
# NOVEL SOFTWARE-DRIVEN VARIABLE-PITCH AND LEVEL FLIGHT CONTROL SYSTEM: PRINCIPLES AND APPLICATIONS FOR SMALL AIRCRAFT WITH A QUADROTOR CASE STUDY

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**Abstract**.

Current large aircraft capitalize on intricate features, such as tail wings, airfoils, and specialized variable-pitch or actuated tilt-rotor designs, to facilitate optimized varying-distance flights and remarkably efficient level flights. In contrast, most small electric aircraft, drones, EVTOLs, and UAVs prioritize the straightforwardness of fixed-pitch propeller propulsion systems and easy-to-operate body-tilting flight mechanisms. While these approaches emphasize simplicity, they inherently suffer from inefficiency and considerably compromise overall performance. Developing a miniaturized, lightweight, efficient, and reliable mechanical variable-pitch mechanism and actuated tilt-rotors for small aircraft is highly challenging, with limited practical implementations yielding suboptimal results. Consequently, the drone industry has resorted to less efficient fixed-pitch and body-tilting flight mechanisms. Moreover, unlike traditional aircraft that get lighter as fuel is consumed, electric aircraft maintain a constant battery weight during flight, exacerbating efficiency and performance issues, particularly in low-battery situations. In light of the demonstrated superiority of variable-pitch propulsion mechanisms and level flight strategies for electric aircraft and drones, as substantiated by nearly a century of human experience, the imperative to re-embrace these technologies is paramount. The successful integration of these methodologies relies on the development of a novel, controllable flow field model. This model is characterized by stepped angles of attack with staggered variables and functions as a dynamic coupling and matching system. It is specifically designed to optimize power output through efficient allocation of power within the optimal range of the angle of attack. In doing so, it effectively synchronizes the aircraft's flight processes and power systems, ensuring seamless integration and coordination of these critical components to achieve peak performance. The realization of this objective necessitates the cultivation of state-of-the-art control strategies and methodologies. The comprehensive implementation of these advancements facilitates the realization of variable-pitch propulsion and level flight capabilities in drones, ultimately engendering a transformative shift in performance standards. A case in point is the quadcopter, which capitalizes on this system's models and strategies to modulate the flowfield and incoming airflow, yielding a noteworthy boost in propulsive efficiency of up to 35%. Further fine-tuning, such as the implementation of pre-set tilt-rotors, has the potential to augment efficiency to 45%. Notably, these advancements do not necessitate additional auxiliary mechanisms or accessories for existing drones but can be achieved through modifications to the flight control system software.

**Keywords:** software-driven variable-pitch and level flight, stepped angles of attack, motor efficiency map chart, pre-set tilt-rotors, matching strategy and coupling measure

## 1. Introduction

In the aviation industry, the pursuit of efficient and reliable propulsion systems is paramount. Large aircraft often incorporate complex features, including tail wings that provide stability and control during flight, airfoils designed to generate lift while minimizing drag, and variable-pitch or actuated tilt-rotor systems that allow for adaptability to changing flight conditions. These advanced designs enable optimal performance in both vertical takeoff and landing (VTOL) and forward flight, enhancing overall efficiency. However, most small electric aircraft, drones, EVTOLs, and UAVs prioritize simplicity, leading to the widespread use of fixed-pitch propeller propulsion systems and body-tilting flight mechanisms. Fixed-pitch propeller systems, with their constant blade angle, compromise performance and efficiency due to limited adaptability to varying flight conditions. Similarly, body-tilting flight mechanisms, chosen for their lightweight design and ease of implementation, introduce inefficiencies and performance limitations during transitions between vertical and forward flight. As a result, there is a significant gap between the capabilities of large and small aircraft concerning adaptability and efficiency during flights. To address this issue, it is crucial to develop miniaturized, efficient, and reliable mechanical variable-pitch mechanisms and actuated tilt-rotors tailored for small aircraft, ultimately enhancing their capabilities and enabling higher efficiency and performance levels comparable to larger aircraft. Efforts have been made to develop miniaturized, lightweight, efficient, and reliable mechanical variable-pitch mechanisms and actuated tilt-rotors for small electric aircraft. However, these attempts have yielded limited practical success, often introducing uncertainties, technological risks, energy consumption, increased maintenance complexities and reduce cost performance, resulting in its extremely limited range of applications. As a result, the drone industry primarily relies on less efficient fixed-pitch and body-tilting flight mechanisms. Despite their simplicity, these systems suffer from significant drawbacks, such as low flight efficiency and reduced maneuverability. Especially, the body-tilting flight mode substantially increases windward area and air resistance, hindering performance and limiting mobility and maneuverability, particularly in challenging weather conditions.

Furthermore, electric aircraft, EVTOLs, and Drones face unique challenges compared to traditional aircraft. While conventional aircraft become lighter as fuel is consumed during flight, electric aircraft maintain a constant battery weight. This constant weight intensifies efficiency and performance challenges, especially when battery levels are low. As the flight progresses, the electric aircraft's propulsion system must continue to generate sufficient lift and overcome drag without the benefit of a reducing overall weight. Consequently, electric aircraft experience exacerbated efficiency and performance issues, which become increasingly acute in situations where battery power is diminished. This highlights the necessity of exploring alternative solutions to optimize the efficiency and performance of electric aircraft throughout their entire flight duration.

The drone industry is rapidly evolving, and ongoing research and development efforts continue to push the boundaries of drone technology in terms of performance, safety, and applications. Currently, many aspects are studied in parallel and remarkable progress has been made, such as: 1) size and form factors, 2) flight control systems, 3) camera and imaging technology, 4) battery technology and flight time, 5) range and connectivity, 6) obstacle avoidance and collision detection, 7) automated flight modes and intelligent features, 8) regulations and geofencing, 9) artificial intelligence (AI) and machine learning, and 10) payload and application-specific capabilities.

Drones come in a wide range of sizes and form factors to cater to different applications. From mini drones that fit in the palm of your hand to large industrial drones with extended flight capabilities, there is a diverse range of options available. Advances in flight control systems have led to improved stability, precision, and autonomous capabilities, in which the output power and speed of each motor can be independently controlled to meet the complex and varied functional requirements. Drones now feature sophisticated flight controllers, GPS navigation systems, and sensor fusion technologies that enable precise positioning, waypoint navigation, and autonomous flight modes. Integrated cameras and imaging systems have become a standard feature in many drones. High-resolution cameras, gimbals for stabilization, and advanced image processing capabilities allow for aerial photography, videography, and even thermal imaging in certain models. Battery technology continues to improve, leading to longer flight times for drones. Lithium-ion batteries and smart power management systems enable drones to stay airborne for extended periods, ranging from 20 minutes to over an hour, depending on the model. Drones now offer improved wireless connectivity options, including Wi-Fi, Bluetooth, and dedicated radio frequency

(RF) systems. These technologies enable reliable control and video transmission over longer distances, enhancing the range of operation for drones. Advanced drones incorporate obstacle avoidance systems using a combination of sensors such as cameras, ultrasonic sensors, lidar, or radar. These systems help detect and avoid objects in the flight path, improving safety and reducing the risk of collisions. Many consumer drones come equipped with automated flight modes and intelligent features. These include follow-me modes, orbiting, waypoint navigation, and pre-programmed cinematic shots. These features simplify the flying experience and allow users to capture professional-looking footage with ease. The regulations and geofencing ensure safety. AI and machine learning techniques are being integrated into drones to enhance their capabilities. This includes object recognition, autonomous navigation, real-time decision-making, and even swarm intelligence for coordinated group operations. Drones are being designed and optimized for specific applications, such as passenger drones, personal flying, aerial mapping, surveying, agriculture, delivery, cargo transportation and search and rescue. These specialized drones may feature specific payload capacities, sensors, or equipment tailored to their intended use.

### 1.1 Propulsion System of Drone

The drone typically use fixed pitch propellers rather than variable pitch propellers. Fixed pitch propellers are the standard choice for drones (such as quadcopters) due to their simplicity, affordability, and ease of use. These propellers have a fixed angle of attack (or blade angle) and are set at a specific pitch during manufacturing. The advantages of fixed pitch propellers for drones include: 1) simplicity, 2) cost-effective, and 3) lighter weight, etc. Fixed pitch propellers have a straightforward design and do not require complex mechanisms for pitch adjustment. This simplicity contributes to the overall reliability and ease of maintenance of drones.

They are generally more affordable compared to variable pitch propellers, making them a practical choice for consumer-level drones. Since fixed pitch propellers lack the additional mechanical components required for pitch adjustment, they tend to be lighter, which can positively impact the overall weight and flight performance of the drone. But the fixed pitch propellers often have some limited adaptability. They are optimized for specific flight conditions. They are unable to perform optimally in varying conditions or when different levels of thrust or efficiency are required.

Although variable pitch propellers offer benefits such as adjustable pitch for improved control and adaptability to various flight conditions, they are not commonly employed in most drones due to several factors. These include increased complexity, higher cost, additional energy consumption, and the extra weight contributed by the mechanical components required for pitch adjustment. As a result, variable pitch propellers are typically found in specialized multirotor aircraft designed for specific applications, such as industrial inspections, aerial cinematography, or research purposes.

### 1.2 Drone Body-Tilting Flight Mechanisms

The body-tilting flight mechanisms in drones involve adjusting the orientation of the drone's body to achieve forward flight. This design enables the aircraft to transition from vertical takeoff and landing (VTOL) to tilt flight by altering the angle of the entire body, instead of changing individual rotor blades. The primary advantage of body-tilting mechanisms is their lightweight design and ease of implementation, which can contribute to reduced manufacturing costs. However, this approach introduces several inefficiencies and performance limitations during tilt flight.

As the drone tilts its body for the transition, the increased frontal area amplifies air resistance and drag, hindering the drone's maneuverability, speed, and overall flight efficiency. Additionally, maintaining stable flight during tilt flight becomes challenging as the continuous changes in attitude adversely affect the drone's aerodynamics and control, making it difficult to maintain optimal flight conditions. In adverse weather conditions, such as strong winds, these issues are further exacerbated, compromising the drone's performance and adaptability. While body-tilting flight mechanisms provide simplicity and cost-effectiveness, they come at the expense of performance, efficiency, and adaptability during tilt flight and different flight conditions, emphasizing the need for alternative solutions to enhance drone capabilities

## 2. The Fundamental Principles and Efficient Control Strategy of the Novel Drone

## 2.1 The Propellers with Different Angles of Attack, Efficiency Curve of Motor and Propeller

The angle of attack has a significant impact on airflow speeds and angles. However, the efficiency of the angle of attack is heavily dependent on the range of angles, typically ranging from 2 to 4 degrees (as illustrated in Figure 1). This efficiency range is related to many factors, such as advance ratio, blade angles, and propeller speed. Conventional aircraft equipped with a variable pitch propeller regulation system, the angle of the propeller blades can be easily adjusted to meet these efficiency requirements. However, the fixed pitch propellers are obviously difficult to adapt to this dynamic demand. As a result, the fixed-distance propellers exhibit optimal efficiency only within a specific speed range, while their efficiency diminishes considerably in other operational states. This poses a challenge for drones as they are increasingly expected to handle diverse tasks and adapt to various situations, such as daily use, passenger-carrying, personal flying, drone delivery, cargo services, aerial photography, agriculture, plant protection, self-piloting for selfies, express delivery, disaster relief, wildlife observation, surveying and mapping, news reporting, power line inspections, film and television shoots, and even military operations. Just like propeller efficiency curves, motor efficiency curves provide a graphical representation of performance across various load points. Both types of curves can be used to optimize performance as part of a Motor Efficiency Management Action Plan (MEMAP), and they have significant implications for improving the efficiency and overall performance of motor-driven systems.

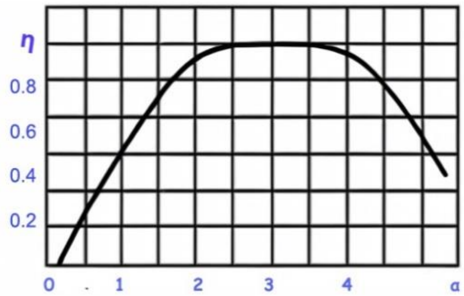



Figure 1 –The efficiency curve for the different attack angles.

We conducted an innovative study to explore the possibility of achieving variable pitch propeller performance using simple and reliable fixed pitch propellers. We used a four-axis drone as an example and performed simulations and tests to evaluate its performance. Multiple propellers with varying blade angles were mounted on the drone to create stepped angles of attack in operation, as depicted in Figure 2. In this configuration, two propellers with the same large blade angle were placed diagonally opposite each other, while the other two propellers with the same small blade angle were positioned on the remaining diagonal, as shown in Figure 4. Deep matching and optimal coupling mechanisms are employed between propellers and the motors [1]. To determine the optimal setup, we tested various combinations of motors with differing parameters and performance levels, as well as propellers with distinct characteristics.

From these tests, we selected representative cases to present, which included the use of conventional motors with advanced cooling systems and low KV value motors paired with propellers featuring high blade angles. This comprehensive exploration allowed us to identify the most efficient and reliable fixed-pitch propeller configurations, paving the way for enhanced drone performance.

Figure 2 –Three propellers with different blade angles.

## 2.2 The Integrated Self-Supercharged Propeller & Propulsion Systems with Efficient cooling [1]

Figure 3(a) was the conventional propeller and propulsion system, while Figure 3(b) shown the integrated self-supercharged propulsion system with the accelerating fan replacing the front cover of the motor. Figure 3(c) was the integrated self-supercharged propulsion system with the accelerating fan, propeller blades, and front cover of the motor all integrated into a single unit [1]. By integrating these components into the propeller and propulsion system, the integrated self-supercharged propulsion system can effectually improve the airflow distribution and pressure characteristics for cooling motor. This, in turn, could enhance the propulsion system and propeller's performance and efficiency.

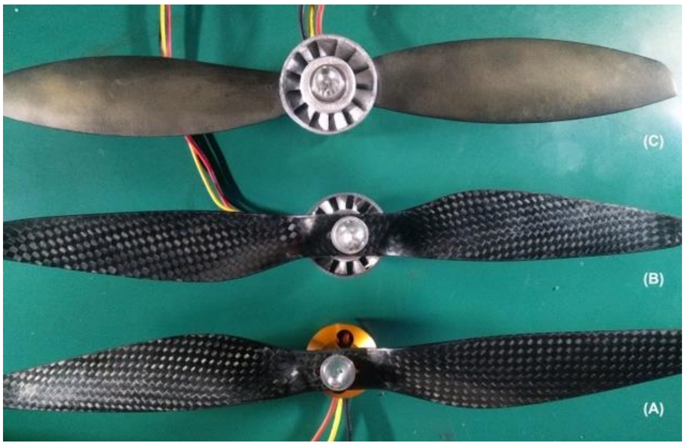



Figure 3 –The Integrated Self-Supercharged Propeller [1].

## 2.3 The Low KV Value Motor Matching Propellers with Big Blade Angles

In the realm of drone propulsion systems, matching low KV value motors with large blade angle propellers has proven to be a highly efficient pairing. Low KV value motors are recognized for their high torque output, which makes them suitable for driving large propellers and high-power propellers. When combined with big blade angle propellers, this configuration leverages the motor's torque to achieve maximum efficiency without occupying additional space. This deep integration and optimized coupling of propellers and motors, based on the Motor Efficiency Management Action Plan (MEMAP), enhances the propeller's capability to move air, thereby improving lift, thrust, and overall performance while optimizing energy utilization.

## 2.4 System and structure layout of the four-axis drone with two type of blade angles propellers and separately matching the efficient cooling integrated self-supercharged propulsion and the Low KV Value Motor

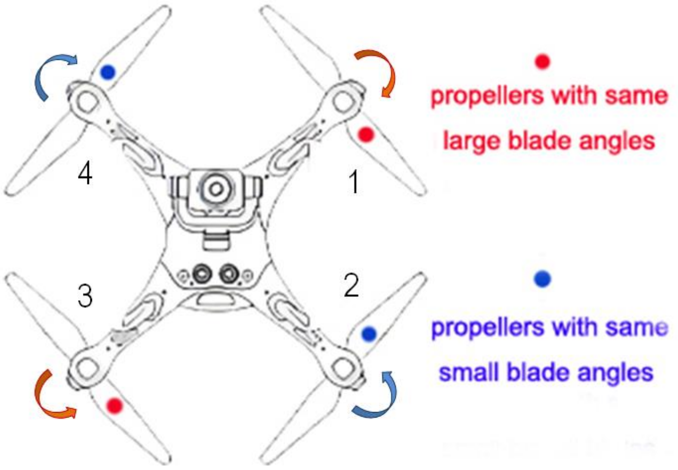



Figure 4 –The propellers layout and setup in the four-axis drone with different blade angles.

The system and structure layout of this novel four-axis drone were basically the same as the original four-axis drones, except for the blade angles of the propeller blades and the specialized rotation characteristics. As shown in Figure 4, the two propellers with large blade angles (Red) were rotating in opposite directions to each other, and the two propellers with same small blade angles (Blue) also were rotating relative to each other. The two propellers with same large blade angles and the two propellers with same small blade angles were separately set on respective diagonals. This also means that the drone can basically maintain balance when one set of propellers is in operation, and basic flight control principle and operation characteristics are fully compatible with the original drones. The basic principle of generating thrust and the operation process are also exactly the same. Therefore, we can directly evaluate the performance and characteristics of this drone and its propulsion system using existing thrust formulas.

The formula for propeller thrust is given by:

$$T = \rho \times A \times V \times (V\_inf - V)$$

(T is the thrust or pull generated by the propeller, $\rho$ is the air density, A is the area swept by the propeller blades, V is the velocity of the air as it passes through the propeller disc, V_inf is the freestream velocity of air approaching the propeller)

This formula considers the difference in velocities between the incoming air (V_inf) and the air exiting the propeller (V), multiplied by the area swept by the propeller blades (A), and the air density (ρ). The optimal blade angle for a propeller depends on various factors such as the desired thrust-to-weight ratio, speed requirements, and specific application, in which the thrust the efficiency are the main concern. The blade angle determines the direction and magnitude of the airflow generated by the propeller.

## 2.5 The Efficient Control Strategies for this Novel Drone

A higher blade angle, often referred to as a higher pitch angle, can generate more thrust by pushing a larger volume of air backward. This is beneficial for applications requiring high acceleration or heavy loads. Conversely, a lower blade angle generates less thrust but can provide better maneuverability and agility. The efficiency of a propeller is influenced by its ability to convert the rotational power from the motor into useful thrust with minimal losses. The blade angle affects the efficiency by determining the angle at which the propeller interacts with the incoming air. An optimal blade angle allows the propeller to efficiently "bite" into the air, minimizing drag and maximizing the conversion of power into thrust. However, if the blade angle is too high, it can create excessive drag and reduce efficiency. Therefore, achieving the optimal balance and layout of blade angles and blade-motor pairing is crucial to enhancing the performance and efficiency of the drone. By carefully considering these factors, it's possible to optimize the propulsion system and maximize the benefits of variable-pitch propellers in small electric aircraft. The superior efficacy and practical results of propellers with large blade angles in high energy consumption stages and propellers with small blade angles in low energy consumption stages are the key focus of this research and investigation. The selection of propellers depends on finding the right balance between thrust, efficiency, and flight characteristics based on the specific requirements of each energy consumption stage. Large blade angle propellers provide the necessary power and responsiveness for high energy-demanding maneuvers, while small blade angle propellers deliver improved efficiency and extended flight endurance during low energy consumption stages.

In the high energy consumption stages, such as takeoff, climbing, and maneuvering, propellers with large blade angles excel due to their ability to generate higher thrust. These propellers capture and move a larger volume of air, allowing the drone to overcome gravity, ascend rapidly, and execute quick maneuvers. The superior efficacy of large blade angle propellers lies in their ability to produce significant thrust at the expense of higher energy consumption.

Ulteriorly, in the low energy consumption stages, like cruising or low-speed operations, propellers with small blade angles offer advantages. These propellers are designed for improved efficiency and reduced power consumption. With reduced drag and optimized blade profiles, they can achieve higher flight efficiency during sustained cruising. Propellers with small blade angles are ideal for scenarios where energy conservation and longer flight times are prioritized.

By strategically utilizing propellers with different blade angles during various stages of flight, it is possible to enhance power and efficiency in a drone system. This is achieved by carefully selecting the most suitable motor for each propeller in the configuration and ensuring deep matching and optimal coupling between each propeller and its respective motor. For instance, in the system illustrated in Figure 4, if Propeller1 and Propeller3 have large blade angles while Propeller2 and Propeller4 have small blade angles, a more energy-efficient setup can be achieved, thanks to the deep matching and optimal coupling of each individual propeller-motor pair.

During high energy consumption stages, such as takeoff, climbing, and maneuvering, primarily engaging propeller1 and propeller3 allows for increased lift and thrust. Conversely, during low energy consumption stages, such as cruising or low-speed operations, the predominant use of propeller2 and propeller4 results in more efficient flight.

To validate this approach, we conducted simulations, tests, and investigations on the system while implementing the above strategies. The results obtained from these studies were highly satisfactory, demonstrating the potential benefits of carefully selecting propeller blade angles to optimize drone performance and energy efficiency.

## 3. Test Methods and Technical Results

### 3.1 An Improved Drone Test System Using for the Efficient cooling Integrated Self-Supercharged Propeller and The Low KV Value Motor Matching Propellers with Big Blade Angles

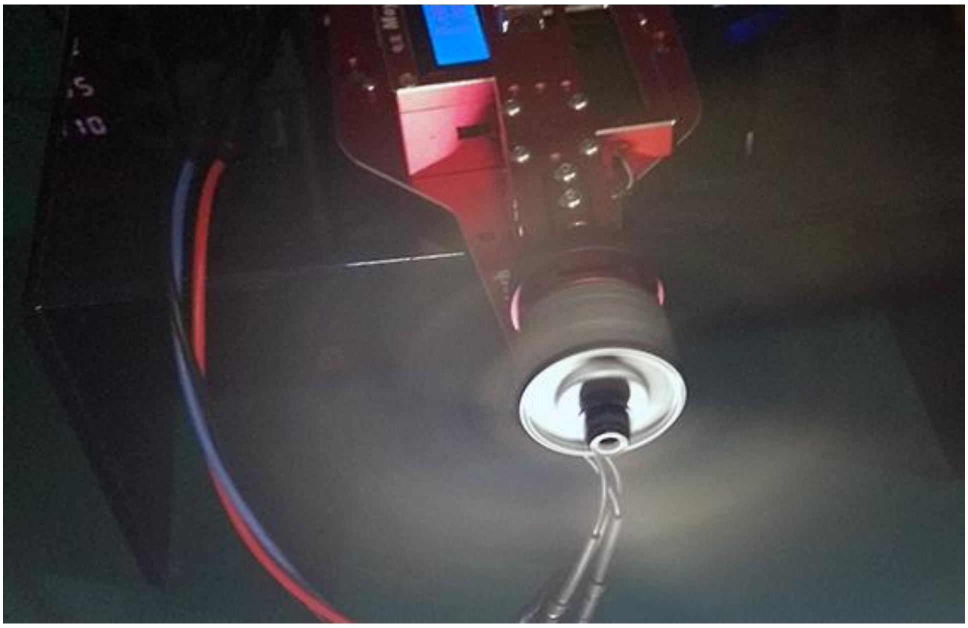


Figure 5 –The test system for the propellers with different blade angles.

The tests conducted in standing air for simulating and vivificating of low Reynolds number and low speed small aircraft is a simple and reliable method. Figure 5 presents the dedicated test system has been modified to match the needs of modern small aircraft electromotor.

In an effort to identify the optimal depth matching mechanism and coupling strategy for drone motors and propellers, we conducted a series of tests on various combinations of motors with different KV values and propellers with distinct shapes, diameters, and blade angles. We also compared the efficiency of motors with the same KV value under various cooling mechanisms to further refine our analysis. The disparity in performance between conventional motors and motors incorporating high-efficiency cooling is well recognized, considering output power, efficiency, torque, thrust value, and force efficiency. Hence, excessive repetition is avoidable. Furthermore, contemporary aviation motors are outfitted with temperature sensing and alert systems, accompanied by intelligent temperature regulation and control mechanisms. Consequently, conventional testing procedures and experimental approaches are insufficient to match the swift progressions in electric aircraft technology.

After examining multiple configurations, we selected the most representative results to showcase the effects of different combinations on overall performance. The test results and comparative analysis are presented in Figures 6 and 7. These findings contribute valuable insights into the complex relationship between motor and propeller characteristics, ultimately informing the design of more efficient drone propulsion systems.

The test results and comparative analysis, presented in Figures 6 and 7, involved the use of three types of propellers: one with a large blade angle, one with a small blade angle, and a compromise propeller. Notably, only the large and small blade angle propellers were equipped with an integrated self-supercharged system for efficient motor cooling, while the compromise propeller was paired with a motor in a traditional cooling state.

In another test, a low KV value motor paired with a large blade angle propeller showed comparable performance to the integrated self-supercharged system without significant temperature increase. Since this motor-propeller combination is primarily used for short-term high-power activities such as takeoff, climbing, acceleration, and resisting strong winds, its performance curve can still refer to the integrated self-supercharged system.

To enhance the simulation process and ensure reliable results, the corresponding data acquisition was performed after a 5-minute preheating period of the motor under full load. This method effectively improved the accuracy of the results. Furthermore, in multi-axis drone performance testing, throttle settings below 30% are typically regarded as having limited practical significance. As such, this principle was adhered to in most of our tests.

## 3.2 The Test Results and Efficiency Comparison

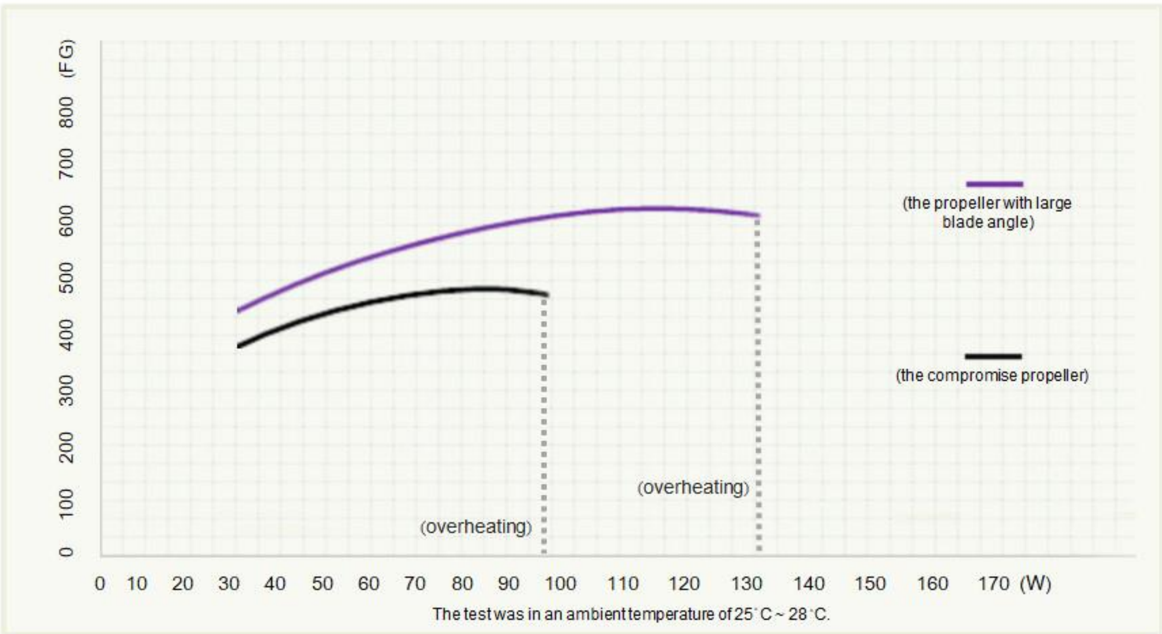



Figure 6 –The test results and efficiency comparison between the propeller with large blade angle and the compromise propeller.

Our repeated tests have consistently demonstrated the following: 1) the compromise propeller is ineffective in both high and low energy consumption stages; 2) the large blade angle propeller also exhibits high efficiency during high energy consumption stages; and 3) the small blade angle propeller primarily demonstrates high efficiency in low energy consumption stages.

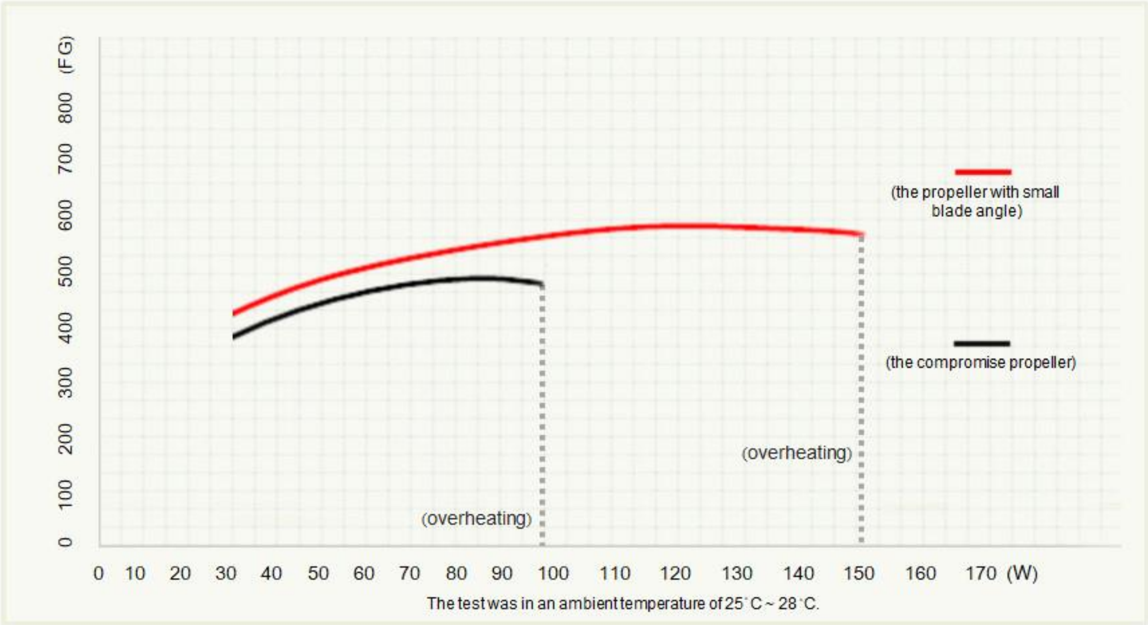



Figure 7 –The test results and efficiency comparison between the propeller with small blade angle and the compromise propeller.

## 4. Exploring Strategy, Discussion, Ongoing Research and Conclusion

### 4.1 Propulsion Optimization Techniques and Power Allocation Strategies

Fixed-pitch propellers are widely used in drone applications; however, they often exhibit inefficiencies due to the compromise they represent between high energy consumption stages and low energy consumption stages. This compromise leads to suboptimal blade angles, inefficient thrust-to-speed ratios, limited adaptability, inadequate thrust control, and a trade-off between thrust and efficiency.

The fixed blade angle of these propellers is optimized for a specific speed range, resulting in suboptimal performance when the drone's speed varies. Consequently, the fixed-pitch propellers may struggle to maintain an ideal thrust-to-speed ratio in different flight conditions, reducing overall efficiency.

In addition, the limited adaptability of fixed-pitch propellers leads to inefficient thrust control. This can create challenges in maintaining stable flight and executing precise maneuvers. Furthermore, the compromise between high and low energy consumption stages forces a trade-off between thrust generation and energy efficiency, limiting the drone's overall performance and flight duration.

Addressing these limitations is crucial for enhancing drone performance and optimizing their energy consumption across different flight stages. By exploring innovative and alternative propeller designs or incorporating advanced control systems, it is possible to improve efficiency and adaptability in varying flight conditions, ultimately leading to more capable and versatile drone platforms.

Given the aforementioned description and conclusion, an optimal control strategy can be devised to maximize efficiency in various flight stages. This strategy involves utilizing propellers with large blade angles during high energy consumption stages, primarily focusing on takeoff and climbing, while small blade angle propellers are mainly dedicated to maintaining balance control of the aircraft.

Conversely, during low energy consumption stages, such as level flight or descent, the propellers with small blade angles are employed, while those with large blade angles are reserved for balance control. Integrating these strategies, methods, and measures into the drone's flight control system software allows for seamless adaptation to varying energy consumption stages. For drone owners, adjusting the aircraft's cargo or auxiliary devices and attempting to control the flight and operation process to adhere to the steps and control procedures mentioned above can help achieve optimal performance.

The key feature is its utilization of stepped angles of attack with staggered variables. Functioning as a dynamic coupling and matching system, it aims to optimize power output by efficiently managing power allocation within the optimal range of the angle of attack. To optimize overall efficiency, the utilization ratio between large and small blade angle propellers can be adjusted as needed based on factors such as the drone's flight speed, payload, wind speed conditions, and propeller parameters. By doing so, the majority of the drone's power can be maintained within the high-efficiency range of attack angles. This optimization process ensures that the propellers operate at their optimal performance level, resulting in enhanced overall efficiency.

This optimization process can be integrated directly into the flight control system software, enabling a balanced workload distribution between the two propeller types. Ensuring each propeller operates within its optimal range leads to a significant improvement in overall performance. Simulations have shown that this method can result in a considerable increase in efficiency, with potential gains of up to 35%. The approach proves to be effective in addressing the compromise between high and low energy consumption stages, ultimately leading to more efficient drone operation and extended flight times.

The position of the overheating curve in Figure 6 serves as a reminder that there is a need for further enhancement in efficient motor cooling, especially in specific operating situations where the drone's motor tends to become hot. This also puts forward higher requirements for tapping the potential of the motor. Meanwhile, the integrated self-supercharged propeller and propulsion system is also a solid technical foundation for the realization of these technical effects. That is to say, the increasing demand to tap into the motor's full potential necessitates higher requirements. However, rapid advancements in modern motor technology have strengthened the technological foundation for our motor-propeller deep matching strategies and optimal coupling mechanisms. Additionally, the integration of self-supercharged propellers and propulsion systems is also one of the practical options for achieving these desired effects.

The drone industry is indeed witnessing rapid advancements, with innovative concept models and matching power modes emerging regularly. Drones have also demonstrated their significance in conflict zones. Adhering to the concept and strategy of optimizing energy consumption stages using the corresponding optimal efficiency of propulsion modes, along with the application of our innovative fixed-pitch propellers featuring different blade angles, can yield significant benefits. This approach not only addresses the evolving demands of the drone industry but also offers a valuable solution for enhancing the efficiency and adaptability of drones in various scenarios, including those encountered in theaters of conflict and deteriorating situations.

In an electric propulsion system, the parameters of motors and propellers cover various aspects. Propeller parameters comprise the number of blades, blades angles, blades mounting angles, diameter, and other factors, while motor parameters involve stator and rotor diameter and length, kV value, torque, and efficiency. The interplay between these parameters is intricate and highly specific, creating a 'narrow efficiency window' where each parameter must be carefully matched with its corresponding counterpart.

This delicate balance is essential for achieving an optimal technical scheme. It is crucial to consider the alignment of these parameters with varying load levels, intended purpose, and operational characteristics of different drones to ensure the most suitable configuration for a particular application. Neglecting this meticulous pairing of parameters can result in a significant decrease in overall system efficiency.

Achieving a truly efficient solution in designing an electric propulsion system for drones requires more than just following the product manual and combining suitable components. It necessitates a creative approach to identify the optimal combination of numerous parameters, a task that can be both intricate and challenging. This process demands a wealth of expertise, extensive databases of specialized tests, and careful consideration of various subfields related to numerous parameters.

Even when considering the parameters provided by suppliers, they often serve as reference values under certain ideal conditions and specific circumstances, which may not directly apply to complex real-world situations. Therefore, achieving optimal results is a challenging endeavor that demands considerable mental and physical effort. It necessitates a thorough analysis and taking into account various factors like load, specific objectives, and tasks to tailor the system to its intended application.

By engaging in this meticulous process, the most effective and efficient solutions can be derived for each unique scenario. Establishing a database of these specific values further enhances the ability to develop customized solutions, ultimately refining the design process for electric propulsion systems in drones. The deep integration and optimized coupling of propellers and motors, based on the Motor Efficiency Management Action Plan (MEMAP), further effectively improves lift, thrust, and overall performance while optimizing energy utilization.

The realm of drone technology is experiencing a paradigm shift, as the implementation of a cutting-edge dynamic coupling and matching system significantly enhances power allocation within the optimal angle of attack range for drones. This innovative technology establishes a seamless nexus between the aircraft's flight mechanisms and power systems, ensuring precise synchronization and peak performance. The successful integration of advanced control techniques and approaches further propels the realization of variable-pitch propulsion and stable flight capabilities in drones. These groundbreaking advancements effectively elevate performance benchmarks, redefining the potential and efficiency of aerial vehicles. Consequently, the landscape of drone technology teeters on the brink of an unprecedented era of progress and evolution.

## 4.2 Ongoing Efforts and Continuing Research

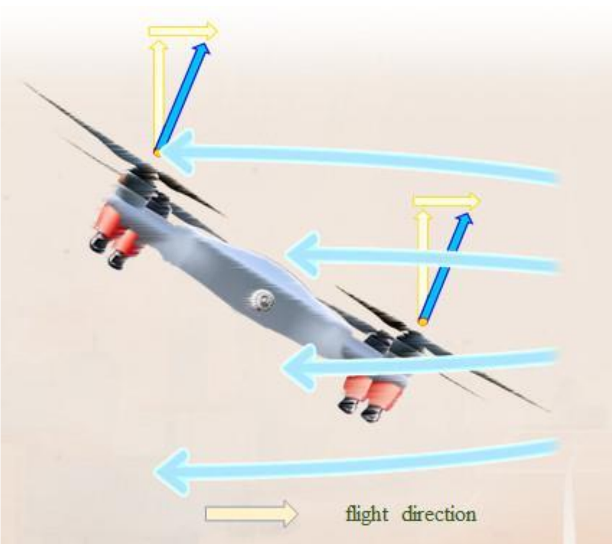
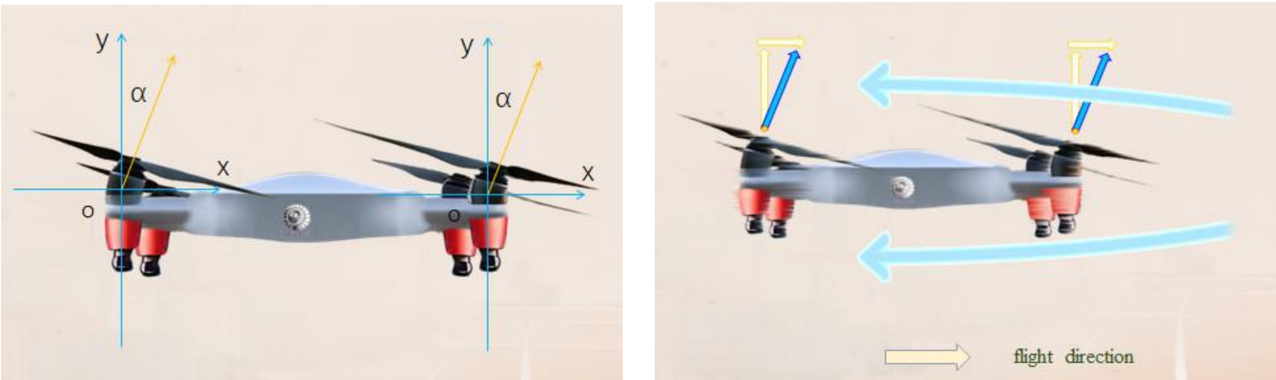



Figure 8 –The existing drones have a tilted fuselage during flight.

In the pursuit of progress, leveraging proven human achievements has consistently demonstrated its immense value. The drone industry is currently at a critical juncture, seeking to build upon nearly a century of experience in refining highly efficient and reliable variable-pitch propulsion mechanisms and level flight strategies. Our objective is to harness inventive ideas and cutting-edge strategies that align with this historical foundation, thereby enabling drones to reap the benefits of variable-pitch propulsion and level flight mechanisms without the complexities and operational challenges present in traditional aircraft. By striking the perfect balance between performance and simplicity, we aim to revolutionize the drone industry.

Our ongoing efforts are concentrated in two primary areas: 1) Performing more experimental and analytical tests to gather additional technical results and insights. These tests are designed to contribute to the development of improved technical solutions and further enhance drone performance. 2) Developing an innovative pre-set tilt-rotors propulsion system, referred to as preset tilt-rotors. This unique design features a propeller and motor driving shaft set at an angle of length α, deviating from the traditional perpendicular alignment to the fuselage plane. The design ingeniously combines the simplicity and reliability of existing drones with the advantages of tilt-rotor designs, all while avoiding the complex actuation mechanisms typically associated with such configurations.

By focusing on these key areas, we are dedicated to advancing drone technology and ensuring a more efficient and accessible future for the industry. Existing drones typically exhibit a tilted fuselage during flight, which presents notable challenges in terms of performance and stability. As illustrated in Figure 8, this flight mode considerably increases the drone's windward area and air resistance, consequently impeding its maneuverability, stability, and mobility. These issues become particularly pronounced when drones are operated in adverse weather conditions, highlighting the need for innovative solutions to optimize drone flight dynamics and ensure reliable performance under various environmental circumstances.




(a) (b)

Figure 9 –Structural characteristics and flight resistance analysis of the pre-vector propulsion.

In our ongoing pursuit to develop pre-set tilt-rotors for pre-vector drones, we have devised a unique design where the propeller and motor driving shaft are angled at length α relative to the fuselage plane. Termed preset tilt-rotors, this configuration offers the simplicity and reliability of existing drones while circumventing the complexity of independently actuated tilt-rotors, as depicted in Figure 9(a).

A significant advantage of pre-vector propulsion and pre-vector drones is their ability to generate lift and thrust without necessitating fuselage tilt, allowing the drone's fuselage to maintain a horizontal position. This feature, showcased in Figure 9(b), minimizes windward area and air resistance, resulting in substantial improvements in the drone's efficiency, stability, operability, and mobility. Preliminary simulations and analog experiments have revealed that this innovative solution effortlessly enhances drone efficiency by 13-20% without incurring additional costs.

Combining different-blade-angle variable-pitch propulsion with pre-set tilt-rotors further amplifies efficiency gains, potentially reaching an impressive 45%. These ongoing efforts underscore the importance of continuous exploration and collaboration in the field, as we work towards developing more effective solutions. Future discussions, conclusions, and data references will serve to expand upon, enrich, and elevate these advancements in the pursuit of optimal small electric aircraft performance.

## 4.3 Conclusions

Our analysis of fixed-pitch propellers for drone applications unveils the intricate interplay between motor and propeller parameters. Striking a balance in the compromise between high and low energy consumption stages is crucial to attain optimal performance and efficiency. By tactfully utilizing propellers with varying blade angles and corresponding matched motors, organically combined with the motor efficiency management action plan (MEMAP), we can substantially improve the efficiency of drones in diverse flight conditions. These approaches effectively address the constraints associated with conventional fixed-pitch propellers and the tilted fuselage flight mechanism.

Our proposed control strategy enhances drone performance by integrating functions and steps into the flight control system software. This approach optimizes the utilization ratio between large and small blade angle propellers, ensuring most operate within their optimal range. Simulations demonstrate potential efficiency gains of up to 35%. Combining different-blade-angle variable-pitch propulsion with pre-set tilt-rotors further amplifies these gains. The drone's maneuverability, stability, agility, and mobility are significantly improved and enhanced, as the driving force affecting drone performance is the difference between the force generated by the propellers and the weight of the drone itself and its payload. Unlike conventional aircraft, where propellers directly influence control due to high wing efficiency, drone propellers must primarily support the drone's own weight and payload.

The findings of our study emphasize the importance of considering various parameters in electric propulsion systems for drones. Our study highlights the significance of examining various parameters in electric propulsion systems for drones. By tackling the limitations of traditional fixed-pitch propellers and tilted body flight, and employing a tailored control strategy, we can pave the way for more efficient and versatile drone platforms.

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## 5. Copyright Statement



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