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P3_3 A Penny For Your Thoughts

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Abstract

In this paper we have discussed how much more massive the Earth would be and how the mass of a penny would change so that if it were dropped from the top of the Empire State building it could kill a passer-by below. We found that in order to be true the Earth would have to have a mass of 4.93×10^{28} kg and the penny would have terminal velocity of 172.8 ms^{-1} .

Introduction

It is a commonly believed myth that if a penny was dropped from the highest point of the Empire State building it could kill a person it made contact with at the base. This fact has been proven false in other literature [1]. The velocity of the penny is reduced significantly due to drag, meaning the force it exerts on impact is far below what would be required to kill someone [1]. However, if the Earth was more massive the penny would feel a greater force due to gravity and its terminal velocity would be higher. The following paper aims to calculate how much more mass the Earth would need for the falling penny to be lethal.

Theory

The force the penny can exert is limited by its terminal velocity, this is the velocity at which the force acting downwards due to gravity is balanced by the resistive force acting upwards due to air drag [1]. We assumed the penny would fall with its flat face down therefore, on Earth, the terminal velocity of a penny is approximately 11 ms^{-1} [2] and the force it would exert on impact can be calculated using Equation 1.

$$F = mv_T/t \tag{1}$$

Where F is the force exerted by the coin in N, m is the mass of the coin in kg, v_{T} is the terminal velocity of the coin and t is the contact time between the penny and the persons head. We use v_{T}= 11 ms^{-1} and m = 2.5 g, the mass of a US penny [3]. We assume that the impact is similar to that of a hard ball hitting a solid floor thus giving a contact time of t= 6ms [4]. This means the penny will exert of a force of 4.58 N. Assuming that a fractured skull will be fatal for the recipient, the penny must exert 73 N on impact to kill someone, as a human skull will fracture under roughly 73N of force at its strongest point[5]. We rearranged Equation 1 to make the velocity the subject and used a force of 73 N to give a value for velocity of 172.8 ms^{-1}.

Using the new terminal velocity, we calculated the force due to drag on the penny as this is equal to the force due to gravity at terminal velocity. We used the drag equation which can be seen in Equation 2.

$$F_D = (\rho C_D A v^2)/2 \tag{2}$$

Where F_D is the force due to air drag in N, v is the velocity of the penny in ms^{-1}, ρ is the density of air in kgm^3, c_D is the coefficient of drag on a penny and A is the area of the penny in m^2. The force due to drag is equal to the force due to gravity at terminal velocity thus we used a force of 73 N, a radius of 9.05 mm [3], a density of 1.2 kgm^{-3} [8] and drag coefficient of 1.17 [9]. We calculated the force due to drag as 201.7 N. This means the force due to gravity on the hypothetical Earth is 201.7 N. This force due to gravity on the penny is equivalent to the weight of the penny.

Using this new weight and Equation 3 we calculated the mass of the hypothetical Earth.

$$M = F_g r^2 / Gm \tag{3}$$

Where M is the mass of the hypothetical Earth in kg, G is the gravitational constant, F_g is the weight of the penny in N and r is the radius of Earth in m. Using Earth's radius, 6.4×10^6 m [6], the gravitational constant, 6.7×10^{-11} $m^3kg^{-1}s^{-2}$[7] and the previously calculated force of 201.7 N we calculated the mass of the hypothetical Earth to be 4.93×10^{28} kg. Using the fact that the true mass of Earth is, 6×10^{24} kg [6] we calculated the hypothetical Earth to have a mass 8220 times greater than the current mass of Earth.

Discussion

We have shown that the Earth would need to be 8220 times more massive for the penny to exert enough force to kill someone. This is a higher value than expected and highlights just how incorrect the claim is. This is also highlighted in the terminal velocity that was calculated, $v=$ 172.8 ms^{-1}, this is over 10 times the terminal velocity of the penny on the true Earth. A few assumptions have been made in this paper which leaves room for future work. For example, wind was not taken into account when calculating the penny's velocity and that the human skull has the same strength at all points. If both these factors were considered a more accurate calculation could be done depending on wind speeds and where on the head the penny impacted.

Conclusion

To conclude, for a penny dropped from the empire state building to kill someone, it would have a terminal velocity of 172.8 ms^{-1} and the Earth would need to be 8220 times more massive. Not only has this paper shown the original claim the be false but it has shown the extent of just how implausible it is. In reality the penny would cause little more than a slight pain as it impacted someone's head. Possibilities for future involving a more accurate, true to life, model as have been discussed in the above section.

References

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