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A6_6 The Dark Knight Rises: The Physics of the 'Batman Forever' Batmobile

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Abstract

The vertical ascent of the batmobile from rest up the side of a building is assessed using Newtonian mechanics. We determine the required power to drive up a 26.25m building in 10s to be 20% of the engine's power. The batmobile is able to drive up the wall dependent on the strength of grip of the tires.

Introduction

In the film 'Batman Forever', Batman drives vertically up a building in his batmobile. Prior to the vehicle's ascent it is stationary, with its tires touching the wall, whilst it hangs from a wire attached to the building top. We consider whether the batmobile's engine has enough power to overcome the downward forces (due to gravity and drag) and drive up the building side.

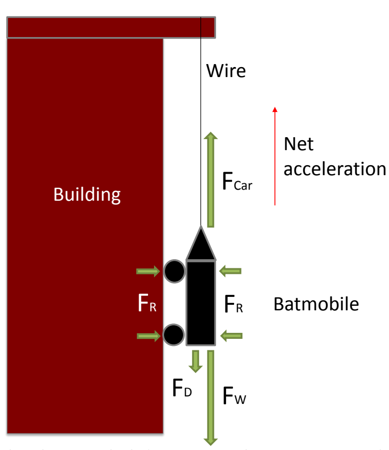

Figure 1: The batmobile's vertical ascent up the building. The green arrows represent the forces (except friction) on the vehicle: Car - Batmobile, D - Drag, W - Weight, and R - Reaction. Not to scale.

Theory

For the batmobile to accelerate up the building, its engine must provide an upward force that is greater than the downward forces (Figure 1). We assume that the object at the top of the building, to which the car's wire is attached, has the strength to hold the car stationary initially. Also, we assume that the light, inelastic wire recedes into the car when it moves upwards, hence the car is no longer reliant on tensile forces upon motion. Furthermore, we assume the tires touching the wall to have strong grip so that there are equating reaction forces between them. These reaction forces create perpendicular kinetic friction forces (vertically upwards) upon movement and prevent slipping [1]. We neglect the magnitude of the frictional forces in our calculations as the proportional reaction forces are assumed small in comparison to the other forces.

The batmobile scales a building of height $z =$ 26.25m in a time of $t = 10$s [2]. Batman's car must have an average velocity $v_{av} = z/t =$ 2.625ms^{-1} in the upwards direction. The drag force on the batmobile is a function of its velocity, so we calculate the average drag force for the ascent using the average velocity. The minimum force $F_{Car,min}$ required to drive up the building is equal to the summation of this average drag force (F_D, first product) and the weight of the vehicle and Batman (F_W, second product):

$$F_{Car,min} = \frac{1}{2}\rho C_D A v_{av}^2 + (m_B + m_{Car})g \quad (1)$$

where $\rho = 1.225\text{kgm}^{-3}$ is the air density [3], $m_B = 81.5\text{kg}$ is Batman's mass [2], $m_{Car} = 1810\text{kg}$ is the batmobile's mass [2], and g is the acceleration due to gravity. The drag coefficient of the batmobile is taken to match that of a Formula 1 car ($C_D = 0.9$) [4]. The surface area of the car in the direction of travel is estimated to be the product of a half of its height and width ($0.5 \times 3.2\text{m}\times 2.4\text{m}$) [2]. Only the lower half of the car is considered as the height takes into account the large fin on the car. The fin is assumed streamlined such that it has negligible drag.

The minimum power required by the batmobile for the ascent, $P_{Car,min}$, is equal to:

$$P_{Car,min} = \frac{F_{Car,min} z}{t} \quad (2)$$

which is the work done by the vehicle in the time taken to scale the side of the building.

Results

The batmobile requires a minimum force of $F_{Car,min} = 19\text{kN}$ and power of $P_{Car,min} = 49\text{kW}$ to drive to the top of the building from rest. The power of the car's engine is $P_{engine} = 246\text{kW}$ [5]. The power required to climb the building in 10s is 20% of the engine's power. The minimum time to reach the building top using all of the engine power is 2.0s, under the assumption of average drag force. This would differ if the drag force was calculated accurately as a function of velocity.

Discussion

The batmobile has the power to overcome downward forces and drive vertically up the building side of height 26.25m in 10s, and has so much power that it could drive this in as little as 2s. Errors are neglected as there is only uncertainty in the drag force, due to the approximation of the surface area. The drag force is only 0.08% of the net force, and so any errors calculated in the drag force will be miniscule once propagated through to the net force and power respectively.

The batmobile's power (246kW) [5] is much larger than that of a standard car (73kW for a 2010 Toyota Prius 1.8L) [6]. However, if the Prius were assumed to have strong grip tires and the batmobile's specifications, it could also climb the building using its maximum power. However, in both cases the assumption of strong tire grip is crucial as if the tire grip is weak, the reaction force with the wall will be negligible. There will be no friction between the tires and wall upon movement, causing the tires to slip as the wheels try to move. No power will allow the batmobile (or any other car) to climb the wall in this case.

An independent group deduced that this event requires a 28kN force. However, their method assumes that the car reaches its maximum velocity (148ms^{-1}) at the building top [2], which clearly the batmobile does not have the power for. We argue our method is more realistic, as we deduce the average velocity from the time for the event. Furthermore, the car's maximum velocity is likely to be achieved horizontally.

In conclusion, we prove that the batmobile has sufficient power to drive vertically up a building, dependent on constraints such as the event time and tire friction, and so the Dark Knight rises.

References

[1] P. A. Tipler and G. Mosca, *Physics For Scientists and Engineers* (Academic, New York, 2008), Vol. 6, pp. 129, 138.

[2] `goo.gl/MOiCgM` accessed 30 October 2016

[3] `goo.gl/xSvtfk` accessed 30 October 2016

[4] `goo.gl/yXy3QM` accessed 30 October 2016

[5] `goo.gl/dz48kY` accessed 31 October 2016

[6] `goo.gl/eGrkCW` accessed 8 November 2016