Experimental study on dynamic efficiency quad-rotor UAV

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Abstract. In recent years, because of its powerful that quad-rotor UAV maneuverability and stability exhibited in civilian and military aspects of great potential, but because of its endurance and power efficiency, it has become a major factor inhibiting the development of UAV applications. In this paper, the power efficiency of the UAV conducted a series of tests. Mainly for motor efficiency and motor temperature-depth comparison test, flight efficiency by comparing different KV values, different pitch diameters and different voltages, summarize results motor rally efficiency optimum range of different quality and reasonable given load motor parameter selection.

Keywords: UAV; motor temperature; motor efficiency; optimal parameters.

1 Introduction

With the quad-rotor control technology matures, more and more quad-rotor wide range of applications, especially in the power sector, with its outstanding features and performance concern. But their endurance capacity compared to fixed-wing aircraft large gap, which greatly limits the development of quad-rotor UAV, partly because of its endurance and quality of the relationship between the battery-powered portable efficiency, on the other hand efficiency is the motor output and the motor operating temperature. In this paper, the power efficiency of quad-rotor UAV performance test systems, from basic research thrust efficiency and motor temperature are two aspects, by testing different motor KV value, paddle trails, output voltage, current, thrust and to compare the degree of throttle opening draw conclusions and derive the appropriate parameters for different motor loads selected on the basis of experimental data and analysis, powered experimental data support systems for the quad-rotor UAV design.

2 The motor rotor principle and classification

2.1 Motor's principle

External rotor motor torque due to larger, quad-rotor UAV are generally selected external rotor brushless motor. Motor KV value is in no-load condition, the motor speed increases 1V voltage of each increase of the amount, the faster the speed, the higher KV value, the smaller the size of the propeller adapted.

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The selection process of the motor, the most concern is the motor thrust-thrust efficiency curve, thrust-power, maximum motor thrust range, the weight of the motor, motor temperature, motors and other parameters. Fig.1 is a schematic diagram of the motor work.

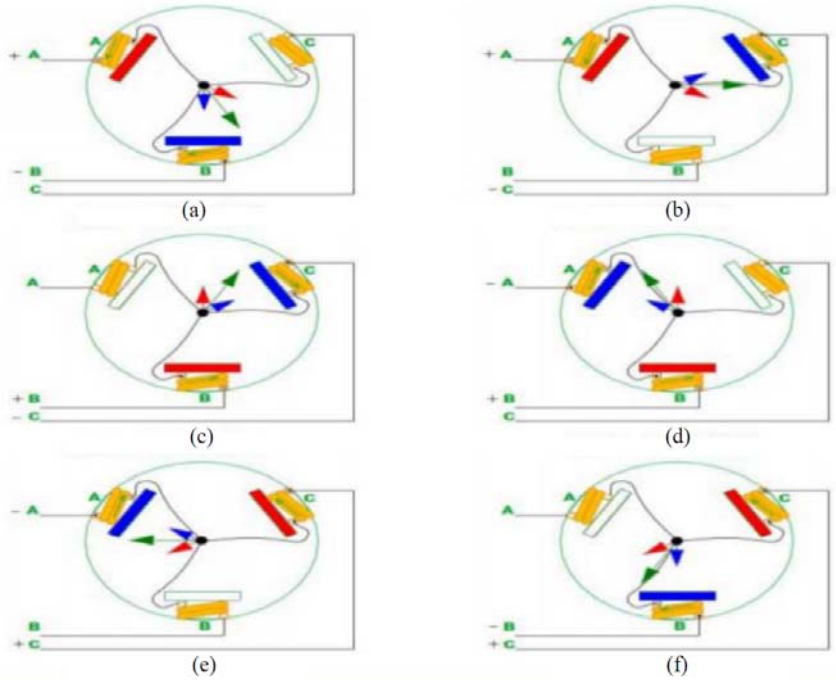


Figure 1. Schematic electrical work.

2.2 Classification rotor

Quad-rotor propeller is generally fixed pitch propeller, generally continuous quad digits, the first two showing propeller diameter, pitch after two represent, the number of units is generally in, 1in equal to 25.4mm; more blades, the greater the lift the lower the corresponding motor propeller thrust efficiency.

Positive paddle-looking down from the top of the paddle counter-clockwise rotating propellers; anti-paddle-looking down from the top of the paddle clockwise rotating propellers. as shown in Fig.2:

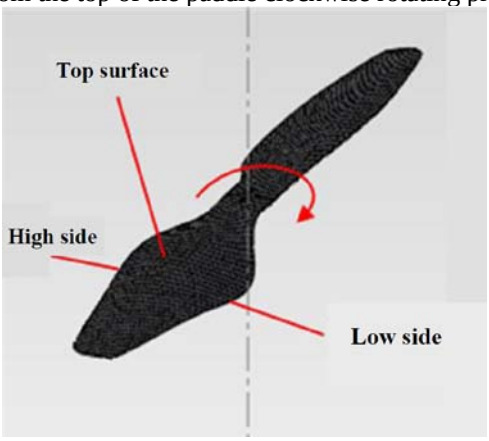
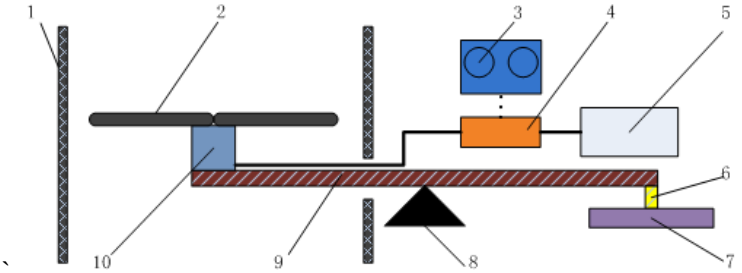


Figure 2. Propeller schematic

3 Simulation model building

3.1 Experimental platform structure

Power module 5 to drive 4 provides power, driven by the remote controller 3 controls the driver 4 drives the motor 10 to operate the propeller 2 rotates, lift the propeller 2 is rotated after driving lever 9 along the bracket 8 tilting, through leverage, the counterweight 6 7 is transmitted to the electronic scales, complete lift measurement; at the same time by the power supply module 5 can be measured by the power supply voltage and current, power consumption power can be obtained.



1.protecting mask 2.propeller 3.remote control 4.motor driver 5.power supply 6.counterweight 7.electronic scales 8.bracket 9.lever 10.motors

Figure 3. Propeller pull test station operating principle

$$P = U \times I \tag{1}$$

Where: P is the electric power consumed per unit W; U voltage power supply unit V; I end to power supply current in A;

According to moment balance theory shows that:

$$(F_{Rise} + G_{Left})L_{Left} = G_{Right} + N_{\mathrm{Press}} + L_{Right} \tag{2}$$

Where: F promoted to lift the propeller unit N; G left the left propeller assembly of the total weight in N; L for the left propeller pitch bearing axis distance in mm; G is the right counterweight weight in N;N pressure counterweight, said electronic pressure unit N; L is the right counterweight to the axis of the rod from the bearing unit mm.

Due to the structure of a size such that:

$$L_{Left} = L_{Right} \tag{3}$$

It can be obtained:

$$F_{Rise} = N_{\mathrm{Press}} + G_{Right} - G_{Lef}t = N_{\mathrm{Press}} + \Delta G \tag{4}$$

Since the electronic scale can be achieved zero operation, it can be made to 0, that the formula can be obtained:

$$F_{Rise} = N_{\mathrm{Press}} \tag{5}$$

According to Newton's third law found:

$$F_{Rise} = N_{\mathrm{Press}} = M_{\mathrm{Read}} \times g \times 0.001 \tag{6}$$

Including: electronic scale readings in *g*; *g* is the gravitational acceleration, in units m/s^2;

$$\eta = M_{Read} / P \tag{7}$$

Wherein: the system thrust efficiency, unit *g/W*;

3.2 Test content

Power system efficiency testing mainly consists of two parts, the thrust efficiency curve test and motor temperature test.Thrust efficiency test, the main test items include the propeller thrust, voltage, current, throttle opening (PWM wave duty cycle);Motor operating temperature test including accelerator opening, motor temperature and other parameters.

Main laboratory equipment: propeller, motor, power supply, power transfer, receiver, electronic, infrared temperature gun, test bench in kind, as shown in Fig.4 and Fig.5.

Figure 4. Test bench panorama

Figure 5. Test bench partial view

4 Thrust motor efficiency and motor temperature experimental test

4.1 Thrust efficiency test

The main thrust for the efficiency of the test is divided into quad steps for testing. Mainly leveraged tension test bench, test steps are as follows:

1) Install the corresponding power of the motor and propeller to leverage the experimental stage;

2) Electrical test bench, set the test voltage, and complete the calibration operation;

3) Controlling the throttle opening of 20% to 100% of the change in intervals of 5% a data collection point, gathering power and thrust readings after each data point stabilization 10s;

4) Power matching each project testing three times and averaged drawn thrust efficiency curve.

Experimental select T-Motor U8 KV100 electrical specifications and 22*6, 26*8.5, 27*8.8, 28*9.5*9.2, 29 five sizes of the two-blade propeller at an input voltage of 22.2V, and 44.4V when the experiment 29.6, each experimental combination experiments recorded as shown in table I, the value in the table is the power calculated value, the current value of the reading, the voltage value of the design value, said electronic propeller thrust F=gravitational acceleration readings on a G; Efficiency = electronic scale reading/power. Data shown in Table 1 as one of a combination of test results, all data refer to electronic accessories.

Table 1. T-Motor U8 KV100 motor thrust efficiency test experimental data table

Motor model	Propeller Model	Governor output	Voltage (V)	Power (W)	Thrust (g)
T-Motor U8 KV100	26*8.5	20%	22.2	13.92	334
		25%	22.2	17.40	397
		30%	22.2	20.89	452
		35%	22.2	24.37	508
		40%	22.2	27.85	571
		45%	22.2	31.33	626
		50%	22.2	34.81	696
		55%	22.2	42.79	826
		60%	22.2	50.76	957
		65%	22.2	58.74	1088
		70%	22.2	70.71	1230
		75%	22.2	82.67	1372
		80%	22.2	96.81	1563
		85%	22.2	110.96	1754
		90%	22.2	116.76	1816
		95%	22.2	122.56	1878
		100%	22.2	128.36	1940

1) Use with a motor, at the same operating voltage, operating current of different sizes propeller, thrust and efficiency were analyzed, as shown in Fig.6 and Fig.7.

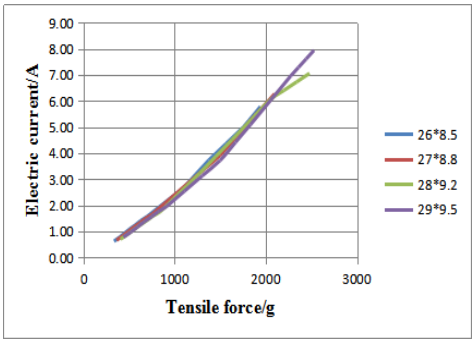


Figure 6. Different blades-current curves

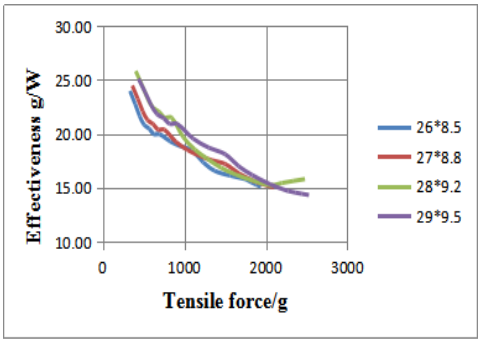


Figure 7. Different blades-efficiency curve

Curve shown in Fig6 and Fig.7, can be drawn: First, T-motor U8 KV100 value of the motor with the increasing tension, the current value at the consequent increasing of different blade, the blade to 26 inches 29 inches blades are in line with the universal law and the propeller diameter, the more able to provide greater tension, but need more current consumption. However, in the same load that is under the same tension, the larger diameter propeller needed to pay current smaller, can be seen from the figure at 1000g and 2000g or less tension than the tension, different propeller diameters smaller gap between the desired current, 1000g~2000g tension in the range, the desired diameter propeller is different between the current gap is more obvious, but are basically in line with the larger diameter propeller needed to pay current smaller this rule. Secondly, T-motor U8 KV100 motor at different values of the blade tension with increasing motor efficiency is decreased. The curves are in line with this law, under this law, with the increase in the diameter of the propeller, the propeller motor efficiency under the same tension will be increased, at 1800g or less tension is particularly evident in the emergence of change after 2000g Rally described 29 inches propeller efficiency decreased significantly after the 2000g.

2) Use with a motor at different operating voltages for different size propellers current, thrust and efficiency were analyzed, as shown in Fig.8 and Fig.9, as shown in Fig.6 and Fig.7 on the basis of the curve plus a different voltage values and different diameter propeller is formed as shown in Fig.7

comparison, verify the current again increases with increasing tension, the motor propeller efficiency as the tension increases.

By comparing the curves of Fig.8 and Fig.9 shows that, while still satisfying the above law, may also be obtained by comparing with a motor, such as T-motor U8 KV100 motor propeller diameter under the same circumstances, the maximum tension value, the larger the value of the maximum current the greater tension and current ranges, under certain conditions of tension, the greater the power supply output voltage (the increase to 29.6V 44.4V), the motor operating current, the higher the efficiency of the propeller motor, but consider a combination of motor rally interval changes, not the big high voltage aging on low voltage value smaller than a combination of efficiency.

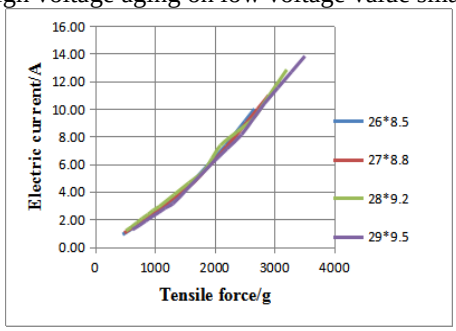


Figure 8. Different blades -current curves

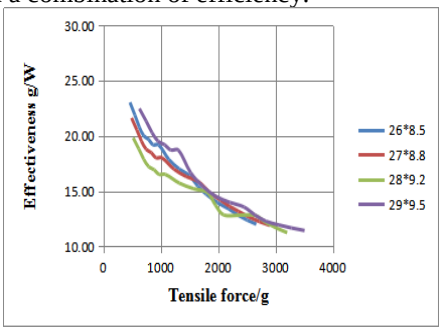


Figure 9. Different blades-efficiency curve

By the Figs. 8 and 9, the same type of motor current would be different KV values, tension and efficiency have a greater impact. The same operating voltage, KV value, the greater the value of maximum tension, and thus the greater the value of the maximum operating current working conditions. The figure are given the same brand of motor propeller 26 inches to 29 inches propeller tension and tension current- efficiency curve, the overall trends are in line with the greater the KV value, the greater the maximum tension, maximum operating current conditions the greater the value of analysis. Meanwhile, in the same tensile force, KV The larger the value, corresponding to the operating current, the lower the efficiency of the motor propeller, 10, Figure 11 shows a similar basic law, but a closer look shows that the tension in the range of possible central region the situation appears different KV value of the curve overlap and cross currents and efficiency point, in these current position and efficiency not distinguish points clear, but significant changes KV value corresponding to the change of the current efficiency and still occupy the main position. Then the motor and propeller efficiency needs to match specific conditions.

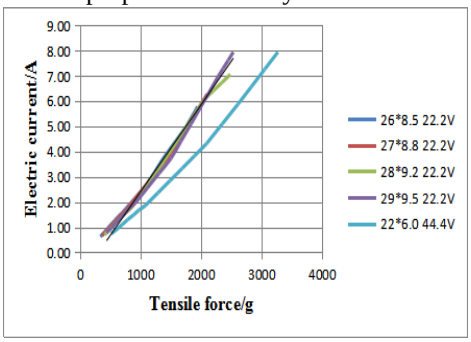


Figure 10. Different voltages,blades-current curve

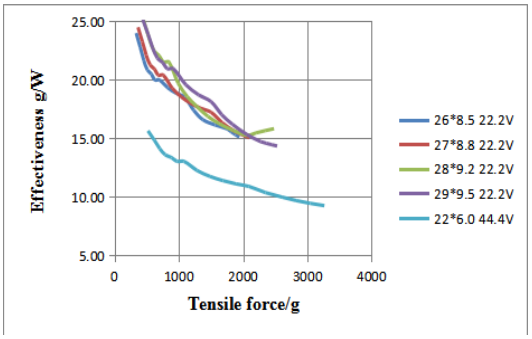


Figure 11. Different voltages,blades-efficiency curve

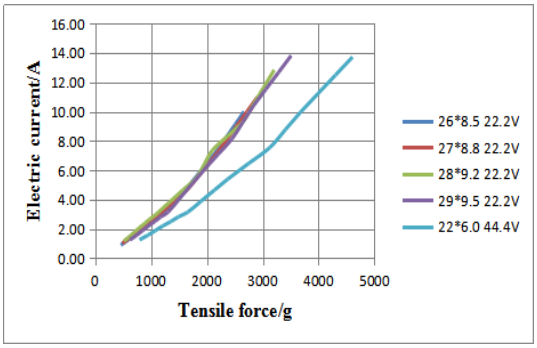


Figure 12. Different voltages,blades-current curve

4.2 Motor operating temperature test

Wherein the motor operating temperature testing is concerned, the use of non-contact infrared temperature measurement equipment IRTP-300L, temperature range of 0~100°C, temperature measurement accuracy of 1%, 24V direct current power supply. By installing infrared temperature measurement equipment in the experiment bench, in turn, can measure the motor operating temperature. Specific test steps are as follows:

In 50% of the governor, 75%, 100% three control signals output location, temperature test motor should be completed the acquisition of three data points in one test.

Install the corresponding power of the motor and propeller to leverage the experimental stage;

1) Electrical test bench, set the test voltage, a calibration operation, and record the ambient temperature;

2) Controlling the throttle opening at 50%, 75%, 100% of all travel 3min, and in turn test the motor operating temperature and recorded;

3) The need to ensure a continuous testing process are basically the same ambient temperature.

Experiments were selected in various combinations and efficiency of the above-mentioned tension tests, temperature tests were, respectively, 50% of the governor, 75%, 100% of the three positions of the control signal output temperature stays 3min, to test the motor should be completes the acquisition of three data points in one test. Finally, the use of infrared temperature measuring device temperature data acquisition, test records as shown in Table II in which the data shown in a combined test result, all data refer to electronic accessories.

Table 2. T-MotorU8KV100Motor operating temperature experimental data table

Motor model	Propeller model	Governor output	Voltage (V)	Power (W)	Temperature (°C)
T-Motor U8 KV100	26*8.5	50%	22.2	34.85	22
		75%	22.2	82.36	26
		100%	22.2	126.98	38
	27*8.8	50%	22.2	37.07	22
		75%	22.2	86.58	27
		100%	22.2	137.86	38
	28*9.2	50%	22.2	39.07	25
		75%	22.2	99.01	30
		100%	22.2	154.96	40
	29*9.5	50%	22.2	43.29	26
		75%	22.2	112.55	32
		100%	22.2	175.38	41
	22*6	50%	44.4	82.58	26
		75%	44.4	191.36	32
		100%	44.4	350.76	45

The power system test test test data requirements have been carried out in Section 6 illustrates in detail the data recorded in the attached spreadsheet all the records is completed. Among them, all data can be compared and trends in quad-angle analysis of quad-rotor analysis based on a combination of different variables. The main change parameters comprising the motor type, motor KV value, operating voltage (power supply output voltage), propeller diameter, the governor output. Here is the work of the experimental data in different states at different angles of analytical content.

1) When the same motor, operating voltage and constant propeller, different governor output, external rotor motor temperature curve. As is shown in Fig.13 and Fig.14:

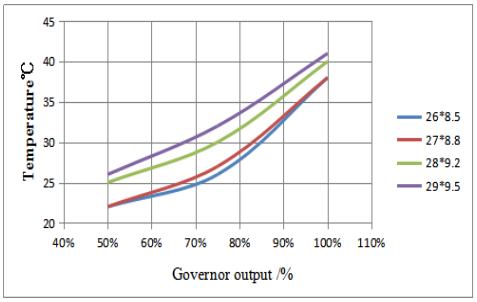


Figure 13. U8KV100 different output-temperature curve

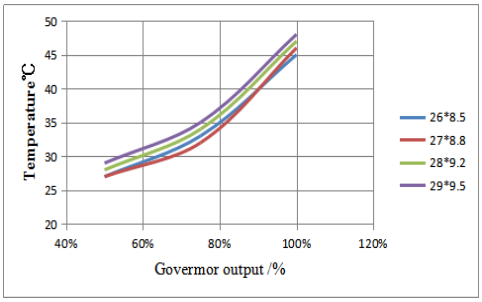


Figure 14. U8KV135 different output-temperature curve

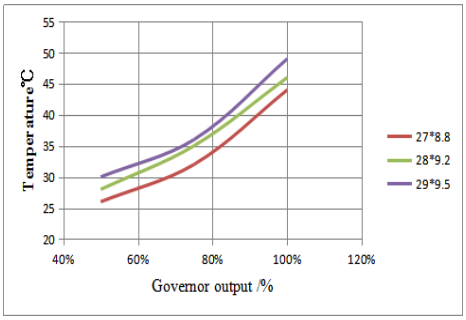


Figure 15. 29.6V different output - temperature curve

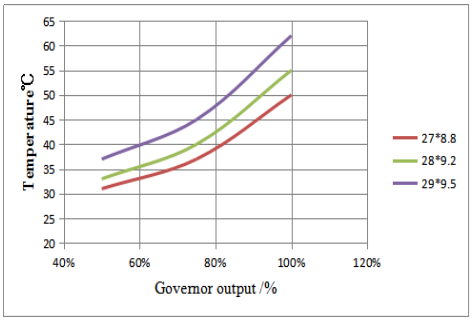


Figure 16. 44.4V different output - temperature curve

In conjunction with Fig.13, the content shown in Fig.15 and Fig.16 it can be seen, as the percentage increase in the output of the governor, the operating temperature of the motor increases, and with increasing percentages, temperature change of the motor gradually increases, i.e., motor operating temperature at any time of the governor output percentage change in the slope of the curve increases with the governor output percentage increases, this variation exists in several different configurations group experiments. At the same time, it can also come with matching motor propeller diameter increasing operating temperature also increases, but the tendency to increase the scope and with different motors have different variations, but the overall trend is similar. We can deduce this universal presence of basic law according to the motor and propeller of the basic working principle, when the motor is matched with a different size propellers, change means the load, or a change in the output tension, causing current and power consumption change, the larger the diameter of the propeller or the output load opposing the greater the tension, and thus the greater the power the greater the operating current, the greater the heat which is generated, but due to different materials of different motor designs and production processes of production, its cooling capacity are also different. Thus, different experimental curve demonstrated by the overall trend is consistent, but the details of the changes are the emergence of different.

2) In the same governor output value, the same output voltage and motor, paddle diameter different temperature curve shown in Fig.17:

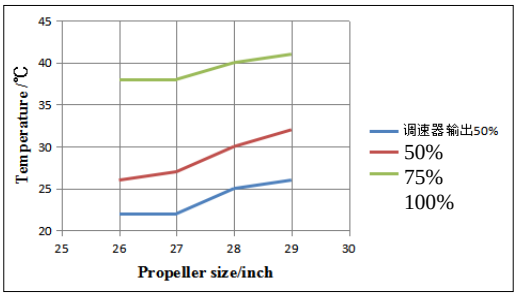


Figure 17. T-Motor U8KV100 22.2V different pitch diameter governor output-temperature curve

Above two figures plotted curve at a speed governor output lower percentage, the impact of changes in the size of the propeller of the motor operating temperature. This set of data can also reflect on a set of data in some of the laws that as this trend increases the size of the propeller of the motor operating temperature increases. The characteristics of this group of data is clearly more clearly shows the changes in the scope and magnitude of this change in the law change. Ie the motor operating temperature variations and non-linear, there are some irregularities, this phenomenon may be due to the characteristics of the motor itself cause, we can also find the percentage change in the output of the governor, the same 25% change in output value by 50 % to 75% of the variation leads to motor temperature rise significantly lower than the 75% to 100% of the change leads to motor operating temperature, the analysis can be drawn by reason of which, on the one hand may be due to the heat of the motor continuous operation accumulation, on the one hand may be due to electrical heating at 100% of the governor output is much higher than 75% of the heat output of the governor.

5 Conclusion

Through the above-described collation and analysis of experimental data, the following results:

1) With a selection of the motor, at the same operating voltage, within a certain range, the same output tension, propeller diameter larger operating current, the higher the motor propeller efficiency;

2) Use the same motor and a propeller, within a certain range, when the same output Rally diameter, the greater the power supply output voltage, current smaller, higher motor propeller efficiency;

3) Select the same voltage and propeller, with different models KV value of the motor, at the same tension, current and efficiency of different work, within a certain range, KV greater the current, the lower the motor propeller efficiency;

4) The same motor, operating voltage and constant propeller, governor output, the higher the temperature of the external rotor motor;

5) In the same governor output value, when the same output voltage and motor, propeller larger diameter, the higher the motor operating temperature;

6) According to the law of experimental data shows that, in general, with the increase of the output value of the tension, the motor propeller efficiency will be reduced, which means that the greater the quad-rotor UAV takeoff weight, the lower the efficiency of the propeller motor for with a UAV is concerned, when the afterburner climb, power output increases, reducing the efficiency of the motor;

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