# DESIGN AND IMPLEMENTATION OF A BRUSHLESS MOTOR THRUST TEST BENCH

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**Abstract** - Electrical motor and propeller efficiencies are of primary importance in small UAV (RC Aircraft) design. Unfortunately, catalogue information for these products are not reliable in a significant number of cases. In this paper a test bench for comparison of given motors and propellers is introduced.

**Keywords** - BLDC, Propeller, Thrust, ESC, RC Airplane

## I. INTRODUCTION

Small unmanned aerial vehicles (UAVs) have become common in terms of their vertical ability to take off and land and hover. Both their hardware and software are key factors in their operational efficiency. In this paper a test bench is introduced for two main hardware components, electric motors and propellers.

In small UAV, aerodynamic force, namely the thrust, is generated by rotations of the propeller. Motor-actuated propellers move the surrounding air to generate the thrust. The performance of the propellers and the actuating motors is significantly correlated. Both electric motors and propellers therefore have vital responsibilities in generating thrust that moves the aircraft.

Brushless Direct Current (BLDC) motor is a common type of electric motor used in an aircraft. In a BLDC, the rotor is a permanent magnet, and the stator has coils. Coils do not need to move, so there is no need for brushes and switches. This BLDC feature brings numerous benefits for the overall system. Such benefits can be described briefly as i) energy efficiency, (ii) easy control circuitry, (iii) longevity, and (iv) low electrical noise.

The other component of hardware which is tested in the test bench is the propeller. It moves the surrounding air and therefore is responsible for the aerodynamic forces that act on the UAV. The proper control of these forces allows an aircraft to move in any direction as well as hanging in the air. Its working has two main parameters: diameter and pitch. The diameter of the propeller is the length between its opposing ends. It is mainly responsible for the efficiency of the thrust. Pitch is defined as the displacement made in one complete rotation by a propeller.

It designs and implements a brushless motor thrust test bench consisting of an ESC unit, dc motor, and propeller. The weighing Sensor Load Cell Kit is used in the experiment setting to detect electrical current in a wire and generate a signal proportional to that current for the torque measurement and current sensor. Power, thrust, speed, density, and weight factor are calculated at different operating conditions. Some models of the BLDC motor and propellers are validated.

## II. PROBLEM STATEMENT

When designing model aircraft of any shape or size, it is useful to know the performance which can be expected from the selected components. This can be difficult for motors and propellers. It is also possible to combine them with testing. But, with the amount of potential combinations of propeller and motor, these data can be tough to get through. It would be better to only do the research in-house and designed a test bench to do so.

## III. EXISTING SYSTEMS

There are some problems that can be improved in the traditional way of the Brushless Motor Thrust Test Bench, to make the process easier and get the best results.

i) No heavy flat base so additional clamps or mounting bolts are needed already installed on a Test Bench
ii) No physical control or built-in LCD screen
iii) Expensive
iv) Only support up to 40A of current – although it's pretty much enough for what we're testing right now, but it's hard to say RC multirotor motors won't evolve in the future and exceed that limit.
v) The ESC control signal is only standard PWM – maybe one-shot or even multi-shot can be implemented in the future (although the flight controller 's external ESC signal may now be used)

## IV. PROPOSED SYSTEMS

Manufacturing, testing and comparison of the static thrust generated by the BLDC motor and selection of the Propeller combination. The relatively simple construction includes a weighing machine, a tachometer and a wattmeter to measure the respective

Thrust, RPM and Current Drawn, and provides comprehensive, accurate and efficient data from the BLDC motor including the Propeller and Electronic Speed Control (ESC).

### 4.1. Advantages

i) Built-in power meter (up to 35V, 40A current)
ii) Probable more reliable data
iii) Direct measurement and continuous data logging
iv) Integrated ESC signal controller (no additional servo tester required), but the external servo tester can be used
v) High frequency of sampling – The load cell is refreshed at a constant 8Hz rate
vi) Calibration capability is very important to ensure consistent test results

## V. HARDWARE

Atmega 328, Tensometric (Load Cell + HX711), BLDC Motor, ESC, Propeller, LCD and Current Sensor

### 5.1. Arduino MicroController (Atmega 328)

The function of the microcontroller is to receive and display information, to and from the user, to monitor the brushless DC motor via the ESC, to collect data from voltage, current and pressure sensors and to transmit data to the host computer through a USB link. The Arduino Microcontroller, shown in Figure 4.1, was chosen to satisfy both of these specifications. It is based on the Atmel-developed ATmega328P architecture that enables native USB functionality without relying on a separate processor. The combination of these functions enables faster serial communication and lower costs. The processor also supports 23 digital input/output (I/O) pins, seven of which have the capabilities of pulse width modulation (PWM) and 12 total analog inputs. Since the modules need four analog inputs, two digital inputs, four PWM outputs, and one digital output for a combined 11 I/O pins, these specifications are required. Compatibility with the Arduino IDE software (integrated development environment) was a great benefit considered when selecting a microprocessor. The IDE is a C-based environment with a large user base providing function libraries which did not need to be written from scratch. The microcontroller also has a small footprint that allowed the module to be more compact overall.

### 5.2. Load Cell

A load cell is defined as a "weight measuring system needed for electronic scales that display weights in Figure its." However, load cell is not limited to weight measurement in electronic scales. Load cell is a passive transducer or sensor translating the force exerted into electrical signals. They are also called "load transducers". The only load cells that predominate, however, are the load cells based on strain gages. The reason why strain gage-based load cells are widely adopted is their characteristics. Small size compared to other load-cell types. Long operating life due to lack of moving parts or friction-generating parts.

### 5.3. HX711 (Weighting Sensor)

Weight Sensor Module is based on HX711, a 24-bit analog-to - digital precision converter designed to communicate directly with a bridge sensor for weight scale and industrial control applications. HX711 not only has a few simple functions compared to other chips, it also includes high integration, rapid response, immunity and other features. The lower chip ds the electronic scale costs, while increasing efficiency and reliability at the same time.

### 5.4. BLDC Motor

Brushless DC Motor is a high speed brushless motor specifically designed for Quadcopters, Drones or toy planes. The motor is type OUTRUNNER where the outside case rotates while staying fixed inside. It's one of the market 's famous models, because it's low cost. Tiny drones and planes are favored. The model is available at various speeds, and should be selected accordingly. The motor features a 3.2 mm reinforced steel shaft, dual ball bearings, and has already mounted 3.5 mm gold spring male connectors and has 3 female connectors for speed controls. Also includes radial motor mount and collet type prop adapter. Mounting holes have a middle spacing of 16 mm and 19 mm, and are tapped for screws of 3 mm (M3).

### 5.5. Electronic Speed Control (ESC)

The brushless DC motor was operated via the ESC. The original device was a normal radio transmitter, which was transmitted to an ESC-connected receiver. The radio transmitter was no longer in use, and the Arduino microcontroller was used to bypass the receiver and replicate the requisite signals directly for the ESC. The ESC has a max current rating of 25 A well above 17 A, the minimum current for 1200-Kv generator.Similar to how a servo is mounted, the ESC needs a PPM (pulse position modulation) signal as input. The Arduino IDE included a servo library with minimal code for running the ESC.

The Arduino and the ESC have a common ground and a signal relation. There is no VCC power (5 V) connected between the Arduino and the ESC because the ESC was connected to the supply voltage and the connection would cause microcontroller damage. This connection is usually used to control the unnecessary Wireless Receiver for this setup. The ESC's three-phase performance was operating on a three-terminal female bullet connector connecting to the module's exterior. That brushless motor had been connected to a male bullet connector, enabling fast swapping of the motors.

The ESC cannot be disabled as a safety function before the appropriate initialization sequence is received. This feature ensures that if the throttle joystick has not been left to the minimum, the motor cannot be started accidentally.

### 5.5. Propeller

A propeller is a tool with a rotating hub and radiating blades set at a pitch to form a helical spiral that performs an action similar to the screw of Archimedes when rotated. By operating on a working fluid such as water or air, it converts rotational power into linear thrust. By creating a pressure difference between the two surfaces the rotational motion of the blades is converted into thrust. In one direction a given working fluid mass is accelerated, and the craft travels in the opposite direction. As with aircraft wings, propeller dynamics can be modelled by the theory of Bernoulli and the third law of Newton.

### 5.6. Current Sensor

A Current Sensor is an important device for power measurement and application management. The ACS712 Current Sensor is an Allegro Micro-Systems device which can be used for accurate measurement of both AC and DC currents. This sensor is based on Hall Effect and a Hall Effect device is built into the IC.

The ACS712 Current Sensor output produces an analog voltage that is proportional to the currents of AC or DC (whichever is sensed).

### 5.7. Liquid Crystal Display (LCD)

The term LCD stands for liquid crystal display. It is one type of electronic display module used in a wide range of applications such as various circuits & devices such as mobile phones, calculators, computers, television sets, etc. These displays are chosen for light-emitting diodes and seven segments in multi-segment formats. The key benefits of using this module are inexpensive; simply programmable, animations, and the showing of custom characters, special and even animations, etc., is not limited. A 16 LCD has two registers including the register of data and the register of commands. The RS (register select) is mainly used to switch between registers. When the set of the register is '0' it is known as the register of commands. Similarly, it is known as the data register when the register set is '1.'

## VI. IMPLEMENTATION

The test bench consists of a physically oriented, fixed pole on an aluminum plate. A rigid pin, whose center is pivoting from the pole's top, has propellers at its two ends (Figure 1). The quadrotor structure consists of three main elements which are responsible for creating the thrust necessary for the vehicle to fly. They are electronic speed controller (ESC), electric motor, and propeller parts. Each propeller is actuated by a BLDC motor. Due to the thrust, as a propeller at one end lifts up, the other end of the rigid bar moves downwards and applies proportional force to the weighing scale. The scale readings and the electrical power transmitted to the BLDC motor are measured in the testing phase to arrive at a conclusion on the suitability of the BLDC motor and propeller being tested.

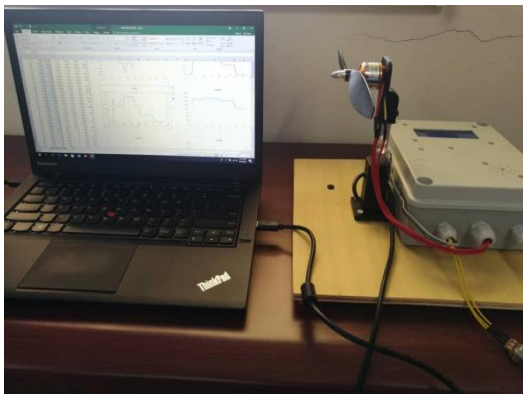


**Fig.1. Brushless Motor Thrust Test Bench**

## VII. BLOCK DIAGRAM

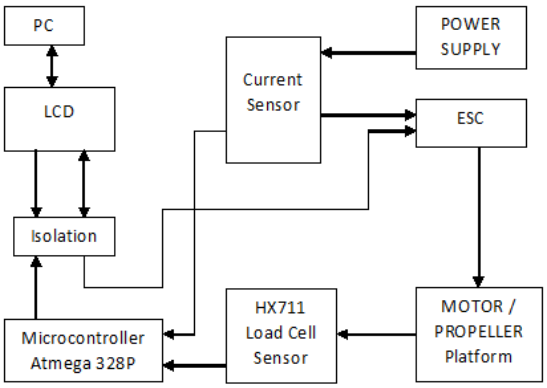



**Fig.2. Block Diagram of Testing Process**

The input signal of the BLDC motor is provided through the ESC unit. ESC is an electronic module with three signal outputs, producing PWM signals in a certain series at these outputs to control the BLDC motor. In the operations series, the BLDC motor shafts are attached to the propellers so that the propeller is actuated. The thrust and torque used to drive the rotor is produced by this rotation. The propellers are preferably rotated using the BLDC motors because of the high efficiency, quiet operation, and high torque production. BLDC's are regulated by ESCs. An ESC controls the speed of a brushless motor.

It changes engine speed by using PWM system to adjust the voltage to the motor. The PWM system operates by switching the ESC 's input current on and off easily. The average voltage value depends on how much current is going through the device and how long the current is not going through. The motor

speed control is performed by setting that value. A 24 bit analog to the digital converter HX711 load cell amplifier was used to calculate the power, in addition to these components.

The changes in the load current resistance were read by connecting this sensor to the microcontroller, and the necessary calibrations were made to provide weight measurement and the propeller thrust values were obtained. The current sensor ACS712 is used to monitor the power and current drawn by the motors.The ACS712 is an internal I2C Shunt and Power Control. The system tracks the decrease in shunt voltage and supply voltage to the bus via programmable conversion and filtering cycles. When paired with an internal multiplier, a programmable reference value allows the current to be read directly in amps. The readings come from the load cell amplifier, and the current sensor is processed by external MCU which communicates via serial communication with the Atmega 328P SMD based 32bit microprocessor card and transfers the sensor data through serial communication to the computer environment. This card supports the language used for programming C. Duty cycle is sent to the ESC card by the microprocessor and readings are passed to a Computer via a serial communication bus. The PC receiving the measurement signals uses Visual Basic software to process the incoming information.

## VIII. EXPECTED RESULTS

A standard simple test for a combination of BLDC motor and propeller is achieved by simply acquiring current, voltage and thrust data from the relevant sensors through each incremental PWM output. The graphics shown in Figure 3 (a) & (b) belong to a 10inch diameter propeller A2212/13T BLDC motor with a pitch ratio of 4.7 inches (10/4.7 inches).

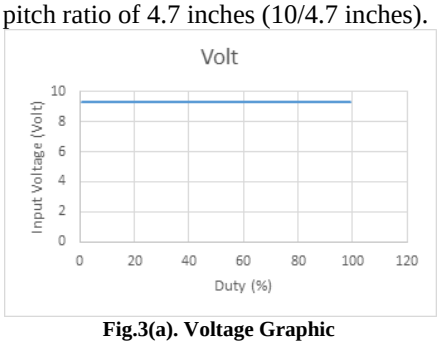



**Fig.3(a). Voltage Graphic**

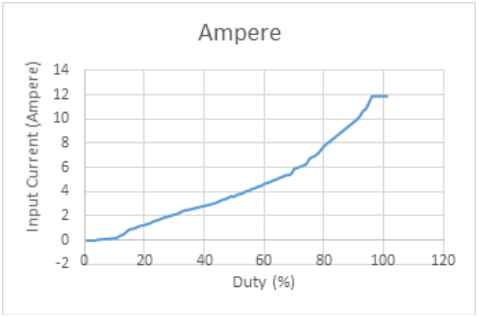



**Fig.3(b). Current Graphic**

Then, measured information is used to get the power graphics shown in Figure 4 and it is more useful to us when the main concern is efficiency.

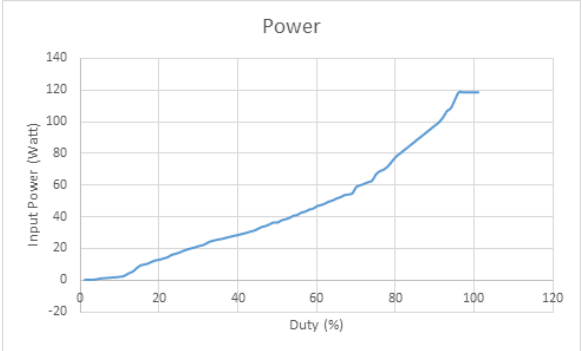



**Fig.4. Power Graphic**

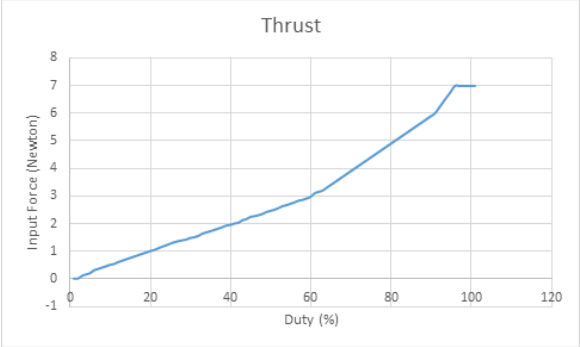



**Fig.5. Thrust Graphic**

Figure 5 displays a thrust-force graph of the same system. Finally, the input power vs thrust force ratio graph can be obtained for incremental PWM inputs as shown in Figure 6.

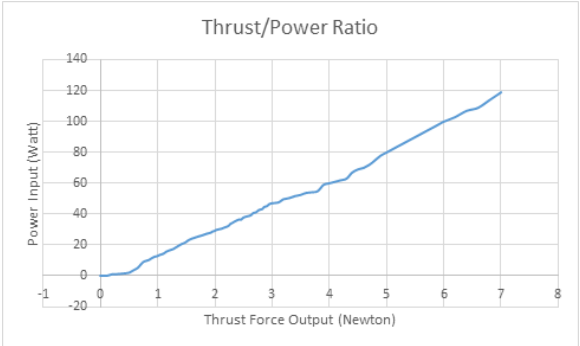



**Fig.6. Thrust/Power Ratio Graphic**

It gives us good information about the combination of motor and propeller, in a sense. The area where the slope is lowest gives us the best performance, so we'll know that the thrust force generated would be less costly in battery power terms. On the other hand, since we can see how much lift per unit power it can create, it's easy to predict how long the battery will last. Since manufacturer data do not include this detail, a quadrotor designer has to find it out. In addition, some second hand motor or propellers that have been randomly acquired do not even have manufacturer details.

## IX. CONCLUSIONS

A propeller-motor test bench is designed to build a powerful RC Plane. In addition, this test bench can be used for educational purposes to allow students to understand the effects of changing the described rotor sections. Within the test bench, the tests of the power ratio are taken thanks to the ACS712 and Hx711 sensors. The appropriate apparatus for the desired PWM ranges can be chosen by checking the graphics drawn in the Visual Basic environment. As a consequence of this, a rotor's energy requirements can be tailored for a given function. Thus, the appropriate types of motor and propeller for the aircraft to be designed can be selected by pre-evaluating the choices.

## ACKNOWLEDGMENTS

The author would like to thanks the School of Aerospace, USM for writing technical support and the Electrical Department of PTSB for the laboratory facilities.

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