Journal of Physics Special Topics
An undergraduate physics journal

P5_5 Time Lord Trickery and the "anti-grav" Bike

T. Cox, K. Penn Fernandez, L. Mead, J. Seagrave

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 3, 2020

Abstract

In an iconic moment on the popular television show Doctor Who, the Doctor presses his "anti-grav" button before driving his motorbike up the side of the Shard skyscraper. We investigate whether this could happen in real life and discover that not only is it impossible, but it would also be impossible even if the gravitational force on the bike were somehow altered. We find that the Shard would need to have a minimum vertical incline angle of 74°, 68° less steep than it is currently, for the bike to have any chance to drive up it.

Introduction

In a motorcycle, the engine produces a torque which is transmitted and amplified through a series of gears until it is exerted on the wheels causing them to rotate. The combination of this rotation and the frictional force of traction between the wheels and the surface they are on propels the bike forwards. Where there is limited traction, the wheels slip [1]. In this scene of Doctor Who, if the motorbike can drive up the side of the Shard then the tractive force propelling the bike forwards must be greater than the component of the weight of the bike opposing its motion and this is what we seek to investigate in this paper.

Analysis

In this scene, the Doctor, played by actor Matt Smith who has a mass of 73 kg [2], rides a motorcycle known as the Triumph Scrambler 1200 which has a mass of 205 kg [3]. Summing these masses gives us a total mass, m, of 278 kg. The Shard is a skyscraper with an exterior made entirely of glass and with a vertical incline angle, θ, of 6°. The Doctor drives up to the 65th floor which has a height of 220 m [4] meaning, using basic trigonometry, he drives a distance, s, of 221 m. We assume the time taken for him to travel this distance, t, is 22 s as this is the length of time of the scene. As the bike moves, aerodynamic drag and rolling friction oppose its motion but these forces are significantly smaller than the other forces involved so for simplicity we will assume they are negligible in this paper. Assuming the initial velocity from the ground is 0 ms^{-1}, we can work out the acceleration of the bike, a, assuming it is constant using $s = 1/2at^2$ where we calculate a to be 0.914 ms^{-2}. Figure 1 shows the main forces exerted on the bike in this scene. For simplicity we can assume the mass distribution of the bike is about equal over both wheels. Using this assumption and the values for the forces in Fig. 1, we find the total maximum tractive force that can be exerted by the road on the wheels is

$$F_T = \mu_T F_N = \mu_T mgsin\theta, \qquad (1)$$

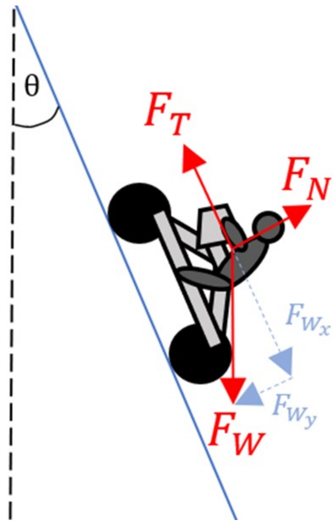

Figure 1: A diagram showing the main forces acting on the bike. F_T is the tractive force, F_W is the total weight of the bike and rider equal to mg where g is the acceleration due to gravity (9.81 ms^{-2}), F_{W_x} is the component of the weight opposing the motion of the bike equal to $mgcos\theta$, F_{W_y} is the component of the weight in the direction perpendicular to the motion of the bike equal to $mgsin\theta$ and F_N is the normal force exerted on the bike by the glass which is equal and opposite to F_{W_y}.

where μ_T is the coefficient of traction [1]. There is a lack of information in the literature on the coefficient of traction between rubber tyres and glass so we use the coefficient of static friction as this pair of coefficients are analogous, so we assume that μ_T has a value of 0.378 [5]. As F_T and F_{W_x} are the main forces affecting the ability of the bike to move, we can set the initial condition for the bike to move as $F_T > F_{W_x}$ which, using Eq. (1), can be simplified to

$$\mu_T sin\theta > cos\theta. \quad (2)$$

By rearranging Eq. (2), we can calculate that the critical angle for the bike to move is $\theta > 69°$ meaning the 6° angle of the Shard, would result in wheel slippage confirming that the Doctor could not drive up the Shard. We can also see that, because g has been cancelled from both sides of Eq. (2), even if the Doctor were able to somehow "switch off" or reduce gravity with his "anti-grav" button, the bike would still not drive up the Shard due to the lack of traction.

By equating all the forces causing or directly opposing motion, we find that the net force is

$$F_{net} = F_T - F_{W_x}. \quad (3)$$

Using Newton's second law ($F_{net} = ma$), Eq. (1) and standard trigonometric identities we can simplify Eq. (3) to become the simple quadratic equation

$$(1 + {\mu_T}^2)cos^2\theta + \frac{2a}{g}cos\theta + \frac{a^2}{g^2} - {\mu_T}^2 = 0, \quad (4)$$

with the only real applicable solution being θ=74°, a 68° difference from the current angle of the Shard. This means that this Doctor Who scene could only be possible if the vertical inclination angle of the Shard is $\geq$ 74° or if a new normal force were exerted to create more traction (e.g. with a jetpack/propulsion system on the back of the bike). We use an idealised model in this paper with many previously mentioned assumptions made as well as the assumption that no additional forces act on the bike when in reality it is a complex physical system with various non-uniform forces acting on it such as variation in the Doctor's weight distribution as he moves. However, using this simple model, we know from basic physics that it is impossible to drive up the side of the Shard with this particular motorcycle and we can make reasonable approximations as to how steep the angle would have to be for such a scenario to be feasible.

References

[1] https://en.wikipedia.org/wiki/Traction_(engineering) [Accessed 17 October 2020]

[2] https://healthyceleb.com/matt-smith/ [Accessed 17 October 2020]

[3] https://www.motorcyclenews.com/bike-reviews [Accessed 17 October 2020]

[4] http://www.engineering-timelines.com [Accessed 17 October 2020]

[5] E. H. Bani-Hani, J. Lopez and G. Mohanan, Data In Brief Volume **22**, 940 (2019).