



Original Research Article

Development of a New Algorithm to Design and Part Selection of Multi-rotors

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ABSTRACT

The proper selection of components and precise optimization of operating parameters in multi-rotor systems to achieve mission objectives with maximum efficiency has long been a critical concern for drone manufacturers. This study introduces a comprehensive and adaptive model for the calculation, analysis, and optimization of these parameters by thoroughly investigating key variables and integrating them into a unified framework. Initially, the fundamental concepts of multi-rotor systems and their core subsystems were examined. Subsequently, the dynamic relationship between these elements was established by analyzing drone performance in both full-throttle and hover-throttle conditions. A MATLAB-based algorithm was developed and validated using experimental data from component manufacturers, which serve as a primary reference for multi-rotor system evaluations under diverse flight scenarios. This algorithm enables analysis of all performance-influencing parameters, helping to resolve design uncertainties before manufacturing or actual flight. Furthermore, it facilitates the identification of the optimal component configuration based on predefined mission requirements and environmental conditions.

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1 INTRODUCTION

Rapid technological advancement, combined with evolving modern demands, has significantly increased the daily use of drones. As a result, engineers and researchers across various disciplines must now gain a deeper understanding of drone technologies and their practical applications. Drones are increasingly used across a wide range of industrial sectors, including aerial imaging of

rugged terrains, inspection of high-voltage power transmission lines, firefighting, and remote sensing. These diverse applications have attracted growing interest from industries worldwide. Initially, drones were primarily of the fixed-wing type^[1]; however, as use cases expanded and the need for flexible flight modes emerged, vertical take-off and landing (VTOL) systems—specifically multi-rotors—entered

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the market [2]. One of the key features of multi-rotors is their ability to hover, i.e., remain stationary in the air at a fixed altitude and location. In this mode, the thrust produced by the motors is solely used to counteract the weight of the drone [3], [4]. This hovering capability is especially valuable for detailed inspection of components in large infrastructures, such as oil and gas pipelines—something not feasible with fixed-wing drones [3]. It also eliminates the need for human presence during inspections, improving both safety and precision [4]. Unlike fixed-wing drones, multi-rotors do not require runways for take-off or landing, giving them a substantial operational advantage [5]. Although unmanned aerial vehicles (UAVs) have proven to be highly efficient tools in many industries, a key challenge remains: how to design multi-rotor systems tailored to specific missions and performance requirements while achieving high efficiency and minimal error [6].

Several parameters influence the design and production of multi-rotor systems [7]. For instance, arm length significantly affects the torque applied by the motors and thus the drone's maneuverability [8]. During the design process, critical variables such as the intended flight mission (e.g., prioritizing maneuverability vs. stability), required thrust, and motor torque must be carefully considered [9]. Another crucial factor is rotor size, which directly impacts motor efficiency and flight quality [10], [11]. Larger rotors demand more electrical power, which increases current draw and raises motor temperatures [12]. This thermal load can shorten motor lifespan and compromise long-term performance [13]. Ultimately, the most fundamental principle in designing an efficient multi-rotor drone is achieving harmonious integration of all components [14].

Various papers have investigated multi-rotors through different approaches. Delbecq et al. developed a generic sizing methodology for electric multirotor UAVs using algebraic scaling laws and multidisciplinary design optimization (MDO) [15]. They achieved a significant reduction in optimization effort by eliminating inequality constraints and created a reusable MDO tool validated against existing UAV specs. Ampatis et al. sought to optimize the propeller selection system for drones based on a set of basic parameters and requirements [16]. They further investigated different subsystems of the drone to calculate the primary specifications of the required propeller. Their study illustrated the influence of

the payload and the number of rotors on the design vector and the MRV size. Pollet et al. incorporated commercial components in UAV design while modeling uncertainties in component performance [17]. His research proposed a robust optimization loop that quantifies and mitigates uncertainties, resulting in more reliable UAV designs under real-world component variability. Chan et al. investigated the optimal flight mode of a multi-rotor for minimum energy consumption and maximum flight time in the cruise phase [18]. Their study demonstrated that the proposed procedure can produce good predictions with percentage errors less than 7.4%. Magnussen et al. focused on the hardware optimization of multi-rotors, calculating optimal flight time for drones with 4, 6, and 8 motors [19]. Their research showed that the design optimization tailored to the specified hardware and payload yields an 11-minute increase in flight time compared to configurations employing the largest available propeller, motor, and battery. Wang et al. applied topology optimization combined with genetic algorithms to rotor shape/design at the component level [20]. Their study introduced GA-enhanced topology optimization for rotors, demonstrating significant aerodynamic improvements over conventional rotor shapes. Despite this progress, most existing studies do not fully address subsystem integration. Additionally, the aerospace industry still lacks a comprehensive, unified database for multi-rotor design equations and procedures. Most drone manufacturers rely on large R&D teams with significant budgets to manage these complexities. In contrast, the algorithm proposed in this study offers a streamlined, error-resistant alternative, capable of performing core R&D tasks quickly and accurately.

This research begins by exploring the core concepts of multi-rotor systems, followed by a detailed analysis of individual subsystems. It then establishes the interdependencies between components, culminating in a novel algorithm that consolidates these relationships. This algorithm evaluates part compatibility, flight characteristics, environmental impacts, and system-level performance to facilitate optimal drone configuration for a given mission. Designed for both experts and beginners, the algorithm is applicable in pre- and post-manufacturing phases. For example, it can be used to assess how changes in environmental conditions affect drone performance, enabling better-informed decisions

for different flight scenarios. Overall, the proposed algorithm provides a systematic approach for selecting components and optimizing operational parameters, ultimately enhancing the reliability and effectiveness of multi-rotor systems.

2 FUNDAMENTAL CONCEPTS

Like all aerial vehicles, such as aircraft and helicopters, drones operate based on fundamental aerodynamic principles. Understanding these core concepts is essential for anyone involved in drone research or manufacturing [21]. One of the most critical performance indicators for drones is the thrust-to-weight ratio (TWR). A minimum acceptable TWR is typically set at 2, which allows the drone to hover at approximately 50% throttle. Slightly increasing the throttle above this level enables the drone to ascend [22], [23]. Therefore, TWR must be carefully selected based on mission requirements and desired efficiency. While a higher TWR allows the drone to lift off at lower throttle levels—thus extending motor life—it also increases production costs.

Another essential design consideration is the drone's frame size [15]. Frame size affects the propeller dimensions, which must be selected to avoid interference among rotors. Additionally, the torque applied by the motors is influenced by the arm length, which plays a key role in the drone's stability and maneuverability. Optimal arm length has long been a focus for engineers aiming to maximize efficiency for a given mission. In rotor-based drones, spinning rotors produce torque that must be counterbalanced. Multi-rotor configurations typically use an even number of motors, with adjacent units rotating in opposite directions (clockwise and counterclockwise). For systems with an odd number of rotors, one motor is often tilted to counteract its torque. Although this approach provides a degree of stability, it complicates thrust direction control—another reason why even-numbered configurations are generally preferred.

Environmental conditions also present substantial challenges in drone design and manufacturing [24]. Altitude and ambient temperature are the two most influential environmental factors. As altitude increases, air density decreases, requiring greater throttle and rotational speed to maintain a constant thrust level. This, in turn, increases input power demands and reduces both motor efficiency and flight duration.

Similarly, higher ambient temperatures can cause motor overheating, leading to increased resistance and potential system failure.

2.1 Subsystems

Subsystems of a multirotor drone include the motor, propeller, electronic speed controller, battery, control system, and flight computer. In this section, we consider the functions of these systems both separately and in connection with one another [25].

2.1.1 Motor and propeller

The motor is the primary component of the propulsion system of a drone. Generating the shaft power, it turns the rotor to produce thrust force [26]. In brushless direct current (BLDC) motors, electrical current flows into the motor coil to induce a magnetic field by means of which the shaft is forced to rotate. The main parameters of a BLDC motor include the electrical current, thrust, torque, rotational velocity of the shaft, coil resistance, and motor temperature. Before all of these parameters can be determined, one needs 6 coupled equations; each of these equations is explained in the following. Noteworthy, in order to consider critical motor conditions, all of the mentioned parameters were calculated in the full-throttle state.

First, the maximum rotational velocity was calculated considering the predefined rotor size. For this purpose, an empirical coefficient f_1 was defined to enhance the accuracy of the calculations. This experimental coefficient was estimated based on experimental tests performed by T-motor Company.

$$f_1 = 18.2 \times e^{-\left(\frac{s-28.08}{19.51}\right)^2} + 13990 \times e^{-\left(\frac{s-124.4}{32.32}\right)^2} \quad (1)$$

Where s is the size of the propeller.

Equation (2) was then applied to produce an initial estimation of the angular velocity [27].

$$\omega_1 = \frac{\omega_{nl} \times f_1}{S} \quad (2)$$

Where ω_{nl} is the no-load angular velocity of the motor [28].

Afterwards, the thrust force generated by the motor and rotor was calculated through the following equation [29]:

$$F = \frac{\rho \times c \times R_p^3 \times \omega^2 \times C_{L\alpha} \times \theta}{3} \quad (3)$$

In which F is the thrust force, ρ is air density, c denotes the aerodynamic chord of the rotor, R_p is the propeller radius, ω is the angular velocity of the motor, $C_{L\alpha}$ represents the propeller lift curve slope, and θ is the pitch angle of the rotor. The following equation was further used to evaluate the torque produced by the rotor [29]:

$$\begin{aligned} \text{Torque} = & \rho \times c \times R_p^4 \times \omega^2 \\ & \times \left(\frac{C_{D0} + C_{Di} \times \theta^2}{4} \right. \\ & \left. + \frac{C_{L\alpha} \times \theta}{3 \times R_p \times \omega} \right) \end{aligned} \quad (4)$$

Where C_{D0} is the zero-lift drag coefficient and C_{Di} is the induced drag coefficient.

Equations (3) and (4) consider the effects of the rotor and rotational velocity on the produced thrust and torque by the motor. The next step is to investigate the effect of the electrical current consumed by the motor on the mentioned parameters. Trivially, the current consumption by the motor increases with the rotor size, and so does the power consumption and mechanical power generation of the motor. This increase, however, may not exceed the maximum admissible current by the motor, as it can cause defects or complete failure of the motor. The following equation was employed to calculate the consumed current by the motor [18]:

$$\text{Torque} \times \omega = (V - R_m \times I) \times (I - I_0) \quad (5)$$

Where V is the motor voltage, R_m is the initial motor resistance, I is the electrical current consumed by the motor in the hovering state, and I_0 is the no-load electrical current of the motor.

Equations (1) through (5) provide initial estimations of the thrust, torque, current, and rotational velocity of the motor. Now, in order to enhance the accuracy, Equation (6) is used to recalculate the rotational velocity, followed by reapplying Equations (3), (4), and (5) to estimate the thrust, torque, rotational velocity, and electrical current at a higher level of accuracy[30]. Investigations indicated that proper outcomes can be obtained after repeating this process once[31].

$$\omega = 0.8 \times KV \times (V - (I_1 \times R_m)) \quad (6)$$

Once finished with estimating the abovementioned parameters, we proceed to investigate maximum motor temperature. In a brushless motor, elevated temperatures increase the internal resistance of the motor coil, thereby intensifying the rise of temperature [32]. That is, these two phenomena

produce a sort of resonance effect that can reach the motor to overheat state if proper controls are not practiced. Brushless motors enjoy quality cooling mechanisms thanks to their mesh-like structure, which allows proper air flow through the motor coil. This cooling quality must be considered to achieve even higher accuracy levels. In Equation (4), the cooling coefficient is denoted by n . Similar to the coefficient f_1 , this cooling coefficient was obtained empirically from the respective datasheet. Ultimately, the following expression was devised to evaluate the effect of temperature[31]:

$$\frac{(V \times I) - (\text{Torque} \times \omega)}{n} = R \times I^2 \quad (7)$$

Where n is obtained from Table 1.

Table1-Cooling quality

n	Cooling quality(max 5)
3	1
3.25	2
3.5	3
3.75	4
4	5

Equation (7) was used to calculate secondary resistance of the motor following the increase in temperature, with Equation (8) used to calculate the secondary temperature [33].

$$R = R_m \times (1 + \alpha \times (T - T_0)) \quad (8)$$

In which α is the temperature coefficient, T_0 is the ambient temperature, and T is the secondary temperature of the motor.

As discussed in the section on fundamental concepts, the effect of altitude on the output power [24] was assessed in the form of the output power reduction coefficient (Equation (9)).

$$po = (1 - 6.875 \times 10^{-6} \times h)^{3.83} \quad (9)$$

Where h is the flight altitude, po is the output power reduction coefficient. It is worth noting that this equation holds true for the troposphere only. However, given that almost all multirotor drones are designed to fly at altitudes below 32,000 ft, one may not need any other equation to account for the stratosphere.

Finally, the calculated parameters were used to obtain maximum input and output powers [31].

$$P_{in} = V \times I \quad (10)$$

$$P_{out} = \text{Torque} \times \omega \quad (11)$$

in which P_{in} and P_{out} refer to the input and output power levels, respectively.

2.1.2 Electronic speed controller (ESC)

Speed control is the module through which the motor is linked to the power supply. The main task for this subsystem is to control the motor speed [34]. The speed control subsystem is characterized by two primary parameters, namely current and voltage. For all multirotor systems, the voltage must be identical at the motor, speed control, and battery. When it comes to the speed control current selection, however, this selection must be performed in such a way as to keep the maximum tolerable current to the speed control some 30% higher than the maximum tolerable current to the motor. This provides the speed control with a safe margin. Indeed, at special moments during a flight (e.g., sudden path changes or stuck of leaves and tree branches in between the rotors), instantaneous current consumption may exceed the tolerable current to the motor, and thus this 30% clearance is considered to develop a safe margin for avoiding speed control failure [35].

$$I_e = I \times 1.3 \quad (12)$$

Where I_e is the speed control current and I denotes the motor current.

2.1.3 Battery

The batteries for drones exhibit two characteristic features: high discharge rate coupled with a high capacity-to-weight ratio [36]. As of present, thanks to the most advanced technologies, two types of battery have been widely used in all electricity-powered drones, including lithium-polymer and lithium-ion battery packs. Three major characteristics of batteries are studied in this work, including the discharge rate, number of cells, and capacity. Each battery cell establishes an average voltage of 3.7 V, with each cell producing a voltage of 4.2 V and 3 V at full charge and fully drained states, respectively.

The discharge rate measures the ability of the battery to provide instantaneous current and is usually indicated as a ratio of the battery capacity [37]. For example, a battery discharge rate of 45C means that the battery can feed the motors with an instantaneous current of 45 times as large as its capacity. Generally speaking, in order to keep a safe margin, batteries are not used at their maximum discharge rate, as this leads to increased temperature and hence reduced lifetime of the battery. Over time, as a battery cell's voltage declines, the battery discharge rate decreases as well. Accordingly, a battery discharge rate shall be

at least 60% higher than the total current consumption by all motors [38].

$$C\ Rate = \frac{I \times N \times 1.6}{Capacity} \quad (13)$$

The above equation calculates the minimum permissible discharge rate for the battery, where C -Rate denotes the battery discharge rate, N is the number of motors, and $capacity$ is the battery capacity.

The capacity coefficient of a battery is directly associated with the flight time of the drone. The flight time can be calculated by using the current consumption via the procedure explained in Section 3.1, coupled with the battery capacity [39].

$$FT = \frac{B \times Capacity \times D}{N \times I} \quad (14)$$

Where B is the number of batteries, D is the maximum battery discharge rate, and FT denotes the flight time. For a given flight time, one can alternatively calculate the required battery capacity.

2.1.4 Control system

The control system of a drone is made up of a transmitter, a receiver, and an antenna. The transmitter is deployed at a terrestrial station while the receiver and the antenna are parts of a drone [40]. In contrast to previous subsystems, the control system imposes no significant effect on the flight of the drone, and is only considered when it comes to range calculations.

A multirotor is powered by electricity. This implies that the drone's weight is not decreased as it flies, and this paves the way to obtain a linear equation for the drone's range in cruise phase [41].

$$Ra = V1 \times FT \quad (15)$$

In which $V1$ and Ra are the cruise speed and the drone range, respectively.

The range obtained by Equation (15) is compared to the maximum distance at which the transmitter can transmit the commands to the drone, and if this distance is shorter than the obtained range from Equation (15), the control system acts as a range-limiting factor.

2.1.5 Throttle

The throttle is not an independent section in multi-rotors, and it only appears in motor analysis. However, due to its high importance and great influence in flight, it is examined separately.

In each and any motor, an increase in throttle boosts all fundamental parameters of the motor, including the thrust and torque. In the meantime, not all of these parameters can be calculated directly at a given throttle level, as they follow nonlinear trends of change. In this respect, using some empirical tests and existing results on the motor datasheets, the following equations can be obtained to demonstrate the trend of changes in the motor throttle from 50 – 100%. In the throttle range of 0 – 50, slope variations were so small that they justified the use of a linear model.

$$T_i = A \times T_{max} \quad (16)$$

$$I_i = B \times I_{max} \quad (17)$$

Where T_i and I_i are required levels of thrust and current. In these equations, variations of the thrust and current were calculated as coefficients of the maximum thrust and current, as explained in Section 3.1. In this formulation, Matrices A and B are coefficient matrices that were calculated based on the throttle.

$$\begin{aligned} A = & 74.41E - 11 \times x^5 - 28.17E \\ & - 8 \times x^4 + 41.60E \\ & - 6 \times x^3 - 29.67E \\ & - 4 \times x^2 + 11.44E \\ & - 2 \times x - 1.64 \end{aligned} \quad (18)$$

$$\begin{aligned} B = & -18.85E - 10 \times x^5 + 68.11E \\ & - 8 \times x^4 - 96.68E \\ & - 6 \times x^3 + 68.78E \\ & - 4 \times x^2 - 23.54E \\ & - 2 \times x + 3.18 \end{aligned} \quad (19)$$

x is the motor throttle.

3 ALGORITHM

The input data for the algorithm included the motor model, rotor specifications, radio control parameters, speed controller specifications, battery characteristics, frame dimensions, and the environmental conditions in which the drone would operate. By developing a novel and efficient algorithm and implementing it in MATLAB, the calculation process was significantly accelerated, thereby reducing the time required to obtain the final results.

The algorithm begins with an analysis of the drone frame. Based on the propeller size, frame dimensions, and the number of motors, the axial spacing between motors is determined. Taking into account a safety clearance—typically 15% of the rotor diameter—between adjacent rotor tips, the

algorithm evaluates the compatibility of these three primary parameters. The next step involves verifying the voltage levels of the selected components. Voltage is one of the most critical parameters: if the motor, battery, and electronic speed controller (ESC) do not operate at the same voltage, the drone cannot function properly, and all subsequent calculations become invalid.

Following this, the maximum current rating of the motor—obtained from its datasheet—is compared against the ESC's current tolerance to confirm compatibility. If the selected ESC cannot safely handle the motor's current demands, the component selection must be revised.

The algorithm then proceeds to analyze the drone in hovering mode, where all performance parameters are calculated. Initially, Equation (3) is used to compute the rotational speed of the motor, followed by Equation (4) to determine the torque. Next, Equations (5), (7), and (8) are applied to estimate the electrical current, the coil's secondary resistance, and the motor's secondary temperature, respectively.

Subsequently, the algorithm evaluates the drone under maximum-performance conditions. Unlike the hover state—where thrust is predefined—the full-throttle scenario involves solving for six unknowns: thrust, torque, electrical current, temperature, resistance, and angular velocity, as detailed in Section 3.1.

From this point, the analysis focuses exclusively on full-throttle flight. The first check is whether the thrust-to-weight ratio (TWR) meets the minimum requirement. This is done by multiplying the thrust produced by each motor by the number of motors and comparing the result to the total drone weight. It is essential to ensure that the motor temperature remains below its critical threshold during operation.

By evaluating the current consumption in both hovering and full-throttle conditions, the flight time under each mode can be calculated using Equation (14). Generally, the maximum and minimum flight durations correspond to the hovering and full-throttle states, respectively. The nominal flight time is typically taken as a combination of these two extremes.

The algorithm also calculates the input and output power of the motor based on torque, current, and angular velocity, thus determining its efficiency. Additionally, it accounts for the effect of altitude on output power reduction, which helps in estimating the required thrust to sustain flight at higher elevations.

Next, the motor's peak current consumption is compared to its maximum rated current. If all checks are passed, the motor is deemed suitable for the design. Using the calculated thrust and power at a specific altitude, the drone's velocity in various flight modes can be estimated [42]. One of the key variables influencing flight speed is the drone's pitch angle during forward motion, as illustrated in Figure 1 [43].

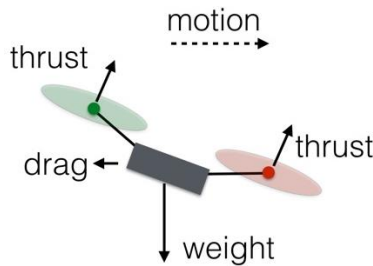


Figure 1- Forces applied to the drone and the drone movement scheme.

The final stage of the algorithm is the evaluation of the battery selection. Three factors are critical: the drone's expected flight time, its operational range, and the battery's ability to supply sufficient power to the motors. A suitable battery must satisfy all these conditions. To verify this, the current drawn by the motors is assessed in relation to the battery's discharge rate.

The complete structure of the algorithm, along with the sequential steps for designing and evaluating a multi-rotor UAV, is clearly illustrated in Figure 2.

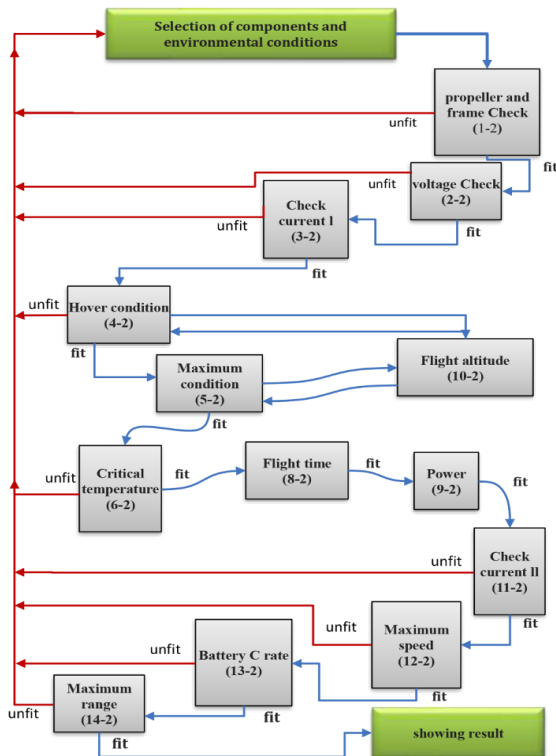


Figure 2- Algorithm for designing and evaluating UAV performance parameters

4 RESULT AND DISCUSSION

In order to verify some of the explained stages in the previous section, the following quadcopter plus with a mass of 4 kg and an arm length of 80 cm, was considered under the defined conditions (with two rotor sizes, namely 17×5.8 and 18×6.1 in) to analyze its performance in the hovering state.

Motor: 170 kV T-motor MN5008

Speed control: 20 A

Battery: 12-cell 4000 mAh 45C

According to the mentioned algorithm, we began by investigating the propeller size and arm length of the drone. As is evident, the arm length was appropriate in relation to the propeller length of 18 in. As a next step, the voltage was checked. The fact that the motor, speed control, and battery were all supplied with a 12-cell battery operating at a voltage of 48 V. Afterwards, the maximum current to the motor was compared to that to the speed control. Acknowledging that the selected motor could tolerate a maximum current of about 15 A, the choice of the speed control was OK. Upon verification of the first three steps of the proposed algorithm, one could consider the drone in a hovering state.

Constant parameters are described in Table 2.

Table 2-constant parameters

unit	value	parameter
$\frac{kg}{m^3}$	1.225	ρ
-	2.87	C_{La}
m	0.06	c
rad	0.14	θ
-	0.035	C_{D0}
-	0.01	C_{Di}
Ω	0.27	R_m
A	0.4	I_0
$\frac{m}{s^2}$	9.8	g

Since the drone weight was supposed to be supported by four motors, we divided the total drone weight by 4, as per Equation (3), which gives:

$$1 \times 9.8 = \frac{1.225 \times 0.06 \times 0.2159^3 \times \omega^2 \times 2.87 \times 0.14}{3}$$

$$\Rightarrow \omega = 314.52 \frac{rad}{s}$$

Continuing with the research, according to Equation (4):

$$\text{Torque} = 1.225 \times .06 \times 0.2159^4 \times 314.52^2 \times \left(\frac{0.035 + 0.01 \times 0.14^2}{4} + \frac{0.14 \times 2.7}{3 \times 0.2159 \times 314.52} \right)$$

$$\Rightarrow \text{Torque} = 0.168 \text{ N.m}$$

Substituting the result into Equation (5) gives:

$$0.168 \times 314.52 = (48 - 0.27 \times I) \times (I - 0.4) \Rightarrow I = 1.54 \text{ A}$$

The rest of the algorithm was implemented as explained in Section 3.1. A comparison of the obtained results against those provided on the datasheet of the motor indicates that:

Table 3-Comparison of propeller 17×5.8 data

ERR(%)	Experimental	Theoretical	parameters
6	335	314.52	ω
1.1	0.17	0.168	Torque
1.2	1.57	1.54	I

Although this percent error is sourced from such factors as the aerodynamic coefficients of the propeller as well as the weather conditions of the site of experimental tests, yet its level is pretty acceptable. Similarly, the following results were obtained for the 18 × 6.1 in rotor:

Table 4-Comparison of propeller 18×6.1 data

ERR(%)	Experimental	Theoretical	parameters
8.6	316	288.67	ω
4.5	0.22	0.21	Torque
5.5	1.8	1.7	I

Now, the considered drone was investigated in different states to check for the proper selection of fundamental parameters like flight altitude, weight, and rotor size. Therefore, considering the hovering flight of the first configuration (i.e., 17 × 5.8 in rotor) and applying Equation (9), the effects of changes in the flight altitude on the output power of the motor at different altitudes were checked.

$$P_{in} = 0.172 \times 314.52 = 59.01 \text{ W}$$

$$p_o = (1 - 6.875 \times 10^{-6} \times 1000)^{3.83} = 0.97$$

Table 5- output power reduction with flight altitude increase

Reduction amount(W)	Reduction coefficient	Power(W)	Altitude(ft)
1.77	0.97	57.24	1000
3.07	0.948	55.94	2000
7.38	0.875	51.63	5000
14.16	0.76	44.85	10000
20.06	0.66	38.95	15000
25.55	0.567	33.46	20000

As is evident in Table 5 and Diagram 1, the output power of the motor is significantly reduced at higher flight altitudes. As a result, one should increase the throttle to ensure that the flight can be continued at the same altitude. This, however, leads to increased power consumption and hence reduced flight time.

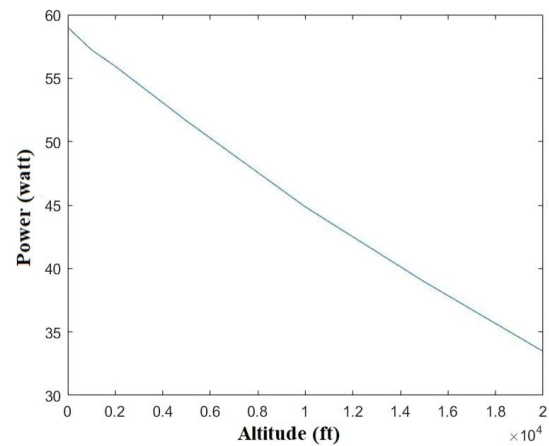


Diagram 1-Changes in output power based on altitude

Subsequently, the effects of mass variations on the power consumption and hence flight time of the drone with the first configuration (i.e., 17 × 5.8 in rotor) were examined:

Table 6- variations of flight time with weight change

Hover flight time(min)	Current(A)	All up weight(kg)
42.1	1.14	3
36.36	1.32	3.5
31.17	1.54	4
28.07	1.71	4.5
25	1.92	5

As is evident from Table 6, the power consumption of the drone increases with the drone's length, thereby decreasing the flight time. Next, variations of torque, angular velocity, and power consumption with a change in propeller size of a 5-kg drone with the first configuration (i.e., 17 × 5.8 propeller) were considered.

Table 7. variations of the main parameters of the motor by changing the propeller size

Current	Torque	Angular velocity	Propeller size
2.06	0.18	439.16	15
1.98	0.192	390.31	16
1.9	0.204	349.16	17
1.83	0.217	314.15	18
1.76	0.23	281.93	19

Dividing the obtained values by the values for a propeller size of 15 gives:

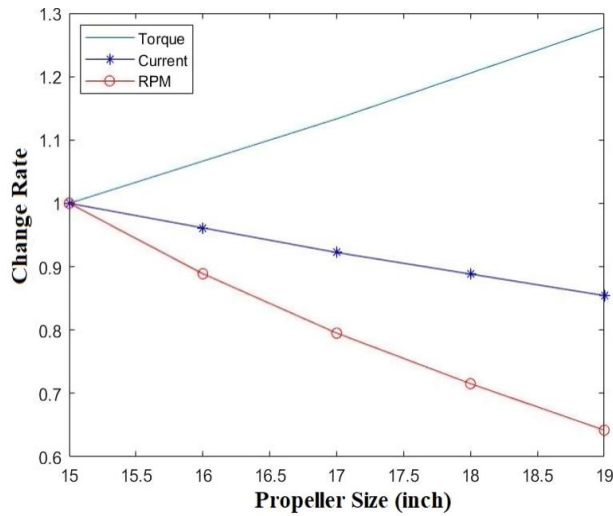


Diagram 2. Variations of the main parameters compared to the change in the size of the propeller

As is clear from Diagram 2, at a given thrust level, an increase in the propeller size boosts the produced torque while reducing the current and angular velocity. However, should the propeller size increase at a given throttle level, all three of the mentioned parameters grow.

Diagram 3 indicates that the variations of thrust and current with throttle follow pretty different paths, with the obtained values at the start point differing by some 75%.

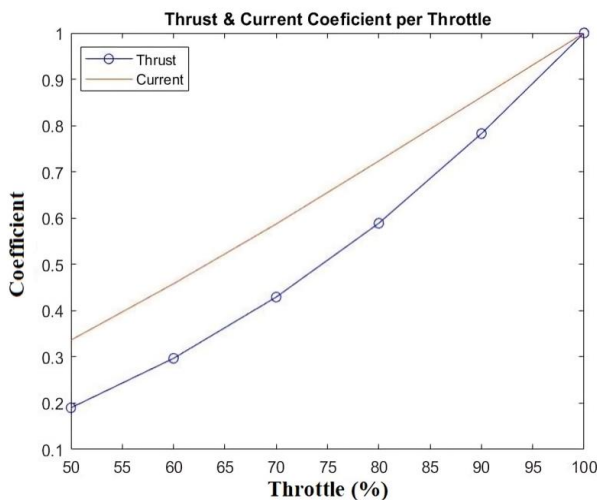


Diagram 3. Variations of thrust and current coefficients as a function of throttle

As a next step, variations of the current and thrust of four different models were investigated at different throttle levels.

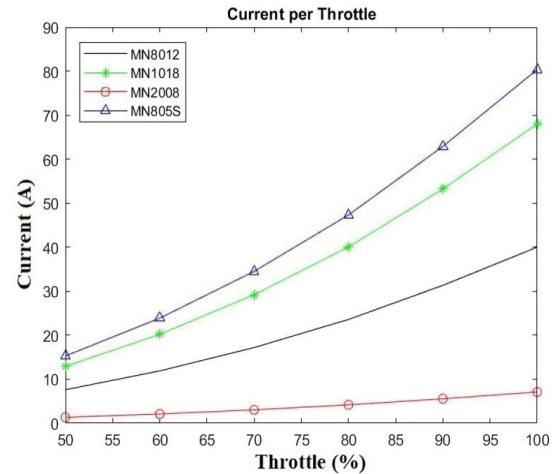


Diagram 4. Variations of current versus throttle

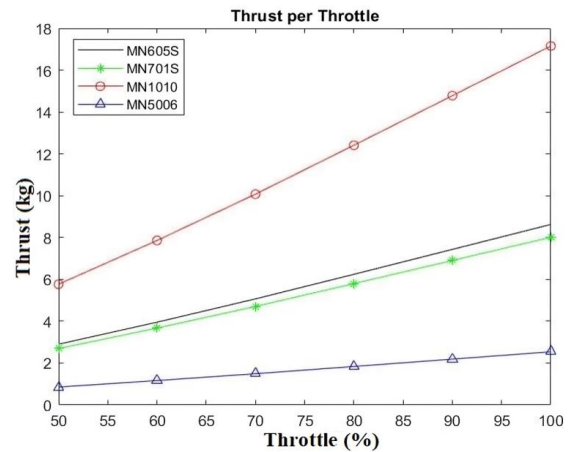


Diagram 5. Variations of thrust versus throttle

As seen on diagrams 4 and 5, the variations are not linear, with the curve slope increasing with the throttle level of the motor. In the next stage, the changes that occurred due to an increase in the maximum take-off weight of the drone in the hovering-throttle state were investigated.

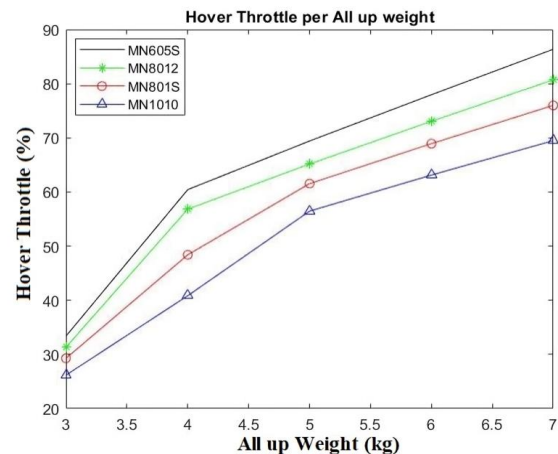


Diagram 6. Variations of hovering throttle level versus maximum take-off weight

As expected, these variations are nonlinear, with the diagram slope decreasing at a throttle level of about 55%. Subsequently, the maximum thrust increase rate was compared across three motors equipped with different rotor sizes.

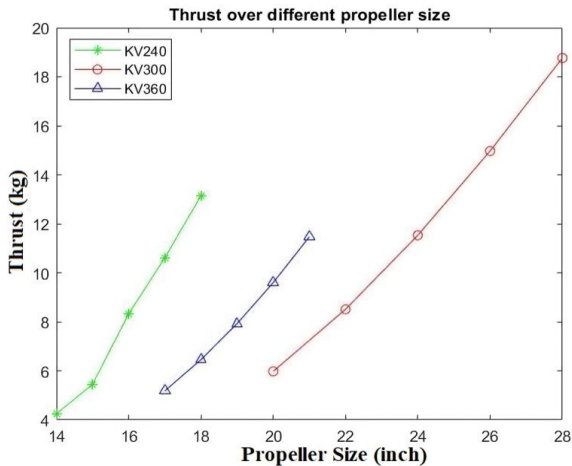


Diagram 7. Maximum thrust variations versus propeller sizes

On diagram 7, it is evident that subtle changes in the rotor length can boost the produced thrust by the motor significantly. However, the significant increase in the motor temperature with increasing the rotor size represents a major limitation hindering the motor thrust improvement. Diagram 7 further shows some safe temperature zones for the three different motors. One can then calculate the overlapping zone and select the ideal motor as per the requirements.

Next, the association of the consumed current with the maximum take-off weight of the drone, which is known to be directly associated with the flight time, was investigated.

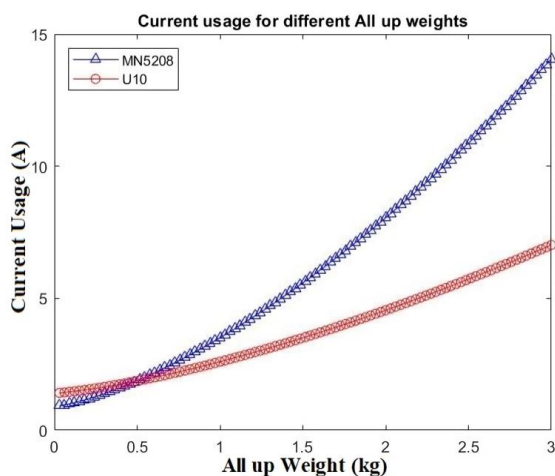


Diagram 8. variations of current consumption as a function of maximum all-up weight

Diagram 8 indicates the very large effect of the drone weight on the drone-consumed current. An important point to note is the effect of the motor power on the increase in the rate. The U10 motor produces the same level of thrust at a lower kV and hence higher power. As a final step, the effect of an increase in flight altitude on the consumed current by the motor was investigated.

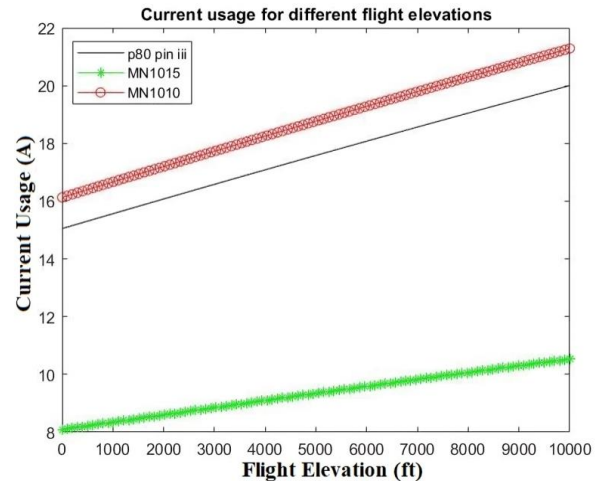


Diagram 9. Changes in current consumption due to altitude increase

In contrast to the previous cases, these variations are linear and can be used to estimate, accurately, the reduction in flight time at higher altitudes due to increased current consumption.

5 CONCLUSION

This study demonstrates that the fundamental operating parameters of drones can be accurately determined using a limited set of readily available input data. Importantly, the proposed algorithm allows users to assess the drone's operational performance—such as generated thrust, power, and flight time—under various environmental conditions, including changes in weather and flight altitude. This predictive capability can help mitigate weather-related risks during flight operations.

Moreover, the algorithm enables comprehensive pre-manufacturing analysis of the selected components to ensure their compatibility, thereby reducing the likelihood of structural issues and minimizing unnecessary costs. Users can also analyze motor performance across different propeller sizes to select the optimal configuration based on specific mission requirements.

The algorithm supports the calculation and evaluation of all critical performance metrics and physical characteristics of a drone across a range of

throttle levels. It also facilitates the study of how both internal system modifications and external environmental changes impact drone behavior, allowing for real-time consideration of operating conditions throughout the flight duration.

Overall, the developed MATLAB-based tool effectively bridges theoretical principles and practical engineering concepts across all drone subsystems. It enables a streamlined, high-speed, and accurate approach to multi-rotor UAV design—covering every stage from initial concept through to mission deployment. Future work (currently in progress as Phase II of this research) will involve optimizing the MATLAB code and integrating artificial intelligence (AI) techniques. This integration aims to automatically suggest optimal drone components for achieving peak performance across a wide range of environmental and operational scenarios.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Erfan Noferesti and Ali Esmaeili. The first draft of the manuscript was written by Erfan Noferesti, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

Not applicable

Consent to participate

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