Journal of Physics Special Topics
An undergraduate physics journal

P5_1 How Far Did Gandalf Fly...You Fools?

M. Sharman, G. Knott, B. Rayson, D. Molloy

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

December 13, 2022

Abstract

In the Lord of the Rings, there is an infamous scene in which Gandalf fights the Balrog of Moria, ultimately causing the pair to fall from the bridge of Khazad-Dûm. This report contains the fundamental physics required to establish the height from which Gandalf fell, and whether he could have survived. The necessary calculations are carried out in Python using an iterative model to continually update position and velocity values, providing the most accurate result. Using this model we were able to arrive at a bridge height of approximately 3800 m and decided it would be possible for him to survive this fall.

Introduction

In The Lord of the Rings, there is a sequence in which Gandalf fights the Balrog of Moria on the bridge of Khazad-Dûm. During this scene, Gandalf and the Balrog fall from the bridge into the water at the base of the chasm. Initially, the Balrog falls as the bridge is destroyed, and Gandalf falls a few seconds later after being tripped. He can be assumed to fall from rest.

We have split the fall into two stages lasting a total of 83 s. In the first 18 s, Gandalf is falling head-first to catch up to the Balrog. In the last 65 s, Gandalf rides the Balrog as they fall, until they land in the lake below [1].

Method

Using Peter Jackson's movie adaptation, we will assume that Gandalf is approximately 1.8 m tall. Gandalf is described as a Maia and, since they are humanoids, we will assume the average height-to-weight ratio is the same as humans. For our model, we have estimated Gandalf weighs around 80 kg. We estimated the height of the Balrog to be 3.5 m by comparing it to Gandalf in the scene. It would be difficult to accurately find the mass of the Balrog so we have used what we feel is a reasonable estimate of 250 kg based on its size in the scene. We have assumed the acceleration due to gravity and air density are the same for Middle Earth as our Earth (these being $g = 9.81$ ms^{-2} and $\rho = 1.225$ kgm^{-3}).

At all times during his fall, he is being acted on by two forces: acceleration due to gravity and drag due to air resistance. There is another force when he collides with the Balrog which acts in the instant of the collision. This is accounted for using Equation 1 to find velocity directly after collision (G denotes Gandalf, B for Balrog). We calculated the drag force using the drag equation and then combined this with the force due to gravity to find the net force at each time step in our model.

$$v_{new} = \frac{m_G v_G + m_B v_B}{m_G + m_B} \tag{1}$$

$$F_{drag} = \frac{1}{2}\rho v^2 C_D A \quad (2)$$

$$F_{net} = -F_g + F_{drag} \quad (3)$$

where $F_g = mg$.

The drag coefficient (C_D) of a human falling head-first is approximately 0.7 [2], so we used this for the first phase of the fall. We treated the Balrog as humanoid, therefore ignoring the drag from its wings, and assumed it was mainly falling on its back. This gives a drag coefficient of 1.0 for the second phase of falling [2]. We estimated the area (A) of Gandalf falling head-first as $0.5 \times 0.2 = 0.1$ m^2, and the area of the Balrog as $3.5 \times 1 = 3.5$ m^2.

At each time step, the new vertical position is calculated using Equation 4, and the new velocity is found using Equation 5.

$$x_2 = x_1 + dtv_1 \quad (4)$$

$$v_2 = v_1 + dt\frac{F_{net}}{m} \quad (5)$$

These two values are then exported to a file, and then the same calculations are done for the next time step (dt).

Results and Discussion

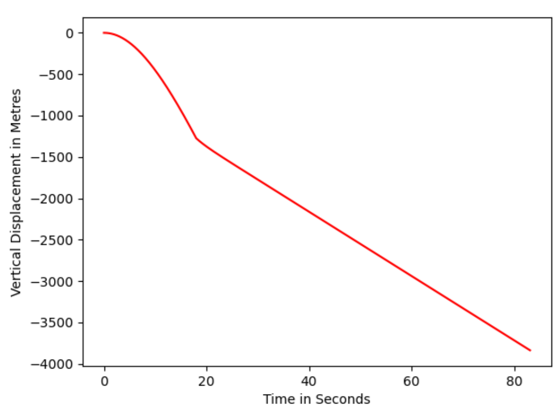

Figure 1: Graph showing the distance fallen by Gandalf with respect to time.

When these results are plotted on a graph of distance fallen against time (Figure 1), we find that Gandalf fell 3840 m (3 s.f.). Figure 2 shows his velocity at the end of the first phase is higher than in the second phase. This is because the Balrog has a lower terminal velocity, which was reached beyond the ~30 s mark.

This also shows that Gandalf impacts the water at approximately 39 ms^{-1}. Solving the drag equation for a human at terminal velocity ($F_{drag} = F_g$) gives $v = 42$ ms^{-1}. There have been cases of humans surviving falls from cruising altitude of aeroplanes, with the highest recorded fall being 10,160 m by Vesna Vulovic [3]. Since Gandalf is actually a Maia and not a human, his capability to survive may be much higher.

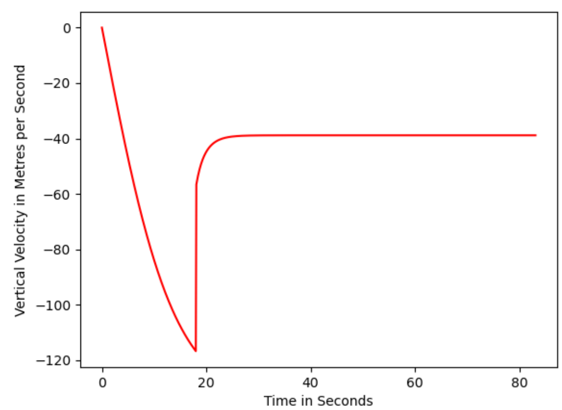

Figure 2: Graph showing the relationship between the vertical velocity of Gandalf with time

Therefore it is technically plausible for Gandalf to survive the impact with the water from this height.

References

[1] *The Lord of the Rings: The Two Towers* (2002) [Film]. New Line Cinema.

[2] URL: https://owlcation.com/stem/Drag-Force-and-the-Terminal-Velocity-of-a-Human.

[3] URL: https://www.guinnessworldrecords.com/news/2022/4/how-vesna-vulovic-survived-the-highest-fall-ever-with-no-parachute-697786.

All websites accessed on [31/10/2022].