Simultaneous Execution of Quad and Plane Flight Modes For Efficient Take-Off of Quad-Plane Unmanned Aerial Vehicles

Preprint · June 2021

DOI: 10.13140/RG.2.2.16676.19848

2 authors:

Janith Kalpa Gunarathna
University of Moratuwa

R. Munasinghe
University of Moratuwa

applied sciences

MDPI

Article

Simultaneous Execution of Quad and Plane Flight Modes For Efficient Take-Off of Quad-Plane Unmanned Aerial Vehicles

A. A. J. K. Gunarathna [1] and S. R. Munasinghe [2,]

[1] UAV Research Laboratory, Department of Electronic and Telecommunication Engineering, University of Moratuwa, Moratuwa 10400, Sri Lanka; janith2010class@gmail.com

[2] Department of Electronic and Telecommunication Engineering, University of Moratuwa, Moratuwa 10400, Sri Lanka, rohan@uom.lk

Abstract: This paper addresses the problem of high energy consumption in the standard take-off mode of quad-plane unmanned aerial vehicles (UAV). In the standard mode, the quad-plane takes-off vertically using the quad mode, and when the predefined altitude is reached the plane mode kicks in. However, the "bird" mode, where both quad and plane modes kick in together, the UAV could achieve altitude and airspeed while consuming lower energy. This paper presents the energy consumption and comparison in standard and bird take-off modes with actual experimental results obtained through flight tests of a small 1.35 kg quad-plane. The experiments showed that as much as 22% energy can be saved if the bird take-off mode is used.

Keywords: quad-plane; flight dynamics; unmanned aerial vehicle; cruise flight control; vertical take-off and landing (VTOL); quad-plane UAV

Citation: Gunarathna A.A.J.K.; Munasinghe S.R. Simultaneous Execution of Quad and Plane Flight Modes For Efficient Take-Off of Quad-Plane Unmanned Aerial Vehicles. *Appl. Sci.* **2021**, *1*, 0. https://doi.org/

Academic Editor: Silvio Cocuzza

Received: 27 February 2021
Accepted: 28 March 2021
Published:

1. Introduction

There are two main types of UAVs - Fixed-wing and Rotor-wing. These two types have inherent advantages and disadvantages. The Fixed-wing type is energy efficient, possesses a longer endurance, however, it requires a large open space to take-off and land. Rotor-wing type, on the other hand can takeoff and land vertically, hence, there is no need of a large open space to operate. But, because they are energy inefficient, the endurance is shorter. The newest type called VToL (vertical take off and landing) is a combination of the mentioned two types so that it takes-off and land vertically like a copter while flying long distances like a plane. Tail sitter [1], Tilt rotor [2], Tilt jet, Tilt wing and Vector thrust [3] are some popular VTOLers. The most common and widely used VTOL UAV type is the quad-plane, for which this paper presents an energy efficient take-off mode named bird take off. Small Quad-plane UAVs consume around 10% energy during take-off which lasts 10–15s and also about 15% energy for landing which lasts about 15–20s. In this research, both Quad and plane modes are simulated and tested separately and integrated together to develop the quad-plane UAV. In the proposed bird take-off, both quad and plane modes are executed simultaneously in order to gain altitude and airspeed at the same time, while reducing time and energy for take-off. It has been experimentally found that having both flight modes can reduce the take-off energy consumption by 22% in the take-off

2. Modelling Flight Dynamics

This section presenting the flight modes of Fixed-wig and rotory-wing UAVs. The two flight modes are decoupled and tuned for best performance. Coupling effects between the two flight modes are considered disturbances that are to be rejected by way of feedback. Two flight modes have been developed separately in Matlab and then combined to form the quad-plane.

2.1. Quadrotor Flight Dynamics

The Quadrotor flight mode has four control inputs—throttle, roll, pitch and yaw. The throttle input is used to climb or descend. The roll input tilts the UAV to make it move side ways. Pitch input tilts the UAV up or down and makes it move forward or backward. Yaw input rotate the UAV around its axis [4]. In order to preform these four motions using throttle, roll, pitch, and yaw commands, the propeller speeds are adjusted as shown in Figure 1 [5].

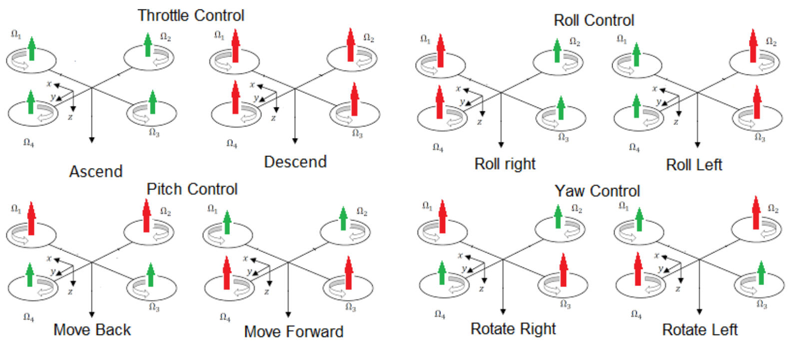

Figure 1. Propeller speeds in throttle, roll, pitch and yaw control. Higher speed is represented by long upward arrow.

Let's assume that the quad-rotor achieves the state of stable hovering when all four motors generate equal PWM (pulse width modulation) value H_{PWM}. Then if a small command is issued in throttle, roll, pitch and yaw $[\Delta T \ \Delta R \ \Delta P \ \Delta Y]$ the motors get their PWM $M_{iPWM}; i = 1,2,3,4$ adjusted according to (1).

$$\begin{bmatrix} M_{1PWM} \\ M_{2PWM} \\ M_{3PWM} \\ M_{4PWM} \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & -1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & 1 & -1 \\ 1 & 1 & -1 & 1 \end{bmatrix} \begin{bmatrix} \Delta T \\ \Delta R \\ \Delta P \\ \Delta Y \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} H_{PWM} \tag{1}$$

An experimental method is followed to map the relationship between the PWM signal and thrust generated by the motor and propeller system. The result is illustrated in Figure 2 revealed a linear relationship between the thrust and PWM signal of the motor.

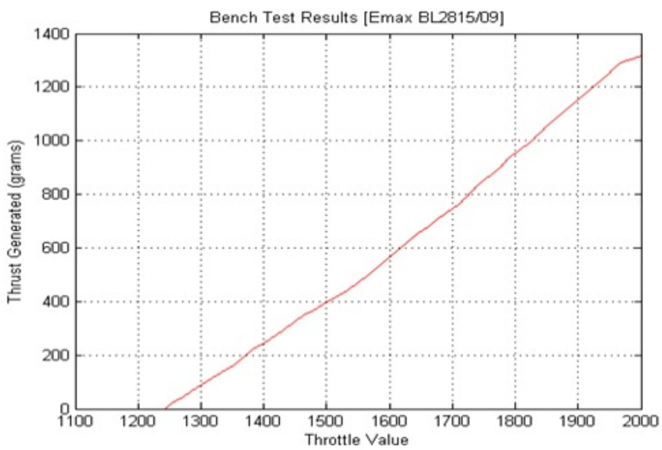

Figure 2. Thrust and PWM signal of the quad motors (2815/09, 1245 propeller 3S battery).

$$F_i = \frac{1.3(M_{iPWM} - 1250)}{725}; i = 1,2,3,4 \tag{2}$$

The four thrust components of the four motors will combine together to form the upward force U_1, rolling moment U_2, pitch momentum U_3, and yaw momentum U_4 on the quad-rotor as follows [6] where B and l stands for yaw moment constant and length of a Quad rotor arm respectively.

$$\begin{bmatrix} U1 \\ U2 \\ U3 \\ U4 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ -l & l & -l & l \\ -l & -l & l & l \\ -B & B & -B & B \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix} \tag{3}$$

According to the forces and moment, the angular and linear accelerations can be calculated as follows, where pitch, roll and yaw angles are denoted by θ, ϕ and ψ. While the angular velocities around the x-axis, y-axis and z-axis are represented by p, q and r, respectively.

$$\ddot{X} = (sin(\psi)sin(\phi) + cos(\psi)sin(\theta)cos(\phi))\frac{U1}{m} \tag{4}$$

$$\ddot{Y} = (-cos(\psi)sin(\phi) + sin(\psi)sin(\theta)cos(\phi))\frac{U1}{m} \tag{5}$$

$$\ddot{Z} = -g + (cos(\theta)cos(\phi))\frac{U1}{m} \tag{6}$$

$$\dot{p} = \frac{Iyy - Ixx}{Ixx}qr - \frac{Jtp}{Ixx}q\Omega + \frac{U2}{Ixx} \tag{7}$$

$$\dot{q} = \frac{Izz - Ixx}{Iyy}pr - \frac{Jtp}{Iyy}p\Omega + \frac{U3}{Iyy} \tag{8}$$

$$\dot{r} = \frac{Ixx - Iyy}{Izz}pq + \frac{U4}{Izz} \tag{9}$$

Angular accelerations can be simplified as follows because the UAV frame is symmetric along the x axis and y axis.

$$\begin{aligned} \dot{p} &= \tfrac{U2}{Ixx} \\ \dot{q} &= \tfrac{U3}{Iyy} \\ \dot{r} &= \tfrac{U4}{Izz} \end{aligned} \tag{10}$$

2.2. Quad Mode Simulation

The dynamic model of the rotor-wing UAV which is shown in Figure 3 was developed in MatLab simulink. The roll pitch throttle and yaw commands are given as controlled step inputs. Then signals are fed to the motion resolver to calculate the individual motor signals (1). Then the signals are fed to the motor model to calculate the thrust produced by each individual motor according to Equation (2). A saturation block is added to bound the motor thrust between 0 and its maximum value. Then the motor system calculated the forces and torque effect on the UAV frame according to the motor thrust (Equation (3)). Then these forces and torques are sent to the dynamic model block which calculates the linear accelerations and roll, pitch and yaw angles according to Equations (4) to (10), and an angle-based PID controller [6] has been used as a model for stabilization. The model was tested for step inputs in roll, pitch and yaw.

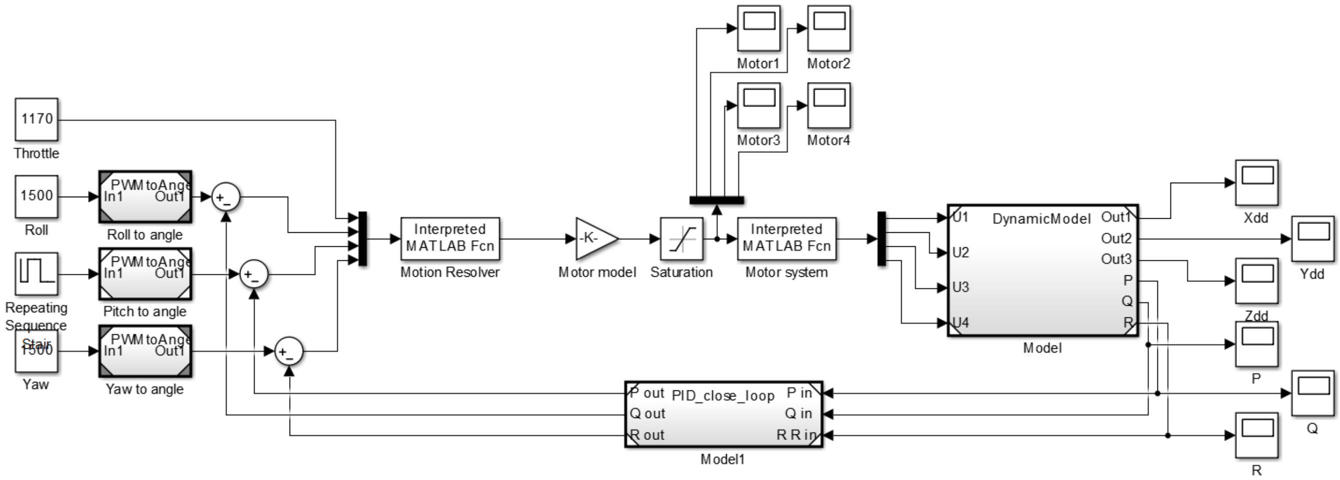

Figure 3. Matlab simulink model of the dynamic model of the Quadrotor UAV with angle feedback.

The quad-rotor was simulated for step response and verified the model accuracy. Step inputs in roll, pitch, and yaw were given one at a time. The results obtained are shown in Figure 4. A PID controller was introduced to stabilize the quad-rotor. Simulation results obtained for m = 1.35 kg and l = 0.5 m were compared with the actual test result to estimate the coefficients C_l = 0.186, C_d = 0.08, for measured inertia I_{xx} = 0.08, I_{yy} = 0.05, and I_{zz} = 0.12 [7].

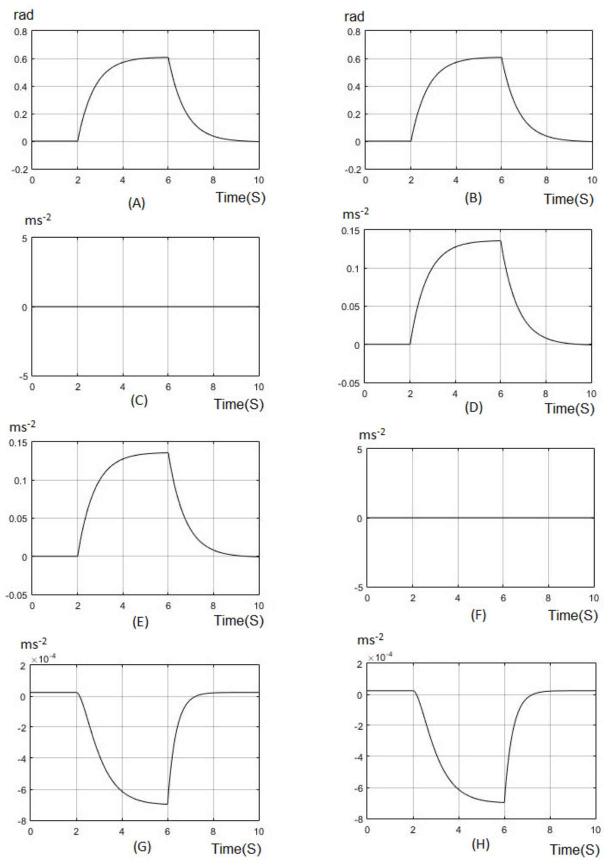

Figure 4. Step response of the quad-rotor for roll (**A**,**C**,**E**,**G**) and pitch (**B**,**D**,**F**,**H**) step inputs. (**A**) Roll angle (**B**) Pitch angle (**C**) and (**D**) Linear acceleration along X-axis (**D**) and (**E**) Linear acceleration along y-axis, (**F**) and (**G**) Linear acceleration along Z-axis.

2.3. Fixed-Wing Dynamics

The fixed-wing flight mode has four control inputs name as throttle, roll, pitch and yaw. As the UAV gains forward speed, the wing generates lift. The lift is given by,

$$F = \frac{C_l A \rho V^2}{2} \tag{11}$$

where C_l is the lift coefficient, V is relative air speed and ρ is the air density [8,9]. The other inputs, roll, pitch and yaw are connected to the aileron, elevator and rudder control surfaces. Placements of the aileron, elevator and rudder on the UAV are shown in the Figure 5. The force generated $F_c; c = A, E, R; A - aileron, E - elevator, R - rudder$ due to a deflection of these control surfaces depend on the relative airspeed, surface area of the control surface, and deflection angle.

$$F_c = \frac{A \rho V^2 \sin \delta_c}{2} \tag{12}$$

Such deflections also create a drag force $Fd_c; c = A, E, R; A - aileron, E - elevator, R - rudder$ given by

$$Fd_c = \frac{A \rho V^2 \cos \delta_c}{2} \tag{13}$$

where A and δ_c are the surface area of the control surface and the deflection angle respectively. The torque force resulting in the deflection of the control surface can be calculated as follows.

$$M_x = 2F_A l_x \tag{14}$$

$$M_y = F_E l_y \tag{15}$$

$$M_z = F_R l_z \tag{16}$$

where l_x, l_y and l_z are the distances from the mid-point of the aileron, elevator and rudder to the center of gravity. Due to these forces and torques, the UAV undergoes linear and angular accelerations as follows, [10]:

$$\dot{p} = \frac{M_x}{I_x x} + \frac{Iyy - Izz}{Ixx} qr \tag{17}$$

$$\dot{q} = \frac{M_y}{Iyy} + \frac{Izz - Ixx}{Iyy} pr \tag{18}$$

$$\dot{r} = \frac{M_z}{Izz} + \frac{Ixx - Iyy}{Izz} qp \tag{19}$$

$$\ddot{x} = \frac{F_p - F_d - Fd_A - Fd_E - Fd_R - mg \sin \theta}{m} \tag{20}$$

$$\ddot{y} = \frac{F_y + mg \sin \psi \cos \theta}{m} \tag{21}$$

$$\ddot{z} = \frac{F_z - mg \cos \psi \cos \theta}{m} \tag{22}$$

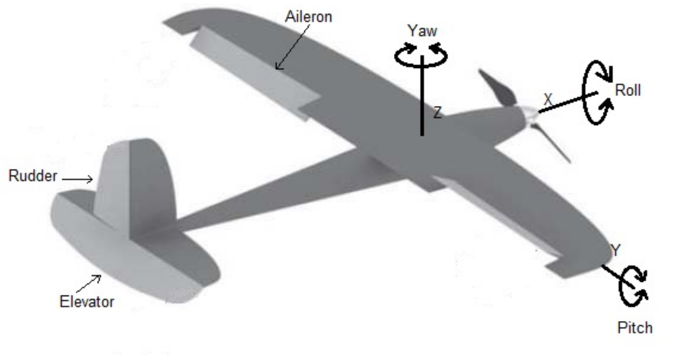

Figure 5. Control surfaces and angular motions of a typical fixed-wing UAV.

Where F_p is forward thrust and F_d is the aerodynamic drag force generated by the body of the UAV. F_y and F_z are the forces along y and z axes. The drag force [11] is as follows.

$$F_d = C_d \frac{\rho}{2} S v^2 \tag{23}$$

2.4. Fixed-Wing Mode Simulation

The Matlab Simulink dynamic model of the Fixed-wing UAV is shown in Figure 6. The model has 5 control blocks. The Radio controller block gives the roll, pitch and yaw control to the control surface model. The control surface model calculates the torque forces along x, y, z axis and the drag force generated due to the deflection of the control surface. The calculated torque forces are input to the dynamic model and the drag forces are input to the forward force model. The forward force model takes the throttle input and the aerodynamic drag forces to calculate total forward force. The calculated forward force is then input to the dynamic model of the fixed-wing UAV. The Dynamic model calculates the angular and linear accelerations along x, y and z axis, altitude and forward speed. Forward speed is then input to the Air frame model to calculate the aerodynamic lift and drag then input to the Dynamic model and forward force models [4] A PID loop is added to the model to stabilize the roll, pitch and yaw angles.

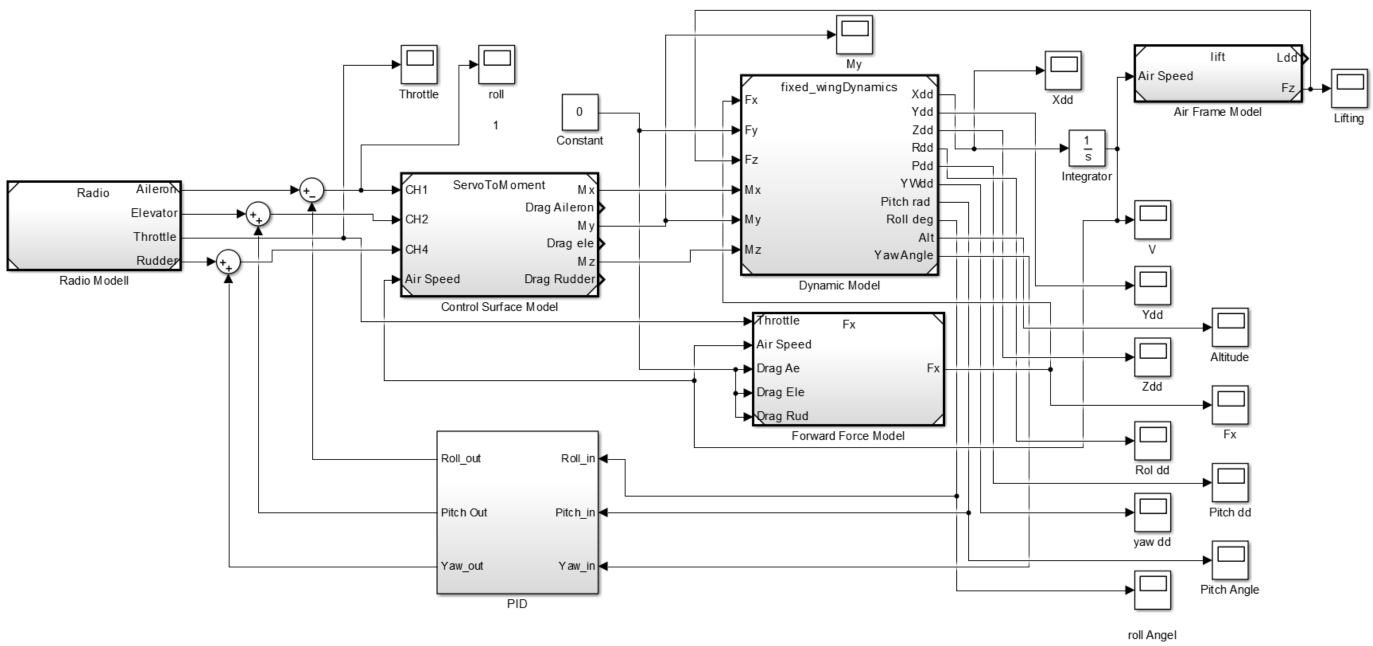

Figure 6. Dynamic model of the Fixed-wing UAV (Matlab simulink).

Nearly full throttle of 1900 PWM was given to the UAV initially. After a while, throttle was reduced to 1500 PWM, and then a roll input of 1600 PWM was given. The simulation results are shown in the Figure 7.

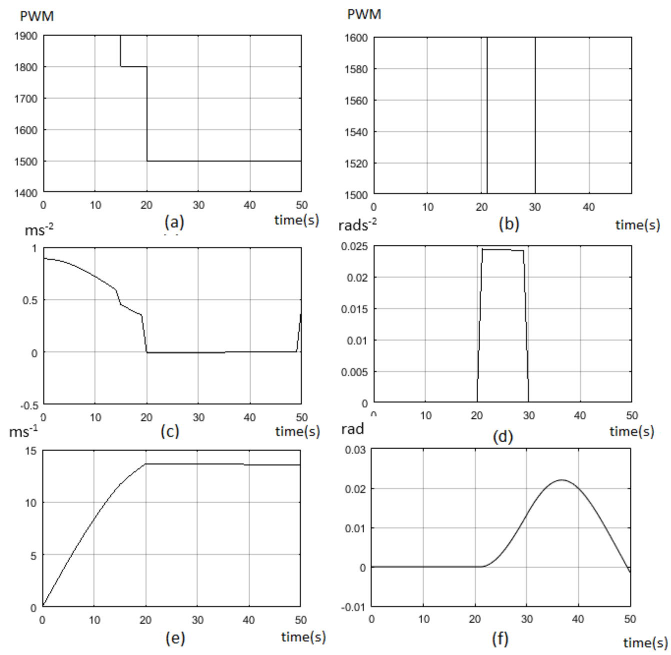

Figure 7. Simulation result of the Fixed-wing UAV for the throttle and roll inputs. (**a**) Throttle control input (**b**) Roll control input (**c**) Linear acceleration along x-axis (**d**) angular acceleration in roll axis (**e**) forward velocity (**f**) Roll angle.

3. Quad Plane UAV

In this section we are introducing the method of development and the Simulation of the Quad plane.

3.1. Quad-Plane UAV Frame

In this research, the quad-plane UAV shown in Figure 8 was built using the sky-skout fixed-wing frame and attaching a custom-designed quad-rotor frame. The UAV has a 1.2 m wingspan and weighs 1.35 Kg. The quad-rotor frame has four 2212/1400 KV motors coupled to 8045 propellers. The quad-rotor motors are controlled by 20A Electronic Speed Controllers (ESC). For the pusher, a 2212/2450 Kv motor driven by a 40 A ESC and coupled to 6060 propellers was used. A Pixhawk 2.4.8 was selected as the flight controller.A necessary sensor system comprising a GPS module, a compass, and an air-speed sensor were used. In addition, a properly calibrated current and voltage sensor was used to monitor and log power consumption data of the UAV. The UAV was powered by a 3 cell 2200 mAh LiPo battery.

Figure 8. Quad-Plane UAV.

3.2. Development of Simulation of Quad Plane UAV

When combining both flight modes together in one single frame, the forces and moment generated by both flight modes are combined together to input them in to the dynamic model of the UAV.

The intermediate block is called transition controller. It is added to the combined system to control the throttle of both flight modes to archive the forward and backward flight transition, (Figure 12).

3.3. Standard Vertical Take-Off Mode

In the vertical takeoff mode the UAV first turns to the quad mode and takes off vertically to the desired altitude. Then it starts the pusher-motor to move forward while the quad-motors are still assisting to maintain level until cruise speed is reached. When cruise speed is reached, the quad-motors slow down and stop in 5s, and the UAV flies in plane mode thereafter. This transition is shown in, Figure 11.

3.4. Bird Takeoff Mode

In this flight mode, the UAV imitates how a bird takes-off from the ground gaining both height and distance simultaneously. Birds push their body at an angle using their legs and then flap their wings to generate both horizontal and vertical forces simultaneously so that the distance and altitude are both gained simultaneously. A UAV can imitate bird take-off mode by turning on both quad (to gain height) and plane (to gain distance) modes simultaneously. Figure 10 shows the descriptive way of the bird takeoff algorithm.

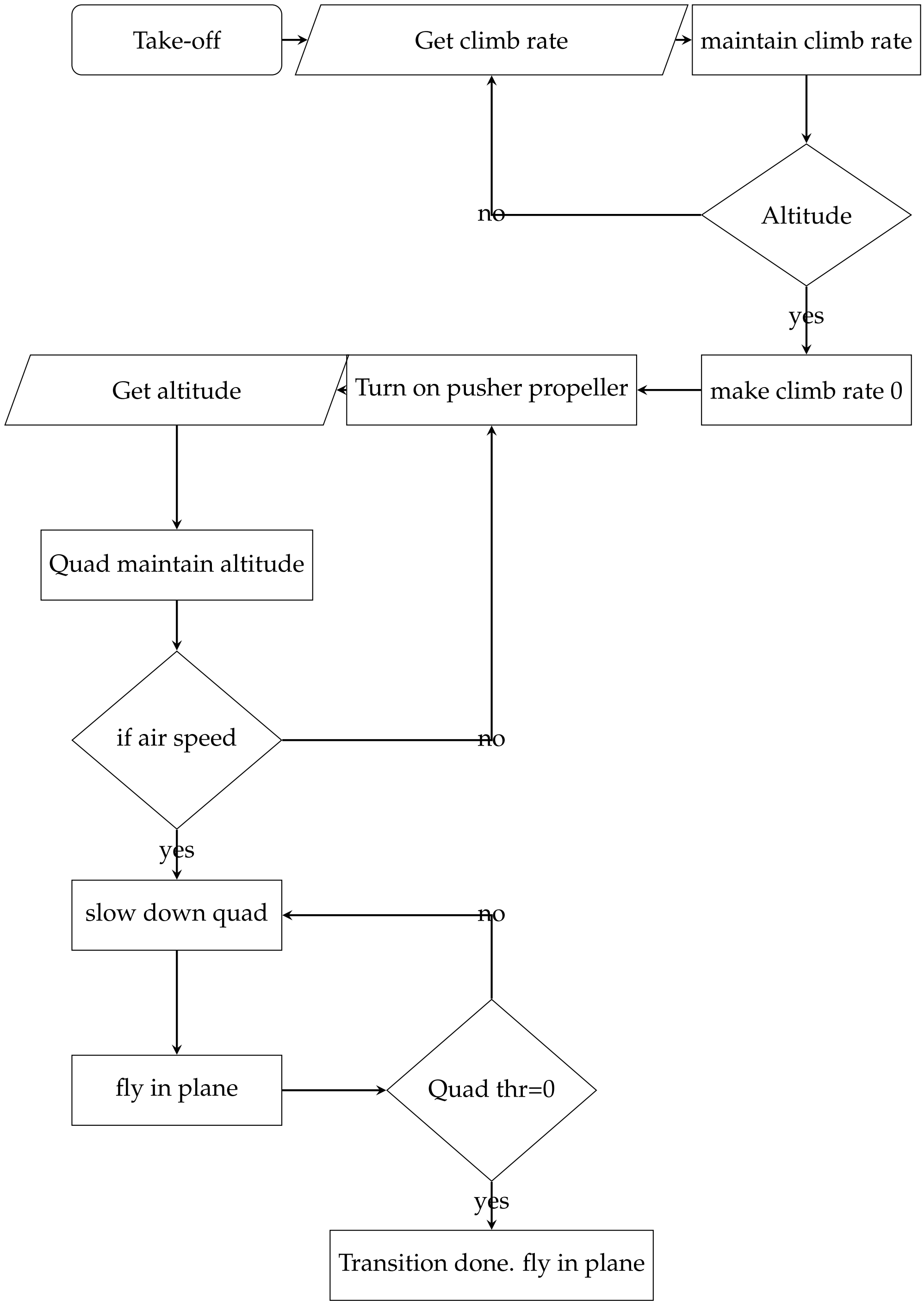

Figure 9. Algorithm of the Traditional takeoff.

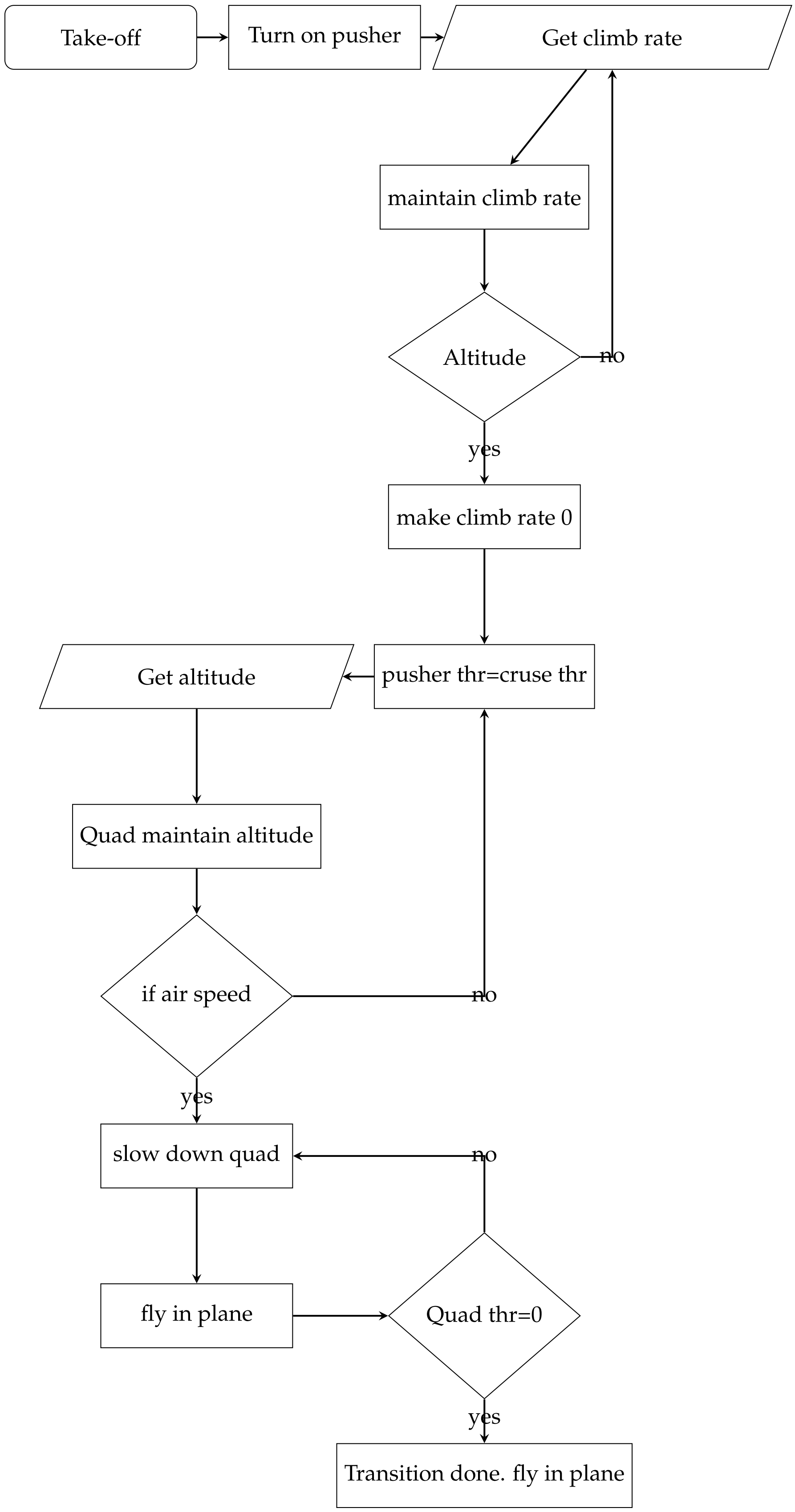

Figure 10. Algorithm of the Bird takeoff.

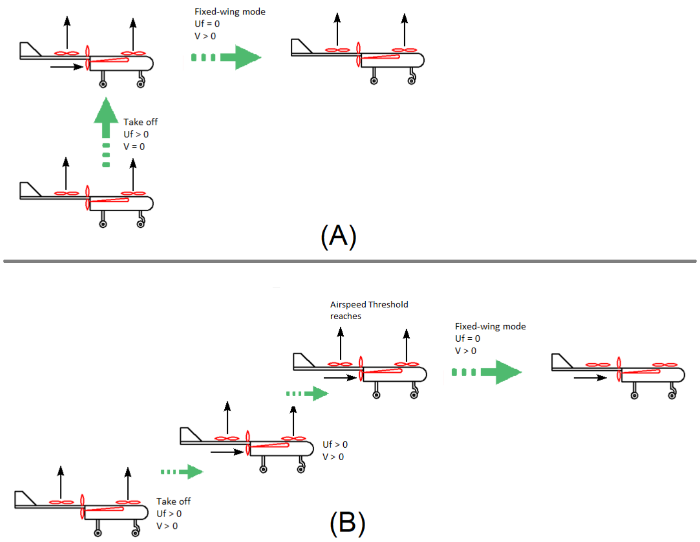

Figure 11. Comparison between traditional Vtol takeoff and bird takeoff, (**A**) Traditional takeoff, (**B**) Bird Takeoff.

The Quad plane dynamic model is used for simulate the both takeoff flight modes. The Transition controller is programmed for achieve the both takeoff mode in the same dynamic model.

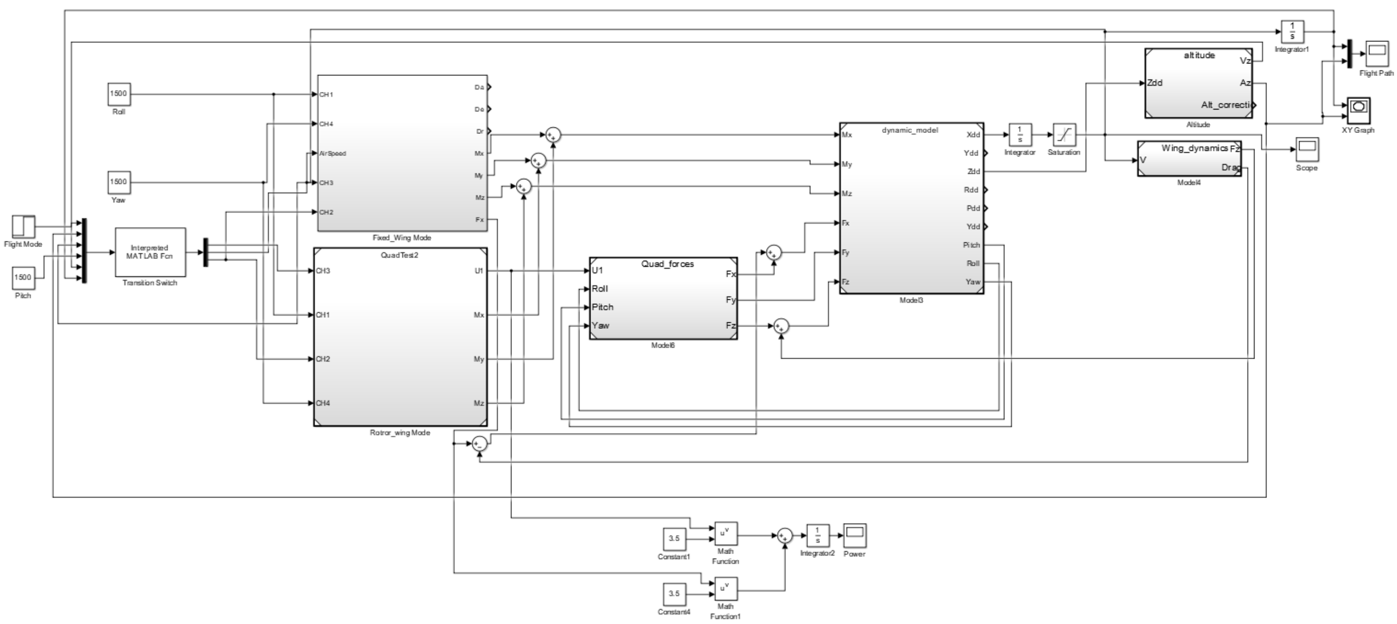

Figure 12. Quad-Plane dynamic Model.

3.5. Takeoff Energy Calculation

Simulation is run for both flight modes to climb to 15 m altitude in VTOL mode and fly horizontally by maintaining the 15 m altitude. Energy consumption was calculated up to the end of the take-off transition, where the quad plane shuts down completely. The motor power consumption was found through a bench test, and added to the simulation with respect to the input signal.

Up to the transition complete, the traditional takeoff method consumes 6483 J of energy and the bird takeoff consumes 4990 J of energy. The bird takeoff saves 1493 J of energy. According to the simulation, results bird take off can save up to 23% of the energy a standard Quad-plane UAV needs in taking off.

Energy consumption comparison between the traditional and bird takeoff method can be found in Table 1.

Table 1. Simulation of energy comparison between standard VTOL and bird take-off methods.

Takeoff Method	Energy Consumption (J)
Slandered VTOL Takeoff	6483
Bird Takeoff	4990
Saving	1493

4. Quad Plane Experimental Flight Tests

A fully autonomous mission of 840 m length at 15m height through four waypoints was preformed in both take-off modes. Both flight tests were carried out with a fully charged 3S 2200 mAh LiPo battery. Both flight tests were carried out back-to-back in the morning on the same day. The time between the two flights was only 20 min for changing the battery and to perform pre-flight tests. During the period of flight tests, wind and the other environment conditions remained unchanged. The flight path was planned to have adequate distance from the take-off point to the first waypoint so that the UAV has enough distance to complete the forward transition before reaching the first waypoint.

Determination of Transition Distance

Forward transition, is the flight until the UAV reaches a threshold airspeed. During forward transition the throttle is maintained significantly high, and the UAV gets a high acceleration, which is given by,

$$\ddot{x} = \frac{F_{fw} - F_d}{m} \tag{24}$$

where $F_f w$ is the forward thrust and the F_d is the velocity-dependent drag force. By substituting drag force, the forward velocity response of the UAV can be derived as follows.

$$\ddot{x} + C_d \frac{\rho}{2} \dot{x}^2 - F_{fw} = 0 \tag{25}$$

Forward velocity can be derived by solving the above equation as follows. set as, *v(t)* = 0 at *t* = 0;

$$v(t) = \sqrt{\frac{F_{fw}}{b}}(1 - e^{-\alpha t}) \tag{26}$$

where $\alpha = \frac{bAe^2}{m}$, $A = \sqrt{\frac{F_{fw}}{b}}$ and $b = \frac{C_d}{2}$. The transition time UAV takes to reach the airspeed threshold at which it starts slowing down quad-motors can be determined as follows.

$$T_{tr} = \frac{1}{-\alpha} ln(1 - V\sqrt{\frac{b}{F_{fw}}}) \tag{27}$$

Transition distance can be determined by integrating the velocity equation as follows.

$$S_{tr} = \int_0^t \sqrt{\frac{F_{fw}}{b}}(1 - e^{-\alpha t}) dt \tag{28}$$

At this time and distance, the UAV starts slowing down the quad-motors. It will take a little time and distance to completely shut down the quad-motors. The additional distance UAV flies after reaching the airspeed threshold is given by,

$$S_{shut} = V_t \times t_{shut} \tag{29}$$

where V_t is the airspeed threshold and the t_{shut} is the time for the quad-motors to shutdown. Thus, the total distance needed for the forward transition is as follows.

$$S_{tot} = S_{shut} + S_{tr} \tag{30}$$

According to the parameters of the Hornet 1.0 UAV, this distance is about 70 m. Therefore, the first waypoint was set 100 m away from the take-off point.

In the case of bird take-off, because both flight modes are executed at the same time, a much higher current is drawn from the battery. It has been experimentally found that the Hornet 1.0 UAV draws 55 A current in taking off in standard VTOL mode, and 40 A when it is flying in plane mode with 100% throttle. Therefore, it was estimated to have 100 A current handling capacity for the UAV to be able to execute both flight modes simultaneously. This was achieved by having a 3S 2200 mAh 60C LiPo battery.

5. Experimental Results

The Quad-plane UAV Hornet 1.0 shown in Figure 8 was tested in both standard and bird take-off modes. In case of standard take-off mode, as shown in Figure 14, UAV climbed vertically to 15m and then started forward transition to fly like a plane while being assisted by the quad motors until the threshold airspeed of 12m/s is achieved. In bird take-off mode, as shown in Figure 11 both modes start together, so the UAV starts flying at an angle. Current and voltage of the two tests were recorded and presented in Figure 15.The standard take-off method, as it climbs up to 15m vertically and then starts moving forward, takes more time for the transition compared with the bird take-off method. The flight attitudes (Roll, Pitch and yaw) in both modes are shown in Figure 13. Despite 105 Amperes drawn in the bird take-off initially, it consumed less energy overall for the forward transition because of being able to reach the altitude and airspeed quickly. The energy comparison between traditional takeoff and bird takeoff can be found in Table 2.

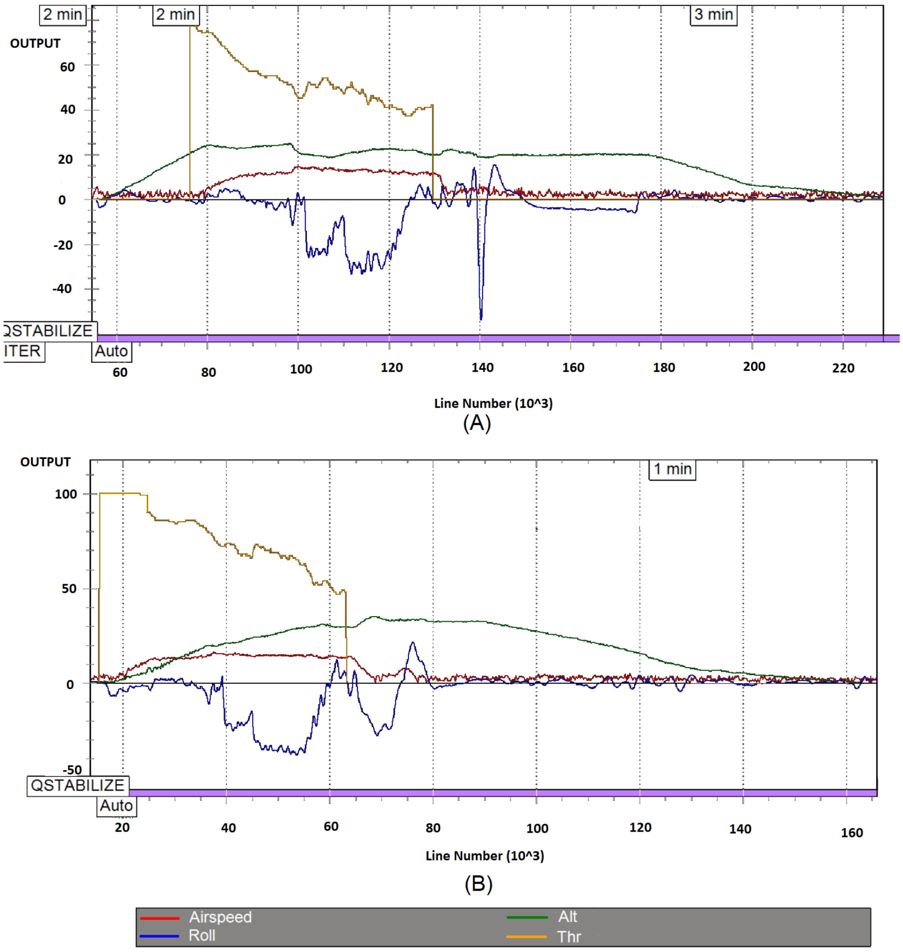

Figure 13. Flight Data, (**A**) Standard VTOL takeoff (**B**) Bird takeoff.

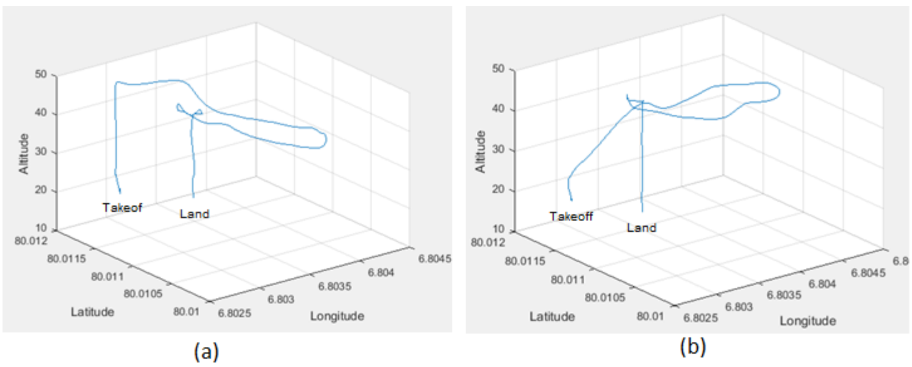

Figure 14. (**a**)Standard VTOL takeoff and (**b**) bird takeoff.

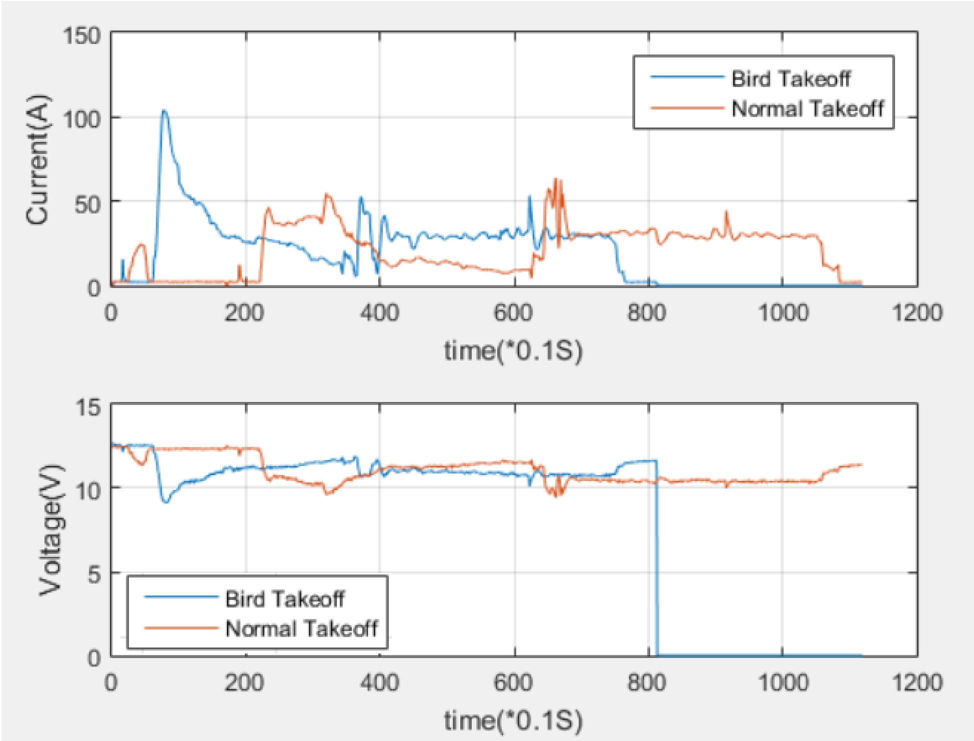

Figure 15. Voltage and current comparison between standard VTOL take-off and Bird take-off.

Table 2. Experimental Result of Energy Consumption of Standard VTOL take-off and Bird Take-off Methods.

Takeoff Method	Energy Consumption (j)
Slandered VTOL Takeoff	6582
Bird Takeoff	5123
Saving	1459

6. Conclusions

In this research, the two main take-off methods of quad-plane UAVs have been compared for their energy consumption. As the experimental platform, a small quad-plane UAV was built by combining a quad-rotor frame and a winged plane. It has been revealed that the bird take-off method where both quad-rotor and plane modes are executed simultaneously for taking off is energy efficient. For a small UAV like the one used in this experiment, the saving was as high as 22%. Energy consumption for taking off a UAV is a significant portion of the total energy consumption of the mission. Reducing this energy, the bird take-off mode helps prolong mission endurance of quad-plane UAVs.

Scaling up the quad-plane UAV to suit actual applications is the next immediate step in this development together with electric to gasoline conversion of the plane mode, which will further prolong the endurance. As for further research, bird take-off mode will be optimized theoretically where thrust control will be adjusted to reduce energy waste during take-off.

Author Contributions: A. A. J. K. Gunarathna is a MPhil student and a researcher in this project who designs and implements quad-plane control system. He involves in system design, testing, flying, analysing results, and publications.

Prof. S. R. Munasinghe is the principle investigator of the project. He supervises the drone development team, check milestone achievements, evaluate performance and provide direction and guidance for research and development.

Funding: This research received funding from National Research Council and AHEAD project. The Senate Research Committee of the University of Moratuwa provided the publication cost.

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Data Availability Statement: Not available yet

The video of the traditional and bird takeoff can be found at,
https://www.youtube.com/watch?v=cu8rdGvTDYY

Acknowledgments: The authors would like to sincerely appreciate the support offered for this project by the members of the UAV Research Laboratory, namely Pasindu Kavisha, Roshan Lalantha and Sanjeewa Fernando.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lyu, X.; Gu, H.; Zhou, J.; Li, Z.; Shen, S.; Zhang, F. A hierarchical control approach for a quadrotor tail-sitter vtol uav and experimental verification. In Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, Canada, 24–28 September 2017; pp. 5135–5141.
2. Öner, K.T.; Çetinsoy, E.; SIRIMOĞLU, E.; Hançer, C.; Ünel, M.; Akşit, M.F.; Gülez, K.; Kandemir, I. Mathematical modeling and vertical flight control of a tilt-wing UAV. *Turk. J. Electr. Eng. Comput. Sci.* **2012**, *20*, 149–157.
3. Intwala, A.; Parikh, Y. A Review on Vertical Take Off and Landing (VTOL) Vehicles. *Int. J. Innov. Res. Adv. Eng. (IJIRAE)* **2015**, *2*, 187–191.
4. kalpa Gunarathna, J.; Munasinghe, R. Development of a Quad-rotor Fixed-wing Hybrid Unmanned Aerial Vehicle. In Proceedings of the 2018 Moratuwa Engineering Research Conference (MERCon), Moratuwa, Sri Lanka, 30 May–1 June 2018; pp. 72–77.
5. Guclu, A.; Kurtulus, D.F.; Arikan, K.B. Attitude and Altitude Stabilization of Fixed Wing VTOL Unmanned Air Vehicle. In Proceedings of the AIAA Modeling and Simulation Technologies Conference, 2016; p. 3378.
6. Bresciani. Modelling, Identification and Control of a Quadrotor Helicopter. 2008.
7. Kaviyarasu, A.; Kumar, A.S. Study of Fixed Wing Aircraft Dynamics Using System Identification Approach.
8. Noth, A.S.B.; Siegwart, R. Dynamic Modeling of Fixed-Wing UAVs. 2006 Master Course Mech, 2006.
9. Ahmed, A.E.; Hafez, A.; Ouda, A.; Ahmed, H.E.H.; Abd-Elkader, H.M. Modeling of a small unmanned aerial vehicle. *Adv. Robot. Autom.* **2015**, *4*, 2.
10. Noth, A.; Bouabdallah, S.; Siegwart, R. Dynamic Modeling of fixed-wing UAVs. In *Swiss Federal Institute of Technology*; 2006.
11. Mobarez, E.N.; Ouda, A.; Zekry, A.A. Mathematical Representation, Modeling and Linearization for Fixed Wing UAV. *Int. J. Comput. Appl.* **2016**, *147*, 24–31.