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P2_6 Spring Loaded Action: The Physics of Link's Clawshot

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Abstract

This paper compares the physical realities of the Clawshot from the game Legend of Zelda: Twilight Princess to in-game actuality. It has been found that the Clawshot would need to travel 10 times faster than shown in the game in order to hit its target at a maximum distance of 25m. In order for the user to be pulled directly towards the target, its inclination would have to be 11°. The force exerted on the user's arm due to the acceleration of the projection would be around 4kN.

Introduction

The Hookshot is a recurring item in the Legend of Zelda series. An updated version known as the Clawshot was featured in Twilight Princess with slightly different capabilities to its predecessors. Described in-game as 'a claw at the end of a long chain' [1] it uses a spring loaded firing mechanism to launch the projectile in any given direction. This allows the protagonist (Link) to pull distant objects towards him and to be pulled towards far-off targets. It can also be used to stun enemies. When fired, the claw travels in a straight line directly towards the target. When being accelerated the user's body also travels directly towards the target with no deviation due to gravity.

Figure 1: A screenshot from Twilight Princess of the Clawshot in action [1]

This paper will look at the forces exerted on the arm when using the Clawshot and the real world feasibility of the specifications. In-game measurements give the Clawshot an approximate maximum extension of 25m. It takes 1 second for the chain to extend fully and a further 1 second for the user to be pulled towards the target.

Perfect Aim

When being fired parallel to the ground, the claw is subject to the rules of projectile motion. Modelling the claw as a projectile with no air resistance and assuming a strong chain of negligible mass, the acceleration due to gravity will make the Claw deviate from its target. We can find this deviation using the equation

$$y = 0.5g\left(\frac{x}{v}\right)^2 \quad (1)\ [2]$$

where y is the distance the projectile falls in the y (vertical) direction, x is the distance travelled by the claw, g is the acceleration due to gravity and v is the velocity at which the claw travels. At a velocity of $25ms^{-1}$ and a displacement of 25m in the x direction the claw would hit 4.9m below its target. Using 0.1m as a reasonable estimated maximum deviation allowed for the hook to still hit the target we can find the velocity the claw would need to be fired at. Rearranging equation 1 for velocity in the x direction we find

$$v = x\left(\frac{g}{2y}\right)^{0.5} \quad (2),$$

which gives a firing velocity of $175ms^{-1}$. At this velocity the hook would reach the target in 0.14 seconds. This is around a tenth of the in game speed.

Skyward Claw

Modelling the claw as a projectile and aiming it directly upwards we can see if the chain would hit a target at 25m at the speed shown in the game whilst under the effect of gravity. The value of g is now negative as the projectile is being directed upwards. Using the standard equation of motion,

$$S = ut + \frac{1}{2}at^2 \text{ (3)},$$

where S is displacement, u is the initial velocity, t is the time taken and a is the acceleration we find the hook would have to be fired at a velocity of $30ms^{-1}$ to reach the target in 1 second. The hook would decelerate to $20ms^{-1}$ before hitting the target.

Perfect Landing

By resolving the forces on the body due to gravity and due to acceleration in the direction of the target the angle at which a body could be pulled towards a target without any deviation due to gravity can be calculated.

In the game it takes 1 second to be pulled a distance of 25m from a standstill (u=0). Using equation 3 and rearranging for a we find a constant acceleration of $50ms^{-2}$ as it travels towards the target in 1 second. Using

$$sin^{-1}\left(\frac{mg}{ma}\right) = \theta \text{ (4)}$$

where the acceleration a is $50ms^{-2}$, gives an angle of 11°. This would allow the Clawshot to be aimed at a target elevated at 5m.

If you were to aim the Clawshot at an inclined angle of 20° (aiming at something elevated roughly 10m), the resultant force would not be great enough to take you all the way to the target. At this angle, the acceleration would decrease to $40ms^{-2}$ and you would travel only 20m before succumbing to gravity and swinging down before being wound in by the Clawshot mechanism for the last 5m.

Shoulder Trouble, Link?

The force exerted on the arm at constant acceleration is given by

$$F = T + mg \text{ (6)}$$

where F is the total force, T is the force exerted by the tension in the chain, m is the mass of the body and g is the acceleration due to gravity. The directions of F, T and mg are indicated in figure 2. Assuming a mass of 70kg the force on the arm is equal to 4100N.

What a Drag

To calculate the effects of drag a simplified model in which the body is modelled as a cylinder and the average velocity is used. To calculate the force we use the drag equation,

$$F_D = \frac{1}{2}\rho v^2 C_D A \text{ (7) [3]}$$

where ρ is the density of air ($1.25kgm^{-3}$ [4]), v is the average velocity ($35ms^{-1}$), C_D is the drag coefficient (0.81 [3]) and A is the frontal area of the cylinder ($0.07m^2$ assuming radius of 15cm). We find that the force added by air resistance is just over 40N.

Conclusions

The firing velocity of the Clawshot in the game is insufficient to counteract the downwards acceleration due to gravity when firing parallel to the ground. Whilst the speeds calculated when firing directly upwards in consistent with in game velocities, assuming the Clawshot's mechanisms only allow one firing speed, the minimum firing speed would have to be $177ms^{-1}$ in order for it to reach a target in any given direction. In order to land directly on the target when pulled towards it, Link can only aim at something with an elevation of 5m at a maximum distance of 25m. Any higher and he'll likely hit the wall he's aiming for before being unceremoniously dragged up it as the chain continues to retract. The force exerted on the arm when being pulled directly upwards is equivalent to a 400kg mass hanging from your arm which is roughly six times an average male's body weight. The effect of drag is negligible in comparison to the force felt due to acceleration and therefore doesn't make much of a difference to the conclusion that using a Clawshot will cause the user serious injury.

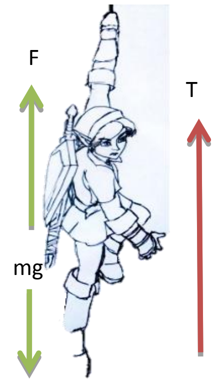

Figure 2 [5] Force diagram of Link hanging by one arm

References

[1] The Legend Of Zelda: Twilight Princess, Ninetendo, first released19th November 2006

[2] J.F Barker, T.M. Conlon, J.C. Coxon, A4_8 Don't aim at him! PST9, (2010)

[3]ftp://ftp.colorado.edu/cuboulder/courses/chen3200/Lectures/DragCoef.pdf (last visited 28th October)

[4]http://hypertextbook.com/facts/2000/RachelChu.shtml (last visited 28th October)

[5] Drawn by author, R.Hall