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A3_1 Falling With Style

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Abstract

In 2010, a paper concluded that Buzz Lightyear could take flight at an optimum flight angle of 13° if he was provided with $62N$ of thrust and was travelling at $55ms^{-1}$ [1]. In this paper we analyse how fast Buzz would need to be travelling to generate enough lift for flight while at an attack angle of 0°, as seen in the films. By making the large assumption that Buzz's wings are similar to those of a cambered airfoil, we calculated that Buzz can generate enough lift to fly with a 10 inch firework by reaching $66.310ms^{-1} \pm 1.500ms^{-1}$.

Introduction

To calculate the necessary velocity for Buzz to generate enough lift for flight we need to equate all the vertical forces acting on him, in this case his weight and the lift of his wings. We first however, need to know the dimensions of Buzz and Woody. Thankfully, since they are confirmed to be just toys, we can use merchandise to get these values. All errors used for these values are taken to be half the resolution of the value.

For Buzz's total wing area, it was necessary to approximate each wing as a trapezium to calculate their area. From there we can use the lift equation to equate the lift to the weight of both characters and their propulsion and rearrange for the velocity needed to sustain flight. The lift coefficient in the lift equation is usually determined experimentally however here we simply looked at the angle of attack used in the film and compared Buzz's wings to that of a cambered airfoil.

Discussion

For this paper we found Buzz's dimensions to be $12.0cm \pm 0.5cm$ in length, $16.0cm \pm 0.5cm$ in width (without his wings extended) and $30.0cm \pm 0.5cm$ in height with a mass of $1.040kg \pm 0.005kg$ [2]. From here, his wings were approximated as trapeziums, each with an area (A) given by equation 1:

$$A = \frac{a+b}{2}h \quad (1)$$

Where a and b are the bases of the trapezium, found to be $5.110cm \pm 0.240cm$ and $4.440cm \pm 0.240cm$ respectively, and h is its height at $10.670cm \pm 0.300cm$. These were found by comparing known lengths from [1] against lengths measured from an image of Buzz Lightyear to find a scaling ratio, this was then used to calculate the needed lengths. In this case we found Buzz's total wing area to be $1.019\text{x}10^{-2}m^2 \pm 4.580\text{x}10^{-4}m^2$. Woody's mass was found to be $0.499kg \pm 0.005kg$ [2], giving a total mass of both characters of $1.539kg \pm 7.070\text{x}10^{-3}kg$. We can then multiply this by the gravitational acceleration (taken to be $9.81ms^{-1}$) to find their total weight to be $15.100N \pm 0.069N$. Next we equated this weight to the necessary lift force (given by equation 2) and rearranged for the velocity needed to sustain flight.

$$L = C_L \frac{\rho V^2}{2} A \tag{2}$$

Here L is our lift (equal to the weight of the system), C_L is the lift coefficient, ρ is the density of air (taken to be $1.225 kgm^{-3}$), A is the area of the wings and finally V is the velocity needed to sustain the lift force. Since C_L is usually determined experimentally, it was necessary to estimate it in this case. For the purposes of this article we can compare Buzz's wing to that of a cambered airfoil (the typical shape of an airplane's wing) and use figure 1 to see how the lift coefficient changes with the angle of attack for this specific shape.

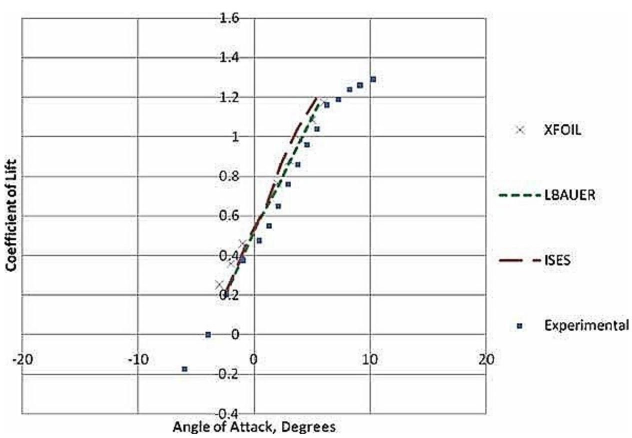

Figure 1: A plot showing modeled data predicting how the lift coefficient changes with the angle of inclination of the wing for a cambered airfoil compared to experimental data [3]

From figure 1, it can be seen that for an angle of attack of 0 degrees (as seen in the movie) the lift coefficient is approximately 0.5500 ± 0.0025. Using all these values in equation 3 returns a lift velocity of $66.310 ms^{-1} \pm 1.500 ms^{-1}$ or approximately $150 mph$. If the remote controlled car (found to be $0.240 kg \pm 0.005 kg$ [2]) is included in the system this velocity is slightly higher at $71.290 ms^{-1} \pm 1.620 ms^{-1}$ due to the added weight.

Conclusion

In order for Woody and Buzz to achieve sustained flight they must be travelling at a minimum velocity of $66.310 ms^{-1} \pm 1.500 ms^{-1}$, or $71.290 ms^{-1} \pm 1.620 ms^{-1}$ if they are flying with the RC car. With the addition of the firework (shown in the film to be slightly smaller than Buzz, putting it between 10 and 12 inches tall) this velocity is attainable as 10 inch shell fireworks have been shown to reach up to $180 mph$ [4]. This means that Woody, Buzz and the RC car would be able to generate enough lift for sustained flight for at least a short time while their velocity was above this threshold. The rocket must detach before Buzz and Woody achieve flight however, as the weight of the powder and its casing will increase the necessary velocity to achieve lift. The largest assumption in this article is most likely the comparison of Buzz's wings to a cambered airfoil in order to estimate a lift coefficient. Buzz's wings are much flatter and thinner than a typical airfoil, making them less aerodynamic, meaning a smaller lift coefficient and higher lift velocity would be needed.

References

[1] S. Jinks, T. Glossop and R. Hopton, *A1_9 To Infinity and Beyond!*, Physics Special Topics, (2010).

[2] `https://www.amazon.co.uk/Disney-Lightyear-Interactive-Talking-Action/dp/B07PQFT83F/ref=sr_1_6?crid=1DIRL85QDWP2N&dchild=1&keywords=toy+story+buzz+lightyear&qid=1633465780&s=kids&sprefix=toy+story+\%2Ctoys\%2C157&sr=1-6` [Accessed 18 October 2021]

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[4] `https://www.fireworkscrazy.co.uk/how-fast-are-fireworks/` [Accessed 18 October 2021]