Flight Thrust Performance of Quadcopter

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ABSTRACT

A quadcopter is a helicopter with four rotors. It is commonly used for small Unmanned Aerial Vehicles (UAV) because of its simple structure. Currently, quadcopters are mainly used in construction inspections, surveillance, search and rescue, and multimedia films. A study on the application of a stable quadcopter for its mapping properties is being held. A basic quadcopter purchased from market becomes the basis of the initial study. For starter, thrust behaviour of the copter needs to be investigated which is the aim of the study reported in this paper. The investigation was based on several experiments. Various parameters were recorded such as thrust, motor rpm, current load, power and speed. The quadcopter was tested with different payload in order to obtain its performance. From the static thrust tests, at maximum RPM of 100% throttle static thrust, the thrust recorded was 485 g per motor, with the maximum current load recorded was 7.0 A, and the maximum power was 77.7 W. The relationship between thrust against RPM and the thrust against power were shown in graphs.

Keywords: *thrust, altitude, speeds, hover, RPM*

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Introduction

Quadcopter is categorized as a multirotor UAV [1]. It is controlled by the angular speeds of four electric rotors. Each rotor produces a thrust and a torque, whose combination generates the main thrust, the yaw torque, the pitch torque, and the roll torque acting on the quadcopter [2]. The two rotors spin at clockwise direction whiles the other two rotors spin at counter clockwise direction. The RPM of each rotors control thrust, torque and speed. The thrust of the rotors plays an important role in handling and keeping the copter hover. Due to the two rotors spinning at clockwise direction while the other two rotors spinning at a counter clockwise direction, it provides balance [3]. Every rotor is connected by a self-tightened pitch propeller. Handling of such complex quadcopter will require precise angle handling [4]. The basic quadcopter working principle is shown in Figure 1 below.

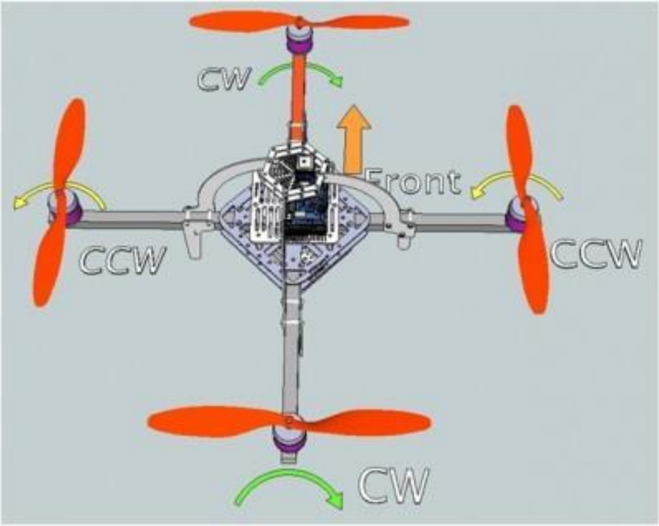

Figure 1: The basic quadcopter working principle

The quadrotor is selected due to an implementation of cost-effective UAV and with an appropriate controller design, it can handle small disturbances and remain stable [5]. Adding extra rotors eg. hexa or octorotor, might enable the copter to carry and lift heavier payloads as well as gaining a higher degree of redundancy [6]. A UAV can be outfitted for autonomous flight by obtaining the accelerometer and gyrometer information and merging with a barometer and Global Positional System (GPS) data [7]. Hence, the flight controller recognises the correct orientation and position. An evaluation of a UAV system that was built to rapidly and autonomously acquire mobile three-dimensional (3D) mapping data was performed by Siebert and Teizer [8]. A performance model for estimating the positional error was developed and tested in several realistic construction environments.

Previously, an advanced autonomous multirotor response system UAV that is able to autonomously flying from one waypoint to another in a stable manner was developed [9]. It became the platform of various sensors system, flight control system, and electric propulsion system. The mini UAV was programmed to be able to lift off and fly to waypoints making use of GPS.

The objective of the work reported in this paper is to determine the flight trust performance of the quadcopter. The experiment were conducted using DJI Phantom 2Vision Plus quadcopter. This project is important as performance of the motor will affect the performance of the quadcopter itself.

DJI Phantom 2 Vision

DJI have made Phantom 2 Vision Plus series [10]. Figure 2 shows the quadcopter after modification.

1) Battery Specification
    a) Capacity : 5200 mAh LiPo
    b) Weight : 400 g
    c) Voltage : 11.1 V
2) Body specification
    a) Weight : 1242 g
    b) Weight without gimbal : 1015 g
    c) Dimension : 290 mm X 290 mm X 180 mm
    d) Motor distance : 350 mm (diagonal between two motor)
3) Propeller specification
    a) Series : DJI self-tightening 9443
    b) Dimension : 228.6 mm (diameter) X 114.3 mm (pitch)
4) Motor specification
    a) Series : DJIPV-05 DJI 2212
    b) Power : 920 kV

Figure 2: DJI Phantom 2 Vision Plus before (top) and after modification (bottom)

Experiment and Procedure

There were four experiments conducted:

1. The first experiment was conducted to determine the maximum flight load that the quadcopter can take up to the height of 3 m. To do this, the copter was flown in hovering condition at 3 m height for various loading, beginning from zero load, with increment of 60 g, until the maximum load that the copter cannot sustain at that altitude. The altitude was not measured above 3 m for accuracy reason, as the measurement was done visually.
2. The second experiment was conducted to determine quadcopter takeoff duration from ground to 3 m height with 60 g load increment were recorded. Time for the quadcopter to arrive at 3 m height from the ground with different payload was recorded. The speed was calculated from the height divided by times.

3. The third experiment was conducted to determine hover duration by quadcopter at 2 m height. This was done by varying payload weight.
4. The fourth experiment was conducted to determine thrust produced by motor through static thrust testing. A simple static thrust device based on a weight scale, together with ammeter and tachometer were set up.

Result

The parameters that were involved and observed were thrust produced, the RPM, load current, power consumption, maximum payload, takeoff speed in a vertical direction, and hovering duration. From this information, the data were then plotted.

Table 1: Maximum payload of the quadcopter

Mass of Quad-copter (g)	Load (g)	Height (m)
1215	0	3
1215	60	3
1215	120	3
1215	180	3
1215	240	3
1215	300	3
1215	360	3
1215	420	3
1215	480	3
1215	540	3
1215	600	3
1215	615	2.6

In Table 1 above, the mass of quadcopter (1215 g) was without gimbal and camera, but an aluminium compartment for payload measurement was attached.

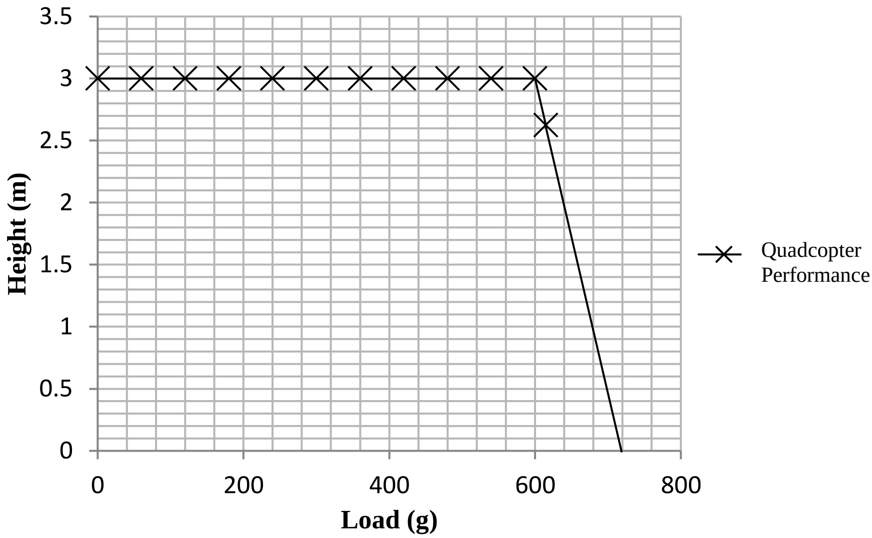

Figure 3: Height vs Load

Based on Figure 3, the 3 m height that can be achieved by quadcopter against load was plotted. As the load increases up to 600 g, the quadcopter was still able to lift off up to 3 m high, but beyond that load, the maximum height decreased. At 720 g, the copter could not lift off anymore. Note: Below the payload of 600 g, the copter can fly higher but was not performed due to safety and accuracy of measurement.

Table 2 below shows the climbing speed (rate of climb) at various load. The height is the distance from the ground up to 3 m high in vertical direction by quadcopter with different payloads. Figure 4 shows the plot of the times needed by quadcopter from the ground to 3 m height against load. As the load increased, the time recorded for the quadcopter to reach 3 m height also increased. Thus, the climbing speed of quadcopter decreased as the payload increased.

Table 2: Data for climbing speed (rate of climb) of quadcopter

Load (g)	Height (m)	Time (s)	Speed (m/s)
0	3	3.96	0.7576
60	3	4.05	0.7407
120	3	4.19	0.7160
180	3	4.36	0.6881
240	3	4.66	0.6438
300	3	4.77	0.6289
360	3	4.86	0.6173
420	3	4.95	0.6061
480	3	5.25	0.5714
540	3	6.45	0.4651
600	3	6.89	0.4354

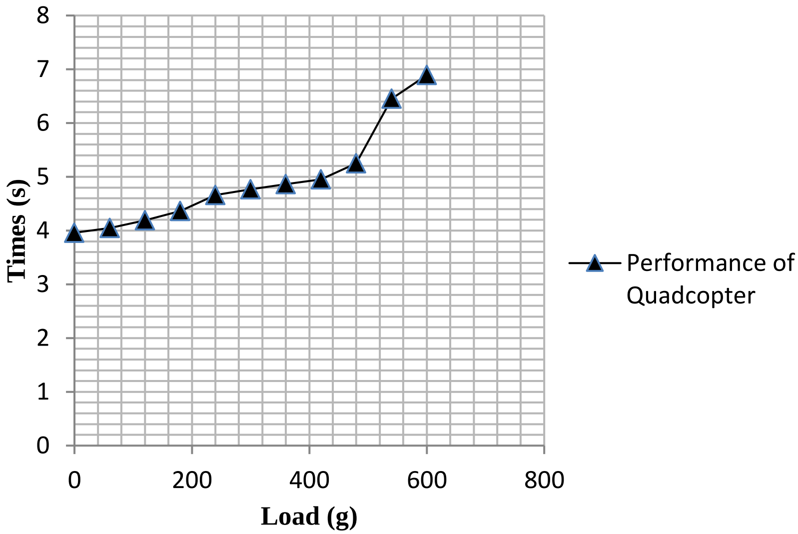

Figure 4: Duration to reach 3 m height with various loads

Table 3 below shows the time recorded of hover duration with various loads. For every load, the battery was fully charged before the test.

Table 3: Hover duration of quadcopter

Height (m)	Load (g)	Times (s)
2	0	585
2	60	501
2	120	429
2	180	407
2	240	366
2	300	359
2	360	310
2	420	285
2	480	267
2	540	229
2	600	186

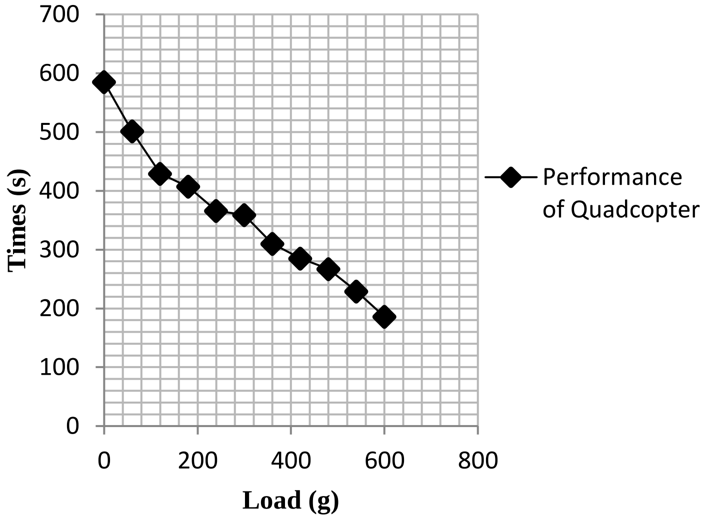

Figure 5: Hovering (at 2 m height) duration vs Load

Based on Table 3, the recorded hover duration by quadcopter at 2 m height with various loads can be plotted as shown on Figure 5. As the load increased, the time recorded for the quadcopter hovering above the ground at 2 m high decreased.

Table 4: Data for static thrust testing of one motor

Throttle (%)	RPM (rev/min)	Volt (V)	Current (A)	Power (W)	Thrust (g)
50%	1405.8	11.1	0.4	4.44	11
60%	6710.2	11.1	5.8	64.38	395
70%	6966.6	11.1	6.5	72.15	460
80%	7363.7	11.1	6.8	75.48	470
90%	7735.8	11.1	6.9	76.59	478
100%	8004.0	11.1	7.0	77.70	485

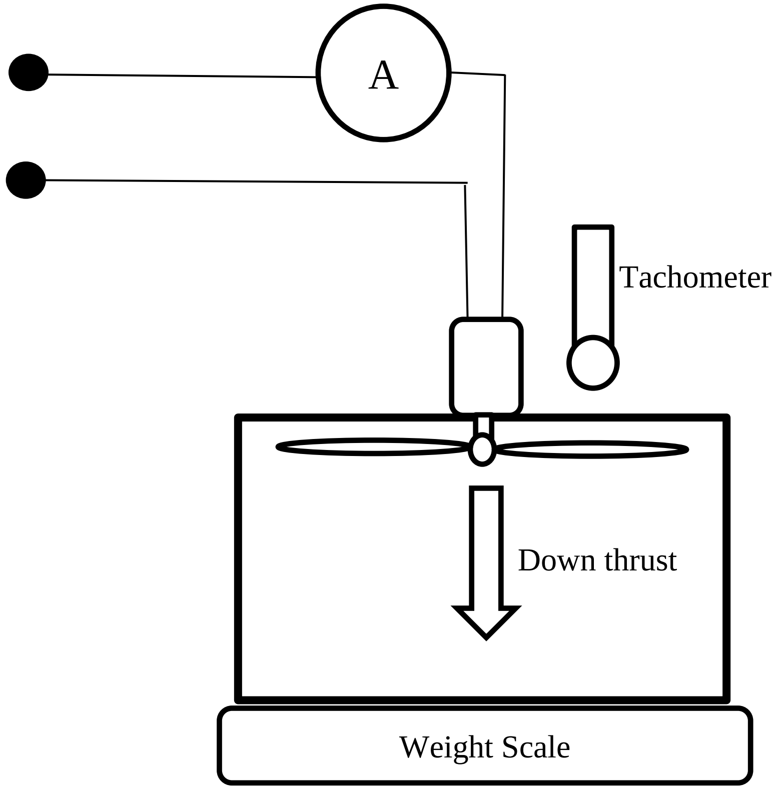

Figure 6: Static thrust test set-up.

Table 4 above shows throttle percentage (%) of the motor against various parameters. The set-up of the static thrust test rig was shown on Figure 6. It is important to test the motor to see the thrust produced. A correlation between thrust and RPM was formulated. The graph is shown in Figure 7. Figure 8 shows the graph of correlation between power and RPM.

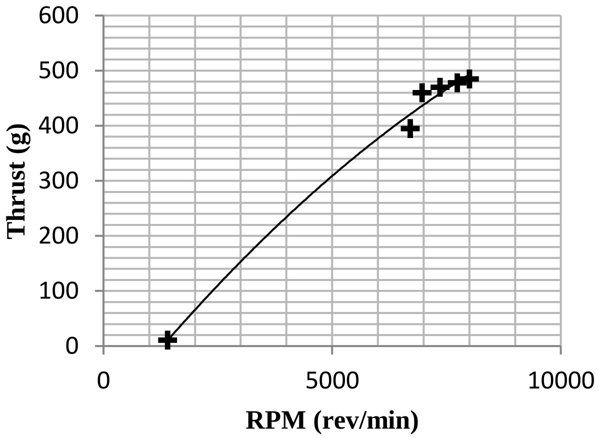

Figure 7: Thrust vs RPM produce by motor

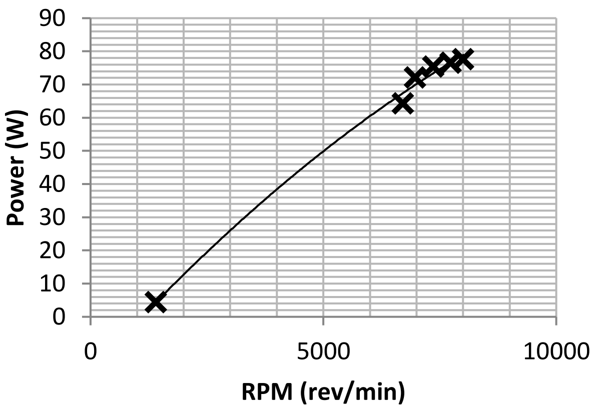

Figure 8: Power vs RPM produce by motor

Conclusion

The thrust behaviour of the copters was investigated and the output data were reported in this paper. Various parameters were recorded such as thrust, motor rpm, current load, power and speed. The quadcopter was tested with different payloads in order to obtain the climb and hovering flight performance of the quadcopter. Static tests also show that at maximum RPM of 100% throttle static thrust testing, the thrust recorded was 485 g per motor, with the maximum current load recorded was 7.0 A, and the maximum power was 77.7 W.

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Development of Tilted Quadrotor for Autonomous Flight

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