Drone Building and Optimization:

How to Increase Your Flight Time, Payload and Overall Efficiency

A free eBook by RCbenchmark

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INTRODUCTION

There are many factors that affect a drone's flight time, payload and overall efficiency. Manipulating these factors can help you achieve top performance and gain a competitive advantage in the fast growing drone industry. This eBook will guide you through the relevant equations and tests for ensuring your drone, RC plane or eVTOL aircraft is performing optimally.

SECTIONS

This guide follows the design and testing process from start to finish, but feel free to jump ahead to the section you need:

1. **Aerodynamics and how drones fly...03**
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1. AERODYNAMICS AND HOW DRONES FLY

In order for a drone to take off and fly it must overcome its weight and drag. A drone's weight is the product of its mass times gravity. Drag is the force resisting the drone's motion through the air, dependent on reference area, air density and flow velocity. The thrust produced by the propellers is translated into lift and horizontal motion, which enable the aircraft to become airborne and fly (figure 1).

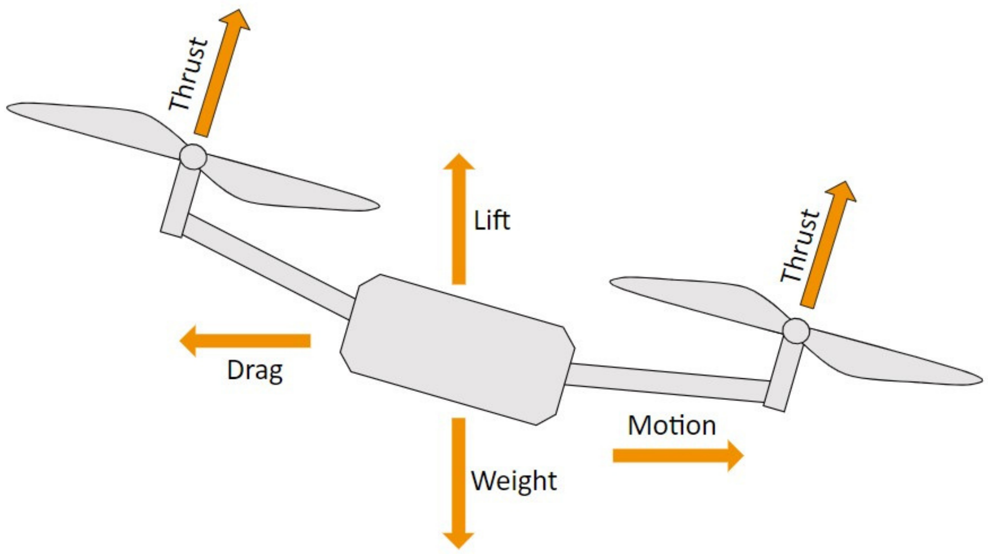

Figure 1: The forces controlling multicopter movement

These forces vary in different types of drones. For example, fixed-wing drones have aerodynamic surfaces that provide lift, so the propellers don't have to work as hard to keep the drone in the air. The thrust produced by fixed-wing drones also has a larger horizontal component as they do not have the capability for vertical take-off and landing (VTOL). In level flight, forward thrust opposes drag and lift opposes weight (figure 2).

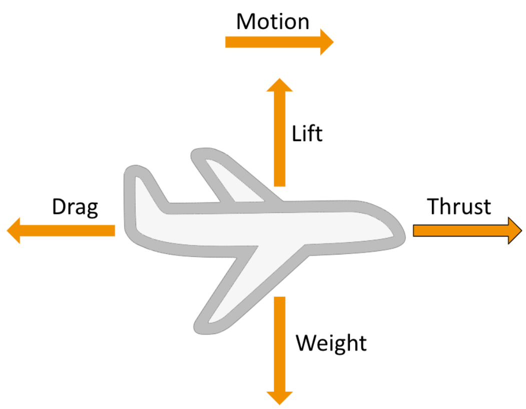

Figure 2: Fixed-wing drone forces

These features give fixed-wing aircraft the ability to fly long distances without refuelling or recharging, but it also makes them unsuitable for applications that require hovering in place. More thrust and battery power is required to keep a VTOL drone in the air, but its design makes it better for flying in any direction and hovering in place.

The amount of thrust required for a drone to remain airborne is mainly dependent on its weight. For a multicopter drone, hovering is possible when the weight of the drone is equal to the thrust produced by its propellers. For a fixed-wing drone, level flight at constant speed (cruise flight) occurs when forward thrust is equal to drag and lift is equal to the weight. Steady flight is all about balancing these forces.

2. THE DRONE EQUATIONS

1. $\text{Hover thrust(N)} = M_{\text{drone}} \times 9.81(\text{m/s}^2)$
2. $\text{Mechanical power(W)} = \text{Torque(Nm)} \times \text{Rotation speed(rad/s)}$
3. $\text{Electrical power(W)} = \text{Current(A)} \times \text{Voltage(V)}$
4. $\text{Propeller efficiency(N/W)} = \frac{\text{Thrust(N)}}{\text{Mechanical power(W)}} = \frac{\text{Thrust(N)}}{\text{Torque(Nm)} \times \text{Rotation speed(rad/s)}}$
5. $\text{Motor efficiency} = \frac{\text{Mechanical power}}{\text{Electrical power}}$
6. $\text{Total electrical power(W)} = \frac{M_{\text{drone}}}{\text{prop}_{\text{efficiency}}(\text{g/W})}$
7. $\text{Battery capacity(Wh)} = \sigma_{\text{battery}}(\text{Wh/g}) \times M_{\text{battery}}$
8. $\text{Flight time(h)} = \frac{E_{\text{battery}}(\text{Wh})}{\text{Power(W)}} = \frac{\sigma_{\text{battery}} \times M_{\text{battery}}}{M_{\text{frame}} + M_{\text{battery}}} \times \text{prop}_{\text{efficiency}}\left(\frac{M_{\text{frame}} + M_{\text{battery}}}{\text{\# of propellers}}\right)$
9. $\text{Heat losses} = \text{Resistance}(\Omega) \times \text{Current}^2(\text{A})$

Where:
E = capacity
σ = energy density
M = mass in grams (g)

This eBook will show you how to use these equations for drone development.

3. ACHIEVING MAXIMUM FLIGHT TIME, PAYLOAD AND EFFICIENCY

The drone equations hold the key to determining which variables should be altered to achieve maximum aircraft performance.

Equation 8 demonstrates that flight time is dependent on the battery capacity and the power generated by the drone. By adding in the equations for battery capacity and total power, flight time becomes dependent on a number of factors including the weight of components, battery energy density, and propeller efficiency. Balancing these factors becomes essential to increasing flight time. Increasing the battery's energy density alone will increase air time, but this requires changing the battery's chemistry, which can be complicated and costly.

One must also find a balance between the number of propellers and the propeller efficiency. We have a simple flight time calculator that you can use to estimate your flight time using your drone's specifications and testing data. Follow the steps on the right-hand side of the calculator document. Ultimately, real-life testing (described in sections 6 and 7) is the best way to determine your true flight time.

Battery info	
Weight Battery (g)	
Capacity Battery (Wh)	
Energy density (Wh/g)	
# of props	
Weight without battery (g)	

Your Flight Time (min)	

Battery capacity (Wh)	Battery weight (g)	Total weight (g)	Control ratio (%)	Thrust / Prop @ Hover (g)
10		0		
20		0		
30		0		
40		0		
50		0		
60		0		
70		0		
80		0		
90		0		
100		0		
125		0		
150		0		
175		0		
200		0		

Figure 3: Flight time calculator

Increasing an aircraft's payload is also a matter of balancing variables. Keep in mind that to have a good control authority over a vertical takeoff drone, it is recommended that the thrust produced by the drone be equal to about twice its weight, so be sure to account for this in your payload calculations.

In terms of maximizing thrust, it's true that it increases linearly with rotation speed, but propeller efficiency also declines with a higher RPM. Adding more propellers can contribute thrust, but will also add weight and likely change your design.

Achieving your drone's maximum flight time or payload ultimately comes down to choosing the most efficient combination of parts. Not all motors and propellers are created equal, nor do they work equally well together. Finding the most efficient combination of parts is a multi-step process involving the drone equations and real-life testing.

Our free database of electric motor and propeller performance can help to speed up this process by comparing results from other designers' public tests (figure 4). Use the "Add filters" tool to narrow results to the motors, propellers and ESCs you are interested in working with, or filter by powertrain data to narrow results with performance cut-offs.

Showing 1 to 5 of 22 entries (filtered from 384 total entries)

	Title	Author	Device	Date	Motor	Propeller	ESC
☐	U15XXL with 62" prop	Dominic Robillard	Series 1780	2020-02-03	T-Motor U15XXL Kv29	T-Motor 62"x24" CF	T Motor FLAME 280A HV
☐	U15XXL and 62"Prop from T-motor	Baiyun Tang	Series 1780	2019-12-06	T-Motor U15XXL Kv29	T-Motor 62"x24" CF	T Motor FLAME 280A HV
☐	RCbenchmark 2407 1500kv 9x4 propeller v2	Audrey Schwartzenberger	Series 1580	2019-11-18	RCbenchmark x Xoar 2407 1500kv	RCbenchmark x Xoar 9x4	RCbenchmark x Xoar F50
☐	RCbenchmark 2407 2300kv 9x4 propeller	Audrey Schwartzenberger	Series 1580	2019-11-18	RCbenchmark x Xoar 2407 2300kv	RCbenchmark x Xoar 9x4	RCbenchmark x Xoar F50
☐	TA130-25 Kv80 with Xoar 40x10	Erwan Labadie	Series 1780	2019-04-16	Xoar TA130-25 KV80	Xoar PJP-T-L 40"x10"	Xoar titan esc

Figure 4: Database of motor, propeller and ESC performance