the weight distribution on the front and rear wheels are related by equation (6) and (7) respectively;

$$W_f = W\frac{b}{L} \quad (6)$$

$W_f =$ Weight at the Front Wheel (N)

$W =$ Total Weight of the Vehicle (N)

The weight at the rear of the Three Wheeled Vehicle is given by;

$$W_r = W\frac{a}{L} \quad (7)$$

$W_r =$ Weight at the Rear Wheel (N)

4.0 Results and Discussion

The three wheeled vehicles use in Nigeria is design to carry the maximum of three passengers at the rear seat, but the riders tend to carry four passengers in order to maximized profit. In the case of carrying additional passenger at the front; the driver's control and operating space are reduced, escalating the chance of for accidents. In Table 1, the fourth passenger was computed in order to show the effects of increase in (number of passengers) weight on the position Centre of Gravity of the three wheeled vehicles.

From Table 1, as the number of passengers increases from 0 to 4, the weight at the front wheel decreases, while the weight at the rear wheels increases. This also increases the weight transfer from the rear wheels to front wheel during braking. Due to this effect and the presence of one wheel at the front, makes the three wheeled vehicles unstable thereby leading to rollover accident during braking. Also, from Table 1, as the vehicle total weight increases due to increase in number of passengers, the distance of Centre of Gravity increases from 1.305m to 1.645m along the base length (wheelbase) from the front axle, with an inverse reduction in length of Centre of Gravity from the rear. This also leads to an increase in distance of Centre of Gravity from the rollover line thereby increasing the rollover propensity of this vehicle. This increase in weight as the result of increase in number passengers on the keke-napep also leads to an increase in height of Centre of Gravity from the 0.602m to 0.828m. This inversely reduces the Static Stability Factor (SSF) of the vehicle as indicated by the last column of Table 1.

Table 1: Effects Weights and Position of Centre of Gravity (CG).
(Developed from; Mukherejee, 2007)

Total No. of Occupant (= Driver + n)	Weight (N)			CG Location (m)					Static Stability Factor (SSF)
	At Front Wheel W_f	At Rear Wheels W_r	Total W	From Front Axle (a)	From Rear Axle (b)	From Rollover Line (c)	From Rollover Line (c'')	Height (h)	
1(= 1 + 0)	1221	2284	3505	1.303	0.697	0.423	0.402	0,602	0.540
2(= 1 + 1)	1349	2927	4276	1.369	0.631	0.445	0.423	0.661	0.492
3(= 1 + 2)	1474	3573	5047	1.416	0.584	0.460	0.438	0.701	0.464
4(= 1 + 3)	1600	4218	5818	1.450	0.550	0.471	0.448	0.731	0.444
5(= 1 + 4)	1179	5410	6589	1.642	0.358	0.534	0.508	0.828	0.393

n = Number of passengers

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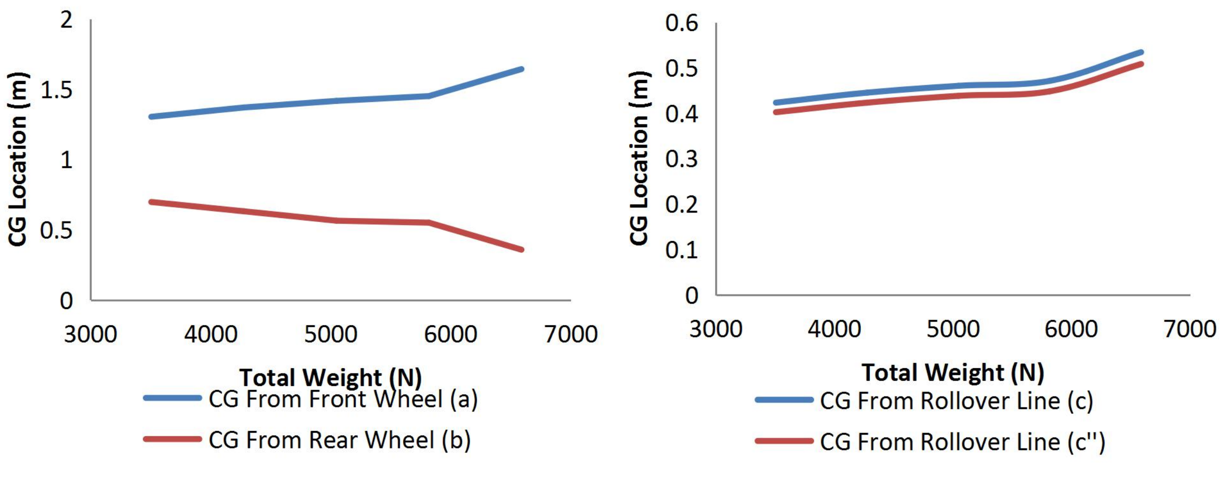
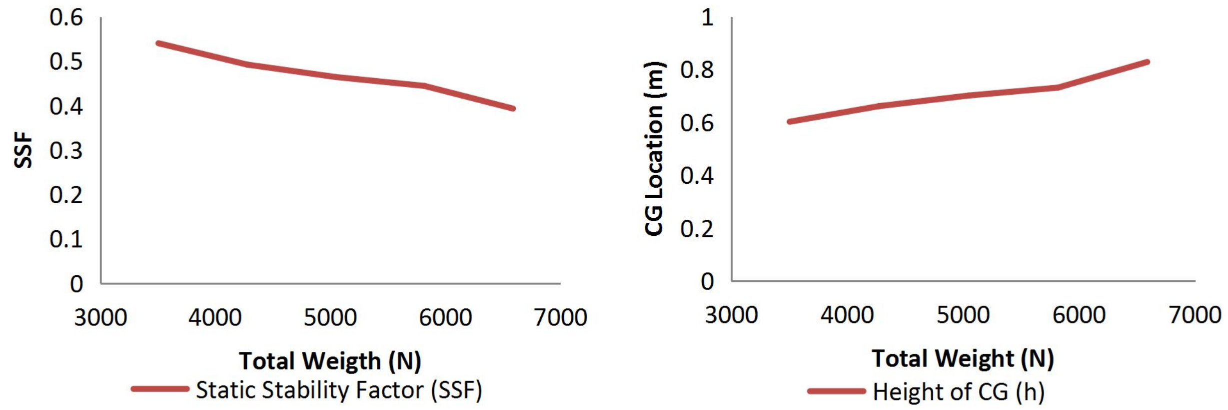
Figure 7 (a), Shows that for every increase in weight (number of passengers), the distance of CG from the front axle (a) are inversely proportional to the distance of CG from the rear axle (b). This justified the work done by Kenneth et al. (1996), which states that if a vehicle is loaded, its position of Centre of Gravity (CG) shifts to the rear. The three wheeled vehicle is a rear-engine, rear-wheel drive vehicles and according to Dolan (1978), increase in weight at the rear of a rear-engine, rear-wheeled drive vehicle tends to make the vehicle unstable at high speeds.

Palash et al. (2014), noted that if the Centre of Gravity height (h) is greater than half the track length (t/2), the resulting force (R) (Figure 3 (b)) would align with the imaginary point (black spot under the tyre) and will roll the vehicle over in a curve. From Table 1, the least value of the Centre Gravity height (h) is 0.602m, while the half of the track length is 0.575m when the three wheeled vehicle is loaded. This shows that the Centre of Gravity height (h) of the three wheeled vehicle is proportionally greater than half its track length. This increases the rollover tendency of the vehicles. Therefore, the higher the weight, higher the position of position of Center of Gravity height (h) from the two symmetric wheels, and the longer the distance of the Centre of Gravity from the rollover line (c and c'') as shown in Figure 7 (d). This reduces the safety margin against rollover of the three wheeled vehicles compared to the four wheeled vehicles.

The Static Stability Factor (SSF) is viewed as the ultimate measure of the rollover resistance of a vehicle. Figure 7 (c), shows that the Static Stability Factor of the three wheeled vehicle decreases with an increase in weight (number of passengers) on the three wheeled vehicles. This increases the rollover propensity of the three wheeled vehicles. Therefore, the riders should not exceed the recommended riding speed and should always maintain the recommended tyres pressure. The three wheeled vehicles are rear-engine, rear-wheeled drive with rear passengers' arrangement. According to Dolan (1978), a rear-engine, rear-wheeled drive vehicles have tendency to over steer (that is the wheels turn too sharply into the curve) and this can be corrected by turning the steering in opposite direction.



(a) (b)



(c) (d)

Figure 7: (a) CG from Front and Rear Wheel (b). CG from Roll Overline. (c) Static Stability Factor (SSF). (d) Height of CG (h).

Under some riding conditions of the three wheeled vehicles, it is possible to have only two wheels in contact with the road surface. This could occur during turning or tight maneuvers whenever enough weight is transferred outside the rollover lines. This tendency requires careful load and passenger positioning inside the vehicle (Motorcycle Operator Manual, 2017). If the loads are not properly positioned on the vehicle, the weights will not be properly distributed at each wheel. This would affect the position of Centre of Gravity and the static and dynamic stability of the vehicle.

Consider the vehicle moving on a horizontal road (Figure 8). Giri (2010), noted that a vehicle weight and its kinetic energy act through the Center of Gravity. This makes the vehicle to pitch forward when the brakes are applied. As a result of this action, some weights are effectively transferred from the rear wheel to the front wheels. Due to the rear-engine, rear-wheeled design of the three wheeled vehicles and the rear position of passengers; the weight at the rear is more than that of the front. This weight is transfer to the front during braking. This changes the position of Centre of Gravity which affects the stability of the vehicle. Therefore, this problem of weight transfer and instability of this vehicle can be improved by;

Designing the height of the Centre of Gravity to a minimum level toward the road surface.

Designing the length of the Centre of Gravity to a minimum distance from the two (2) rear wheels.

Significant increase in length of the rear wheel track length.

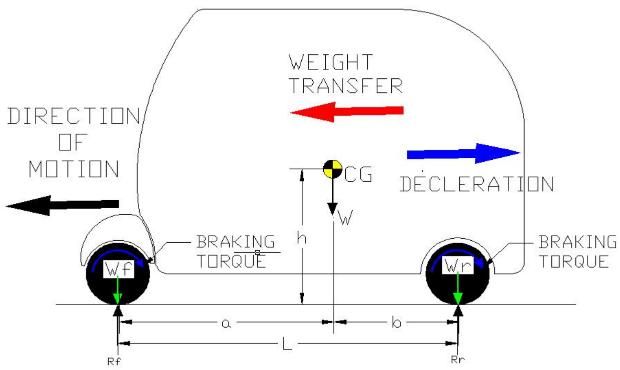


Figure 8: Weight Transfer (Developed from; Giri (2010)).

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Overloading puts massive strain on vehicle tyres and chassis and also makes the vehicle less sable, difficult to steer, takes longer time to stop and causes damages to the road and road users. To reduce the number of road accidents; the government should set measures to regulate the operation of these vehicles. The Federal Road Safety in conjunction with the Vehicles Inspection Officers should enforce this illegal art.

5.0 Conclusion and Recommendations

The paper presents the effect of number passengers (loading) on the Centre of Gravity of a three wheeled vehicle (keke-napep). This analysis shows that the inclusion of each passenger (load) on the three wheeled vehicles, raises the Centre of Gravity (CG) height (h) and decreases the vehicle Static Stability Factor (SSF). Also, the farther the position of Centre of Gravity (CG) from the two symmetric wheels towards the single wheel, the shorter the distance (c) from the Center of Gravity to the rollover line. This reduces the safety margin against rollover effect of the three wheeled vehicles compared to the four wheeled vehicles. This implies that the three wheeled vehicles with minimum number of passengers (loads) would be more stable in rollover condition than a three wheeled vehicle with high number of passengers.

The keke-napep is a rear wheel drive vehicle with rear engine and rear passenger arrangement. This makes the vehicle to have high load concentration at the rear wheels. This subjects the vehicle to high weight transfer during braking. This affects the position of Centre of Gravity and the instability of the three wheeled vehicles. Therefore, it is hereby recommended that the wheelbase, track length, loading space and the Centre of Gravity position should be given a critical consideration during chassis design in order to improve the static and dynamic stability of these vehicles. Also, Components such as the engine and the transmission system should be rearranged to obtain a more reliable position of the Centre of Gravity.

Finally, as the numbers of these vehicles increases as a means of commercial transportation in Nigeria, the rate of traffic congestion, air pollution and road clashes would also increase. Therefore, the Federal Ministry of Transport and Environmental should set aside future measures to combat these phenomena.

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