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REVIEW ON TADPOLE DESIGN – ISSUES & CHALLENGES

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Abstract

Due to rapid industrialization and development of the economy the expectation of the customer and their ability and willingness to pay for the product has changed drastically. Everyday new products are being launched and new niche markets are developing. To meet out this change and expectation and to maintain the value of the product the companies has to undergo continues process of product upgradation incorporating both technical and cosmetic changes. Major problem for the designer of the automobile is to retain its utility and continue to enhance the value, so that the product acceptability and preferability to competitor's product is maintained.
Automobiles now – a – days doesn't means simply as a mode of transport but also the comfort, performance and durability contribute to its value.
As the world moved into the 20th century, three-wheelers gained in popularity as low-cost, lightweight vehicles -- that is, until about the late 1920s, when cars generally started going more along the four-wheel track. A three-wheel car is, by design, basically a triangle shape. Depending on where the passengers sit, the location of the engine, and the placement of other critical mechanical components, this means the car either has two wheels up front and one in the rear – Tadpole Design or two wheels in the rear and one up front – Delta Design.

***Keywords**:* Automobile, Three – Wheelers, Design, Tadpole Design, Delta Design

1. Introduction

A three wheeled car, also known as a tricar or tri-car, is an automobile having either one wheel in the front for steering and two at the rear for power, two in the front for steering and one in the rear for power, or any other combination of layouts. Due to its handling superiority, an increasingly popular form is the front-steering "tadpole" or "reverse trike" sometimes with front drive but usually with rear drive.

Figure 1 Tadpole Design

A three-wheel car is, by design, basically a triangle shape. Depending on where the passengers sit, the location of the engine, and the placement of other critical mechanical components, this means the car either has two wheels up front and one in the rear or two wheels in the rear and one up front. The engine can drive the single rear wheel or the two rear wheels, and the steering can be done either way as well.

Having one wheel up front and two in the back is known as the delta configuration. Karl Benz's creation followed this setup, as did the Reliant Robin. The original three-wheeled Mazda automobile, the Mazda-Go, was configured this way to allow for a pickup truck bed in the back.

The benefit to the delta setup is its inherent low cost. Most cars set up this way have the engine driving the rear wheels and leave steering to the front one. It's relatively easy (and inexpensive) to build a steering setup with only one wheel.

The second type of three-wheeler setup is called the tadpole or reverse trike. The opposite of the delta, this formation has two wheels up front and one in the back. This setup is the basis for the speedy Campagna Motors T-Rex, as well as the exciting Volkswagen GX-3 concept vehicle.

Tadpole designs are much more stable than the delta setup because the back wheel drives the vehicle while the two wheels up front are responsible for steering. There's also an aerodynamic benefit, since the vehicle is shaped almost like a teardrop -- wide and round up front and tapering off in the rear. This allows air to flow easily over the vehicle's bodywork.

The tadpole design is becoming more and more favored among auto designers for its stability, aerodynamics and ability to house a fuel-efficient engine. In fact, a number of current hybrid and electric concept vehicles use a three-wheel setup along these lines. As cars get more eco-friendly, you may be seeing more and more three-wheelers on the road than ever before.

2. History

Three-wheeled cars have been around for a very long time, even pre-dating the Patent Motor Wagen design. For instance, in the 15th century Leonardo da Vinci created sketches of a primitive, three-wheeled car that was propelled using a wind-up mechanism similar to a clock. And French engineer Nicolas Cugnot created a large, tractor-like vehicle in 1769 that used a three-wheel design and was powered by a steam engine.

As the world moved into the 20th century, three-wheelers gained in popularity as low-cost, lightweight vehicles -- that is, until about the late 1920s, when cars generally started going more along the four-wheel track. But after World War II, things changed once again. In war-torn countries like England, France, Germany and Japan, gasoline and mechanical supplies were scarce, but people still needed a way to get around. In many cases they couldn't afford full-sized, four-wheel cars or those cars simply weren't available and a motorcycle was far too small to meet their needs.

In postwar England, Bond Cars Ltd. found success in making small, three-wheel cars powered by single-cylinder motorcycle engines. These small cars proved popular among motorcyclists looking to protect themselves from the elements, and as an added benefit, the car didn't require an automobile driver's license. In addition, their ability to achieve more than 100 miles per gallon (42.5 kilometers per liter) was extremely helpful at a time when fuel was expensive and supplies were scarce. Bond Cars continued to make three-wheelers well into the 1970s.

BMW began selling a three-wheel version of the colorful, egg-shaped Isetta micro car during the 1950s. Again, the three-wheel variant of this car was extremely popular in Great Britain, because they could be driven there

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with a motorcycle license. In Japan, car companies like Daihatsu made three-wheelers that became popular as taxis, light trucks and other utility vehicles. Again, many were small and powered by inexpensive motorcycle engines. England's Reliant Robin, a fiberglass micro car, was made off-and-on for more than 30 years, and arguably remains one of the most iconic three-wheelers of all time.

3. Analysis

i). Center Of Gravity Position:

Consider first a 4-Wheeler as seen from the rear, like here to the right. If the vehicle is in a curve towards the left, for example, we can imagine that a centrifugal force (magenta color) is exerted on the center of gravity (black and yellow circle) of the vehicle-occupants system, while the vehicle's weight exerts a downward gravitational force (cyan color).

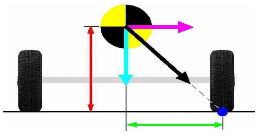

Figure 2. Center of Gravity (a)

Thus, the centrifugal force (magenta) tends to roll the vehicle over towards the right, around an imaginary point (deep blue) under the right tires, while the gravitational force (cyan) holds the vehicle back to avoid rollover.
It's as though the centrifugal force and the gravitational force combined together into a resulting force (black) exerted on the center of gravity to turn it around this imaginary point (deep blue). We can thus easily understand that if the center of gravity height (red) is greater than the half-track (in green) (the half distance between the two wheels seen from the rear), the resulting force (black) will be aligned over the imaginary point (deep blue) and will thus roll the vehicle over in a curve.
The ratio of the center of gravity height (red) to this half-track (green) thus plays a crucial role in determining the stability against rollover of a 4-Wheeler. Ideally, this center of gravity height (red) should be low like for a sports car, in order to insure a safety margin against rollover. In the case of 'sport-utility' 4X4s, this height is relatively larger than for regular family cars. This explains why these vehicles have a higher rollover propensity.
In the case of 3-Wheelers, another factor comes into play:
As can be seen for a 4-Wheeler, the 4-Wheeler rolls over around a line (blue) corresponding to the imaginary point (deep blue) of the previous illustration.

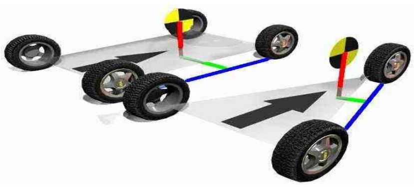

Figure 3. Center of gravity (b)

But in the case of a 3-Wheeler, the vehicle rather rolls over around a line (blue) going from the unique wheel to one of the two symmetrical wheels. We can immediately see that the green line between the center of gravity and the rollover line is thus shorter than in the case of the 4-Wheeler, even though the center of gravity height, the length and the track of the 3-Wheeler are the same as those of the 4-Wheeler. The center of gravity height (red) is thus proportionately greater, which reduces the safety margin against rollover in curves.
Moreover, a 3-Wheeler in a curve can also be subject to a braking or accelerating force that will combine with the lateral centrifugal force, which may further increase chances of rolling over of this 3-Wheeler. For example in the case of the single-front-wheel 3-Wheeler, here above to the right, braking in a curve towards the left will increase chances of rolling over this 3-Wheeler.
So in the case of a 3-Wheeler:

- The center of gravity height should be low in relation to the half-track, like for a 4-Wheeler.
- But the center of gravity's position also has importance: The farther it is from the two symmetric wheels towards the single wheel, the shorter is the distance from the center of gravity to the rollover line, which reduces the safety margin against rollover of the 3-Wheeler compared to the 4-Wheeler.

ii). **Accelerating or Braking in a straight line:**

When going straight, a 3-Wheeler may be accelerating or braking. Thus:
- It may tip backward while accelerating, as in the case of a two rear wheels 3-Wheeler where the center of gravity is located too far back,
- Or, while braking in the case of a two front wheels 3-Wheeler, it may roll around the blue point under the front wheels and tip forward.

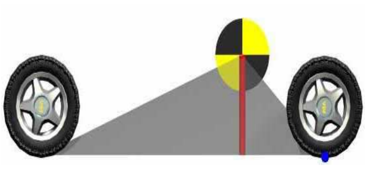

Figure 4. Accelerating or braking in a straight line (a)

Summarizing, the 3-Wheeler's center of gravity must be low and close to the two symmetrical wheels, that are alone to avoid a rollover in curves. But this center of gravity must not be too close to these two symmetric wheels, to avoid tipping backward or forward.

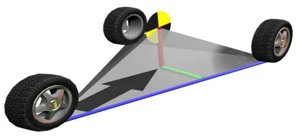

Figure 5. Accelerating or braking in a straight line (b)

Basically, the center of gravity must be located under a pyramid, as shown in the case of a two-front-wheel 3-Wheeler, to avoid rolling over sideways or tipping forward.

iii). Rollover Stability of Conventional Non-Tilting Three-Wheeler

A conventional, non-tilting three wheel car can equal the rollover resistance of a four wheel car, provided the location of the center-of-gravity (cg) is low and near the side-by-side wheels. Like a four wheel vehicle, a three-wheeler's margin of safety against rollover is determined by its L/H ratio, or the half-tread (L) in relation to the cg height (H). Unlike a four-wheeler, however, a three-wheeler's half-tread is determined by the relationship between the actual tread (distance between the side-by-side wheels) and the longitudinal location of the cg, which translates into an "effective" half-tread. The effective half-tread can be increased by placing the side-by-side wheels farther apart, by locating the cg closer to the side-by-side wheels, and to a lesser degree by increasing the wheelbase.
A simple way to model a three-wheeler's margin of safety against rollover is to construct a base cone using the cg height, its location along the wheelbase, and the effective half-tread of the vehicle. Maximum lateral g-loads are determined by the tire's friction coefficient. Projecting the maximum turn-force resultant toward the ground forms the base of the cone. If the base of the cone falls outside the effective half-tread, the vehicle will overturn

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before it skids. If it falls inside the effective half-tread, the vehicle will skid before it overturns.

iv). Oversteer / Understeer Characteristics

The single front wheel layout naturally oversteers and the single rear wheel layout naturally understeers. Because some degree of understeer is preferred in consumer vehicles, the single rear wheel layout has the advantage with the lay driver. Another consideration is the effect of braking and accelerating turns. A braking turn tends to destabilize a single front wheel vehicle, whereas an accelerating turn tends to destabilize a single rear wheel vehicle. Because braking forces can reach greater magnitudes than acceleration forces (maximum braking force is determined by the adhesion limit of all three wheels, rather than two or one wheel in the case of acceleration), the single rear wheel design has the advantage on this count. Consequently, the single rear wheel layout is usually considered the preferred platform for a high-performance consumer vehicle in the hands of the non-professional driver. But race car drivers often prefer slight oversteer to under steer. Oversteer gives the skilled driver the ability to perform extreme maneuvers that an under steering vehicle would simply mush through and refuse to perform. Moreover, by varying tire size and pressure, a single front wheel vehicle can be designed for neutral steer with oversteer present only at the limit of adhesion. Much depends on the details of the design, as well as driver preferences and skills.

v). Canadian Motor Vehicle Safety Regulations:

These new Canadian Motor Vehicle Safety Regulations of 2003, stipulate in Standard 505 that:"The height of the center of mass, shown in Figure 1, of a motor tricycle or a three-wheeled vehicle shall not exceed one and a half times the horizontal distance from the center of mass to the nearest roll axis."

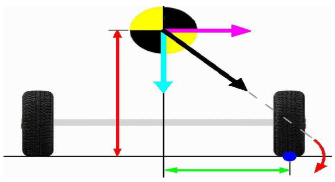

Figure 6. Canadian motor vehicle safety regulation (a)

So according to this regulation, the center of gravity height (in red) may thus be one and a half times the green line between the center of gravity and the rollover line, as illustrated at the right. The resulting force (black) may thus be aligned over the imaginary point (deep blue) and roll the vehicle over in a curve.
Obviously, this regulation is very large if not too large, since it lets certain insufficiently stable vehicles circulate on public roads.
As a counter part, this new regulation has the merit of bringing order to the world of two and three wheel motorcycle definitions and regulation. Also, while avoiding going too far, there are less chances of killing the touring motorcycle aftermarket, where goodwill manufacturers can continue replacing single rear wheels by two rear wheels, on motorcycles used by goodwill people that use them carefully and do not ride fast.
This new Canadian regulation also stipulates in article 505, that:
"The total weight of a motor tricycle or three-wheeled vehicle on all its front wheels, as measured at the tire-ground interfaces, shall be not less than 25 per cent and not greater than 70 per cent of the loaded weight of that vehicle."

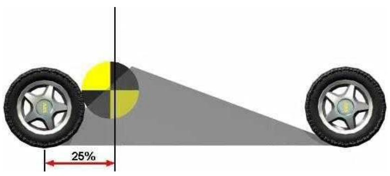

Figure 7. Canadian motor vehicle safety regulation (b)

The image at the right illustrates the case of a single-front-wheel 3-Wheeler having its vehicle-occupants center of gravity located at less than 25% of the wheelbase length from the rear wheels. This leaves less than 25% of the weight on the front wheel. The image below illustrates the case of a two-front-wheels 3-Wheeler having its vehicle-occupants center of gravity located at more than 70% of the wheelbase length from the rear wheel. This leaves more than 70% of the weight on the front wheel.

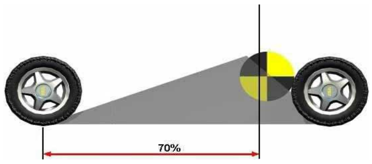

Figure 8. Canadian motor vehicle safety regulation (c)

Even though this new regulation may bring order to motorcycle definitions and regulation, it's nonetheless peculiar that:
- There is no 'mechanical' reason to treat differently these two types of 3-Wheelers: The first could 'merit' 30% of the weight on its unique front wheel. Or the second could 'merit' 75% of the weight on its two front wheels.
- In each of these two cases illustrated above, the vehicle-occupants center of gravity is located below the pyramid, so that the single-front-wheel will not flip backwards when accelerating and the two-front-wheel will not tip forward when braking.
Summarizing, there is no reason to treat differently the risk of overturning laterally (rolling) and the risk of flipping backwards or tipping forward.
In both cases:
- It seams more appropriate to consider overturning, flipping or tipping points or axes.
- And to insure an adequate ratio between the vehicle-occupants center of gravity height and the horizontal distance between the center of gravity and these points or axes, instead of a weight percentage on the front wheels.

4. Conclusion

Having one wheel in front and two in the rear for power reduces the cost of the steering mechanism, but greatly decreases stability. However, a configuration of two wheels in the front and one wheel at the back has many strong proponents among automotive designers and enthusiasts. Two advantages are its improved aerodynamics, and that it readily enables small lightweight motorcycle power plants and rear wheels to be used. Alternatively, a more conventional front-engine, front wheel drive layout as is common in four-wheeled cars can be used, with subsequent advantages for stability and traction.
For the lowest wind resistance (which increases fuel efficiency), a teardrop shape is desirable. A tear drop is wide and round at the front, tapering to a point at the back. The three wheel configuration allows the two front wheels to create the wide round surface of the vehicle. The single rear wheel allows the vehicle to taper at the back. Having one less wheel also increases fuel efficiency because of decreased rolling resistance.
The disadvantage of a rear drive, non-tilting three wheel configuration is instability - the car will tip over in a turn before it will slide, unless the centre of mass is much closer to the ground or the wheelbase is much wider than a similar four wheel vehicle. To improve stability some three wheelers are designed as tilting three wheelers so that they lean while cornering like a motorcyclist would do. The tilt may be controlled manually or by computer. Electric three-wheelers often lower the center of gravity by placing the heavy battery pack at the base of the vehicle.
This conclusion is easily understandable if a 3-Wheeler with two front wheels, is considered. If the center of gravity of the vehicle-occupants assembly is sufficiently low to be under the pyramid, the vehicle will not roll sideways in a curve and will not tip backward when accelerating or tip forward when braking.

So if the location of the center of gravity is adequate, a 3-Wheeler may then have a safety margin against rollover as good as for any 4-wheeler. Thus, any 3-Wheeler *'can'* be stable on the road provided it's well designed.

References

1. J.C. Huston, B.J. Graves and D.B. Johnson, "Three wheeled vehicle dynamics", *SAE 1982*, Paper no. 820139, 1982.
2. T.E. Tan and J.C. Huston, "Three wheeled ATV - A no-suspension rigid rider systems, part 1: Modelling and parameter values", *SAE 1984 Trans.*, paper no.841058, 93 (4), pp. 4806-4817, 1984.
3. A. Sponziello, F. Frendo and M. Guiggiani, "Stability analysis of a three-wheeled motorcycle", *SETC 2008*-32-0062/20084762.
4. M. Barker, B. Drew, J. Darling, K.A. Edge and G.W. Owen, "Steady-state steering of tilting three-wheeled vehicle", *Vehicle System Dynamics*, Vol.48, No. 7, pp. 815-830, 2009.
5. "Two and Three Wheelers in India" published in June 2009 by International Council for Clean Transportation.
6. "Dynamic Stability of Three Wheeled Vehicles in Automotive Type Applications" by Robert Q. Riley.
7. Patrick Fenner," On the Golden Rule of Trike Design" , 2010
8. Rickey M. Horwitz, "The Recumbent Trike Design Primer ", 2010
9. N. Amati, A. Festini, L. Pelizza and A. Tonoli, "Dynamic modelling and experimental validation of three wheeled tilting vehicles", *Vehicle System Dynamics*, Vol.48, No. 12, 2011.

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