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A1_1 Faster than a speeding bus

L. Allen, P. Edwards, J. Wynn

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

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Abstract

The film Speed portrays a bus making a large and seemingly unlikely jump between two sections of partially constructed freeway. This article investigates the feasibility of such a jump by determining what incline the road would need to be at for the bus to successfully make it across; finding that it would need to be at least 7.6 degrees, which is less than that shown in the film, however the energy of the impact would almost certainly damage the bus to the extent that it would no longer be capable of motion.

Introduction

In the film "Speed" (1994) a disgruntled former police officer attaches a bomb to a bus on its morning commute, rigged to explode if the bus' speed drops below 50 miles per hour (22.35 metres per second) [1]. This leads to a dramatic high speed drive through the city of Los Angeles, which at one point takes the bus up onto a partially constructed freeway. Seeing a gap in the road ahead the driver accelerates to the bus' maximum speed which is shown to be 67 miles per hour (29.95 metres per second)[1]. Of course the film doesn't end with the bus failing to make the jump and everyone dying, but we will examine the mechanics of the scene to determine if it is actually possible and under what conditions the bus could make such a leap.

Theory

Assuming that the end point of the jump is at the same elevation as the start then it is evident that if the road is completely flat the bus would not make the jump, because if any time passed it would end up at a lower point than where it started. Therefore, we can assume the road is inclined at an angle θ greater than zero, which can be calculated as

$$\tan\theta = \frac{V_x}{V_Y} \qquad (1).$$

Where V_x is horizontal velocity and V_y is vertical velocity. They can be found by

$$V_x = V\cos\theta \qquad (2)$$

and

$$V_Y = V\sin\theta \qquad (3).$$

Where V is the initial velocity up the ramp. To calculate θ we must examine both the horizontal and vertical components of the bus' motion.

In the horizontal component the bus has an initial velocity $V\cos\theta$ and is decelerating due to air resistance.

Deceleration can be calculated using the following equation

$$\frac{F_D}{m} = \frac{1}{2m}\,\rho V_X^2 C_d A = a \quad (4),$$

where F_D = force of the drag, ρ = density of air, V_x = velocity of bus in the horizontal component, C_d = drag co-efficient, A = Cross sectional area of bus, m = mass of the bus and a = deceleration due to drag.

We can sub this into the constant acceleration formula to get an expression for the horizontal motion of

$$x = tV\cos\theta - t^2\frac{1}{4m}\,\rho V^2\cos^2\theta C_d A \quad (5).$$

Where x = horizontal displacement and t is the time of flight.

By looking at the vertical component we can calculate the time the bus will take to return to its original elevation and thus the time it must cross the gap in.

Vertical drag can be neglected as the bus' motion follows a parabolic trajectory so at any point on its ascent up the arc, where drag is pushing down, there will be a point on the decent with an equal velocity where the drag pushes up with an equal force cancelling it out. The only situation where this would not be the case is if Vsinθ was greater than the bus' terminal velocity which was found to be

$$V_t = \sqrt{\frac{2mg}{\rho C_d A}} = 74.6 \text{ ms}^{-1} \text{ (6)}.$$

So even if the bus was launched straight upwards it would not reach terminal velocity. Hence we can neglect vertical drag.

So this gives an expression of vertical motion of

$$0 = tVsin\theta - \frac{gt^2}{2},$$

$$t = \frac{2Vsin\theta}{g} \text{ (7)}.$$

Subbing (7) into (5) will give us an expression for θ in known terms of

$$0 = \frac{2\sin\theta}{g} V^2 cos\theta - \frac{1}{mg^2}\rho V^4 sin^2\theta cos^2\theta C_d A - x \text{ (8)}.$$

Discussion

We now need to sub in the known values into (8). According to the International Standard Atmosphere the density of air at sea level is 1.225 kg/m^3 [2]. We know the velocity of the bus to be 29.95 metres per second [2]. We approximate the bus as a cuboid which gives a drag co-efficient of 1.05. [3] A standard single-decker bus has a cross sectional area of 2.5 m by 3.2 m assuming wheels are negligible, giving a value of *A* of 8m^2 [4]. The mass of the bus is taken to be 14400kg [5]. The horizontal displacement appears to be two bus lengths [1] which are 24 meters [5].

Subbing these values in gives the following expression of the bus' motion.

$$\frac{2\text{Sin}\theta}{9.81}(29.95)^2 cos\theta - 24 - \frac{1}{(14400)(9.81)^2}(1.225)(29.95)^4 sin^2\theta cos^2\theta (1.05)(8) = 0,$$

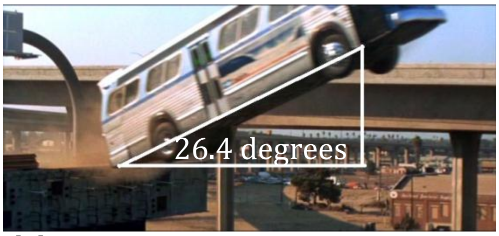
$$0 = 183\sin\theta cos\theta - 5.97 sin^2\theta cos^2\theta - 24,$$

$$\theta = 0.1333 \, radians = 7.6 \, degrees$$

This Gives the minimum angle necessary as 7.6 degrees.

Conclusion

We can see the actual angle of jump from the film



[1]

Which when subbed into (5) take the bus 71 metres which is more than enough.

So the jump shown in the film would be theoretically possible although it is unlikely that a freeway would have such a large incline as that shown. However it is likely that landing from the jump would cause significant damage to the bus as the kinetic energy of the bus in the vertical direction would be

$$KE = \frac{1}{2}mV^2 \text{ (9)},$$

$$= \frac{1}{2}(14400)(29.95 sin 26.4)^2,$$

$$= 1.27\text{MJ}.$$

Which although divided between two axels would damage them to the extent that they would cease to function causing the bus to drop below 50 miles per hour which would detonate the bomb and kill everyone anyway.

References

[1] Speed (1994) Jan de Bont (director)

[2]http://www.engineeringtoolbox.com/international-standard-atmosphere-d_985.html accessed 17/10/12

[3] http://www.engineeringtoolbox.com/drag-coefficient-d_627.html accessed 28/10/12

[4]http://www.scotland.gov.uk/Publications/2009/01/27140909/7 accessed 17/10/12

[5] http://www.alexander-dennis.com/product-details.php?s=82&subs=43&tableID=220&itemID=1 accessed 28/10/12