

Examining the Physics of the Video Game *Dark Souls<sup>TM</sup> II*

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A capstone report submitted to the faculty of  
Brigham Young University  
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Bachelor of Science

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## ABSTRACT

### Examining the Physics of the Video Game *Dark Souls<sup>TM</sup> II*

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I studied the Newtonian physics present in the video game *Dark Souls<sup>TM</sup> II* to examine its realism. This study determined multiple physical parameters through experiments done in the game, allowing this project to serve as an example of how video games might be used to practice physics reasoning, experimentation, and equations. The project centered around discovering the fundamental constants used in the game's world and the realism of the player character's physical capabilities. These were found by performing experiments involving actions the player character could take, such as their velocity when jogging, gravitational acceleration when falling, and their ability to throw or move objects. Overall, the player character performed at average to above average human capabilities in most cases, though there were notable outliers. In one case, the player can survive a fall of 410 m, nearly the height of the Empire State Building. Meanwhile, falls much shorter elsewhere in the game are harmful or fatal. Lastly, despite wielding common medieval weapons normally, the player can also wield a variety of exaggeratedly large weapons with moderate effort. The most extreme of these, called the Smelter Hammer, would weigh approximately 2,550 kg (5,620 lbs.), or about as much as a car. The game world's gravity also behaved differently from real life in two major cases. The first was the player's falling acceleration. I found this to be  $-20.6 \text{ m/s}^2$ , over twice what it would be on Earth. This acceleration is three times that for projectiles in the game, which have an average acceleration of  $-6.95 \text{ m/s}^2$ . I also present these experiments and results in two videos, with another two in progress.

Keywords: Scientific reasoning and problem solving, Experimental techniques, Determination of fundamental constants, Fundamental physics, Kinematics

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# Chapter 1

## Introduction

Physics students face a major challenge in their study of physics: gaining the intuition to solve multifaceted physics problems. This includes understanding physical interactions in the problem's context, identifying what is known and unknown, solving for what is unknown using applicable equations, and recognizing whether such an answer is reasonable. In classes, abstract problem sets help in beginning this process, but true understanding of how to apply physics in other contexts still takes more practice. Unfortunately, students are becoming less familiar with the real world, which would make application to real life easier [1]. Experimental physics classes, on the other hand, help students gain applicable physics understanding through hands-on work and scientific trials. And yet, a focus on experimental physics also poses its own challenges. Most experimental setups are only available with physics lab equipment that may be expensive or unobtainable outside the classroom. Not to mention, there can still be a disconnect between practical applied physics learned in labs and theoretical physics learned in lecture-focused classes.

In recent years, educators have begun to investigate the uses of video games as potential physics teaching tools [1]. One of the most popular examples of this is the sandbox-style game *Minecraft* [2] and its more specialized version for use in school settings, *Minecraft: Education Edition* [3,4]. In these sandbox games, it is easier for instructors and students to create and customize experiment

setups for testing within the game. Then, students can investigate physics behavior through video analysis and applying physics equations to the footage, as in a 2009 paper analyzing the physics of the game *Line Rider* [5]. More advanced tools also allow for data gathering in real time using the game's own source code, as in this 2024 study of *Fortnite* with "physics islands" for students to experiment in [6]. Whether through analyzing footage manually or using a computer program to assist with analysis, educators are finding ways for video games to help blend experimental and theoretical physics education.

In this project, I performed a similar analysis of the physics in the PlayStation<sup>®</sup> 4 (PS4<sup>™</sup>) version of the video game *Dark Souls<sup>™</sup> II: Scholar of the First Sin* by FromSoftware, Inc. I chose this game out of my familiarity with it and a likely connection between the game's difficulty and the realism of the game's physics. *Dark Souls<sup>™</sup> II* takes place in a dark fantasy world and is renowned for its high difficulty, where most opponents are as strong or stronger than the player. In addition, the player character, a human, appears to have more realistic mobility than most other video game characters in similar games. For example, the player's movement does not involve superhuman powers, such as flight or double jumping in midair, and most equipment is similar to medieval-style weapons and armor, with notable exceptions. The game's difficulty and player character's limited mobility led me to hypothesize that the game's difficulty came from the player having average human abilities and realistic physical interactions with this fantasy world.

I analyzed the physics of *Dark Souls<sup>™</sup> II* by applying equations and experimentation methods learned in physics classes. Most equations were taken or modified from the online OpenStax textbook *University Physics Volume 1* [7]. In this project, I gathered and examined footage manually rather than using a program to draw information from the game's source code. In my experiments, I focused on examining the realism of the game's Newtonian physics, especially as it relates to the player character. By "realism," I mean similarity to Earth's physics when describing the game world.

When describing the player character's physical capabilities, "realistic" means within average to professional adult human athletic ability.

During this project, I was largely in control of the player character's motion on the ground. For example, I could choose where to have the character stand, when and where to aim and throw objects, and whether to move laterally or jump. But I could not adjust the game world nor its physics, such as how quickly the character falls after stepping off a platform nor how high or large that platform is. If I needed to perform an experiment, I had to find suitable locations within the established game world using character actions programmed by the game's developers. I could not build my own locations to test with, but I could bring the player to any location accessible through normal player actions, such as walking, climbing ladders, or jumping. This included using checkpoint locations called "bonfires" as places the player could "teleport" to. This was done for convenience instead of having the character run everywhere. Again, these bonfires were placed by the developers, not by me.

The main goals of this project were to determine fundamental constants of the game's world and the physical capabilities of the player character. To determine this information, I performed tests centered around understanding the player's horizontal and vertical kinematics, their strength, and the behavior of projectiles they throw. The measurements from these tests helped determine aspects of the world the player interacts with and vice versa, such as taking a known height and determining gravitational acceleration then using that acceleration to calculate the height of tall buildings. As an analogy, this is similar to sending a rover to another planet to examine how it differs from Earth. Just as tests on that planet would depend on the dimensions, capabilities, and perspective of the rover, so too did my experiments in the game world depend on the player character and the information I could derive through these experiments.

Overall, the character's athletic abilities tended toward being above average, though rarely more than within the achievements of past athletes. Two cases of extremely unrealistic physical

capabilities appear, though. For one, the player character can survive the longest fall in the game, which is as tall as a skyscraper, without any harm. Even much shorter falls can be fatal in the game elsewhere. And second, certain weapons would require superhuman strength to even lift, let alone wield in any practical way. I studied the most extreme example in the game: a giant iron hammer weighing as much as a car. The player is not only able to lift this and carry it around with moderate effort, but they can swing it at speeds matching cars on the freeway.

In addition to this report, I made videos presenting the experiments and results involved with the project. Those unfamiliar with the game may find them especially helpful in visualizing the experiments and results obtained. So far, I have made two videos which examine horizontal and vertical motion. I am working on a video for projectile motion and another video for rotational motion as well. The completed videos are linked below:

- *Dark Souls 2 Physics: Units & Horizontal Motion*: <https://www.youtube.com/watch?v=eoi-1YCsOrE>
- *Dark Souls 2 Physics: Vertical Motion*: <https://www.youtube.com/watch?v=ywiGh5RnXLo>

# Chapter 2

## Methods

In this chapter, I will explain the methods I used to perform experiments and calculate values used for the physics in *Dark Souls<sup>TM</sup> II*.

For all experiments, I recorded gameplay footage using the onboard video and image recording software of the PS4<sup>TM</sup> console. Then, such footage was compiled and examined at a maximum precision of 1/30 of a second due to the technical features of SHAREfactory<sup>TM</sup>, which is a video editing software available for the PS4<sup>TM</sup>. To account for slight differences in tests, such as paths followed and when time was counted, I included an uncertainty of 1/15 second (2 frames) on time measurements. This was done to distinguish significantly different time measurements from similar values in decimal form. For time measurements,  $t=0$  was taken as when the player character's animations reach a point relevant to the physics concept being studied in each experiment. As an example in studying projectile motion, the time would start as soon as a thrown object leaves the player's hand but not include their wind-up animation before throwing.

Distance measurements required an in-game measuring standard. For this, I used the player character's own height of 1.7 m [8]. From that height, several other physical parameters could be determined through calculations or manually measuring objects on screen with a ruler compared to the player. This included bridge lengths, ladder heights, player running speed, and so on. The main

Newtonian physics topics studied in the game were horizontal and vertical kinematics, projectile motion, and rotational motion.

All experiments were done within normal gameplay parameters as well. There were no modifications made to the game’s code, nor did I examine the code myself. This meant I was limited to wherever the player can normally go and camera angles possible from a third-person perspective roughly centered on the player or a first-person perspective from the player’s view. Many experiments would have given clearer results with a camera angle perpendicular to the experimental setup, like what was done in the *Fortnite* study [6], but this option was unavailable to me. This approach of not examining the game’s code allowed for greater focus on the physics process rather than just getting the correct values, as Allain and Williams also observed [5].

## 2.1 Horizontal Motion

For horizontal motion, I measured the player’s step length at full stride first. By equipping a helmet called Pharros’ Mask, the player left footprints on the ground, allowing steps to be measured reliably. This was done in a tiled plaza outside the Cathedral of Blue area with a flat surface and small tiles for comparison, as inspired by an online post trying to establish similar measurements in the game [9]. With a helmet called Pharros’ Mask equipped, the player character was magically soaked in water, allowing the character to leave behind footprints. These footprints could be measured in proportion to the character’s known height of 1.7 m as the player walked perpendicular to the camera. An example of this is shown in Figure 2.1. The player’s step length  $l$  was calculated with this equation:

$$l = 1.7 \frac{l_m}{h_m}, \quad (2.1)$$

with  $l_m$  and  $h_m$  being the player’s respective step length and height as measured on the television screen. This allowed me to calculate the player’s step length to height ratio and then convert it to



**Figure 2.1** Side view of the player during a jogging stride at the plaza next to the Cathedral of Blue. The red arrows point at the front of the footprints the player leaves with each step. Note that both footprints are slightly ahead of the player's foot position, but the spacing between footprints is consistent between strides.

meters in the game world, regardless of screen size. Next, I had the player walk away from the camera in a straight line so that a top view could be taken of the tiles' length. These tiles were then useful in measuring the length of a melee weapon called the Smelter Hammer, which is examined in Section 2.4 Rotational Motion.

Once I established the character's step length, I then performed tests in a larger area so that the player could take more steps, and thus I could find better average velocities. This new area was an iron bridge shown in Figure 2.2. It is found next to the Ironhearth Hall bonfire in the Iron Keep area. By running across the bridge, its length could be determined from  $N$  number of steps taken times the walking step length  $l$ . This bridge length, combined with the time  $t$  it took to walk or sprint



**Figure 2.2** Back view of the player jogging across the bridge used for testing in the Iron Keep. The player is currently in a large, square section of the bridge while heading toward a narrower section with regular panels. Another such section of panels is found on the other side of the bridge behind the player.

across the bridge, allowed me to determine the player's walking and sprinting velocities  $v^1$  through the equation:

$$v = \frac{Nl}{t}. \quad (2.2)$$

---

<sup>1</sup>The player character has an attribute called "equipment load" which is shown as a percentage. This indicates the weight of equipment they can carry without restricting their mobility. Through the test methods above, I confirmed that jogging and sprinting velocities are unchanged at equipment loads of 100 percent or less, but they decreased above 100 percent. As such, the walking and sprinting velocity results in this project are for loads below 100 percent to maintain consistency.

## 2.2 Vertical Motion

Studying vertical motion began by finding the heights of platforms the player could fall from. The most convenient way was to compare the player's height to a nearby ladder to find the number of rungs tall the player is  $n_r$ . From this, I could derive the distance from one rung to the next  $h_r$ . Then, I multiplied this distance by the number of rungs in the ladder  $N_r$  to calculate the height of the ladder  $h_l$  as follows:

$$h_l = h_r N_r = \left( \frac{1.7}{n_r} \right) N_r \quad (2.3)$$

Having the known height of a ladder allowed me to use the kinematic equation

$$h = v_0 t + \frac{1}{2} a t^2 \quad (2.4)$$

to solve for the player's gravitational acceleration  $a$  after substituting in the ladder height  $h_l$  for  $h$  in Equation (2.4).

Then, I set the player character to stand at the top of platforms next to ladders and move laterally to fall off without any initial vertical velocity. This allowed me to set the initial vertical velocity  $v_0$  as zero and rearrange (2.4) as follows:

$$a = \frac{2h_l}{t^2}. \quad (2.5)$$

These platforms were in four locations: two next to the Ironhearth Hall bridge in the Iron Keep and the top of the pit in Majula to the bottom of the medium and long ladders there. I then measured the time until the player landed  $t$  at each of these locations. Once I calculated the average acceleration from these falls of known heights, I turned my attention to longer falls that did not have ladders.

Instead of using ladders to determine the heights of these falls, I used the gravitational acceleration to then solve for their heights. However, in extremely long falls, the player appeared to reach terminal velocity after a time, complicating the process to calculate fall heights. To confirm how the player's falling velocity behaves, another test was performed in a tall building called the Brume



**Figure 2.3** A view of the Brume Tower's interior as the player is falling. The player is near the bottom of the screen wearing mostly white for visibility. I used the bronze columns extending from near the top corners downward to estimate the player's position while falling. Note especially the varying widths of the rings making up the columns. In gathering data, I counted the start of a section as when one of the widest rings reached the top of the screen, such as at the top of the rightmost bronze column in the photo.

Tower. As the player falls in the building, several metal columns with distinct sections pass by in the background. By counting the time to pass each section, the pattern of distance fallen and falling velocity were found. Figure 2.3 is a photo of the Brume Tower's interior while the player is falling in this experiment.

After plotting this data, I created several comparison plots using Python's Matplotlib package to examine which matched both the distance and velocity data best. Three models were examined: falling with air resistance, no air resistance, and no air resistance with sudden terminal velocity after reaching the last position and velocity data point at 3.07 seconds. I tested these three models to see exactly how the player's falling mechanics work. This came from my hypothesis that incorrect models would not match the position or velocity data, but the actual model would line up with both the position and velocity data. The equations used for the linear air resistance models are shown below, as taken from page 53 in the textbook *Classical Mechanics* [10], though each was multiplied by -1 to represent downward motion. The position is represented by  $y_{ar}$  in Equation (2.6), and the velocity is represented by  $v_{ar}$  in Equation (2.7).

$$y_{ar}(t) = -v_{ter}t - (v_0 - v_{ter})\tau(1 - e^{-t/\tau}) \quad (2.6)$$

$$v_{ar}(t) = -v_{ter} - (v_0 - v_{ter})e^{-t/\tau} \quad (2.7)$$

In both equations,  $v_{ter}$  is the terminal velocity, which is reached in a characteristic time  $\tau$ , and  $t$  is the time that has passed after the player started to fall.

Since the air resistance model matched both the position and velocity data best, it would be preferred for finding fall heights. Due to time constraints, I did not find the constants required to calculate the player's in-game fall heights with air resistance, though. Instead, I took the average of the no air resistance models with and without a terminal velocity, since this provided a close match to the model with air resistance. The sample data from the fall tests compared to the best fit models are shown in Figure 3.3 in the Vertical Motion section of the Results chapter. For the air resistance models, I used  $\tau = 3.07$  since the player appeared to reach terminal velocity by 3.07 seconds from the data and footage.

To calculate heights with these two models, I again used Equation (2.4) to find the height of falls. For the model without terminal velocity, this was the only equation used to find these heights.

Since the player started falling with no initial vertical velocity due to falling after moving laterally,  $v_0 = 0$ . This gave the first model's fall height as follows:

$$h_1 = \frac{1}{2}at^2 \quad (2.8)$$

The second model, which included terminal velocity, also required using  $v_{ter} = v_0 + at$  to find the terminal velocity after 3.07 seconds of falling. Again,  $v_0 = 0$ , so  $v_{ter} = at$ . The combined height of falling with constant acceleration and then at terminal velocity,  $h_2$ , was found as follows.  $t_1$  was the time from starting the fall to terminal velocity and  $t_2$  was the time from terminal velocity to landing:

$$h_2 = \frac{1}{2}at_1^2 + vt_2. \quad (2.9)$$

These two models' calculated heights were then averaged together to give  $h_{avg}$ , the best approximation to the air resistance model's predictions:

$$h_{avg} = \frac{h_1 + h_2}{2}. \quad (2.10)$$

## 2.3 Projectile Motion

Projectile motion combined the methods from the horizontal and vertical kinematics experiments to determine the gravitational acceleration and velocities of thrown projectiles. These included throwing knives, urns, and fireball spells which travel in parabolic arcs. Due to the limitations of the game's camera, finding the precise angle of throws was impractical. As such, whenever possible, the camera was positioned so the player would throw objects horizontally and eliminate additional angles from calculations. The exception to this came from objects thrown diagonally upward like shot puts. For these objects, time counting was started when the objects reached the top of their arcs. I performed horizontal velocity tests at the Iron Keep's bridge, and vertical acceleration tests at a nearby platform to give space for full throwing arcs. Small columns found nearby allowed for



**Figure 2.4** A demonstration of the player throwing an object from a raised platform in the Iron Keep to test projectile motion. The player is throwing a fireball away from the camera in this case, and part of the fireball's path can be seen in the shadow to the left of the player's head. Several more realistic objects such as urns and knives also had parabolic trajectories and were studied using projectile motion principles. Since summoning fireballs is a form of magic in the game, I do not have an explanation for why they follow a parabolic trajectory like these other objects.

height measurements relative to the player and camera alignment for consistent aiming. In Figure 2.4, I show an example of throwing a fireball spell in this location.

After finding the horizontal and vertical behavior of the projectiles, I found the magnitude of their total velocity  $v$ . I combined the projectiles' horizontal and vertical velocity components,  $v_x$  and  $v_y$ , respectively, in this form to find  $v$ :

$$v = \sqrt{v_x^2 + v_y^2}. \quad (2.11)$$

$v_y$  was taken as the projectile's vertical velocity just before impact with the ground.

## 2.4 Rotational Motion

The rotational motion tests centered around a melee weapon called the Smelter Hammer. It is a solid lump of iron about the size of the player. Its volume was approximated by combining two measurement techniques. To establish the length of the hammer in the game, it was placed horizontally and compared to the tiles on the ground in the plaza next to the Cathedral of Blue. The size of these tiles had been found after determining the player's step length. Next, the Smelter Hammer's proportions were estimated by taking measurements of a side-view image of the hammer in Google Slides. Line segments were placed onto the image to determine the relative dimensions of the hammer, as shown in Figure 2.5.

After taking these measurements and establishing the proportions of the hammer, I approximated its volume by calculating the volume of a cone and a hemisphere with the same proportions as the Smelter Hammer. At its widest point, the hammer's diameter was  $2/7$  of its length  $L$ . The hemisphere and cone would meet at this point, making their radius  $r = L/7$ . To better follow the hammer's shape and avoid air being included in the hammer's volume, I excluded the handle by taking  $4/5 L$  as the height of the main mass of the hammer since the handle had a length of  $1/5 L$ . Since  $1/7 L$  is included in the hemisphere and  $1/5 L$  is excluded due to the handle, this means the cone's height is  $23/35 L$ . The hammer's mass  $m_H$  was calculated with the following equation, assuming the hammer is solid iron with a density  $\rho$  of  $7,860 \text{ kg/m}^3$ :

$$m_H = \rho(V_{\text{hemisphere}} + V_{\text{cone}}) = \rho\left(\frac{2\pi r^3}{3} + \frac{\pi r^2}{3}\left(\frac{23}{35}L\right)\right). \quad (2.12)$$

After substitution of  $L/7$  for  $r$  and simplification, we obtain the following equation for the mass of the Smelter Hammer  $m_H$ :

$$m_H = \frac{11\pi L^3}{1715}. \quad (2.13)$$

One of the moves the player can perform with this hammer is a whirling spin attack resembling an exaggerated baseball bat swing. During the move, the player holds the hammer horizontally



**Figure 2.5** A side view of the Smelter Hammer held by the player character in the Majula area. Note the hammer's exaggerated size compared to the player character. The red, blue, and gray lines were drawn in Google Slides to estimate the hammer's length-to-width ratio so its volume could be calculated. The red line estimates the length of the whole hammer, and the gray lines outline a cone-shaped section of the hammer. As shown here, the mass would be overestimated if the area surrounding the handle were included in the hammer's volume. Background image source: <https://www.fandomspot.com/ds2-best-strength-weapons/>



**Figure 2.6** A demonstration of the start and end of the Smelter Hammer's exaggerated spin move at the Iron Keep bridge. In the top image, the player is mid-rotation during the first of three spins, with motion blur showing part of the hammer's path. The bottom image shows the player lying prone after being carried forward by the hammer's momentum following the third rotation. There are several user interface features visible in the image corners as well. The green-and-yellow bar in the top-left of the top image shows the remaining energy of the player to perform actions, referred to as "stamina" in the game. In the bottom image, this bar is completely empty, conveying the effort required to swing the hammer this way.

while rotating in a circle three times. At the end of the third rotation, the player is pulled off of their feet and carried a short distance forward with the hammer's momentum before landing face first in a prone position, still holding onto the hammer with outstretched arms. The start and end of this move are displayed in Figure 2.6. Since there are three full rotations, the average time for all three was used in further calculations as the rotational velocity  $\omega$ . Rotational motion equations can be applied during the spin move before launch, including the rotational velocity equation

$$\omega = \theta/t, \quad (2.14)$$

with  $\theta$  being the angle the hammer passed through within the time  $t$ . Since the hammer is somewhat top-heavy, with an elongated teardrop shape, the distance from the end of the handle to the center of mass  $R$  was estimated to be  $3/4 L$ . The rotational velocity  $\omega$  was then converted to linear velocity  $v$  using the equation

$$v = \omega R = \frac{3}{4} \omega L. \quad (2.15)$$

The centripetal acceleration  $a_c$  of the spin move was found with this equation:

$$a_c = \frac{v^2}{R} = \omega^2 R. \quad (2.16)$$

This then allowed me to apply Newton's Second law to determine the force  $F$  required to hold onto the hammer during this move. Substituting in the relevant values results in the following equation form:

$$F = ma = m_H a_c. \quad (2.17)$$

# Chapter 3

## Results

In this chapter, I will present the results from the experiments and calculations described in the Methods chapter. I used the decimal precision provided by my calculator for each calculation using the values I was able to gather from the footage. I rounded the results to three significant figures for this paper, though I used more digits in the calculations to obtain them.

### 3.1 Horizontal Motion

I calculated the player's average step length to be 0.93 times their height, or 1.59 m. These steps also covered 6.92 tiles each in the plaza near the Cathedral of Blue, as shown in Figure 3.1. This makes each tile 22.9 cm long. It took 18 steps to go from the first whole panel of the Iron Keep bridge to the last, making the bridge 28.6 meters long. From the time it took to cross the bridge, I found the player's jogging velocity is 4.1 m/s (9.17 mph) while their sprinting velocity is 5.76 m/s (12.9 mph).



**Figure 3.1** A top view of the player and footsteps in the tiled plaza by the Cathedral of Blue area. Measuring from the front of one footstep to the other shows the player steps about 6.92 tiles in a single stride. The text and white block were added to the image to demonstrate this.

## 3.2 Vertical Motion

I found the player was 4.14 ladder rungs tall, making each rung spaced 0.41 m from the next, as shown in Figure 3.2. So, the ladder next to the Iron Keep bridge which was 20 rungs tall is 8.2 m tall. Falling from the top of this and other ladders yielded an average gravitational acceleration of  $-20.6 \text{ m/s}^2$ . After falling for 3.07 seconds, the terminal velocity for the no air resistance model with sudden terminal velocity was  $-63.1 \text{ m/s}$ .

Using the average of the two no-air-resistance models, the height for Drangleic Castle's elevator shaft was found to be 118 m tall. The elevator shaft from Drangleic Castle to the Shrine of Amana was 127 m tall. The Brume Tower was 266 m tall, from the first bonfire level to the top of the Fume Knight's boss arena. Lastly, the fall leading down to the Old Chaos was 410 m. The heights of four of the longest falls in the game are summarized and compared to real-life buildings in Table 3.1. In addition, I have included the plots of each model in Figure 3.3.



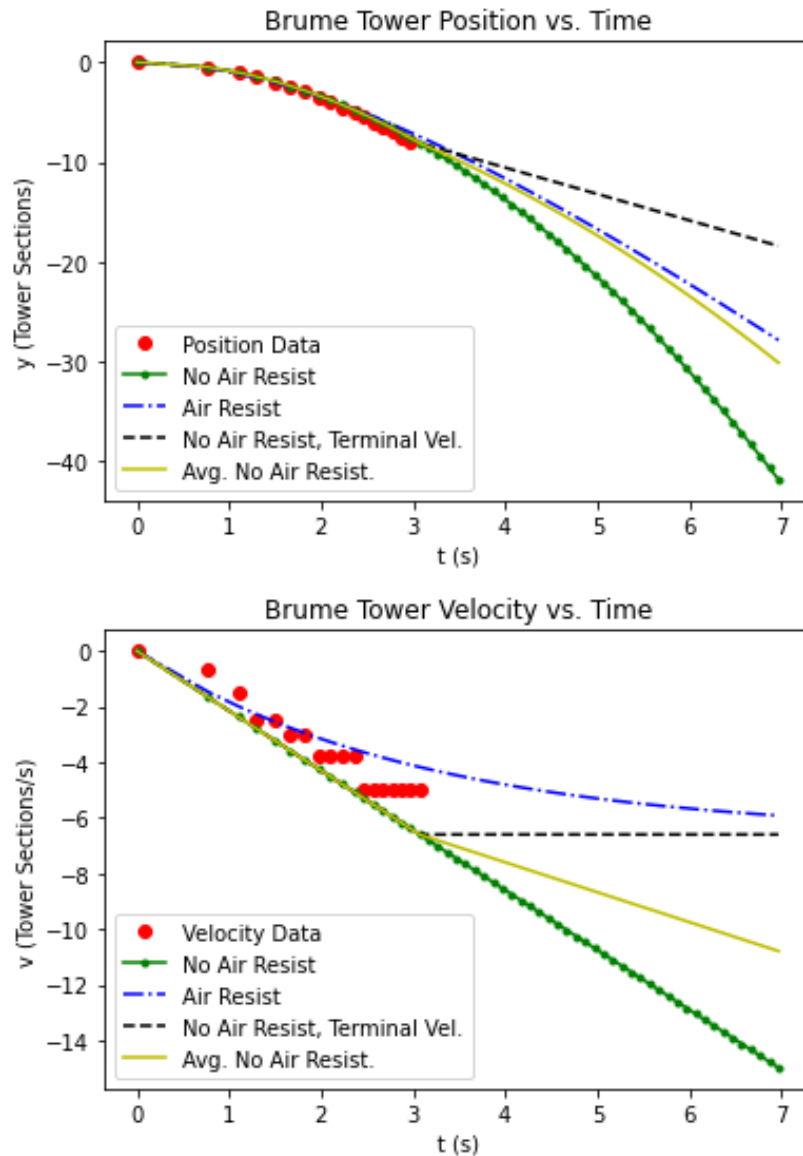
**Figure 3.2** A view of the player compared to a ladder in the Iron Keep, with text and a blue measuring block added to the image for demonstration. The player is 4.14 ladder rungs tall, making each rung 0.41 m from the next rung.

<i>Dark Souls™ II</i> Location	Height	Comparable Real Bldg. (Height)
Drangleic Castle Elevator	118 m	Kyoto Tower (131 m)
Shrine of Amana Elevator	127 m	Kyoto Tower (131 m)
Brume Tower	266 m	Chrysler Building (319 m)
Old Chaos	410 m	Empire State Building (449 m)

**Table 3.1** Summary of the heights of four of the longest falls in the game. These were determined by taking the average height of two fall distance models. Both models had no air resistance, while one had no terminal velocity and the other included a sudden terminal velocity of  $-63.1$  m/s after 3.07 s. Comparable real-life buildings are presented next to each location with their respective heights [11, 12].

### 3.3 Projectile Motion

The platform near the bridge in the Iron Keep used for throwing tests was 3.4 m above the ground. This allowed me to find the average vertical acceleration values for light, medium, and heavy projectiles. They were  $-7.49$ ,  $-6.61$ , and  $-7.42$   $m/s^2$ , respectively. For all objects, flight times were



**Figure 3.3** Plots of the position and velocity data gathered from long fall testing at the Brume Tower with several best-fit models overlaid. The red data points show the position and velocity of the player character during a fall. Then, the models extrapolate with different conditions to examine which best describes the game's physics. The black dashed lines represent a no air resistance model where a sudden terminal velocity was reached. The solid yellow lines represent the average of the previous model (black) and a no air resistance model without terminal velocity shown by the green lines with dots. Lastly, the model with air resistance is shown by the blue dash-dot lines.

very similar, all being around 1.2 s. For heavy, shot-put-like objects, this refers to after reaching the peak of their arc. A more specific analysis of Holy Water Urns, which are medium objects, showed they had a horizontal velocity of 9.32 m/s and a vertical velocity just before impact of -8.16 m/s. This shows they traveled at a total velocity of 12.4 m/s (27.7 mph) just before impact with the ground below the platform. These results are summarized in Table 3.2.

Object Type	Example Items/Spells	Avg. Flight Time (s)	Vert. Accel. ( $m/s^2$ )
Heavy	Lightning Urn, Firebomb	$1.2 \pm 0.07$	$-7.42 \pm 0.9$
Medium	Holy Water Urn, Fireball	$1.22 \pm 0.07$	$-6.61 \pm 0.79$
Light	Throwing Knife	$1.17 \pm 0.07$	$-7.49 \pm 0.94$

**Table 3.2** Summary of throw animation types, and examples, flight times, and vertical acceleration values for each type. Note that for shot put throws, flight time was started as soon as the object reached the peak of its arc. All other throws were aimed such that the object was launched horizontally. Note also that fireball spells behaved similarly to medium objects, and thus they were included in that object type.

### 3.4 Rotational Motion

To begin, I calculated the Smelter Hammer's dimensions and weight. The hammer's length was 2.52 m (8.27 ft) by measuring against the plaza tiles near the Cathedral of Blue. Excluding the handle, the hammer's volume was found to be  $0.324 \text{ m}^3$ . With iron's density being  $7,860 \text{ kg/m}^3$ , this gives the hammer a mass of approximately 2,550 kg (5,620 lbs).

An average rotation of the hammer's spin move took 0.356 s to complete, making its angular velocity 17.7 radians/s. This converted to a linear velocity of 33.4 m/s. The centripetal acceleration was found to be  $591 \text{ m/s}^2$ , meaning the force to keep hold of it would be 1.5 MN (337,000 lbf).

# Chapter 4

## Discussion

By engaging with a video game world using the methods and equations of physics, I learned intricacies of even the basic physics used in *Dark Souls<sup>TM</sup> II*. But most importantly, I gained experience in using physics as an investigative tool. I found that physics for the player character in *Dark Souls<sup>TM</sup> II* is realistic or reasonably close to realistic in most cases. The player jogs and sprints at 4.1 m/s (9.2 mph) and 5.76 m/s (12.9 mph), respectively, which is a bit higher than average but not extreme [13]. The player can also throw small objects at 12.4 m/s (27.7 mph). This is significantly slower than what professional baseball pitchers are capable of [14], but the objects may be much heavier than a typical baseball and not designed for such fast throws.

There are several extreme exceptions to the generally realistic physics of the player character, however. For one, gravitational acceleration for the player is over twice the magnitude of that on Earth's surface, this being  $-20.6 \text{ m/s}^2$  in the game versus  $-9.8 \text{ m/s}^2$  on Earth. In addition, the player is unharmed by a fall of 410 m (1,345 ft), which is nearly as tall as the Empire State Building [12]. And this was done without using a parachute or other protective equipment. Lastly, everything the player can do to wield the 2,550 kg (5,620 lbs) Smelter Hammer, which weighs more than an average car [15], also goes far beyond realistic physics for a human being. While pushing a car on

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its wheels is reasonable, lifting the car and swinging it around at freeway speeds of 33.5 m/s (74.9 mph) as shown in the game would require superhuman strength.

Since this was the first study of its kind on *Dark Souls<sup>TM</sup> II*, as far as we know, I focused on studying fundamental physics topics. First, it was key to establish fundamental measurement units horizontally and vertically. Without clear, rigorously established units to work with, any dependent calculations would be skewed. Next, I focused on values which could be found most simply while illustrating basic Newtonian mechanics. This allowed efforts to yield the most information about the game's physics in the time available. And lastly, a variety of mechanics concepts were tested rather than spending a large amount of time studying any one area in great depth. Again, this allowed for more diverse information to be analyzed about many aspects of the game.

Studies with similar methods have been done on the physics of other video games, with comparable results. For example, the study on *Fortnite* revealed that the game used a gravitational acceleration of  $26 \text{ m/s}^2$ , likely to speed up jumps for a better gameplay experience [6]. Similar reasoning may apply to *Dark Souls<sup>TM</sup> II*, where gravity is also much stronger than on Earth at a magnitude of  $20.6 \text{ m/s}^2$ . This illustrates the vastly different gravity which can be present in video games, which was found through similar analysis as that done in this project. So, it is reasonable to find exaggerated physics results for gameplay reasons when studying physics in a video game. Likewise, more realistic physics may also provide a better gameplay experience. For *Dark Souls<sup>TM</sup> II*, the player's more realistic throwing speed may give other players more time to react to projectiles to make the game more balanced and slower paced. In all these cases, the developers were free to adjust their games' physics according to the type of experience they wanted to give users.

Future work on this game's physics could involve finding needed constants to specify air resistance rather than approximating it through other means. The player's movement could be examined further as well, such as how the player's movement slows down when carrying heavier loads, the effects of walking through deep water, jumping mechanics, and more. Although there is

much left to explore, I was able to discover several main aspects of the physics in *Dark Souls™ II*, providing insights into the inner workings of the game. Furthermore, this project provided the opportunity to compile the footage and explanations into four videos on the subjects covered in this study. So far, two of these videos are complete, while work is being done on two more. These videos present the experiments and results from this project in a more visual way that may be more accessible to wider audiences, allowing them to gain insights into physics reasoning and methods from this project as well. Despite the seemingly unrelated nature of a virtual video game and physics learned in school, the game was a suitable location to use experimental methods and equations from physics. As such, this project could serve as yet another example of a way to learn to apply physics outside a strictly academic context. In addition, this study provided details that gave possible insights into the design of the game, especially when the game's physics diverted from that of real life.

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