Journal of Physics Special Topics

An undergraduate physics journal

A3_4 Fly High, Gyroid!

K. Holland, L. Flood, T. Leversha, M. Manley

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

October 31, 2022

Abstract

In this paper, we investigated whether a small rocket in the game *Super Smash Bros. Ultimate* would be viable, based on whether it could hold the amount of fuel required to reach its maximum altitude. We found that the volume of liquid hydrogen/liquid oxygen fuel required is less than the volume of the rocket booster, so the rocket would be viable in this sense.

Introduction

In the game *Super Smash Bros. Ultimate*, characters from different video game franchises battle it out in a fight for glory. One such character, Isabelle the shih tzu, has an attack that involves launching a pressure-detonated rocket, Lloid, vertically into her opponents. This paper investigates whether such a rocket would be viable, by determining if it could carry enough fuel to reach its' maximum altitude.

Building Our Model

In order to determine Lloid's dimensions, we loaded the game into 'training mode,' which features a 1 cm square grid in the background for our reference (we assumed this scale by comparing the grid to characters with more realistic human proportions). Using this grid, we approximated Lloid as a cylinder (ignoring his arms) with radius $r_L = 0.300$ m, length $l_L = 1.10$ m and, consequently, volume $V_L = 0.311$ m^3. Additionally, we approximated that Lloid reaches a maximum altitude of $h = 6.00$ m.

Next, we needed to determine Lloid's empty mass. To do this, we assumed that he was a hollow shell constructed from the same 6061-T6 aluminium plates as the Orion spacecraft, which have thickness $w_{Al} = 0.635$ cm [1] and density $\rho_{Al} = 2700$ kg m^{-3}. [2] Fig. 1 shows the definitions for the radius, r_h, and length, l_h, of the cylindrical hollow area inside the shell, which has volume V_h. By subtracting V_h from V_L, we found that the volume of the aluminium shell, $V_{Al} = 0.0165$ m^3. Finally, by multiplying ρ_{Al} and V_{Al}, we found that the total mass of the shell, $m_{Al} = 44.5$ kg.

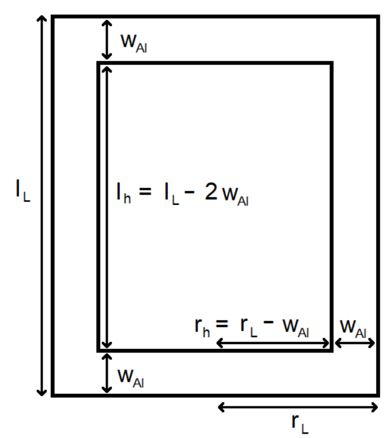

Figure 1: A cross-sectional schematic of the rocket, outlining the definitions of r_h and l_h.

We used the game's frame data to determine Lloid's velocity. Aside from the initial acceleration, Lloid appears to fly at a constant velocity v_L, which we assumed to be his maximum achievable velocity. It takes a total of 48 frames for Lloid to reach h. [3] Since the game runs at 60 fps, we simply divided 48 by 60 to determine that the flight duration, $T = 0.800$ s. Then, we applied the speed-distance-time equation and calculated $v_L = h/T = 7.50$ m s^{-1}.

Finally, we needed to model the rocket itself, which we assumed to be a cylindrical liquid rocket booster (LRB), fuelled by liquid hydrogen/liquid oxygen (hereby referred to as H/O). These typically have a radius $r_{LRB} = 2.75$ m, a length $l_{LRB} = 45.5$ m and an empty mass $m_{LRB} = 52,000$ kg. [4] For the sake of simplicity, we scaled these values down so that the booster would fit vertically inside of Lloid, occupying the most space possible. We divided each of these values by the ratio l_{LRB}/l_h, such that the scaled down booster has radius $r_b = 0.0657$ m, length $l_b = l_h = 1.09$ m and empty mass $m_b = 1240$ kg. We also calculated the booster's volume, $V_b = 0.0148$ m^3.

Applying the Rocket Equation

The Tsiolkovsky rocket equation describes the propulsion of an idealised rocket with no external forces, such as aerodynamic or gravitational forces, acting on it. It is given by

$$\Delta v = I_{sp} g \ln\left(\frac{m_0}{m_f}\right), \tag{1}$$

where Δv is the rocket's change in velocity, I_{sp} is the specific impulse, g is the gravitational constant, m_0 is the wet mass and m_f is the dry mass. Eq. 1 can be rearranged to give an expression for the required mass of fuel, m_{fuel}:

$$m_{fuel} = m_f \left(\exp\left(\frac{\Delta v}{I_{sp} g}\right) - 1\right), \tag{2}$$

since m_{fuel} will be the difference between m_0 and m_f, which represent the mass of the system with and without fuel respectively. Here, $\Delta v = v_L$ (since the rocket accelerates from 0 m s^{-1}) and $m_f = m_{Al} + m_b$. For H/O fuel, $I_{sp} = 350$ s. [5] This resulted in a value $m_{fuel} = 2.81$ kg.

Finally, to determine the volume this would occupy, V_{fuel}, we needed to assume that the fuel was a 50/50 split of H/O. This allowed us to approximate the density of the fuel as $\rho_{fuel} = (\rho_H + \rho_O)/2 = 606$ kg m^{-3}. [6] [7] Then, we calculated $V_{fuel} = m_{fuel}/\rho_{fuel} = 0.00464$ m^3.

Conclusion

Since $V_{fuel} < V_b$, the rocket has the capacity to hold the required amount of fuel. Therefore, we conclude that the rocket is viable. However, this is based on a very simplified model that does not account for the effects of gravity, drag or the mass of other mechanisms required for the rocket to function, such as the detonation electronics.

References

[1] `https://www.cmrp.com/blog/bending/bending-6061-t6-aluminum-space.html` [Accessed 17 October 2022]

[2] `https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6` [Accessed 17 October 2022]

[3] `https://ultimateframedata.com/isabelle` [Accessed 17 October 2022]

[4] `http://www.astronautix.com/s/shuttlelrb.html` [Accessed 17 October 2022]

[5] `https://www.grc.nasa.gov/www/k-12/rocket/rktpow.html` [Accessed 17 October 2022]

[6] `https://energies.airliquide.com/resources-planet-hydrogen/how-hydrogen-stored` [Accessed 18 October 2022]

[7] `https://lasers.colostate.edu/wp-content/uploads/2019/04/Cryogenic-Safety-Manual.pdf` [Accessed 18 October 2022]