Journal of Physics Special Topics
An undergraduate physics journal

A4_2 Flipping Vehicles

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December 1, 2017

Abstract

Vehicles sometimes roll over when driving. We investigated whether this was due only to excessive speeding or if other factors were at play. By creating a model comparing bend radius, velocity and angle to the vehicle's centre of mass, we concluded that in most cases other factors relating to the road surface would be involved.

Introduction

We discuss whether vehicles that roll do so exclusively because of excessive speed, or whether there are factors relating to the road surface including: pot holes, leaving the road, and collisions. An equation to find the velocity required for a car to topple over is derived, and applied first to a Fiat Punto as an example of speeds at which a common car will roll, and then to a top loaded double decker bus, giving an example of a vehicle with enhanced risk of toppling.

Creating the model

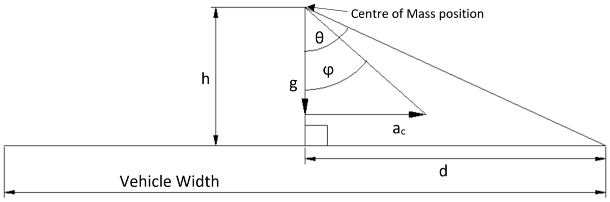

Figure 1: Dimensions to find θ.

To find when a vehicle, with centre of mass at height (h), and distance to outside edge (d), will topple over, we first took the arctangent of d divided by h to find θ. Assuming the friction between tyre and road is sufficient to keep the vehicle on track, centripetal acceleration, a_c is given by vehicular velocity (v), and radius of the curve (r),

$$a_c = v^2/r. \tag{1}$$

The vehicle will topple when φ is larger than θ (Figure 1). Then assuming the aerodynamics of the vehicle produce negligible effects, the velocity at which the vehicle will roll is derived from Eq. (1) using trigonometry,

$$v > (gr\tan(\theta))^{1/2}, \tag{2}$$

where gravitational acceleration, g, is 9.81 ms^{-2}. By varying θ, and r, Figure 2 was produced which shows maximum velocities around a corner. Below the surface in Figure 2, velocities will not flip the vehicle, and above it they will.

Discussion for a Hatchback

First we looked at a Fiat Punto, which has width of 1.687 m, height of 1.490 m, and weight of 1190 kg [1]. We estimated the centre of mass to be at 35% of its height, due to heavy mechanical components located at the base of the car. We take an average male driver whose mass is 79 kg [2], and say that his centre of mass is positioned a quarter of the way in from the right of the car, and at 50% of its height. Using this data, an angle of 62° is found for a right hand

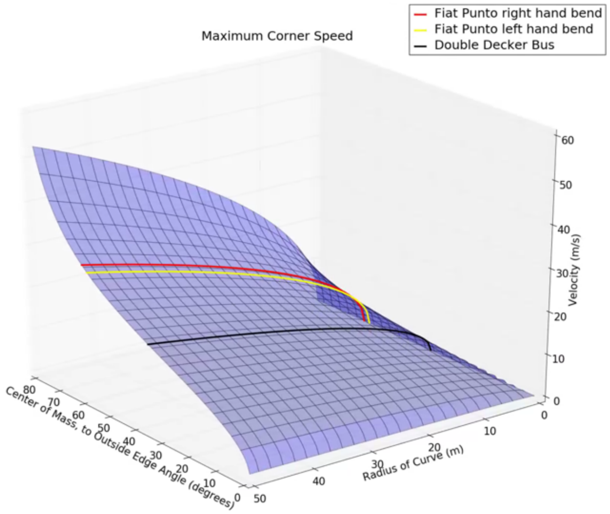

Figure 2: A graph showing maximum vehicle speeds given different curve radii and θ.

bend and 60° for a left hand bend (Figure 2). This shows the bend direction does have an effect on maximum corner velocity. The smallest bend a Fiat Punto can do has a radius of 5.5 m [3], giving a velocity of 10 ms^{-1} (22 mph) which is very fast for a radius, at which for reference, you would do a 3-point turn. The larger corner radii here would also require very high velocity for rolling, 30 ms^{-1} (67 mph) for a radius of 50 m. This shows that an extremely high velocity would be required to be the exclusive reason for rolling. In addition to this, at velocities of 30 ms^{-1} it is not reasonable to assume the roughly wedge shaped Fiat Punto would have no downforce produced, increasing the required velocity further.

Discussion of a Double Decker Bus

Next, the case of an old double decker bus was investigated. A London Route Master has a mass of 7500 kg, a height of 4.38 m, and width of 2.44 m [4]. It has 40 seats upstairs [4] which were filled with males of average weight 79 kg [2] to increase h, and the bottom left empty except the driver, also an average male. We assume the bus and passengers' mass is evenly distributed horizontally and estimate a h of 20% the bus' height and the passengers are averaged at 1 m below the roof. This gives a θ of 37° (Figure 2). At the bus' minimum bend radius of 7.7 m [5], it will topple at a velocity of 7 ms^{-1} (16 mph). This is likely faster than a bus driver would take a corner of this size. As a bus is close to a cuboid in shape, it would produce very little downforce. Therefore, the calculated velocities at larger corner radii would also be valid, and are also very fast 18 ms^{-1} (40 mph) for a 50 m corner.

Conclusions

As the height of the centre of masses were estimates, the numbers given are also estimates of the particular vehicles, but give an indication to velocities required for toppling. It was shown that the velocity needed to topple is dependent on the direction of a bend for small cars. Figure 2 shows that excessive velocity can, but is usually not, the sole reason for vehicles rolling. It is likely that when vehicles roll it is due in part, to uneven or reverse cambered surfaces, leaving the road, or a collision. When aerodynamics are taken into account it is likely the velocities required to roll on corners with larger radii will change, for this reason, future investigation into aerodynamics would be beneficial.

References

[1] `http://www.auto-data.net/en/?f=showCar&car_id=16758` [Accessed 7 October 2017]

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[5] `https://nacto.org/publication/transit-street-design-guide/intersections/transit-route-turns/turn-radii/` [Accessed 8 October 2017]