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P1 7 A Superhuman Jump

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Abstract

This paper calculates the force required for Mario to jump in close proximity to a black hole, as shown in Super Mario Galaxy. This value, F_J, was found to be 6.67×10^{16} N. We applied this value to a similar jump on Earth and determined that the velocity when Mario leaves the ground is 4.54×10^{7} ms^{-1} or approximately 0.15 c. This value is significantly higher than Earth's escape velocity indicating Mario would never return to Earth if he jumped on the spot.

Introduction

Black holes are a common danger found throughout various worlds and levels within the Super Mario Galaxy game[1], with Mario regularly walking and jumping near them or falling into them. This paper investigates the force required for Mario to jump in the presence of a black hole as shown in Super Mario Galaxy gameplay[2] and how this relates to what would happen if he was on Earth.

For the purposes of this paper, since he is not moving at a relativistic speed in the game when next to the black hole, we can use Newtonian gravity as a good approximation. In addition to this, we have ignored any effects of air resistance or friction on Mario.

Method

Firstly, to determine Mario's total jump force, F_J, we have added the upwards resultant force, ma_1, to the force required to overcome his weight in the gravitational field of the black hole as shown in Equation 1.

$$F_J = ma_1 + \frac{GM_{BH}m}{r^2} \tag{1}$$

Here, Mario's mass, m, is 50.0 kg[3], a_1 is Mario's acceleration in ms^{-2} in the presence of the black hole which is calculated later in the paper, G is the Gravitational constant, M_{BH} is the mass of the black hole in kg, and r is the distance in m from Mario to the centre of the black hole. Given Mario's height is 1.55 m[3], and using the gameplay, we have approximated the distance from Mario to the centre of the black hole, r, to be 5 times Mario's height or 7.75 m[2].

In order to find a value for F_J, we made a two step substitution for a_1 and M_{BH}. Firstly we rearranged the constant acceleration equation shown in Equation 2 into the form given in Equation 3.

$$x = v_0 t + \frac{1}{2}a_1 t^2 \tag{2}$$

$$a_1 = \frac{2x}{t^2} \tag{3}$$

Here, x is Mario's vertical displacement as he extends his legs from crouching to standing up in preparation for jumping. We can assume this value is approximately 0.775 m from half of his height. The term v_0 is the initial velocity which has a value of 0 ms^{-1}, and t is the time taken to move from a crouched position to standing up before he leaves the ground which is 0.0670 s measured from gameplay[2].

Next, Equation 4 was rearranged to give Equation 5 to provide a substitution for M_{BH}. Here, r_s is the radius of the black hole, which is 1.15 times Mario's height[2] from gameplay or 1.78 m, and c is the speed of light in $\mathrm{ms^{-1}}$.

$$r_s = \frac{2GM_{BH}}{c^2} \tag{4}$$

$$M_{BH} = \frac{r_s c^2}{2G} \tag{5}$$

By substituting Equation 3 and Equation 5 into Equation 1, we simplified this to form a new equation to determine a value for F_J as shown in Equation 6.

$$F_J = m\frac{2x}{t^2} + \frac{r_s c^2 m}{2r^2} \tag{6}$$

Using a mass, m, of 50 kg, displacement of crouch to standing, x, as 0.775 m, time taken from crouching to standing, t, of 0.067 s, c is the speed of light, r is 7.75 m, and r_s is 1.78 m we have determined that the force Mario outputs when he jumps, F_J is 6.67 x 10^{16} N.

After calculating F_J, we compared this to what would happen on Earth if Mario were to jump in place vertically upwards. To calculate Mario's jump height on Earth, we first determined his launch velocity, v_1, as he leaves the ground from standing using Equation 7.

$$v_1^2 = v_0^2 + 2a_2x \tag{7}$$

Here, v_0 is the initial velocity of 0 $\mathrm{ms^{-1}}$ whilst Mario is crouched, x is 0.775 m or half of Mario's height as stated earlier, and a_2 is the new acceleration as Mario extends his legs on Earth which can be calculated using Equation 8.

$$F_J - mg = ma_2 \tag{8}$$

By substituting the required values into Equation 8 such as the force Mario outputs when he jumps, F_J, which is 6.67 x 10^{16} N, Mario's mass, m, of 50.0 kg, and the force of gravity, g, 9.81 $\mathrm{ms^{-2}}$, the value for a_2 was calculated to be 1.33×10^{15} $\mathrm{ms^{-2}}$. This in turn was used to determine the launch velocity, v_1, in Equation 7, giving a value of $4.54\times10^{\ 7}$ $\mathrm{ms^{-1}}$ or approximately 0.15 c.

Conclusion

Our calculations show that the resultant force Mario outputs when he jumps, F_J, in close proximity to a black hole, as shown in Super Mario Galaxy is 6.67×10^{16} N. Whilst this is an incredibly large value, we can show just how impressive this would be by drawing a comparison to Earth conditions.

It was calculated that if Mario were to jump on Earth with the same force as in the game where he jumps on the spot, the velocity, v_1, he would have when leaving the ground is $4.54\times10^{\ 7}$ $\mathrm{ms^{-1}}$ or approximately 0.15 c. This value is significantly greater than Earth's escape velocity of 11.2 $\mathrm{kms^{-1}}$[4], meaning Mario would never return to the ground if he jumped on Earth.

References

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