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P1_6 Quick Quadcopters: Top Speed of a Racing Drone

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Abstract

Drone racing is becoming an increasingly popular sport. These drones are capable of flying above 100mph [1] which poses the question, how fast can a racing drone fly? In this paper, we investigated this question, finding that a typical racing drone can fly up to 132mph.

Introduction

Pilots race their drones by viewing a live video stream from an on-board camera, racing around flags and through narrow gaps. These drones are typically built by the pilot. Whilst building, it is important to consider the maximum speed the drone may be able to achieve.

Aerodynamics of flight

Racing drones typically have 4 electric motors and propellers, which provide the thrust required for flight. Figure 1 shows the forces exerted on/by the drone while flying at velocity v.

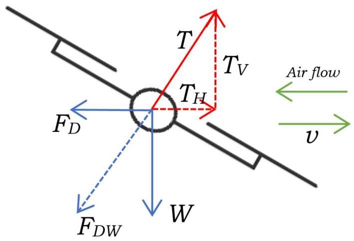

Figure 1: A diagram of the forces during flight

T is the thrust generated by the drone, T_V is the vertical component of thrust, T_H is the horizontal component of thrust, W is the weight of the drone, F_D is the aerodynamic drag and F_{DW} is the combined vector of weight and drag. To maintain altitude, the drone must provide enough vertical thrust to counteract its weight, so $T_V = W$. At its terminal velocity, the horizontal component of thrust must equal the aerodynamic drag, so $T_H = F_D$. Likewise, at terminal velocity, $F_{DW} = T$. The thrust generated by the drone is always perpendicular to the propellers, so to achieve horizontal motion, the drone must be inclined giving the thrust a horizontal component, reducing its vertical component. The thrust generated by the drone is not constant, but depends on the airspeed perpendicular to the propeller, the propeller design and torque applied to it by the motor.

Modelling such a system is beyond the scope of this paper. Thrust values are often determined experimentally, so we used an existing data set for a typical racing drone motor and propeller [2]. It is important to note that in our case the propellers will not be perpendicular to the flow of air as shown in Figure 1. We have assumed that this will not affect the thrust generated as the drone will be partially tilted into the air flow. We have also assumed that the drag is independent of the drone's inclination as it will not vary at top speed.

Calculations and discussion

Solving this problem by hand proved to be very difficult, so it was done iteratively on a computer. First, we made a list of velocities from 1 ms^{-1} to 65 ms^{-1}. Next, we calculated the thrust at each velocity. Using the existing data set, we calculated the thrust as a function of airspeed $F(v) = T = -0.9384v + 60.577$ assuming a linear regression (shown in Figure 2), which allowed us to compute the thrust at each velocity. Next, we calculated T_H using Pythagoras' theorem,

$$T_H = \sqrt{T^2 - {T_V}^2} \quad T_V = W = mg$$
$$\therefore T_H = \sqrt{T^2 - W^2} = \sqrt{T^2 - (mg)^2}. \tag{1}$$

Where m is the mass of the drone and g is the acceleration due to gravity. Since mg is a constant and T is known for all velocities, we can compute T_H for any velocity. We know that at terminal velocity, $F_D = T_H$. F_D can be approximated as,

$$F_D = \frac{1}{2} C_D \rho A v^2, \tag{2}$$

Where C_D is the coefficient of drag of the drone, ρ is the density of air and A is the cross sectional area of the drone [3]. These calculations are enough to determine the terminal velocity. We can also calculate F_{DW} using Pythagoras' theorem and use this to check our results since at terminal velocity, $T = F_{DW}$. Figure 2 shows our findings, where $C_D = 0.25$ (taken as a rough value from the graphs in [4]), $\rho = 1.225$ kgm^{-3}, $m = 0.5$ kg and $A = 3 \times 10^{-3}$ m^2 which are approximate values based on my racing drone. We can see in Figure 2 that $T_H = F_D$ and $T = F_{DW}$ (where the yellow line meets the red line and the blue line meets the green line) at about 59 ms^{-1} or 132 mph. We believe this to be a reasonable value as the current world record is 165 mph [5]. In our model, the primary limiting factor is the reduction in thrust with velocity which results in the drone not being able to lift its own weight. The drag remains a comparatively small force. Using a propeller optimised for higher speeds would increase the top speed considerably. However, this would likely reduce the performance at lower speeds, making it a less viable option for drone racing pilots, who benefit from better performance at low speeds. In reality, there are many more parameters that affect a drones maximum speed, but we feel 59 ms^{-1} is a reasonable ballpark figure.

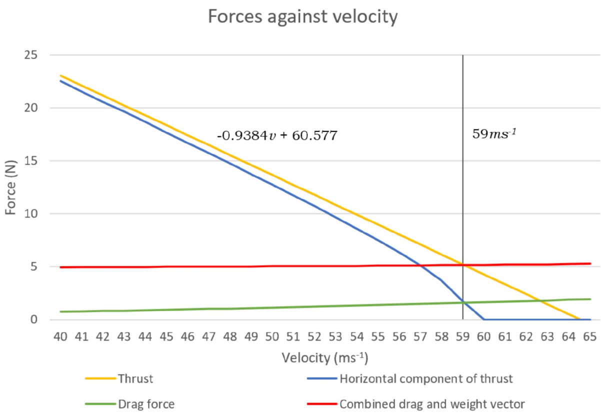

Figure 2: A graph of the thrust and restrictive forces on a drone with respect to velocity.

Conclusion

The results show that the top speed of a typical racing drone is roughly $59ms^{-1}$. This is an approximate figure as there are many parameters that alter a drones top speed. We believe the primary limiting factor is the design of the propeller, which could be optimised to provide more thrust at higher velocities.

References

[1] https://tinyurl.com/vo2n7m9 [Accessed 20.10.19]

[2] https://tinyurl.com/wlyxjgt [Accessed 20.10.19] ”together” Racekraft data

[3] https://tinyurl.com/vyq99fr [Accessed 21.10.19]

[4] https://tinyurl.com/t87xgz8 [Accessed 21.10.19]

[5] https://tinyurl.com/wpo5ts7 [Accessed 21.10.19]