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The Augmentation of a Flight Control Mechanism for a Hybrid Fixed-Wing VTOL Drone for Parcel Delivery

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Abstract: Several companies are experimenting with multicopters drones to deliver packages to customers. Although they are less aerodynamically efficient than fixed-wing aircraft, their ability to do the vertical take-off and landing (VTOL) makes them ideal for delivery services. In this study, two methodologies will be used to build the drone which is software simulation and experimental approach. Software such as SIMNET is used to simulate and design an electronic operation of the drone while Mission Planner is used to setup the flight controller. Electronics layout is done prior to ensure a clear sight of work, components and information through the software. The flight controller used is called Pixhawk which is an open hardware mainly used for drone. The radio control system is also setup to be used as the link to control the flight controller. Flight tests were also performed to study the behavior of the drone at various percentage of throttle. At 60 percent throttle, the drone yaws continously to the left at 63.43 degrees at 4.879 degrees per second during test flights. With a payload weight of 516g, it tilted to the front nose down, with support provided at the tip of the left wing. With more design and calibration advancements, experimental findings that are similar to theoretical outcomes might be attained. Flight data after each test flight is extracted from the software and analysed for further improvement. The fabrication of complete prototype could not be finished within the stipulated time due to a delay in acquiring new parts such as propeller due to a problem, as well as procuring the appropriate material for the wing. A test of the drone motions including roll, pitch, and yaw, is also carried out using flight charts to validate the suggested design parameter. The drone tends to fly better with the motor turning with the same orientation rather than turning with different orientation due to better stability. This flight chart allows users to choose the best design parameters by determining the length of the wingspan, motor RPM, and propeller diameter that are expected to meet the performance requirements in these three flying motions. The procedure for estimating the drone's battery usage has also been presented in the flight chart.

Keywords: UAV, VTOL, multicopter, fixed wing drone, Pixhawk

1. Introduction

Unmanned Aerial Vehicles (UAVs) or drone are aircraft that can be operated remotely via direct radio frequency communication or that are fitted with autonomous equipment to conduct mission flights on their own. Drones have seen a surge in popularity and availability in recent years [1]. They are popular in civil applications and fields like agricultural observation and aerial photography. Parcel distribution is another intriguing application. Vertical take-off and landing (VTOL) hybrid drone is planned for this purpose. The VTOL in hover flight is depicted in Fig. 1. The ability to switch from hover to forward flight is its key design function [2]. A transforming drone combines the manoeuvrability of a

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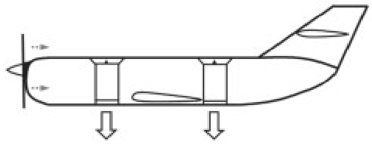
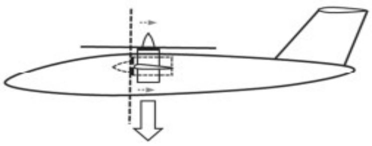
quadcopter with the efficient forward flight of a conventional aeroplane. A specific control strategy that requires no flying skills from the user is designed for intuitive manual control of VTOL.

Fig. 1 - VTOL in hover flight [1]

The best way to offer any aircraft VTOL capability is to fit lift motor to the airframe which is shown in Fig. 2. A lift engine is a vertically mounted jet engine that is highly optimized to produce a relatively large amount of thrust for the short duration of take-off and landing. Lift engines can also be equipped with a single high-power operating stage. Fig. 2(a) shows the aircraft use lift engines for hover only, and separate engines for cruise only [3].



(a)



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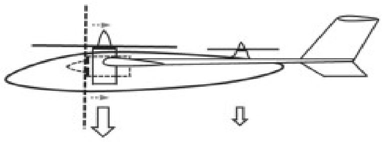


(c)

Fig. 2 - Method of VTOL for a) Lift + cruise; b) Lift = cruise; c) Lift + lift/cruise [2]

An aircraft can achieve VTOL capability when it uses the same propulsion system for both cruise and hover just in Fig. 2(b). This reduces the need for a secondary propulsion system, which will only increase dead weight to the flight during the cruise or loiter phase [4]. During forward flight, the powerful motor result in poor performance and high energy consumption. In Fig. 2(c), the cruise engine is use to support lift engine. The cruise engines are used for both forward and hovering operation, but they are replaced by a dedicated powered lift system. This minimizes the huge weight and volume rise for a dedicated propulsion system, while keeping the cruise propulsion system's performance loss within acceptable limits [5].

The motors of a tiltrotor are used for both vertical and horizontal flight. It has the ability to rotate its propellers, rotors, ducts, and nacelles in such a way that the thrust vector can sustain the aircraft's weight in vertical flight while still providing forward thrust in level flight. To avoid losing control, a system that synchronizes the movement is required.

Due to the wings located below the rotors impinging wake induce a download to lower the net lift, the rotors are placed near the wing tips to reduce exposure [6]. Conventional take-off is usually impossible for propeller driven aircraft, because the size of the rotors prevents a forward tilt on the ground [7]. Tiltrotors provide the advantages of lower weight and increased aerodynamic efficiency. Due to the wings located below the rotors, hovering allows for low-speed flight. Conventional take-off is typically difficult for propeller-driven aircraft. This, like the hover download, may be avoided by using a jet propulsion system.

Tricopters, as illustrated in Fig. 3, are among the commercially available multirotor drones. Running three propellers requires less electricity. The tricopter has the benefit of having three rotors, which provides a broader field of view for a body-mounted camera than other multirotor platforms [8]. Tricopters have one less electrical speed controller and motor to fail, making them potentially more reliable. A tricopter has better yaw authority since it tilts the propeller rather than varying motor torque. The torque of the motors cannot be totally cancelled due to the uneven number of motors. To control yaw, at least one (occasionally two) of the three rotors is operated to pivot and generate torque. The actuation forces are non-trivial due to gyroscopic forces generated by the fast-spinning motors [9].

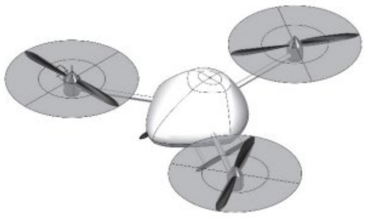


Fig. 3 - Tricopter

2. Methodology

2.1 Mission Planner Software

The program updates Pixhawk with the right firmware for the specific configuration of the vehicle type. This program is also used to fine-tune the PID control gains in order to ensure the best possible stability. The software setup is the first step on which the user must choose the frame class of the drone. In this study, Arduplane V3.3.0 (Fig. 4) was chosen as the firmware since the objective was building a fixed-wing drone.

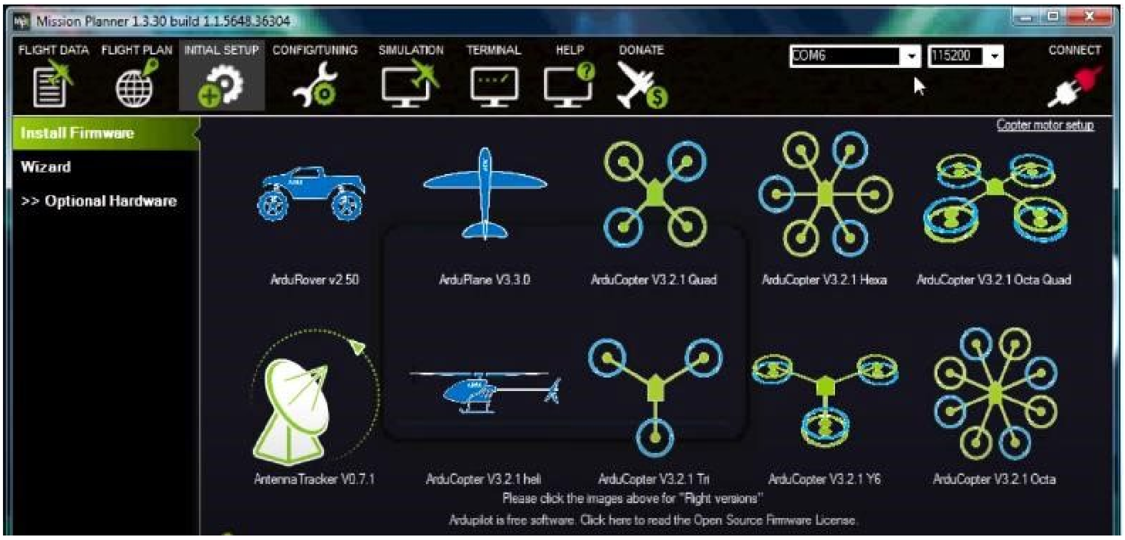


Fig. 4 - Frimware taskbar

Initial setup includes the mandatory hardware and optional hardware. The user will see a flashing light on the Pixhawk which indicating that the GPS is attempting to obtain its first GPS lock. The first time GPS is turned on, it can take up to 15 minutes to get its first lock. The accelerometer calibration is a setting that gives input regarding the accelerometer and to teach the board what level feels like.

The next step is to calibrate the magnetometers. All the compass includes two magnetometers within the Pixhawk which is good because it means it's using both of them to establish it's heading and that gives much better GPS performance because it provides orientation as well as position information. The same things go for this setting as the accelerometer, the Pixhawk is moved to all sorts of position to give the Pixhawk an accurate reading of the environment.

For radio calibration, the receiver of the radio control system should pick up the signal from the radio system. Fig. 5 shows an example of the calibration. Once connect the receiver and the software, the screen will show all of the readings of the controller that needs to be calibrated. Radio calibration is conducted by moving all the gimbal of the controller in all direction and toggle all switch in order for the software to receive the input.

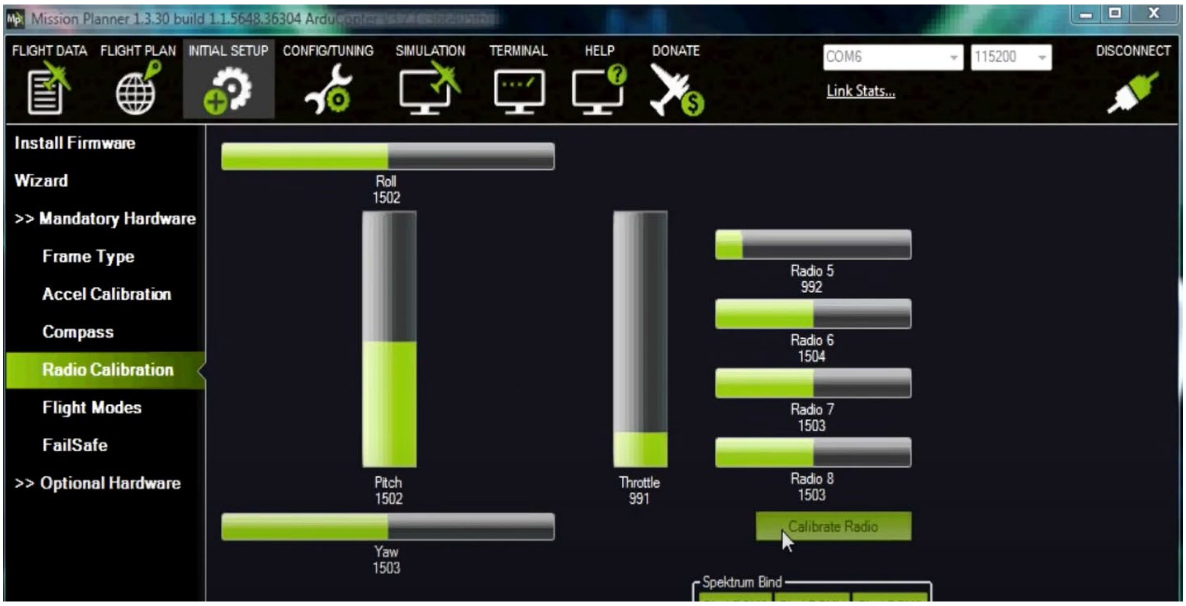


Fig. 5 - Radio Calibration

Calibrating the flight modes is the final step of the mandatory hardware. In this setting, there are modes to support different levels/types of flight stabilization and a sophisticated autopilot. Flight modes are controlled through the radio using a transmitter switch, mission commands, or using commands from a ground control station (GCS) or companion computer. Table 1 shows the flight mode that is used in the control system. Table 2 shows the servo output function that is assigned in the flight controller that is used to be recognised by the radio control system.

Table 1 - Flight mode

Flight Modes	Summary
Stabilize	Self-levels the roll and pitch axis
Alt Hold	Holds altitude and self-levels the roll & pitch
Loiter	Holds altitude and position, uses GPS for movements
RTL (Return to Launch)	Returns above take-off location, may also include landing
Auto	Execute pre-defined missions

Table 2 - Servo output assign

Name	Function	Min Output	Trim	Max Output
Aileron	RCIN4	1200	1500	1900
Rudder	RCIN2	1200	1500	1900
Throttle	RCIN3	1200	1500	1900
Elevator	RCIN1	1200	1500	1900
Tilt Servo	RCIN6	1200	1500	1900

2.2 Electronics Layout and Operation

The wiring design for the electric section of the VTOL drone is shown in Fig. 6. The RC Receiver is to receive radio signals from the drone remote controller (Fig. 7). The Telemetry unit is for the drones to provide its position and health information. The GPS unit is to set the drone's location relative to a network of orbiting satellites. The Power Module will provide a regulated power supply from the battery to the flight controller, along with the information on battery voltage and current. The Pixhawk Flight Controller unit is used to calculate the desired speed for each motor and to determine the state needed for stabilization and autonomous control. A power distribution board is to distribute the power to all different components of the drone. There are three motors for this drone. Each motor has their own ESC

(Electronic Speed Controller). ESC allow the drone flight controllers (Pixhawk) to control and adjust the speed of the electric motor based on the signal received from the user's RC. Lastly, the servo motors are to deflect the main control surfaces, i.e. Aileron, Elevetor and Rudder, and managing the tilting mechanism of the tilt motors and parcel attachment system.

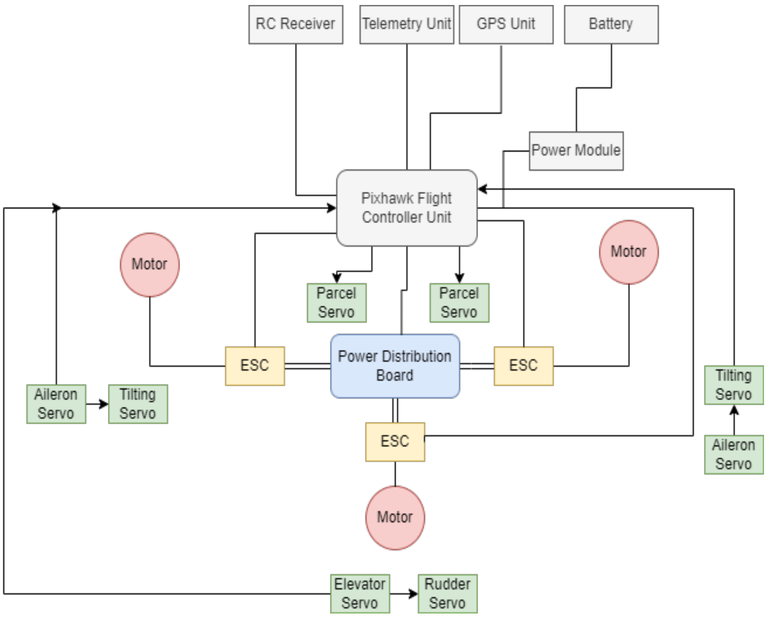


Fig. 6 - Wiring diagram

2.3 Radio Control System Setup

The radio control system that is used in this project is Futaba T6ex. Fig. 7 shows the image of the radio controller. Every controller has their own receiver. The receiver on a drone is an electrical system that detects radio transmissions from the drone controller using built-in antenna.

Fig. 7 - Futaba T6ex

The first step in setting up the controller is by binding the receiver with the controller. Setting up the controller is as follows: Model name, channel assignment and failsafe design options. Model names can include up to 20 characters, including spaces, and can be chosen by the user. Table 3 shows the channel that has been setup for the project. Since the radio controller has only six channel, each channel is assigned as table 3.

Table 3 - Channels assigned

Channels	Function
1	Aileron
2	Rudder
3	Throttle
4	Elevator
5	Flight Mode
6	Tilt Servo

2.4 SIMNET

SIMNET is a web-based research and simulation platform for next-generation drone development (Fig. 8). It can analyses multiple aspects of the drone design such as aerodynamics, mass and balance, stability characteristic, and flight performance in real time. The design is begun by designing the main body followed by tail, wing and payload. Information such as chord, span and sweep are taken under considered when designing the aifoil. By using Fig. 9 as the reference, the design is started by the main body followed by tail, wing and payload. Inserting necessary component such as servo, Electronic Speed Controller (ESC), motors and other components as illustrated in Fig. 6. For the tilting mechanism, a rod which act as the tilting of the motor, is inserted in the designated software. The shape of the plane is then compared to the planned design using the actual diameter from the model itself. For the airfoil, National Advisory Committee for Aeronautics (NACA) 2412 airfoil for the root and S7055 airfoil for the tip is used as the reference when designing the airfoil.

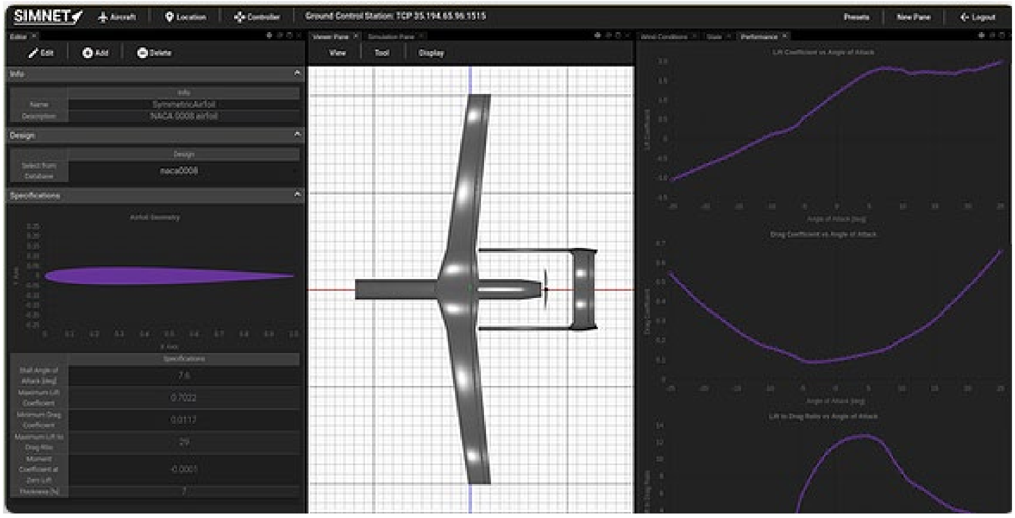


Fig. 8 - SIMNET's graphic user interface

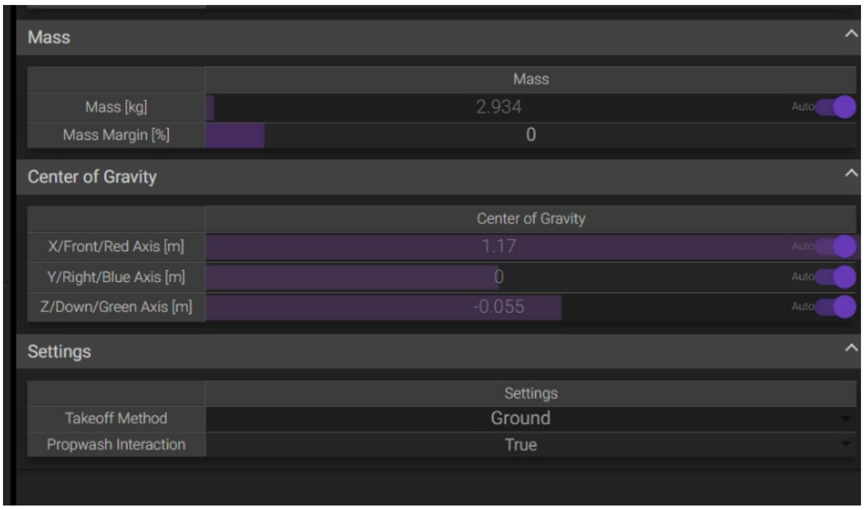


Fig. 9 - Mass and centre of gravity setting of the VTOL drone

3. Results And Discussions

3.1 Design Paramter

The body of the airframe is made from foam. The main motor is equipped with the tilting mechanism as shown in Fig. 10. The tilting mechanism is use to change the flight mode from hover to cruise and vice versa. The wing is supported by a rod made from carbon fibre. The body is attached using hot glue gun to strengthen the structure due to high vibration when hover. As shown in Fig. 9, the total weight with all the components excluding the payload adds up to a total of 2.934kg. Based on the software calculation and the weight of the aircraft, the centre of gravity is located at the parcel delivery box which is 1.17m from the tail.

Fig. 10 - Final design for flight test

3.2 Components Layout

The end design once installed with the component is shown in Fig. 11. Locations where all major components are installed are labelled by alphabet A-F and the detail of the components are listed in Table 4. Meanwhile, the wiring of each component can be referred to the Fig. 6.

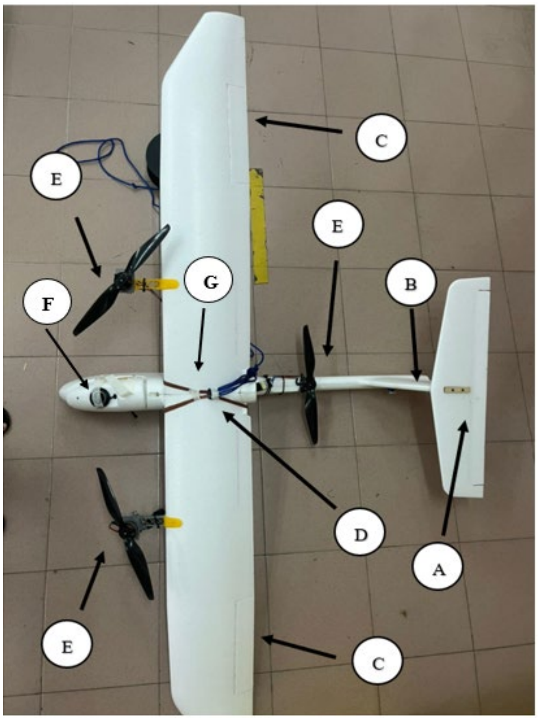


Fig. 11 - Hybrid VTOL drone and the location of its major component

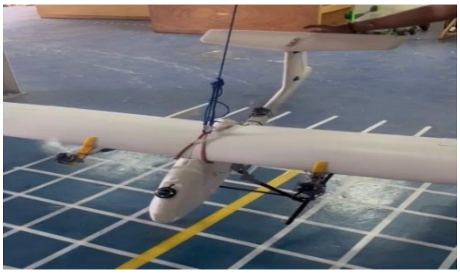
Table 4 - Drone's major components

Location	Component Image	Component Name	Location	Component Image	Component Name
A		Micro Servo	E		Tarot 650kv Motor
B		Micro Servo	E		Tilting Servo
C		Micro Servo	E		Propeller 1455
D		Pixhawk	F		GPS Module
D		Lipo Battery	G		Futaba Receiver
D		ESC 30A	G		Power Module
D		Power Board			

3.3 Tethered Flight Test

When the drone tries to hover in manual flight mode, it is detected that all 3 three motor spins at the different rotation per minute (RPM) which uses the KV of 650KV. KV is used to describe the rotation per minute (RPM) of a motor does per volt that is put into the motor. This drone uses a total of three motor.

Table 5 - Throttle capacity

Throttle Percentage	Image	Behaviour
20%		No movement of the drone. The drone starts to vibrate. The drone is still on the ground.
40%		The tail starts to lift. The vibration is stronger. The wing shows movement.
60%		The tail of the drone is lifted and the vibration is quite strong causing it to move slightly. The drone showing small movement to the left.
80%		The drone starts to roll to the left by 40˚ despite having support by rolling the aileron to the right. The whole drone is lifted along with the parcel with no payload. The drone starts to move forward.
100%		The drone starts to roll hard left despite moving the aileron to roll 63˚ to the left. The tail is lifted quite high causing the drone to move forward with the tail lifted higher than the body of the drone.

When the drone is lifted, the drone tends to roll 10-20 degrees to the left wing. Even by countering the motion of the drone by rolling the aileron to the right, it does not seem to counter react to the radio control system due to the high torque that is given by the two main motor. To test whether the drone needed some tuning or correction due to its structure, the test flight was done again in a backward position which is the opposite method from the first test flight. A recalibration on the accelerometer and on the Electronic Speed Controller (ESC) was needed to be done on the software.

Theoretically, the drone starts to roll hard right because of the imbalance thrust cause by the motor. This is due to the orientation of the propeller which has two going counter clockwise and one clock wise. Besides that, the rolling is caused by other factor as well which is the speed of the motor. The power of the back motor has to increase twice the amount of the thrust of the rear motor in order to counter the motion created by the rear motor which need to be decrease by half of the current RPM. The setup of the calibration is changed in the parameter setting just as the solution mentioned.

3.4 Power Output

3.4.1 Battery Consumption

The flight test results are presented in Table 6 for reference purposes in terms of power usage. Theoratically, when the throttle is increased, the power consumption will increase as well. Therefore, the graph is linearly increasing with respect to the throttle.

Table 6 - Drone power output

Throttle (%)	PWM Output	Rotation Speed (RPM)
100	2993	10660
80	2548	8880
60	2103	7100
40	1350	5330
20	720	3992

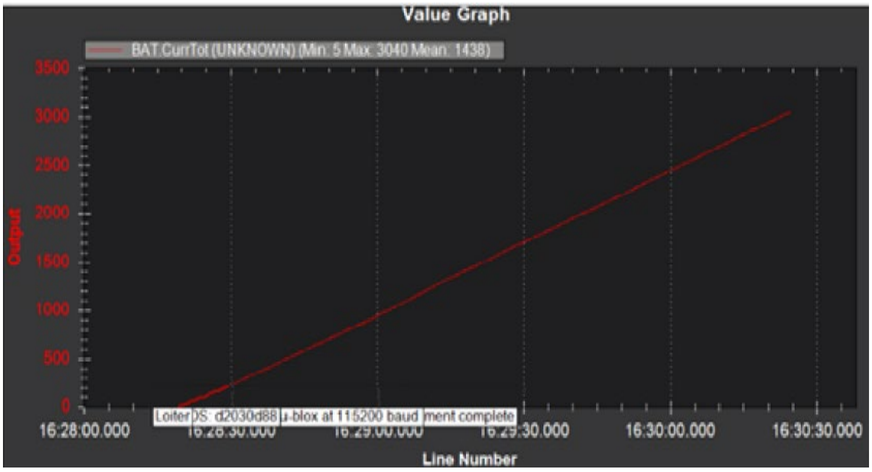


Fig. 18 - Battery consumption

3.4.2 PWM Value to Throttle Percentage

After the flight test, the PWM data is converted to the RC throttle percentage which is listed in Table 7 and it is aligned with the output setting as in Table 2.

Table 7 - PWM output

PWM Output	Throttle Percentage (%)
1883	100
1790	80
1640	60
1462	40
1302	20

4. Conclusions

An overview of VTOL development was presented, with a focus on fixed-wing vehicles. A test of the drone motions including roll, pitch, and yaw, is also carried out using flight charts to validate the suggested design parameter. The graph of the motion which the motor has the same orientation is more stable when giving input to the flight controller. Due to that reason, the drone tends to fly better with the motor turning with the same orientation rather than turning with different orientation due to better stability.

The assembly of the fixed-wing VTOL drone is currently ongoing. Some components of the drone's design, as well as its creation, are currently under development. Due to a shortage of facilities, resources, and equipment, deploying the prototype to completely meet the given objectives is problematic. The VTOL is not only a mechanical system that needs mechanical expertise but also necessarily involves electronic and radio frequency (RF) transmission capabilities.

Certification and validation by authorized agencies such as Civil Aviation Authority Malaysia (CAAM) and Standard and Industrial Research Institute of Malaysia (SIRIM) are required. System upgrade was followed for the design of this particular drone to make a drone that produce more efficiency than the current commercial drone. Composite material may be employed in the fabrication process for an effective and cost-effective design of a low weight material for drones such as carbon fibre.

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