



Design of Multirotor Test Rig Multirotors Performance test

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Abstract—In this paper we have designed a multi rotor test rig, which involves static and dynamic sections depending on the type of multi rotor model chosen for testing. Starting with the Static Test Hub, we proceeded to create a setup to test individual motors based on rpm, thrust, voltage, amperes, power consumption, motor efficiency, propeller efficiency, and copter endurance. Secondly, the Dynamic Test Hub deals with the testing of pre designed and fabricated copter where the entire model is placed between the test arms and tested for roll, pitch, and yaw movements and also the pre flight on board system check for command reception and telemetric flight data transfer.

Keywords— test rig, multi-rotor, thrust, orientation, endurance, pre flight test,

I. INTRODUCTION

This paper is about modeling, designing and fabricating a multi rotor test rig, which involves testing a copter (quad copter, tri copter, hexa copter, octa copter). The major problem faced today with multi rotor designers is the response of the copter when it is tested on field for the first time. The ultimate use of a test rig is to provide values of max thrust offered by all motors together and also its roll pitch yaw response for manual and PID tuning [2][1]. Control of vehicle motion is achieved by altering the pitch and rotation rate of one or more rotors discs, thereby changing its torque load and thrust characteristics. This paper majorly deals with the designing of a test rig, which is used to compare theoretical and experimental values of the drive electronics on board of a multi rotor. The project consists of the development of four main areas, the first being the on-board measurement systems including gyroscope, Accelerometers, and barometers, the communication systems, the control of the individual rotors and the main processor which pull all these together. The project also required the development of a method of allowing the user to communicate and verify their performance prior to field test with the help Matlab Simulink.

II. CONCEPTUAL APPROACH

A. Methodology:

Our model is made out of central housing from GRP – Glass Fiber Reinforced sheet attached to ball and socket and a central spring-loaded suspension hub for 6 degree of freedom. It is mounted on a wooden base and a central hub for mounting the APM and telemetry for data transfer, with the help of Mission Planner software the altitude pitch roll and yaw movements are modified making the copter agile or sluggish with respect to the signal input from an RF transmitter[7].

B. Model Specifications

1. Arm length = 750mm
2. Varying Motor to Motor distance: Minimum= 300mm and maximum = 720mm
3. Flight Controller = APMV2.6
4. Telemetry = 455Mhz APM module.
5. Ball and socket setup at hub
6. Spring loaded Suspension system in the middle.

III. PROTOTYPING AND TESTING

The Static Test Hub Prototype was fabricated out of aluminum and High Density Foam (HDF) and load cell attached to a base to obtain the thrust value at varying throttle percentage and rpm was obtained [1].

We considered 3 basic conditions:

1. Motor and Propeller kept constant and battery varied.
2. Motor and battery kept constant and propeller varied.
3. Propeller and battery kept constant and motor varied.

Initial testing was done with the following prototype.



Fig 1 Prototype of testrig

A. observations

The observation was done with varying propeller initially and the results are specified below.

1) First set of testing

TABLE I. Motor= 1000kv; Propeller= 8x4.5

Prop Speed	Thrust (grams)		
	Theoretical	Practical	% Error
2200	31.61354803	36	12.2
3200	66.88486195	80	16.4
4222	116.4298496	142	18.0
5092	169.3575913	208	18.6
6124	244.9617311	307	20.2
7178	336.5385246	428	21.4
7788	395.7614904	505	21.6
8481	469.8097276	590	20.4
9981	650.6927825	820	20.6

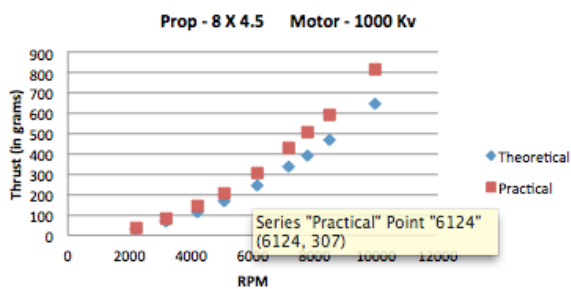


Fig 2 Graph plot of theoretical and practical values (8x4.5)

2) Second set

TABLE II. Motor=1000kv; propeller=10x4.5

Prop Speed	Thrust (grams)		
	Theoretical	Practical	% Error
2500	79.73296875	70	13.9
3362	144.1960406	125	15.4
4360	242.5106948	217	11.8
5370	367.8802634	345	6.6

Prop Speed	Thrust (grams)		
	Theoretical	Practical	% Error
6180	487.2309497	466	4.6
6820	593.3714777	585	1.4
7245	669.6296837	680	1.5
8020	820.5530309	840	2.3
9168	1072.277336	1150	6.8

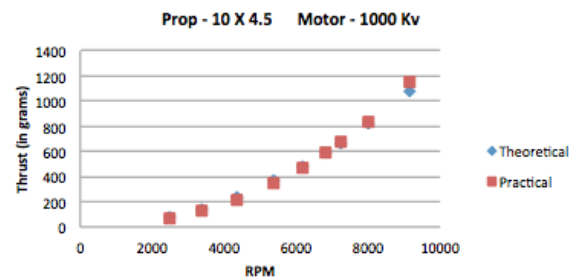


Fig 3 Graph plot of theoretical and practical values (10x4.5)

3) Third set

TABLE III. Motor=1000kv; Propeller=9x4.7

Prop Speed	Thrust (grams)		
	Theoretical	Practical	% Error
2004	39.00912638	35	10.2
2720	71.86353855	64	12.3
3830	142.4847346	125	14.0
4720	216.3987696	198	9.3
5220	264.6743139	240	10.3
6000	349.6820107	360	2.9

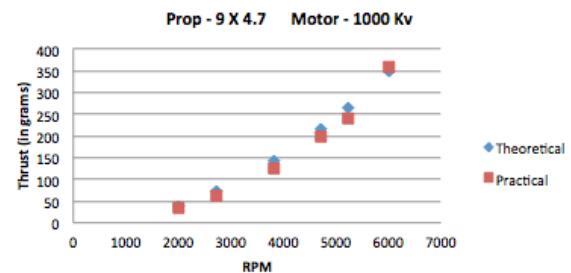


Fig 4 Graph plot of theoretical and practical values (9x4.7)

IV. MODEL DESIGN

The test rig was basically designed to accompany models of diameter varying from 300mm diameter to 1000mm diameter. The model is designed to offer 6 degrees of freedom with the help of a spring-loaded suspension attached to a ball and socket at the central hub below the copter. It is designed to constrain any degree of freedom depending on our need. The catia design is shown below:

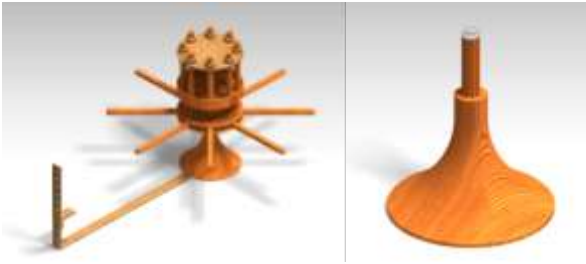


Fig5 Multirotor test rig(left) , Test rig stem with ball and socket (right)

A. Static Test Hub:

The static test hub is designed to accompany various types of multi rotor configuration from bicopter to octa copter.

- 1) Material: Rubber Wood
- 2) Diameter: 200mm
- 3) Hub thickness: 10mm



Fig 6Static Test Hub (octa configuration)

B. Dynamic Test Hub

The dynamic test hub is meant to test a complete model rather than testing fitting the rotor to the static hub. The model arms are placed between the vertical support rods of the dynamic hub and constrained with the help of disc locker [1].



Fig 7 Dynamic Test Hub with locking disk

V. DESIGN METHODOLOGY

The design process starts by setting up various constraints based on the application: In this case propeller diameter provides the necessary constraints. In practice, the propeller span defines the overall span of the multi rotor. Using the propeller diameter, one can estimate the characteristics of the propeller in term of thrust, drag and power for a range of angular speeds [3]. So, the mass, the drag moment and the thrust/weight ratio are enough to fully define the motor power requirements. This allows us to choose the range of data that are required to power the copter

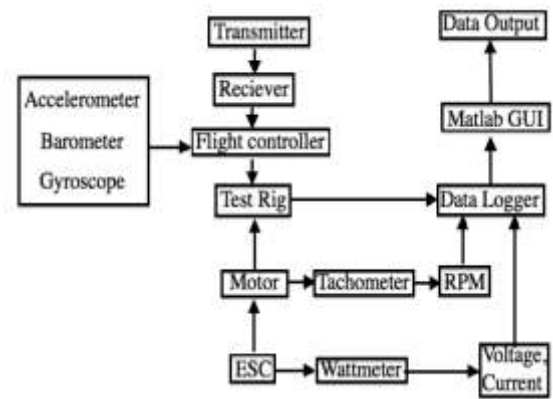


Fig 8 Data Logging

VI. CONTROL SYSTEM DATA LOGGING

The flight controller setup on the hub is the APM V2.6, consists of barometer, gyroscope and accelerometer sending in data of roll yaw pitch and altitude of the copter [6].

A. Sensor Data Output

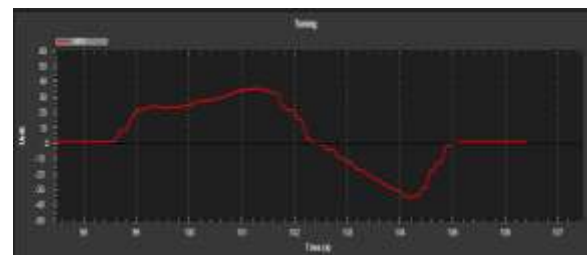


Fig 9 Pitch curve – pitch response

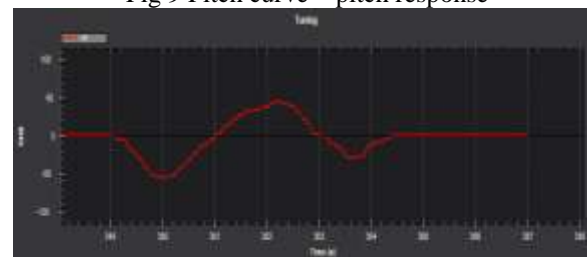


Fig 10 Roll curve- roll response

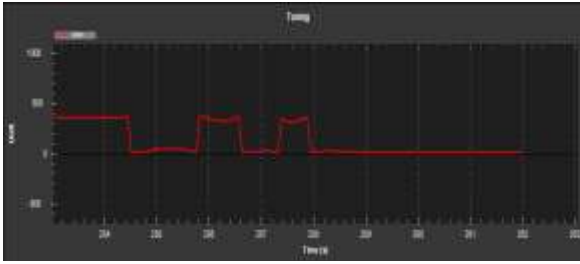


Fig 11 Yaw curve-yaw response

B. Power Data Output

In order to extract the data of voltage input to motors from battery and the outburst current of the electronic speed controllers to the brushless motors, a wattmeter is placed between the battery and electronic speed controller, when the motor rpm increases, we considerably see the change in current drawn and voltage input from the battery to motor via ESC. Thus battery-monitoring circuitry measures motor voltage and current. Data is captured to the computer using an Atmel microprocessor to measure the analog signal at 400 Hz [5].



Fig 12 Wattmeter data- battery discharge rate

C. Motor Data Output

The motor rpm is found by attaching a reflective thin sticker on the motor and using a tachometer the rpm of the motor at varying throttle is obtained. The Entire test rig is mounted on a load cell providing us with the total thrust offered by the motors in required units i.e. in kilogram or ounce. Thus the calculated value via Matlab GUI is verified with the practical values.

D. Mathematical Calculation

Brushless motors are used for all multi copter applications [4]. For electric motors, the torque produced is given by

$$\tau = K_t(I - I_0) \quad (1)$$

Where τ is the motor torque, I is the input current, I_0 is the current when there is no load on the motor, and K_t is the torque proportionality constant. The voltage across the motor is the sum of the back-EMF and some resistive loss:

$$V = IR_m + K_v\omega \quad (2)$$

Where V is the voltage drop across the motor, R_m is the motor resistance, ω is the angular velocity of the motor, and K_v is proportionality constant (indicating back-EMF generated per RPM). This description of the motor is used to calculate the power it consumes. The power is

$$P = IV = ((\tau + \tau K_t I_0) (K_t I_0 R_m + \tau R_m + K_t K_v \omega)) / K_t^2 \quad (3)$$

For the purposes of simple model, assume a negligible motor resistance. Then, the power becomes proportional to the angular velocity.

$$P \approx (\tau + K_t I_0) K_v \omega / K_t \quad (4)$$

Further simplifying the model, we assume that $K_t I_0 \ll \tau$. This is not altogether unreasonable, since I_0 is the current when there is no load, and is thus rather small. In practice, this approximation holds well enough. Simplified equation for power is obtained

$$P \approx \frac{K_v}{K_t} \tau \omega \quad (5)$$

The power is used to keep the multi copter aloft. By conservation of energy, we know that the energy the motor expends in a given time period is equal to the force generated on the propeller times the distance that the air it displaces moves ($P \cdot dt = F \cdot dx$). Equivalently, the power is equal to the thrust times the air velocity

$$P = T v_h \quad (6)$$

Assume vehicle speeds are low, so v_h is the air velocity when hovering. We also assumed that the free stream velocity, v_∞ , is zero (the air in the surrounding environment is stationary relative to the quadcopter). Momentum theory gives us the equation for hover velocity as a function of thrust,

$$v_h = \sqrt{\frac{T}{2\rho A}} \quad (7)$$

Where ρ is the density of the surrounding air and A is the area swept out by the rotor. Using our simplified equation for power, we can then write

$$P = \frac{T^2}{\sqrt{2\rho A}} \quad (8)$$

Note that in the general case, $\tau = \vec{r} \times \vec{F}$; in this case, the torque is proportional to the thrust T by some constant ratio K_τ determined by the blade configuration and parameters. Solving for the thrust magnitude T , we obtain that thrust is proportional to the square of angular velocity of the motor:

$$T = K \omega^2 \quad (9)$$

Thus the derived equations are added to Matlab for theoretical calculation.[9]

E. Matlab GUI

The various output obtained and specification of the drive electronics are provided as input values into the GUI and the corresponding output values are obtained.



Fig 13 Matlab Graphic User Interface.

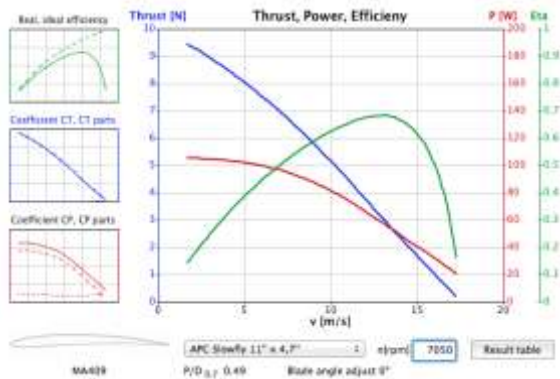


Fig 14 Thrust, power, efficiency graph

VII. STATIC HUB TESTING

The static hub was fabricated using rubber wood and the functionality was tested and verified with the theoretical calculation and the error percentage was taken into account. The environmental condition, room temperature, wind velocity, blade oscillation, slip factor, motor vibration, propeller material etc. weren't taken into consideration.[8]

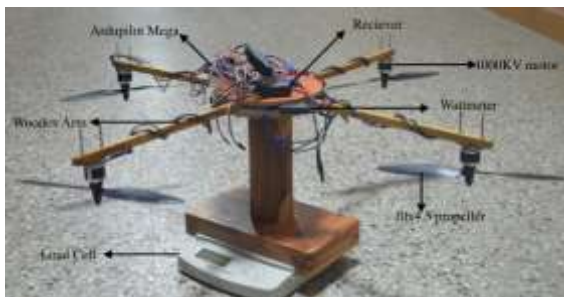


Fig 15 Fabricated Static Test Hub

VIII. TUNING USING SIMULATION

A. Simulation:

The equations of motion describing the dynamics of the system can be used to create a simulation

environment, which is used to test varying inputs and obtain results [4]. In MATLAB

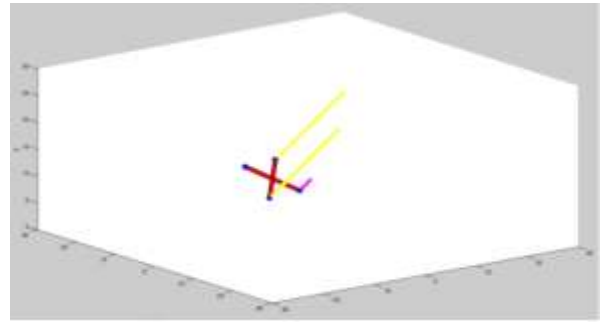


Fig 16 Matlab Simulink Results

Thus providing the required PID values to the APM Mission Planner in order to do the manual tuning of the copter and testing its response in the test rig.

IX. POSSIBLE UPGRADES

A. Adding strain gauges:

Adding strain gauges to arm joint with the central hub would help us find the amount of stress acting at the joints and the max load the arm could withstand with fracture can be found.

B. Tilt rotor accommodation:

Need to develop static test arm in order to mount motor in tilt rotor configuration and test its dynamics.

C. Vibration and Noise reduction

Setting up a seismometer to check the level of vibration and also attaching a microphone to record the propeller noise and finding solution to reduce it and testing it until desired results.

X. CONCLUSION

In the present day technology, there are various ways to build a multi rotor and fly but in order to achieve optimum results, use of multi rotor test rig is necessary. A practical solution to test the efficiency, effectiveness and airworthiness of the copter can be obtained. The calculated values via MATLAB Graphic User Interface and Simulink can be used to manually tune the PID values of the copter through APM mission planner. Various parameters such as roll, pitch, yaw, load, thrust, motor efficiency, propeller efficiency, power, outburst current, maximum voltage etc. are easily obtained in a single test and logged data are input in the data logger for auto tuning. Though there are various ways to log these data, optimum way is to create a setup, which can offer all values at once. Further many testing and tuning can be done using the test rig before hardware testing or flight-testing in order to prevent crashes and also loss of money and time.

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