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PROPELLER-MOTOR MATCHING FOR MINI-UAV: THRUST AND EFFICIENCY ESTIMATION BY USING THE LY-MICRO-MAX TEST STAND

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Abstract: *Unmanned Aerial Vehicle design and implementation are evolving rapidly to meet the stringent demands of civil and commercial applications. In particular, Miniature Unmanned Aerial Vehicles with a maximum take-off mass below 15 kg have seen widespread use in various sectors. Continuous technological improvements require the development of new propulsion systems in order to satisfy these new challenges. In this paper, the AXI 4130/20 Gold Line V3 brushless direct current motor, equipped with Aeronaut CAM Folding propellers, will be evaluated using a commercial-off-the-shelf test bench: the LY-10KGF Micro-Max Test Stand. The identified propeller-motor characteristics could be used as a guide for selecting the optimal propeller for small Unmanned Aerial Systems.*

Keywords: *UAV, propeller, BLDC motor, testing.*

1. INTRODUCTION

Small Unmanned Aerial Vehicles (UAVs) were initially primarily used for recreational purposes by aeromodelling enthusiasts. They subsequently found applications in the military sector, and the 21st century [1-8] has seen an expansion in their use for both military and civilian surveillance and reconnaissance missions. Today, multicopters dominate the hobbyist market due to their ease of use and Vertical Take-Off and Landing (VTOL) capabilities, which totally eliminate the need for a runway. Most of these small UAVs are powered by brushless direct current (BLDC) motors and batteries that supply energy to the UAVs. Furthermore, they can carry various types of sensors, including Electro-Optical/Infrared (EO/IR) sensors, rangefinders, weather and pollution sensors, and other specialized equipment.

For conceptual UAV design, there are numerous software tools and textbooks [9-12] available for preliminary UAV sizing and performance estimation. The accuracy of these methods is in direct correlation with the motor-engine performance data, which are often difficult to obtain or estimate accurately. In this paper, the AXI 4130/20 GOLD LINE V3 BLDC motor is evaluated alongside its propeller to estimate static propeller performance. The motor characteristics were previously validated and documented in [13]. According to the manufacturer data [14], this motor is designed for large sailplanes weighing up to 7 kg and sports aerobatic models up to 5 kg. The recommended propellers for various UAV configurations are 15×10, 15×12, 18×10, 18×8, 18.5×12, and 16×10 inches. The specifications of the AXI 4130/20 BLDC motor used in this study are summarized in Table 1.

Table 1. Technical specifications of the AXI 4130/20 GOLD LINE V3 BLDC motor

Number of cells	6-8s Li-Poly
RPM/V	305
Maximal efficiency	90%
Maximal efficiency current	18-40 A (>84%)
No load current	1.1 A
Current capacity	56 A/60 s
Internal resistance	43 mΩ
Dimension (diameter x length)	49.8 x 64.4 mm
Shaft diameter	6 mm
Weight	0.410 kg
Maximal Power	1650 W

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As shown in Table 1, the maximal motor power is 1650 W, which is sufficient to power small UAVs of even greater weight (up to 15 kg). However, for such higher weights, the take-off is usually performed using an external launch mechanism. The most commonly used launchers are pneumatic and mechanical systems [15, 16], favored for their reliability and compact design. To evaluate UAV performance, propeller data must be analyzed. During the take-off phase, the sufficiency of the control authority must be considered [13, 17, 18]. In order to select an adequate propeller, or to narrow down the number of potential candidates, the data from [13, 19, 20] should be used as a guide.

In this paper, the AXI 4130/20 Gold Line V3 BLDC motor, equipped with Aeronaut CAM folding propellers, is evaluated under static conditions using a commercial-off-the-shelf test bench: the LY-10KGF Micro-Max Test Stand. The results presented in this paper, together with the motor characteristics identified in previous work [13], serve as a valuable basis for optimizing the propeller–BLDC motor combination across various UAV configurations, and are especially useful for multicopter design. By analyzing measured performance parameters specifically: torque, power, and thrust, this dataset enables the selection of the optimal propeller for a defined UAV mission.

2. EXPERIMENTAL TESTING OF MOTOR-PROPELLER PERFORMANCE

In previous work, the AXI BLDC motor characteristics were defined at various supply voltages [13]; therefore, that procedure is not repeated here in detail. Typically, the battery supplies energy to the electronic speed controller (ESC), which converts direct current (DC) into a three-phase trapezoidal supply that drives the BLDC motor. The characteristics of the battery and ESC can be assumed constant in the presented experiment, as they primarily depend on the manufacturing and production processes. Based on this assumption, and the fact that all propellers are tested under identical operating conditions, any differences in the measured results are directly correlated with the specific propeller types.

In order to identify the characteristics of the different propellers, testing must be performed at defined supply voltages. In the presented analysis, an 8S battery configuration with a nominal operating voltage of 29.6 V was used. The characteristics of the AXI 4130/20 Gold Line V3 BLDC motor, based on the data from [14], are marginally different from the AXI 4130/20 Gold Line BLDC motor identified in previous work [13]. Therefore, the identified characteristics of the AXI 4130/20 Gold Line BLDC motor shown in Figure 1 will be used, with a sufficiently small error that will not affect the final results.

Propeller performance was tested by using the LY-10KGF Micro-Max Test Stand [21], shown in Figure 2. The system is designed for static thrust and torque measurements of small propulsion units. It enables the simultaneous measurement of thrust force, torque, rotational speed (RPM), current, and voltage. These measurements allow for the accurate determination of power and efficiency.

The calibration of the test bench was performed before the experimental measurements according to the manufacturer's recommendations in order to zero the thrust and torque sensors. The tests were conducted under laboratory-controlled conditions with a constant ambient temperature of 20°C. This constant temperature ensures a consistent air density throughout all experimental measurements.

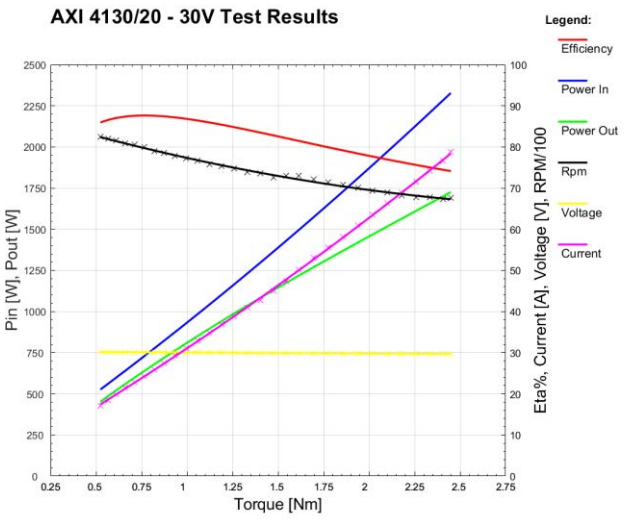


Figure 1. AXI 4130/20 test results at supply voltages of 30 V: Experimental measurements (markers) and identified (solid lines)

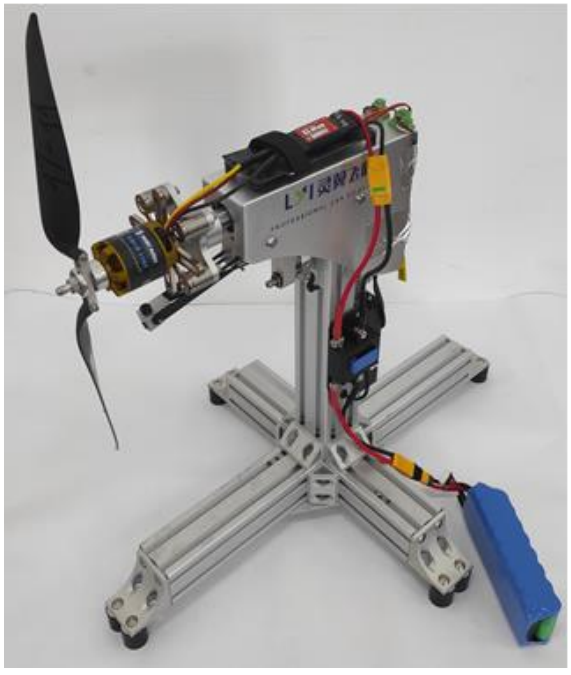


Figure 2. LY-10KGF Micro-Max Test Stand

The experimentally obtained results for motor–propeller torque, thrust, input and output power, and motor efficiency for five Aeronaut CAM Folding propellers (16×10, 16×13, 17×11, 17×13, and 18×11) at 100%, 90%, 80%, 70%, 60%, and 50% throttle settings are presented in Table 2. These measurements were conducted using a

propeller spinner with a diameter of 52 mm.

Table 2. Measured AXI 4130/20 GOLD LINE V3 BLDC motor-propeller characteristics

Propeller: 18×11 in						
Throttle [%]	**M [Nm]**	**F [N]**	**RPM**	**P_{in} [W]**	**P_{out} [W]**	**η_{motor} [%]**
100	1.72	55.31	6645.72	1429.51	1198.41	0.84
90	1.68	54.68	6588.19	1380.35	1160.84	0.84
80	1.30	35.16	6008.36	1018.76	820.00	0.80
70	0.86	28.38	4833.80	525.91	436.70	0.83
60	0.63	20.83	4125.71	333.27	271.75	0.82
50	0.32	11.59	3147.59	139.51	104.35	0.75
Propeller: 17×13 in						
Throttle [%]	**M [Nm]**	**F [N]**	**RPM**	**P_{in} [W]**	**P_{out} [W]**	**η_{motor} [%]**
100	1.89	43.72	5981.44	1532.10	1186.29	0.77
90	1.85	44.14	6265.80	1486.76	1212.56	0.82
80	1.50	35.72	5699.28	1089.52	897.94	0.82
70	1.28	30.08	5250.82	850.27	701.21	0.82
60	0.97	23.61	4629.02	578.32	471.42	0.82
50	0.69	17.16	3992.73	357.86	287.70	0.80
Propeller: 17×11 in						
Throttle [%]	**M [Nm]**	**F [N]**	**RPM**	**P_{in} [W]**	**P_{out} [W]**	**η_{motor} [%]**
100	1.89	51.12	6115.75	1550.38	1210.94	0.78
90	1.84	50.21	6408.50	1504.64	1235.18	0.82
80	1.47	41.57	5822.24	1091.48	898.35	0.82
70	1.23	35.18	5362.55	837.52	691.64	0.83
60	0.93	26.76	4716.51	564.15	461.73	0.82
50	0.66	19.09	4081.48	356.75	280.92	0.79
Propeller: 16×13 in						
Throttle [%]	**M [Nm]**	**F [N]**	**RPM**	**P_{in} [W]**	**P_{out} [W]**	**η_{motor} [%]**
100	1.88	40.43	6143.73	1555.55	1210.58	0.78
90	1.83	39.67	6426.01	1510.16	1234.11	0.82
80	1.49	31.93	5868.04	1114.88	914.94	0.82
70	1.22	27.55	5380.92	835.81	688.54	0.82
60	0.93	21.78	4754.31	563.89	460.61	0.82
50	0.67	15.79	4046.01	353.19	282.12	0.80
Propeller: 16×10 in						
Throttle [%]	**M [Nm]**	**F [N]**	**RPM**	**P_{in} [W]**	**P_{out} [W]**	**η_{motor} [%]**
100	1.53	41.71	6618.74	1308.31	1061.39	0.81
90	1.49	40.75	6939.03	1269.55	1082.93	0.85
80	1.11	33.60	6322.33	861.38	736.79	0.86
70	0.91	28.34	5779.34	645.28	549.09	0.85
60	0.68	21.38	5050.63	431.12	359.69	0.83
50	0.48	15.51	4297.77	271.40	216.57	0.80

It must be noted that propeller efficiency could not be defined, as static performance was evaluated, and under such conditions, propeller efficiency is mathematically undefined (since output power, as the product of thrust and airspeed, is zero during static tests).

3. DISCUSSION OF THE RESULTS

First, the characteristics of the AXI 4130/20 BLDC motor were identified to provide a solid basis for an accurate estimation of motor-propeller performance.

From an initial analysis of the data in Table 2, it is evident that propellers with a 13-inch pitch (17×13 and 16×13) are less efficient than propellers with a smaller pitch at maximum throttle settings. Based on the identified data, it can be concluded that the optimal throttle for a UAV using a runway for take-off is not necessarily the maximum throttle, according to the recommendation in [18]. The AXI 4130/20 BLDC motor equipped with the 16x10 in propeller exhibits the highest efficiency within the throttle range of 60% to 90%. This high efficiency likely explains why this specific propeller is suggested for sailplane UAVs weighing approximately 7 kg.

The data from Table 2 indicate that the 18×11 in propeller provides the highest static thrust, which enables the shortest take-off distance from a runway. Additionally, it features the best thrust-to-torque ratio, making it an ideal choice for the take-off phase, especially for unconventional UAV designs [8]. Additionally, the identified static thrust and the remaining motor–propeller data can be used to optimize the hover capability of UAVs designs.

3. CONCLUSION

The conducted experimental and numerical investigations including motor parameter identification from previous work, as well as static thrust and torque measurements have provided comprehensive data on motor–propeller performance across various configurations.

The results obtained from the motor–propeller characterization (Table 2) clearly indicate that selecting the optimal propeller for a UAV is a complicated task. It must account for maximum thrust, the torque-to-thrust ratio, propeller rotational speed, and the UAV's maneuvering capabilities.

Based on the results presented in Table 2, the 18×11 in propeller demonstrated the highest static thrust force and the most favorable thrust-to-torque ratio. These data indicate that it represents an optimal choice for UAVs that require special emphasis on the take-off flight phase. Furthermore, the results indicate that the AXI 4130/20 V3 BLDC motor, when equipped with the 16×10 in propeller, achieves the highest efficiency. This explains why this specific propeller is recommended as the optimal choice by the motor manufacturer.

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