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Performance characteristics optimization of quadrot or propellers

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ABSTRACT

In recent years quadrotors have become very popular due to small size, good manoeuvrability, simplicity of mechanics, survivability and an increased payload. This work describes the theory and validation of an aerodynamic propeller model based on the performance characteristics calculation is based on the idea of predicting the performance of a given propeller geometry by considering the aerodynamic forces produced by the two-dimensional blade sections.Quadrotors, as unmanned aerial vehicles, are controlled using an electronic control system and electronic sensors. They usually consist of several basic and of some additional components like a frame, Electronic speed controllers, motors, propellers, battery, and control board. Quadrotors vary according to size, number of battery packs, propeller size and the choice of the components themselves.The thrust test stand permitted research into the performance of individual motors and propellers. Performance characteristics of different sized propellers compared in results.

Keywords— **Aerodynamic, Battery, Propellers, Quadrotors, Unmanned aerial vehicles.**

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I. INTRODUCTION

Forecast of flight loads plays an important role in the design process of quadrotoraircraft. This requires models to describe the structural loads due to aerodynamic forces and aeroelastic effects with sufficient accuracy, but low enough computational effort in order to be feasible for practical application. This work describes the theory and validation of an aerodynamic propeller model based on the performance characteristics calculation is based on the idea of predicting the performance of a given propeller geometry by considering the aerodynamic forces produced by the two-dimensional blade sections. This paper described the important relation between thrust and power coefficients of the airflow by the propeller with variations in rpm. In recent years quadrotors have become very popular due to small size, simplicity of mechanics, good manoeuvrability, survivability and an increased payload. These small sized flying robots are used for inspection of solar panels and also bridges, in the field of aerial imagery, military and law enforcement. In addition, quadrotor can assist in rescue missions after natural disasters or explosions, or monitor wildlife and crop. Quadrotor also replace humans during activities that could be harmful to life, such as reconnaissance in areas with a high level of radiation. Quadrotors, as unmanned aerial vehicles (UAV), are controlled using an electronic control system and electronic sensors.Quadrotorsusually consist of a frame, Electronic speed controllers, motors, propellers, battery, control board. Quadrotors vary according to size, number of battery packs, propeller size and the choice of the components for designing the Quadrotor. Small UAVs, such as quadrotors, are typically powered by one or more Lithium Polymer batteries, because of their high energy density, high charge and discharge rates, long lifetime, lack of memory effect and affordable cost.

II. BACKGROUND

The idea of a quad-rotor aircraft has existed since early in the 20th century. Throughout the 20th century very few rotor-craft designs had been developed. The earliest workable designs for a quad-rotor were developed by Etienne Oemichen, D.H. Kaplan and George DeBothezat.Oemichen‘s quad-rotor design is the earliest mention of a complete four-rotor hovering vehicle in history. Oemichen‘s first design in 1920 failed in the initial attempt to become airborne, thereby requiring Oemichen to add additional lifting power and stability of a helium-filled balloon. After a number of recalculations and redesigns, Oemichen was able to come up with a design that actually was capable of lift off and even established world helicopter flight records of the time, remaining airborne for up to 14 minutes at a time by 1923.The only manned quadrotor helicopter to leave ground effect was the Curtiss-Wright X-19A in1963, though it lacked a stability augmentation system to reduce pilot work load, rendering stationary hovernear impossible,6 and development stopped at the prototype stage. Recently, advances in microprocessorcapabilities and in micro-electro-mechanicalsystem (MEMS) inertial sensors have spawned a series of radiocontrolled(RC) quadrotor toys, such as the Roswell flyer (HMX-4),and Draganflyer,which include stabilityaugmentation systems to make flight more accessible for remote control (RC) pilots.Many research groups are now working on quadrotors as UAV testbeds for control algorithms for autonomous control and sensing,consistently selecting vehicle sizes in the rangeof 0.3 - 4.0 kg. Severaltestbeds have achieved control with external tethers and stabilizing devices. In the last few decades, small-scale unmanned aerial vehicles (UAVs) are used for many applications. The need for aircraft with greater hovering ability and maneuverability has led to a rise in quadcopter research. The four-rotor design allows quadcopters to be relatively simple in design yet highly reliable and maneuverable. Research is continuing to increase the abilities of quadcopters by making advances in multi-craft communication, environment exploration, and maneuverability. If these developing qualities can be combined, quadcopters would be capable of advanced autonomous missions that are currently not possible with other vehicles.

Some current researches include: The Bell Boeing Quad TiltRotor concept takes the fixed quadcopter concept further by combining it with the tilt rotor concept for a proposed C-130 sized military transport.The Aermatica Spa Anteos is the first rotary wing remotely piloted aircraft (RPA) to obtain official permission to fly in the civil airspace, by the Italian Civil Aviation Authority (ENAC), and will be the first able to work in non-segregated airspace.

ArduCopterandAeroQuad are open-source hardware and software projects based on Arduino for the DIY construction of quadcopters.

Parrot AR.Drone is a small radio controlled quadcopter with cameras attached to it built by Parrot SA, designed which is to be controlled by smartphones or tablet devices.

Nixie is a small camera-equipped drone that can be worn as a wrist band.

III.EXPERIMENTATION

A. Components Selection

The following is a brief review of the components selected. A brushless electronically commutated DC motor is chosen based on the propeller and voltage supply battery.

1) VoltageSupply:

Energy is supplied to the aircraft through the battery.

Fig. 1 2200mAh lithium polymer battery

The voltage and the capacity characteristics are to be chosen for the battery. The mass of the battery has a considerable effect on the overall mass. Additionally an increase in capacity will increase the maximum current draw. Lithium polymer (LiPo) batteries currently have the best storage to mass ratio. The maximum rate of current draw from the battery is related and expressed relative to the capacity (C) of the battery considered.

2) ElectronicCommutation:

Electronic speed controllers (ESC) convert control inputsinto the switching required for a network of field effect transistors. A Hyperion electronic speed controller is shown below in Fig2. ESCs are sized according to the maximum applied current. The input to an ESC is a pulse-width-modulated (PWM) signal between 1ms and 2ms, where a 1ms pulse is off, 2ms is constantly on, 1.5ms is 50% and linear variation between. The weight of an ESC is small compared with other components so the suggested ESC for the motor chosen should be used

Fig. 2 SimonK 30A electronic speed controller

3) Brushless Motor:

The motor rotates at the speed that the ESC provides, provided that adequate power is provided to the motor, and the motor is able to dissipate the heat. The motor requires more energy to rotate the load for a larger motor load.

Fig. 3 A28 series-D2826 G-Power Motor

The motor is rated according to the number of cells it can support (voltage) and the current that it can support continuously (continuous current rating). There are several other current ratings but we are concerned with the continuouscurrent rating due to the expected continuous high speed operation of the motor.

The motor contributes more mass than the ESC and, in quadrotor configuration, is located at the extremities of the craft. The brushless motor is required to be of a sufficient voltage, current rating and max speed to allow the rotation of a suitable propeller. The next section investigates the characteristics of a suitable propeller.

4) Propellers:

Propellers are shown Fig4. The propeller thrust and propeller drag are depends on the properties of the air surrounding the propeller and the motion of the propeller relative to the air. The relationship between the coefficients of propellers and various parameters are discussed in next section.

Fig 4 APC-SF 11x4.7 propeller with attachment hub assembly

APC have propellers designed for slow flight, rotational speeds or minimum load which have a maximum rotational speed dependent on the manufacturing specifications and dimensions. The APC-E propellers are their lightest and have a larger maximum rpm.It is unknown if the E type props will be able to support the weight of the vehicle, the SF propellers are expected to be capable of supporting weight in this direction due to a larger cross sectional area of the blade. However, the unavailability of pusher propellers (or equivalent) requires the selection of E type. Propeller attachment is dependent on the propeller and motor used. Hyperion provides attachment hubs for APC propellers. The hub selected is shown in Fig4.

5) Force Sensitive Resistor (FSR):

Force Sensing Resistors, or FSRs, are robust polymer thick film (PTF) devices that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. The standard 402 sensor is a round sensor 18.28 mm in diameter. This FSR gives actuation force as low as 0.1Nand sensitivity range to 10N.

Fig. 5 Standard 402 Force sensitive resistor

6) Arduino Uno microcontroller:

Arduino is a tool for making computers that can sense and control more of the physical world than desktop computer. It is an open-source physical-computing platform based on a simple microcontroller board, and a development environment for writing software for the board.The Arduino is based on Atmel's ATMEGA8 and ATMEGA168 microcontrollers.Arduino Uno microcontroller is programmed to perform motor control through its pulse width modulation (PWM) outputs, and to acquire analog inputs from the load cell.

Fig 6Arduino Uno microcontroller

B. Thrust Test Stand setup

In order to evaluate motor, rotor and battery characteristics, a thrust test stand setup is developed, shown in Fig7.It measures the forces and torques using a load cell. The mounting point on the lever is adjustable to allow load sensitivity variations. An Atmel microprocessor board is programmed to perform motor control through its pulse width modulation (PWM) outputs, and to acquire analog inputs from the load cell, esc, and battery voltage. Battery monitoring circuitry measures motor voltage and current. Data is captured to the computer using an Atmel microprocessorto measure the analog signal at 400 Hz.

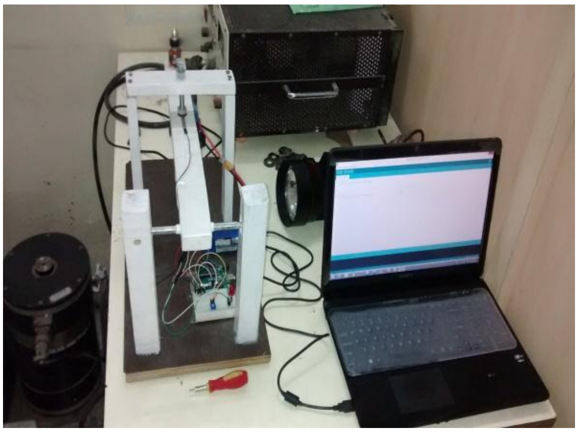

Fig. 7 Thrust test stand used to measure thrust using load cell. Battery monitoring circuitry measures motor voltage and current. Data is captured to the computer using an Atmel microprocessorto measure the analog signal at 400 Hz

The microprocessor board interfaces with a data acquisition program on the Laptop to perform automated tests, making measurements at different rpm of the propeller. Propeller rpm is measured using digital stroboscope, with a rated accuracy of ±10%. The thrust is provided by A28 series-D2826 G-Power Motor, APC10×4.5, 11x4.7, 9x4.7, 7x6 Slow Flyer propsand SimonK 30Aspeed controllers, resulting in highest thrust output recorded is with the 11x4.7" APC rotor at 7000 rpm with 9.46Nper motora total max gross thrust of 32 N of a quadrotorand lowest thrust output recorded is with the 7x6" APC rotor at 9000 rpm with 5.49N.

IV. PROPELLER PERFORMANCE AND CHARACTERISTICS

Though the refined theories are helpful in design of propeller blades, the propeller characteristics obtained from the wind tunnel tests are used for estimation of aircraft performance. These characteristics are presented in terms of certain parameters. The propeller performance is expressed in terms of the following coefficients.

1) Advance ratio:

$$J = \frac{V}{nd}$$

2) Power coefficient:

$$C_P = \frac{P}{\rho n^2 d^5}$$

3) Thrust coefficient:

$$C_T = \frac{T}{\rho n^2 d^4}$$

4) Speed power coefficient:

$$C_S = V\left(\frac{\rho}{Pn^2}\right)^{\frac{1}{5}} = \frac{J}{\sqrt[5]{C_P}}$$

5) Propeller efficiency:

$$n_P = \frac{TV}{P} = J\left(\frac{C_T}{C_P}\right)$$

6) Torque coefficient:

$$C_Q = \frac{Q}{\rho n^2 d^5}$$

7) Torque speed coefficient:

$$Q_S = \frac{J}{\sqrt{C_Q}} = V\sqrt{\frac{\rho d^3}{Q}}$$

Where, P = Power in watts,
T = thrust (N),
V = flight velocity (m/s),
n = rotational speed (rev/s),
d = diameter of propeller (m)
ρ = density of air at propeller (kg/m^3)
Q = Torque (Nm) = $P/_{2\pi n}$

V. RESULT & DISCUSSION

This section presents to compare theoretical calculation with experimental data for thrust output and power. In order to do so, rotors with the different diameter and undergoing the same environmental conditions are tested for thrust output and power consumption while varying the rotor's diameter and pitch.

A. Coefficients for Different Propellers

The coefficients of different propellers at different rotational speed as shown in below figures which are useful for calculation of thrust and power of rotor discussed in previous section.

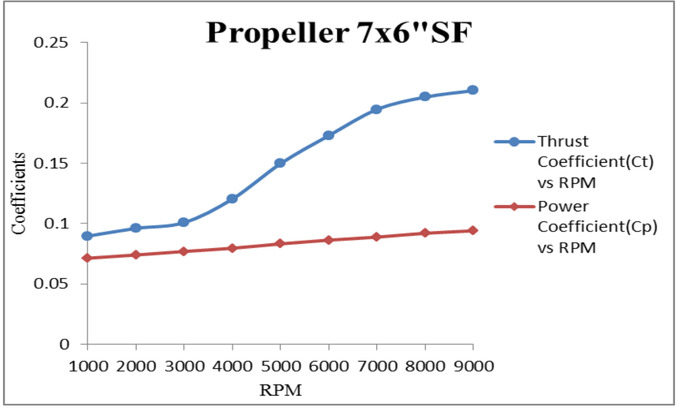

Fig.8Coefficients for Propeller 7x6"SF

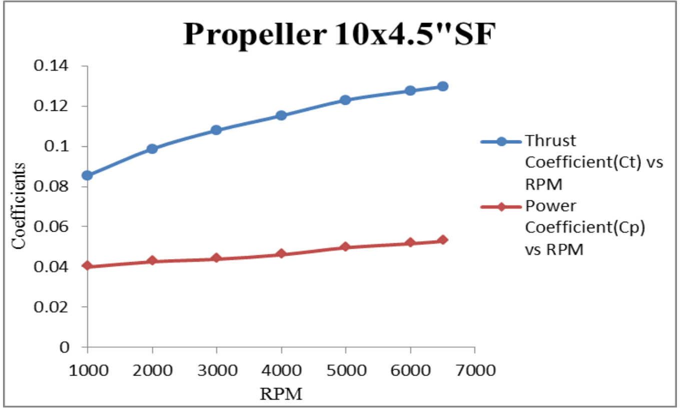

Fig. 9 Coefficients for Propeller 10x4.5"SF

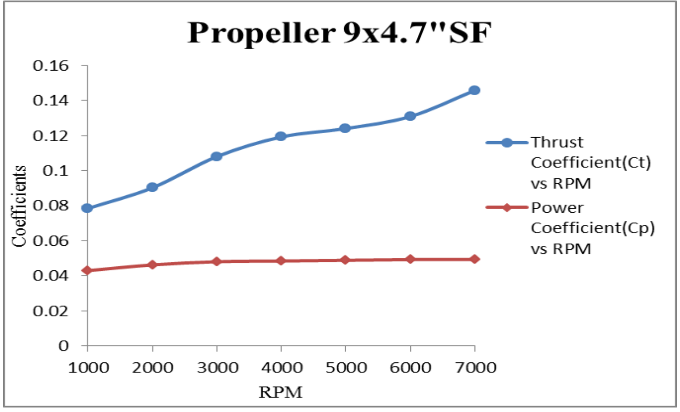

Fig. 10Coefficients for Propeller 9x4.7"SF

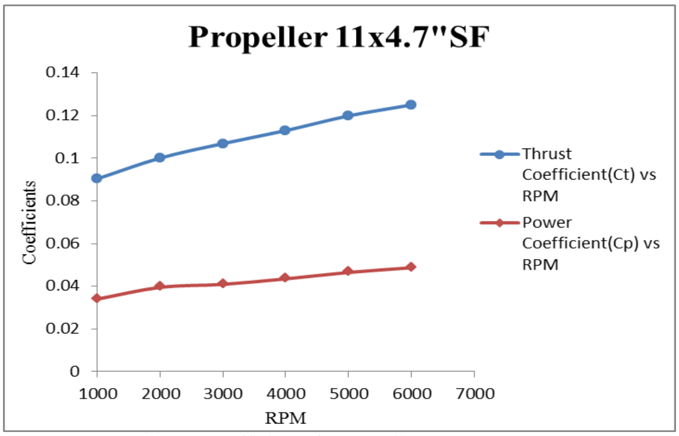

Fig. 11 Coefficients for Propeller 11x4.7"SF

B. Thrustdeveloped by for propellers

Figures shown below indicate the thrust developed by different sized propellers with respect to rotational speed. It is clear that the higher the rotor's rpm, the higher the thrust output is for all tested rotors. Furthermore, it is found that the bigger the rotor'sdiameter, the higher the thrust output is at the same rpm. The highest thrust output recorded is with the 11x4.7" APC rotor at 7000 rpm with 9.46N.The lowest thrust output recorded is with the 7x6" APC rotor at 9000 rpm with 5.49N.

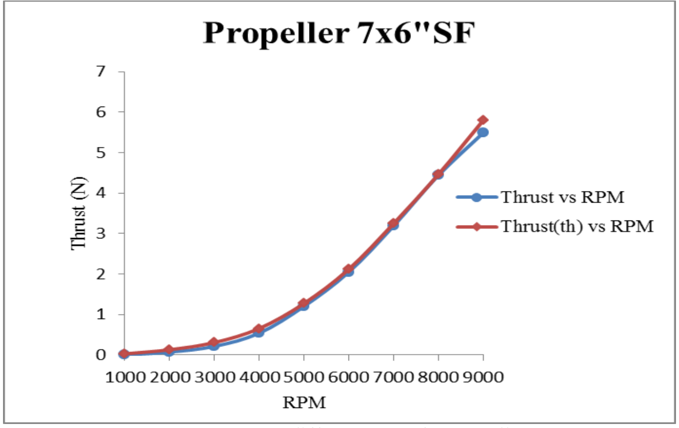

Fig. 12Thrust generated at different RPM for Propeller 7x6"SF

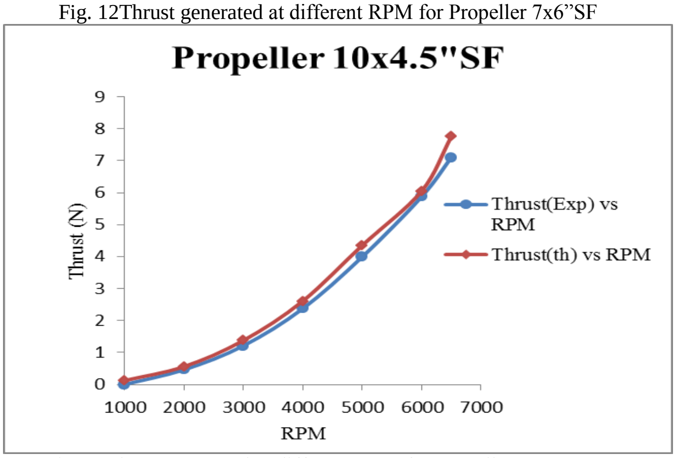

Fig. 13Thrust generated at different RPM for Propeller 10x4.5"SF

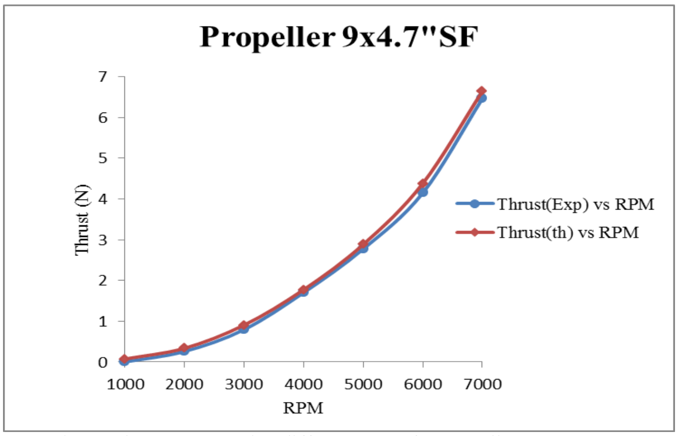

Fig. 14Thrust generated at different RPM for Propeller 9x4.7"SF

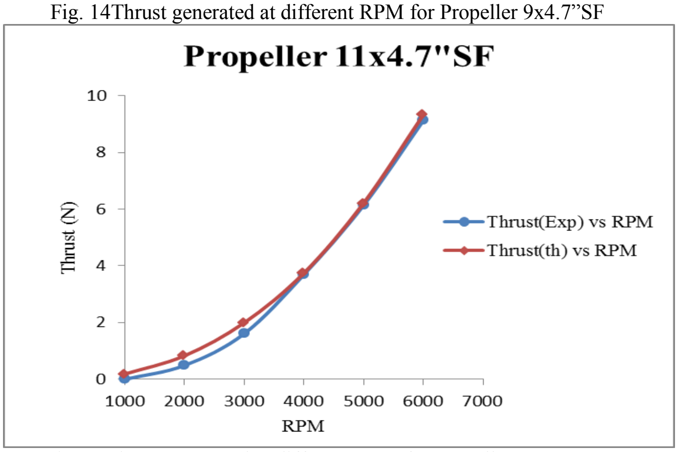

Fig. 15Thrust generated at different RPM for Propeller 11x4.7"SF

C. Power consumption by Propellers

Figures shown below indicate the power for different sized propellers with respect to rotational speed.It is also obvious that the higher the rpm of any ofthe tested rotors, the higher their power consumption. The highest powerrecorded is found to be around 102 W with the 11x4.7" APC rotor, at a speed of7000 rpm.The lowest power recorded is found to be around 59.9 W with the 9x4.7" APC rotor, at a speed of 7000 rpm.

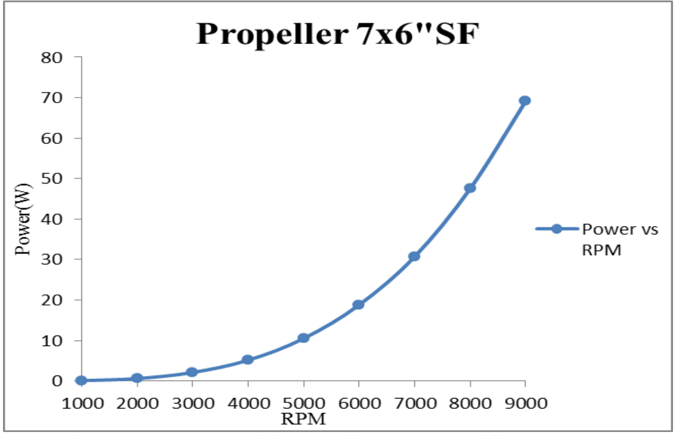

Fig. 16Power consumed by Propeller 7x6"SF at different RPM

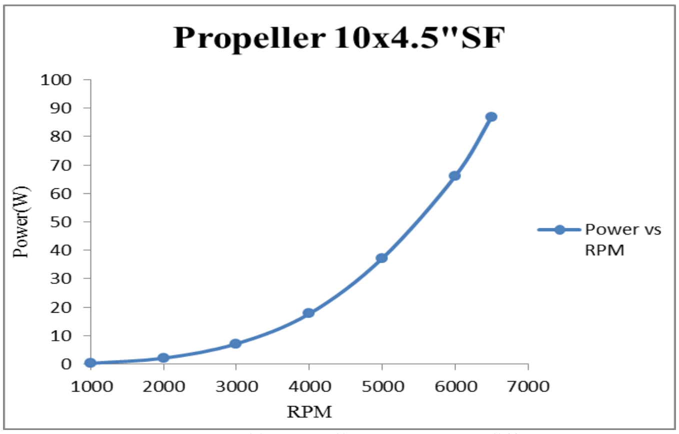

Fig. 17Power consumed by Propeller 10x4.5"SF at different RPM

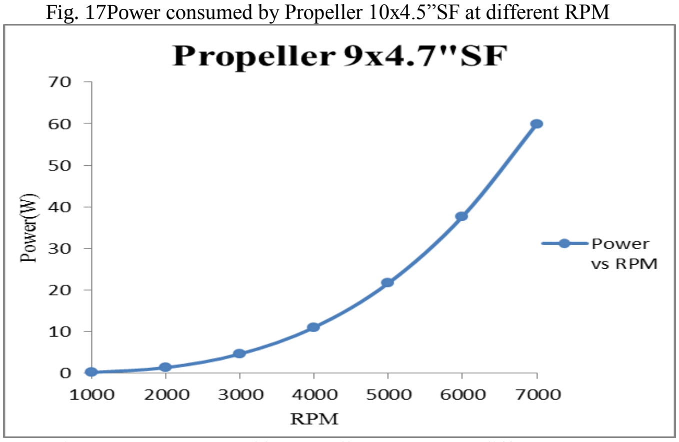

Fig. 18Power consumed by Propeller 9x4.7"SF at different RPM

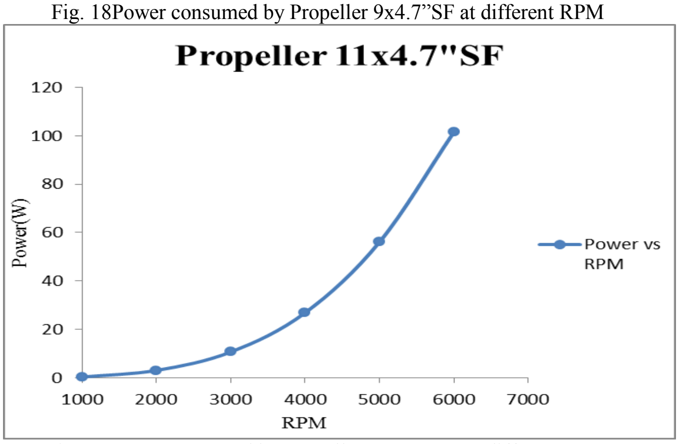

Fig. 19Power consumed by Propeller 11x4.7"SF at different RPM

V.CONCLUSION

The paper exposes the performance characteristics of simple model accounting for the aerodynamics of the propeller on quadrotor.The objective of this paper is to present a numerical model to analyze rotor's performance in order to use it as an analysis tool for future quadrotor design projects. Propulsion tests are performed and the experimentaldata helped in the validation of the developed model as the model is subjected toan average of 4.6% discrepancy in terms of thrust prediction. The discrepancy is due to somewhat inaccurategeometrical data entry and the exclusion of the motor losses in the theoretical powerconsumption calculations. Moreover, the optimization of the propulsion system is not entirely depending on the rotor selection; however, it depends on the optimumcombination of the propulsion components, such as the batteries, the motor and the controller.

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