A VTOL DRONE WITH ONLY TWO PROPELLERS

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March 2023

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1 Introduction

1.1 Background

Nowadays, drones, as an important carrier of modern technology and advanced productivity, have become a vital part of the development of new aviation forms. They have been used in many different areas such as military, civilian, commercial, and so on. With the breakthroughs in wireless communication, sensor technology, computer technology and lithium battery technology in the 21st century, there is evidence that a new era of flying vehicles is upon us. Electric and hybrid powered aircraft are taking an increasing share of the market. Traditional vertical takeoff and landing (VTOL) aircraft like the V-22 have complex internal combustion machines, and complex mechanical arrangements. [1] In contrast, electric VTOL aircraft have a simpler mechanical structure, which increases the fault tolerance and improves the safety issues of traditional VTOL aircraft. [1] At the same time, the relatively simple structure of e-VTOL reduces production costs and the use of electricity also reduces noise and air pollution well. From a market perspective, e-VTOL also demonstrates very significant growth potential. According to the International Air Transport Association (IATA) 2022 annual report, international air travel is recovering from the low point of COVID-19 toward 2019, while air cargo traffic also increases in 2022, but the growth rate is relatively low compared to 2021. The growth rate has slowed down compared to 2021. [2] Because the market is growing at a faster rate, now is a good time to develop aircraft. In addition, Jet fuel and crude oil prices have risen to 2.2 times last year's level because of the war in Ukraine and the international economic situation, which further demonstrates the advantages of electric aircraft. [2]

1.2 Objectives

Traditional drones like helicopters have shortcomings in flight speed while fixed-wing aircraft require a runway for takeoff and landing. Vertical takeoff and landing (VTOL) aircraft not only have helicopters' accessibility and flexibility to take off and land in small spaces, thus they can fly to destinations that are not easily accessible by traditional aircraft, such as remote areas or areas with poor infrastructure; the design of VTOL also allows for faster deployment and response times which is especially important in emergency situations where every second counts. Most of the e-VTOLs we can see in the Electric VTOL Configurations Comparison overview article are made of multi-rotors. [3] There are wingless e-VTOLs like the E-Hang 184, whose traditional quad-rotor structure makes it more stable during takeoff. [4] There are also those with both vertical and horizontal rotors like the KiKitty Hawk Cora geometry. [5] In order to reduce the extra weight during horizontal flight, we decided to design an e-VTOL with fewer propellers.

Our goal is to design a small e-VTOL with a wingspan of about one meter to achieve both vertical takeoff and landing and horizontal flight like a fixed-wing aircraft by means of only two rotatable propellers located at the ends of the mean wings. Such two flight modes and the transition between them require a very precise perception and adjustment of the aircraft's attitude. To do this, we need a high-frequency motherboard and some gyroscopic sensors to receive and process the aircraft's attitude information and make feedback adjustments. This places high demands on the control section, and on the mechanical side to ensure structural rigidity, reduce unpredictable jitter in the wings and other components. What's more, for the rotatable propeller section. It is important to reduce the inertia of the rotating part while reducing the complexity of the structure and making it more reliable. While designing the aircraft structure with sufficient strength. We also consider the arrangement of the location of each electronic component, the heat dissipation of electronic components, sufficient storage space, certain water resistance, easier maintenance, etc.

1.3 High Level Requirements

- The two propellers combined must provide a force greater than 15N to ensure that the aircraft can take off vertically. Also ensure that the gravitational force on the aircraft itself is less than 15N.
- The wings need to provide at least 15N of lift to ensure that the aircraft can fly horizontally at the preset speed.
- The development board needs to reach approximately 2 kHz flight control loop rate in order to receive the attitude changes from the sensors in time and react quickly.

1.4 Visual Aid

To make our project easier to understand, we drew this simple Visual Aid. Our VTOL UAVs are operated by both a human controller and a flight control system. The human operator uses the controller to send signal to the radio receiver on the drone. The Teensy 4.0 development board then receives signals from the receiver and sensors, and outputs signal to control servos motors and propellers on both ends of the aircraft's wings. Thus, stable flight will be achieved.

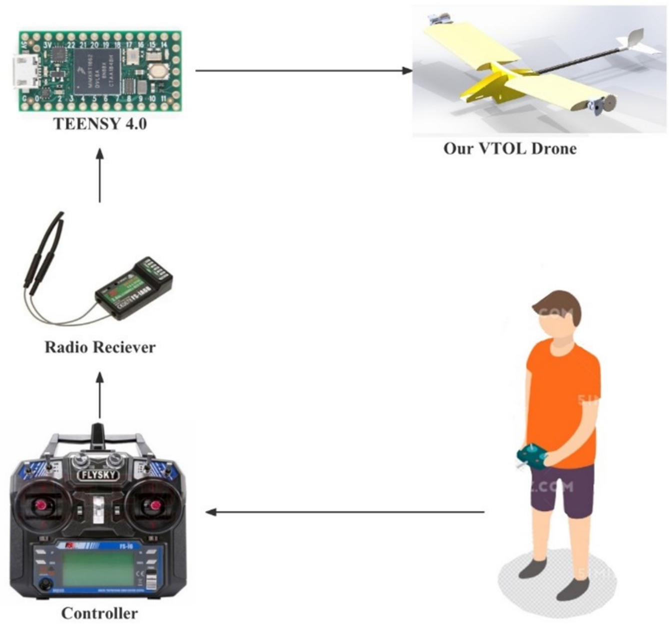

Figure 1: Flow of operations of our VTOL Drone

2 Design

2.1 Block Diagram

Our VTOL Drone basically includes four subsystems as shown in the Figure 1 below: Power Subsystem, Control Subsystem, Transmission Subsystem and Mechanical Subsystem. The 14.8V DC battery in the power subsystem offers the electricity needed for the control subsystem through an electronic speed controller, which will transfer the 14.8V into 5V DC. The Teensy 4.0 board in the control subsystem will receive the signal from the radio receiver and the MPU-6050 and it will complete the PID controls through the code and send the signal to motors and servos. The transmission subsystem includes the radio controller and radio receiver, and the radio receiver will send the signal from the radio controller into the board. The mechanical subsystem contains servo motors and brushless motors, through the linkage of PLA 3d printed parts, stepper motors control the directional rotation of brushless motors and propellers to complete the adjustment of aircraft attitude and various directions of movement with the cooperation of two propellers. Meanwhile, the 3d printer body reinforced by carbon fiber tube, and glass fiber sheet has good reliability.

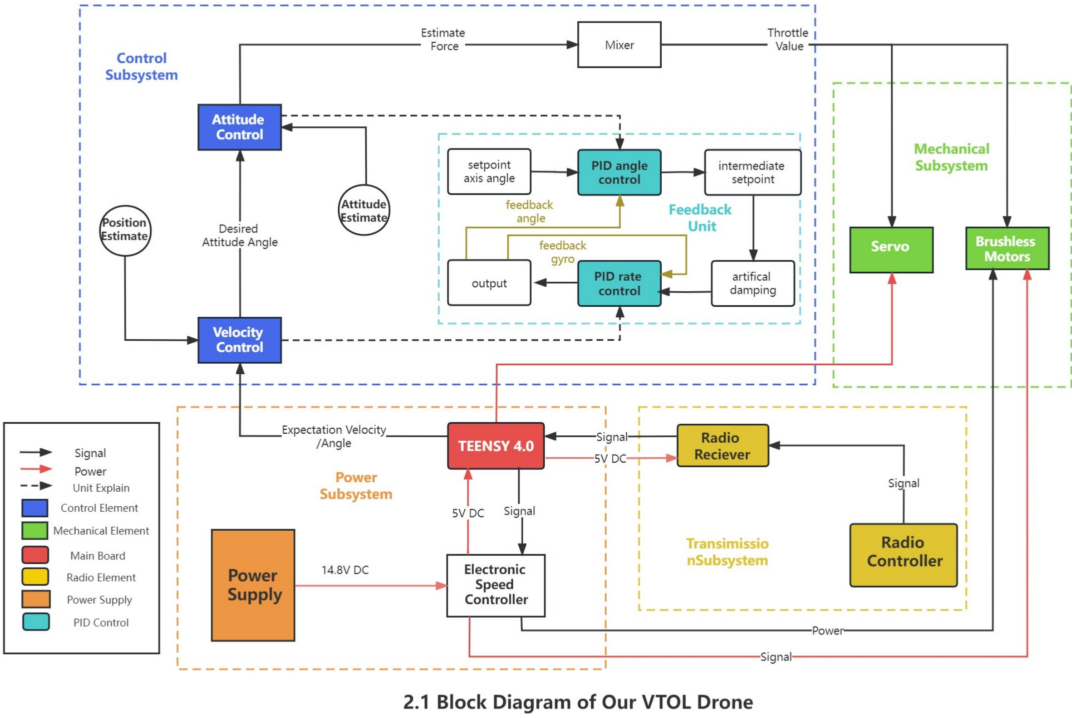

Figure 2: Block Diagram

2.2 Physical Design

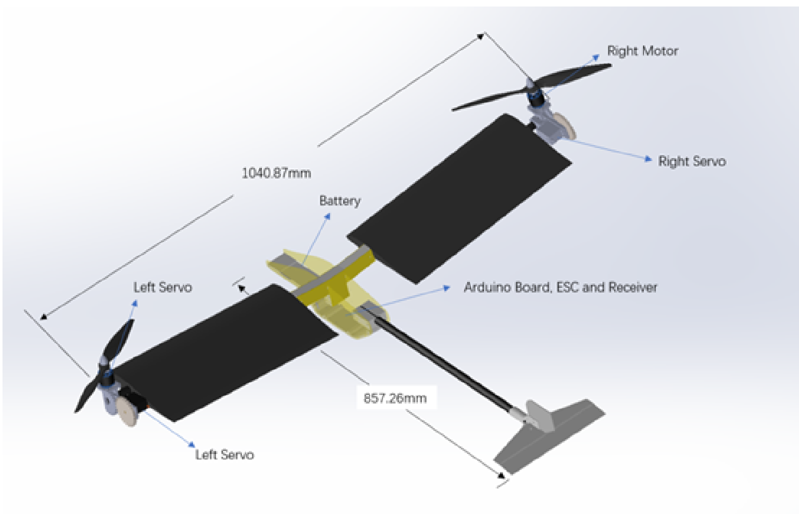

Figure 3: Physical Design

The physical design, as shown above, mainly consists four parts: the fuselage, the left wing, the right wing and the tail. The entire drone is 857.26mm long and 1040.87mm wide, which is an acceptable size. The 14.8V battery is placed in the front of the fuselage while the Arduino controller, electronic speed controllers and the receiver would be placed at the bottom. The two brushless motors are fixed individually at the left and right end, each with one servo that controls the direction of the output. All electric wires that connect from the fuselage to the servo or motor are hid in the hollow carbon fiber tubes.

2.3 Power Subsystem

Power subsystem includes battery, electronic speed controller and the Teensy 4.0 board like shown in the Figure 16. The 14.8 V DC battery will first power the 2 electronic speed controllers, which will transfer the voltage into 5V to power the Teensy board. The ESCs will directly power the motors and the 5V output of ESC will power the servos.

2.3.1 iMAX B6

iMAX B6 is the charger of the battery. It features an AUTO function that controls the charge rate during charging and discharging. For Lithium batteries, this can prevent overcharging which may lead to an explosion due to the user's setting the charge rate improperly. It will disconnect the circuit automatically and initiate an alarm if there is any malfunction. All the operating modes of this charger are controlled through two way communication, between the charger and the battery to achieve maximum safety. All the settings can be configured by the user[6]. We mainly use it to charge our Li-Po Battery to 14.8V.

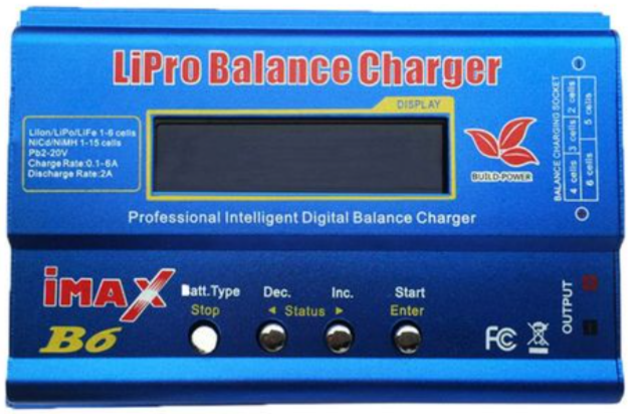

Figure 4: iMAX B6

Requirement	Verification
1. Be able to charge our high discharge Li-Po battery to 14.8V-16.8V and the output voltage should be stable and it can automatically shut off when the battery if sully charged. 2. Charging at maximum current and voltage can be sustained below 125°C 3. Can be reused	1. A. Discharge the Li-Po Battery to 14.8V(4 *cell voltage). B. Charge the battery at the output of the iMAX B6 from an input of 17.6V, without limiting current. C. At the termination of the charge cycle, the charger should show the status of the battery and it should automatically end charging when the battery reaches 16.8V. 2. Observe the temperature if the charging cycle. Use an IR thermometer to ensure that the charger doesn't reach the temperature of 125°C []. 3. Repeat the first steps three times to see if it can be reused.

2.3.2 Battery

The iMAX B6 charger will power the battery, which will feed into the two electronic speed controllers. The Li-Po battery must be able to keep the circuit continuously powered when the drone is flying. Since we need it to power the ESCs, we need a Li-Po Battery which satisfies the basic needs of the ESC. For Lithium Battery, we need 2-4 lithium battery packs to supply the power. In order to make it last long, we select a 4S1P 2400mAh Li-Po battery, which will satisfy our needs.

Figure 5: Grepow 4S1P 2400mAh

Requirement	Verification
1. Can store > 2400mAh of charge. 2. Should not reach $60°C$ when working a long time.	1. A. Charge the Li-Po Battery with the charger until it's fully charged(16.8V). B. Discharge the battery at 300mA for 6 hours. Use a voltmeter to ensure the voltage is above 14.8V(4x cell voltage) 2. Observe the temperature if the discharging cycle. Use an IR thermometer to ensure that the battery doesn't reach the temperature of $60°C$ [7].

2.3.3 Electronic Speed Controller

We use two electronic speed controllers in our drone. They will be supplied with 14.8V DC from the Li-Po battery and they will transfer the voltage into 5V DC for the use of the Teensy board and the servos. In addition, it will create a changing output voltage for the motors according to the signal from the Teensy board.

Figure 6: Electronic Speed Controller

Requirement	Verification
1. Should output a 5V±5%from a 14.8V-16.8V battery 2. Should be under 65°C when working	1. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 5% of 5V 2. Observe the temperature if the discharging cycle. Use an IR thermometer to ensure that the battery doesn't reach the temperature of 65°C [8].

2.4 Control Subsystem

Teensy 4.0 is used as the main board of our drone's control subsystem which is powered by 5V DC through the ESC. We can upload the control code into the board through Arduino IDE (with the help of Teensyduino). It will receive the signals from the radio receiver in the transmission subsystem and the MPU-6050 (gyroscope and accelerometer) and output the signals to the servos and motors(through ESCs) after finishing the PID control inside the board. The MPU-6050 is a 6-axis IMU, which combines a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die. It should be placed in the center of the drone and receiver the information of the flying drone.

2.4.1 TEENSY 4.0

Teensy 4.0, a microcontroller which can offer a relatively free pin settings to users. Since we use PWM signal inputs from the radio receiver, we will assign 6 pins for the 6 channels from the receiver. In addition, we will set another 2 pins for the IMU. The board will be charged from the ESC's 5 V DC output and the controlling code will be uploaded through the USB. It has a relatively high performance cost ratio. The Teensy 4.0 features an ARM-Cortex M7 processor with a clock speed of 600 MHz. It has 31 PWM-enabled pins and 40 digital i/o pins which are all interrupt capable.[9]

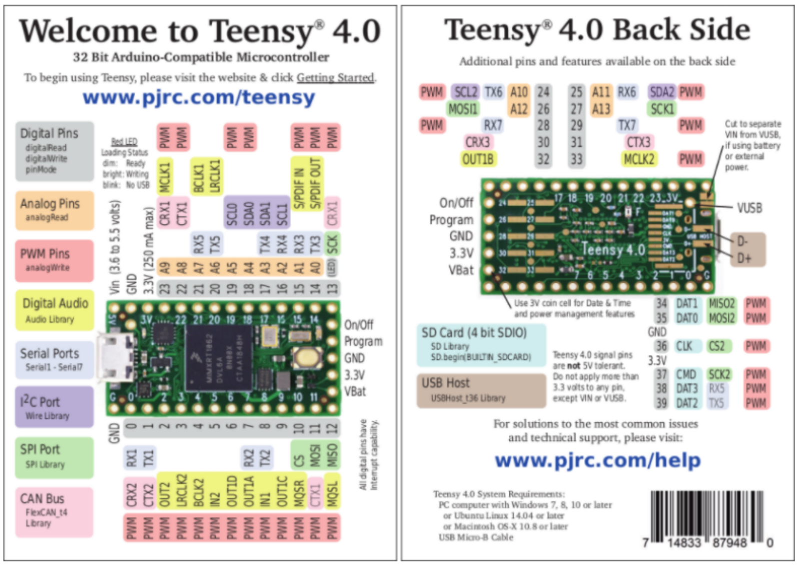

Figure 7: TEENSY 4.0

Requirement	Verification
1. Can both receive and transmit PWM signals at 50Hz	1. A. Connect microcontroller to USB, and to a terminal such as Putty. B. Start timer, which can send a 50Hz signal data from the USB bridge into the Teensy. C. Echo data back, this time transmittng over PWM from the Teensy and we stop timer ensure that data received matches data sent, and that time elapsed does not exceed $\frac{1}{50} * 2 = 0.04s$

2.4.2 MPU-6050

The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor, which processes complex 6-axis MotionFusion algorithms. It will send the current velocity and angle information to the Teensy board to comlete the PID controls in the board. It should be powered by the 3.3V DC output of the Teensy Board.

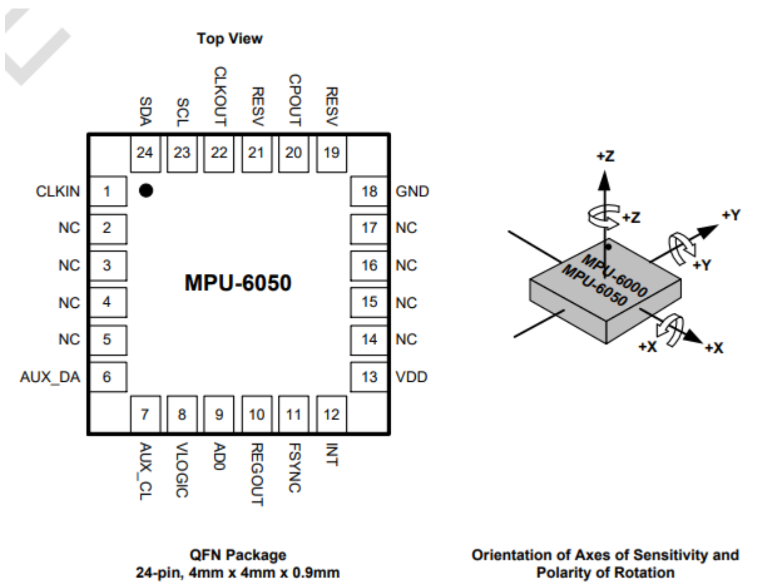

Figure 8: MPU-6050

Requirement	Verification
1. Provides the PWM signal to the board at 50Hz	1. A. We will first power it with 3.3V DC, and stick it onto a simple drone model built by cardboard. B. Then We will connect it to the board and write a program to test this with the Teensy board. C. Try to make some adjustment of the position of the drone model and see if there's signals shown in the screen through the Teensy. D.Set the time clock to get the signal to be 0.02s to see if the MPU-6050 get the information at 50 Hz

2.5 Transmission Subsystem

Our transmission subsystem mainly refers to the radio connection part of our drone, which includes FS-i6 radio controller and FS-iA6B radio receiver. Since the FS-iA6B has 6 PWM channels for control output, we will set the controller's channels corresponding to the receiver, then we can simply use the controller to realize the control commands after the receiver and controller matches successfully.

2.5.1 FS i6

The FS-i6 is an entry-level transmitter built for fixed-wing / glider / helicopter modes. Featuring the AFHDS 2A protocol, upgradeability (up to 10 channels) as well as Chinese and English firmware versions[10]. It has totally 6 channels which is enough for our use.

Figure 9: FS i6 Radio Controller

Requirement	Verification
1. Can realize basic functions of drone's control. All the 6 channels of the radio output should work with the radio receiver successfully.	1. A. First, match the controller and the receiver. B.Then, use the system setup in the radio controller to set the channel's definition(Channel 1 - Channel 4 is already defined). C. Then charge the receiver and plug the motors(through esc) and the servos onto the radio receiver. D. Then shake the rocker to see if the motors and servos do the correct actions we want. E. If so, then the radio controller and the receiver both work well.

2.5.2 FS iA6B

FS-iA6B is a radio receiver with 6 PWM channels.The wireless frequency is 2.4GHz and can work in the range of 500-1500m. We use the 5V DC to power it and it will receive the signals from the FS-i6.

Figure 10: FS iA6B Radio Receiver

Requirement	Verification
1. Wireless frequency is 2.4GHz 2. Can receive signals from 500m away	1. A.Match the receiver with the controller. B. Connect the FS-iA6B with an oscilloscope. C. Send signals to it from the controller to see the frequency shown, 2. A. First match it with the controller and connect it with a motor in the third channel. B. Put it 500m away, and shake the rocker of the FS-i6 to see if the motor works successfully.

2.6 Mechanical Subsystem

The MG996R servos, powered directly by the radio receiver and controlled by the Teensy 4.0, should be able to rotate in a range of 180 degrees and thus, change the output angle of the brushless motors. And the brushless motors should be able to supply enough lift force, which is higher than the total weight (about 1.5 kg) of the plane, during the VTOL process and thrust during level flight.

2.6.1 Brushless motor and propeller module

In this module, we choose to use SUNNYSKY motor V2216-KV800 and propellers APC1047 to provide thrust. As shown in Figure 11, the motor with propeller would provide different thrust with different efficiency corresponding to the circuit. Through this, ESC could adjust the thrust of each motor. It is observed that the maximum allowed circuit of the motor is 16.8A at working voltage 14.8V. At this time, the motor and propeller would offer the maximum thrust of 1240g.

Prop (inch)	Volts (V)	Amps (A)	Thrust(g)	Watts (W)	Efficiency (g/W)	全油门负载温度
APC1047	14.8	0.4	100	5.92	16.89189189	
		1.2	200	17.76	11.26126126	
		2.1	300	31.08	9.652509653	
		3.1	400	45.88	8.718395815	
		4.4	500	65.12	7.678132678	
		5.7	600	84.36	7.112375533	
		7.1	700	105.08	6.661591169	
		8.9	800	131.72	6.07348922	
		10.5	900	155.4	5.791505792	
		12.5	1000	185	5.405405405	
		14.5	1100	214.6	5.125815471	
		16.8	1240	248.64	4.987129987	66°

Figure 11: Performance of the brushless motor V2216-KV800

Requirement	Verification
1. The brushless motor would rotate at 14.8V input and reaches the maximum thrust of 1150g when the effective current is 16.8A. 2. The highest temperature for the motor is no more than 75℃.	1. A. Place the motor on the test platform and connect the motor with the test clamp as shown in Figure 12. B. Adjust the voltage to 14.8V and change the duty ratio to simulate the output of ESC. C. Investigate the variances of the effective current and thrust shown on the screen. We will ensure the thrust could reach 1150g when it's 16.8A . 2. A. Through out the entire test process, use IR thermometer to ensure the temperatures of the motor doesn't reach temperatures greater than 75℃.

Figure 12: Motor test platform

2.6.2 Servo and gear set module

In this module, the servo is fixed on the 3d printed plates, which is fixed on the carbon tube. As shown in Figure 13, the shaft of the servo is connected to the spur gear on the left. Because the servo could rotate in 180 degree range and the radius of the pitch circle of the two gears are the same, the right gear could also rotate in 180 degree range. Thus, the plate that holds the motor could rotate and the output direction control is realized.

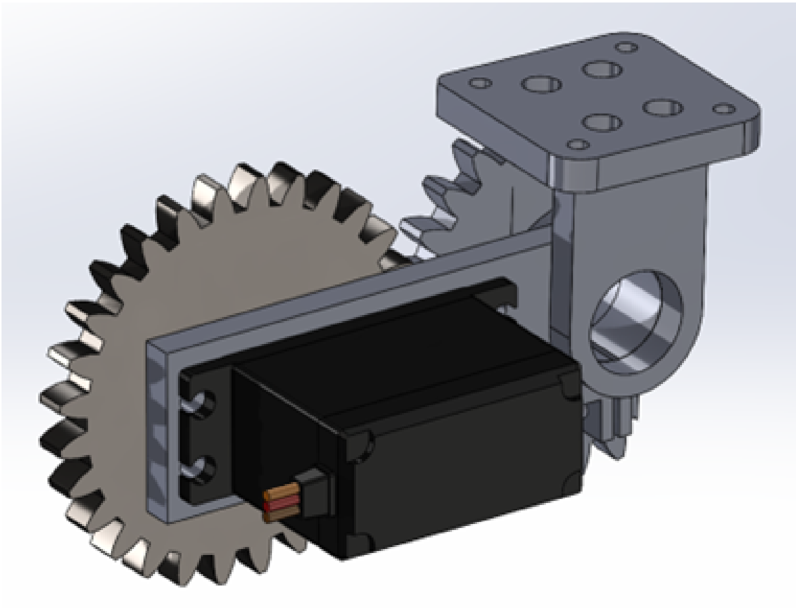

Figure 13: Servo and gear set module

Requirement	Verification
1. The servo could rotate in a range of 180°. 2. The servo could provide the maximum torque of 5kg/cm.	1. A. Connect the brown and the red wire to the positive and negative terminals of a 5V power supply. B. Connect the orange wire of the servo to a function signal generator. Adjust the machine so that its output signal period is 20ms PWM signal. C. Adjust pulse width between 0.5ms and 2.5ms. Ensure the rotation degrees of the servo could reach 0 degrees and 180 degrees. 2. A. Repeat the procedures in 1 and but attach the shaft to a 1cm long bar with 4kg weight hanging at the end. Ensure the servo could still rotate.

2.6.3 Carbon tube connector module

We will use PLA material to 3D print a suitable size connector to link the 15mm carbon fiber tube to the fuselage. In order to ensure the strength and lightweight 3d printed parts, we chose a wall thickness of 1.2mm and top layer thickness and used a 5% fill rate. We also sandwiched the 3D printed part with a 1mm thick glass fiber plate to enhance its strength. At the same time, the connectors need intermediate penetrations to ensure the passage of wires.

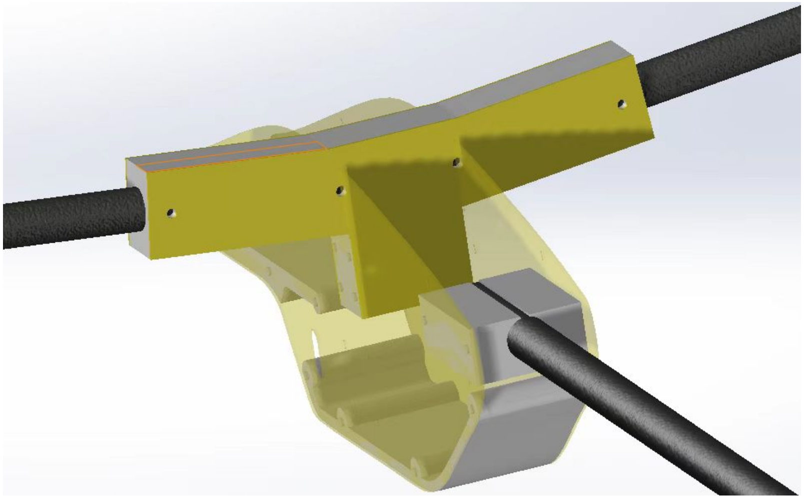

Figure 14: Carbon tube connector module

Requirement	Verification
1. The PLA connection part needs to withstand a torque of 20 Nm in x, y and z directions. And the deformation at the end of the connection is less than 2 mm.	1. A. Assemble two carbon rods in PLA connection part, assemble glassfiber plate. B. Fix the end of one carbon tube near the connector to the vise. Measure and record the coordinates from the end of the connector to the bench vise with a vernier caliper. C. Apply a force of 25 N perpendicular to the carbon tube with a tensiometer at the end of the principle connector of the other carbon tube. D. Observe the PLA connector for deformation visible to the naked eye and measure and record the coordinates from the end of the connector to the bench vise with a vernier caliper. E. Compare the deformation of the end of the connector before and after the applied force is greater than 2mm. F. Repeat steps 3 to 5 for the other directions.

2.6.4 Aircraft body module

For the fuselage we also used a combination of 3d printed parts and fiberglass panels. In this part, we will use the fiberglass plate as the main material, PLA material 3d printing suitable size of the connector to link the fiberglass plate on both sides of the fuselage, and reasonable separation of the different functional areas of the aircraft fuselage. At the same time, we set aside space for the front of the aircraft to place the battery, using Velcro to fix the battery, to more easily adjust the center of gravity of the aircraft. The body also needs to ensure sufficient heat dissipation to prevent the electronic components from accumulating heat to melt or soften the 3d printed parts.

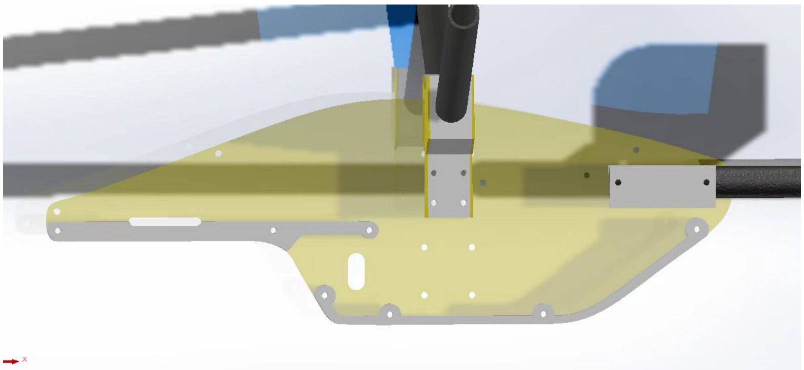

Figure 15: Aircraft body module

Requirement	Verification
1. The space is set up in such a way that the center of gravity of the aircraft is directly below the center of the wing attachment. 2. Need to withstand a torque of 20 Nm in x, y and z directions from the connection part.	1. A. Complete assembly of all aircraft components. And use a marker to draw the wing carbon tube connectors and the plane where the carbon tubes are located on the aircraft's shell. B. Find a roller to place on the bottom of the aircraft and roll it back and forth until a position where the aircraft is no longer tilted forward or backward. Adjust the position of the battery until the point where the roll is tangent to the bottom of the aircraft falls on the mark of the marker. Record the position of the battery at the next time. 2. A. Fix the bottom of the aircraft on the vise. Measure and record the coordinates from the screw holes of the connectors to the bench vise with a vernier caliper. B. Apply a force of 25 N perpendicular to the carbon tubes with a tensiometer at the end of the principle connector of the other carbon tube. C. Observe the PLA connector for deformation visible to the naked eye and measure and record the coordinates from the screw holes of the connectors to the bench vise with a vernier caliper. D. Compare the deformation of the screw holes of the connector before and after the applied force is greater than 2mm. E. Repeat steps B to D for both wing connectors and back connector on the other directions.

2.7 Schematics

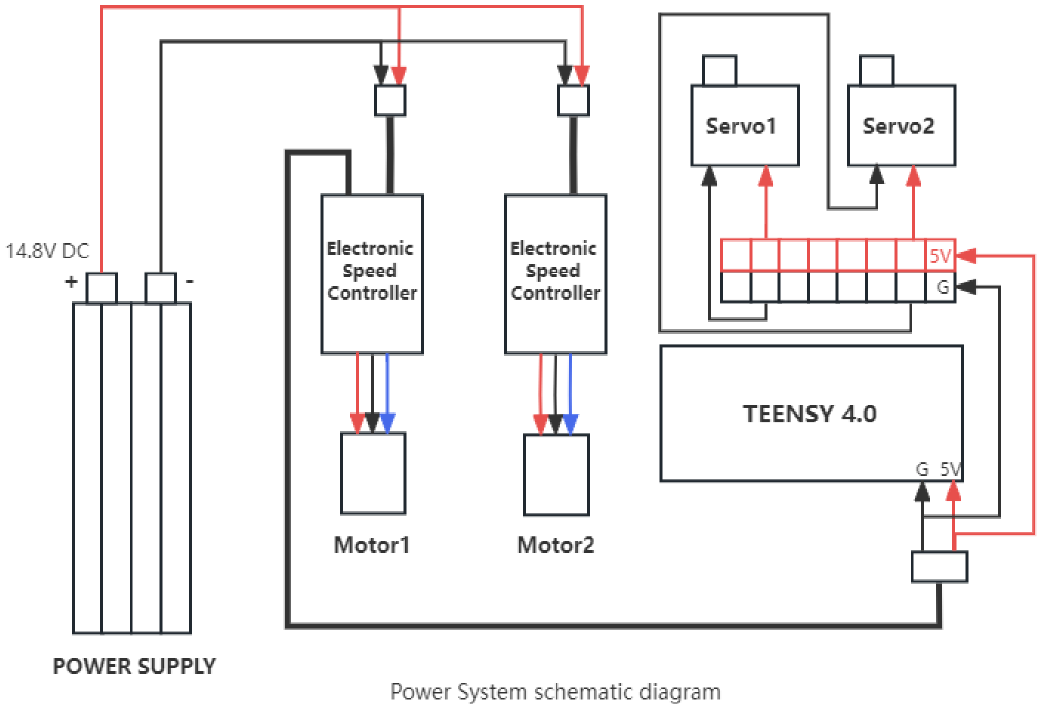

Figure 16: Power Subsystem Schematic

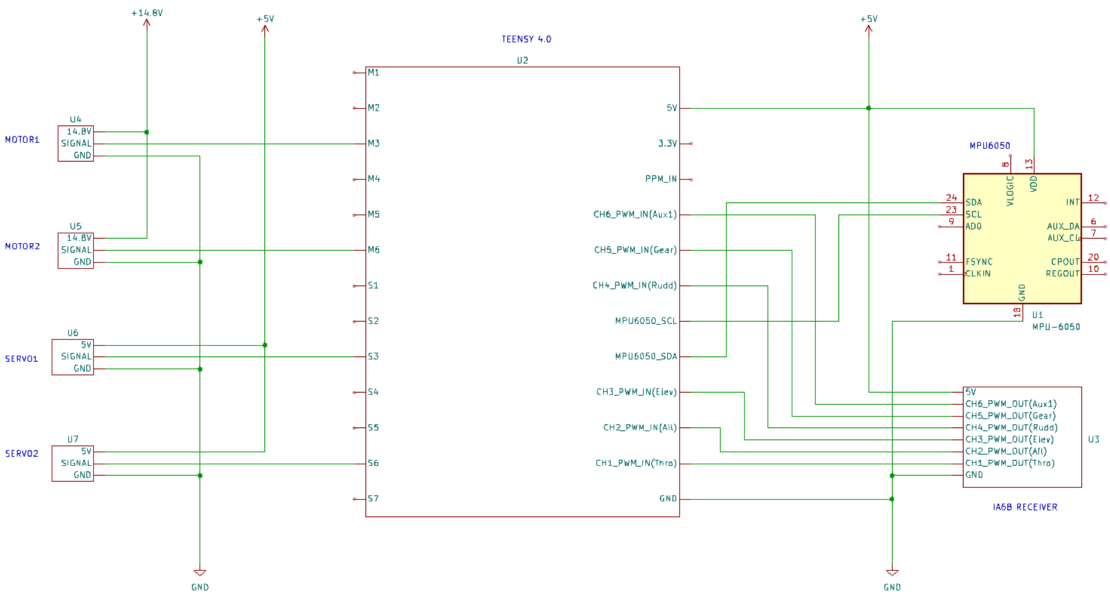

Figure 17: Control Subsystem Schematic

2.8 Software

2.8.1 Data transmission protocol

Data transmission protocol refers to the set of rules and mechanisms used to transfer data securely and reliably between unmanned aerial vehicles (UAVs) and ground control systems (GCS). The protocol involves the way information is encoded, formatted, and transmitted over the wireless or wired communication link. We choose Radio Control System (RCS) to transfer our command between UAVs and remote control. RCS is a traditional method of UAV control that operates using a remote-control transmitter and receiver. It is simple and reliable, but it only allows basic communication and control functions.[11] Using this Data transmission protocol, we need to consider the following aspects:

- Bandwidth: UAVs generate a large amount of data (such as high-definition video, telemetry data) that needs to be transferred in real-time, which can easily saturate the available bandwidth, especially in congested areas.
- Latency: due to the time-sensitive nature of UAV operations, latency (delay) in data transmission should be minimized or reduced to ensure prompt and accurate decision making.
- Security and reliability: UAVs often operate in hazardous, remote, or sensitive areas, and the integrity and confidentiality of the data must be ensured, as well as the reliability of the communication link to prevent data loss.[12]

PWM (Pulse Width Modulation) is a technique used to control the speed of a motor. This is commonly used in UAVs (Unmanned Aerial Vehicles) to control the speed of the DC motors that drive the propellers. In our drone, there are two motors, one on each arm, and they all need to spin at the same speed to maintain balance and stability in the air. The speed of each motor is controlled by the UAV's flight controller, which adjusts the amount of power sent to the motor based on how the UAV is being controlled by the pilot.

To do this, receiver sends a PWM signal to mainboard. After calculation of feedback unit, the flight controller sends a PWM signal to an ESC (Electronic Speed Controller), which is connected to each motor. The ESC receives the signal and converts it into a specific voltage that determines the speed of the motor. The PWM signal consists of a series of pulses, and the width of the pulses determines the amount of power sent to the motor.PWM is a critical component of UAV control systems, as it allows the flight controller to adjust the speed of the motors and maintain stability and control in flight.

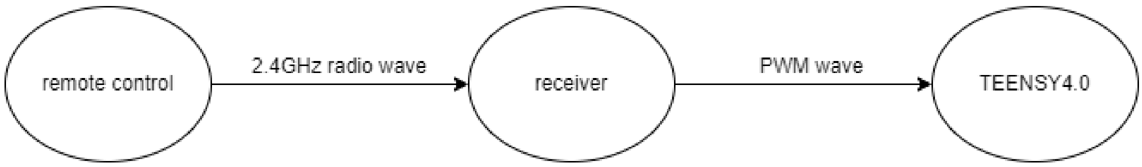

Figure 18: Data transmission Schematic

2.8.2 Control Code

Our control code mainly based on the dRehmFlight sample[13], we will modify the code to make it fit our two-propeller VTOL drone. The General contents in the main Arduino sketch follows the figure below:

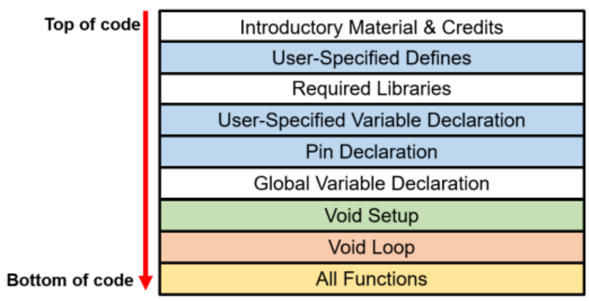

Figure 19: General contents in the main Arduino sketch[13]

We will first assign the Pins of the Teensy 4.0 in the pin declaration section. Then we need to make some global variables for use in the global variable declaration section. Then it comes to the void setup section, where we will setup the code and functions which will be executed one time when we start. In the void loop section, we will realize the flight control here. It will run automatically after the void setup works, and the basic control architecture for a flight control loop is shown in Figure []. and Figure [] expands on the specific processes occurring within the void loop to achieve this functionality. In the end, we have all the critical functions which are called within the void setup and void loop.

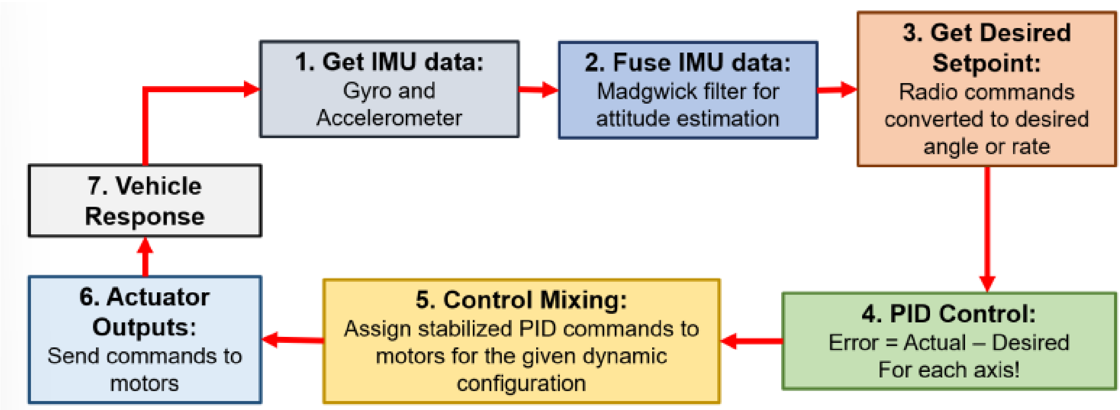

Figure 20: General overview of a flight control loop allowing stabilization of a small aerial vehicle[13]

Step	Function/Process	Description
1	Print Data (commented out default)	Multiple print statements used for troubleshooting; prints data to serial monitor at 100 Hz
2	getIMUdata()	Pulls raw gyro, accelerometer, and magnetometer data from IMU and low-pass filters to remove noise
3	Madgwick()	Uses IMU data to estimate absolute vehicle attitude
4	getDesState()	Convert raw radio commands to normalized values based on saturated limits (max rate or max angle in user-specified variables section)
5	Controller	Option of controlANGLE(), controlANGLE2(), or controlRATE() PID control to generate stabilized axis variables based on estimated attitude and desired state; gains adjusted in user-specified variables section
6	controlMixer()	Mixes PID controller outputs to scaled actuator commands based on dynamic configuration
7	scaleCommands()	Scale motor/actuator commands to required range for writing out to designated pins (OneShot125 default)
8	throttleCut()	Directly set motor commands to low/off value if throttle cut switch is engaged
9	commandMotors(), Command servos	Send ESC commands to OneShot125 pins and write servo commands to PWM pins
10	getCommands()	Get current radio commands to be used in next loop iteration
11	failsafe()	Check if received radio commands are valid and default to failsafe values if they are not
12	loopRate()	Idle in main loop until specified loop frequency is achieved (2 kHz default)

Figure 21: Flow of operation in the void loop() run continuously after startup[13]

2.9 Tolerance Analysis

The most challenging requirement of our VTOL drone is to ensure that there is enough lift at take-off and level flight. To analyze the take-off, we start with the overall weight and the center of gravity. As shown in Figure 5, our VTOL drone is symmetric with respect to x-z plane and brushless motors provide lift at the left and right wing ends. Thus, when considering the influence of the center of gravity, we only need to get the position of the gravity center of each part on the x-axis and their individual weights. For each part, the weight and the y position of the gravity center are shown below.

Part	Mass(g/each)	Quantity	X Position
Wing	100	2	74.97
Carbon wing tube	55.98	2	73.83
Body glass fiber	38.29	2	66.04
Body PLA-1	25	1	103.91
Body PLA-2	19	1	-39.95
Body PLA-3	21	2	68
Body PLA-4	11	1	174.56
Servo	55	2	119.42
Brushless motor	77	2	69.98
Spur gear	7	2	128.74
Motor connect-1	2	2	73
Motor connect-2	5	2	78.71
Motor connect-3	4	2	71.75
Servo connect	6	2	94.12
Carbon tail tube	55.98	1	299.56
Tail	7	1	699.14
Li-po battery	250	1	-45
ESC	43	2	102
Extension cord	23	6	73.83
Teensy 4.0	15	1	103.91
Receiver	7	1	102
Propeller	10	2	68.84

According to the weight of each part, we could calculate that the overall weight of the entire drone and the center of mass of the flight:

$$M = \sum_{1}^{n} m_i N_i = 1376.52g$$

$$x_{center} = \frac{\sum_{1}^{n} m_i N_i x_i}{M} = 70.07$$

The lift of each brushless motor is 1240g, which means the total maximum lift at take-off is 2480g and much larger than the total weight. Neglecting those extreme air conditions, our drone should be able to take off successfully. And as we can see above, the mass center of our drone and the two motors, which provide lift, are almost in the same plane. As a result, the drone wouldn't lean forward or back greatly due to the instability of the center of gravity when receiving vertical lift. This can ease the burden of the motors balancing the drone during takeoff and leave more power for extreme air conditions.

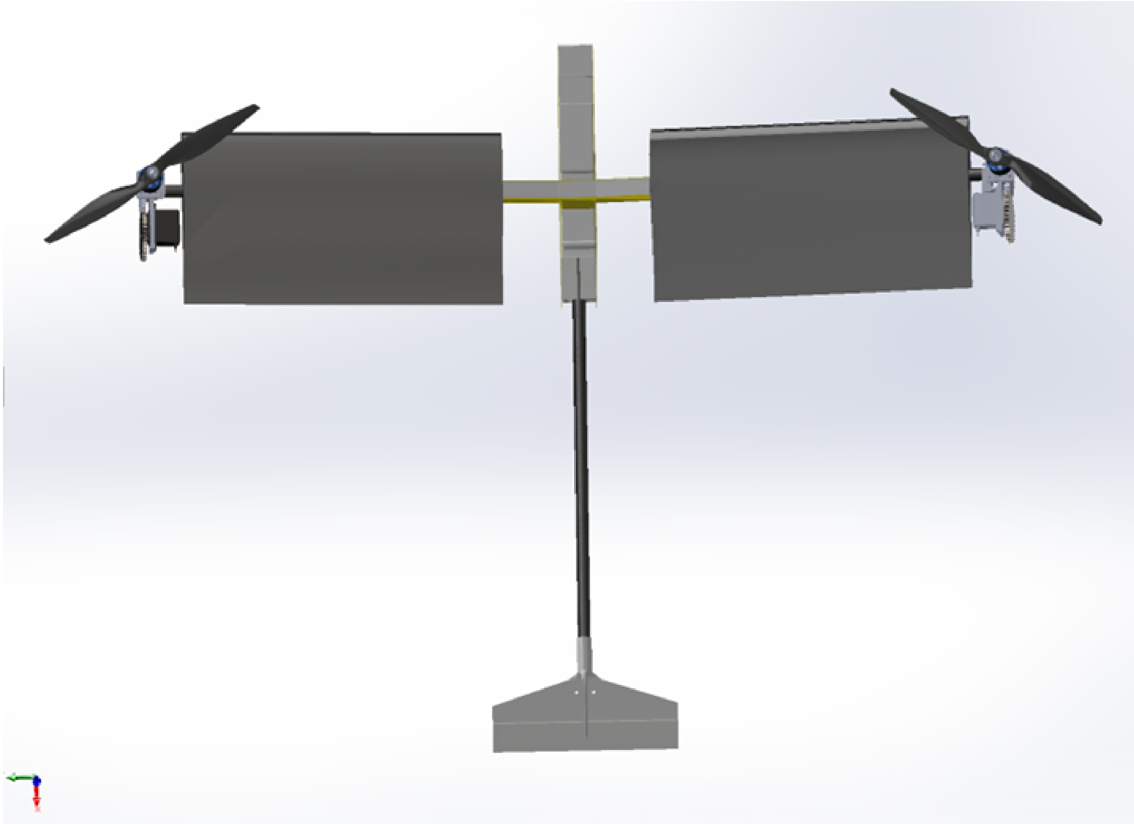

Figure 22: Planform of our VTOL drone

After our VTOL drone turns into horizontal flight mode, we need to calculate the drag force and lift force in typical speed. Here we assume after totally horizontal flight, the horizontal speed (V) for our drone is around 40 m/s.
Reynold number: $Re = \frac{\rho V l}{\mu}$
At standard atmospheric pressure, 15 degrees Celsius, $\rho = 1.225 \frac{kg}{m^3}$
Characteristic length: $l = 0.2m$
Dynamic viscosity at standard atmospheric pressure, 15 degrees Celsius:

$$\mu = 18\mu Pa \cdot s = 18 \cdot 10^(-6) \frac{kg}{m \cdot s}$$

Thus we can get the Reynold number for $V = 40m/s$ is $Re = \frac{\rho V l}{\mu} = 544444$
From Airfoil Tools' website (NACA 4412 (naca4412-il) (airfoiltools.com)) We can get the Dat file of airfoils, wing drag coefficient, wing lift coefficient. They record the coefficients at $Re = 500000$, where $V = 37m/s$.

When the angle of attack$\alpha = 0deg$, we can read from the plots that $C_L = 0.5, C_D = 0.007$. To calculate the drag force(D) and lift force(L):

$$D = C_D \cdot \frac{1}{2} \rho V^2 S_{ref}$$

$$L = C_L \cdot \frac{1}{2} \rho V^2 S_{ref}$$

Where S_{ref} is the wing reference area, $S_ref = 2 \cdot d \cdot L = 0.1623m^2$, where $L = 0.8m$ is the wing Length at one side and wing thickness from the front view and

$$d = \frac{\Delta y}{\Delta x} L = \frac{y_{max} - y_{min}}{x_{max} - x_{min}} L = \frac{0.0980 - (-0.0228)}{1.0 - 0} \cdot 0.8 = 0.10144m$$

Thus, for wing at $V = 37m/s, \alpha = 0deg$,

$$D = C_D \cdot \frac{1}{2} \rho V^2 S_{ref} = 0.9526N$$

$$L = C_L \cdot \frac{1}{2} \rho V^2 S_{ref} = 68.04N$$

For other components on the plane, they also provide drag forces, based on the equivalence surface area and drag force of wings, we can get:

$$D_{total} = D + D_{other} \approx 4N < F_{motor} = 24.8N$$

From the previous analysis, the Gravity force of the drone is $G = 13.7652N < L$ which means that at $V = 37m/s$, ur drone can still go upwards using only 15% of motor forces. The calculation above proves that our drone will work well in horizontal flight mode.

3 Costs

According to UIUC public data [14], the average starting salaries for computer engineering is $105352 per year from 2020 to 2021. Without average working time, we just simply assume that the working time is 8 hours per day, 5 days per week and 52 weeks per year. Thus, our fixed labor costs are estimated to be $50/hour, 10 hours/week for four people. Neglecting the wastage of the PLA and other provided tools in the innovation studio, our labor cost for each person is:

$$\frac{50\$}{hour} * 2.5 * \frac{10hours}{week} * 16weeks = 20000\$$$

So the total labor cost for all partners is $80000.

Part	Manufacturer	Description	Quantity	Cost
Brushless motor	SUNNYSKY	V2216, KV800	2	$37.67
Servo	XUANTEJIA	MG996R	2	$4.93
Battery	GREPOW	14.8V 2400mah	1	$25.79
ESC	HOBBYWING	50A, XT60	2	$22.03
Receiver	FLYSKY	FS-iA6B	1	$8.55
Audio adapter board	SPARKFUN	Teensy 4.0	1	$67.82
Carbon tube	HONGWANGXIN	15*13*1000mm	3	$14.78
Fiberglass plate	CHUANGYIFU	500mm*500mm*1mm	2	$3.62
IMU	TELESKY	GY521 MPU6050	1	$1.67
TOTAL	\	\	\	$186.86

As shown above, our labor cost is $80000 and parts purchase cost is $186.86 in total. Thus, our total cost is $80186.86.

4 Schedule

Week	Tianqi Yu	Yanzhao Gong	Jinke Li	Qianli Zhao
03/06/2023	Brainstorming of aircraft structures and modeling of aircraft fuselage and skeleton structures in CAD design software.	Search related website for information about VTOL drone design, discuss the basic physical structure.	Read related materials to figure out what hardware is needed and understand the basic control logic of a VTOL drone	Consult relevant literature, draw the feedback control schematic with PID method
03/13/2023	Design of rotatable propeller section. Calculate the force and center of gravity.	Collect the information about the components that need to purchase and communicate with related shops.	Consulted relevant literature, found some relevant UAV hardware equipment, and chose our hardware equipment based on the calculated data	Draw a flowchart of the feedback control process. weld the mainboard TEENSY 4.0 and gyroscope.
03/20/2023	3D print the PLA parts and laser cut the glass fiber parts. Add protection part to gear set. Assemble the Drone.	3D print PLA parts and process related components, check the purchased components, assemble the drone.	Assemble the hardware equipment and connect the radio receiver and board	Connect and test the component, make sure that two motors and two servos can work properly
03/27/2023	After installing the first version of the model, we will look for points in the design that needs improvement and tried to improve them.	Search for problems of the drone and improve the entire structure.	Test the receiver through the controller and set the channels and pins of the board	Connect the control system to the power supply system to test whether each part can work properly
04/03/2023	Try vertical takeoff and optimize existing models.	Test the vertical takeoff function, discuss the problems found and try to improve the model.	Modify the code of the control subsystem and test the code	Write the code of feedback unit
04/10/2023	Lightweight slicing design for the wings.	Test light weight PLA printing for wings	Test and adjust the code so that the drone can fly smoothly	Copy our code into mainboard and try to control the drone
04/17/2023	Wing assembly and strength testing	Assemble the wings and test the strength	Test and adjust the code so that the drone can fly smoothly	Test and modify the code so that the drone could fly smoothly
04/24/2023	Test complete flight capability and make improvements.	Evaluate the flight capability of the drone and test.	Prepare for the final presentation	Prepare for final presentation
05/01/2023	Final report and presentation.	Prepare for the final presentation.	Prepare the final report	Prepare the final report
05/08/2023	Final report.	Final report.	Final report	Final report

5 Ethics and Safety

5.1 Ethics

Our design aims to improve the performance of current ordinary drones, providing the people with more convenient and efficient tools for production and life. After careful consideration of the UAV's functionality and potential range of applications, we promise that we would put the safety, health and welfare of the public first [15], refusing to provide any products or related technology to the wrongdoers in any way and prohibiting the use in espionage or military activities. Besides, in order to avoid "endangering the public and the environment" [15], we guarantee that we would inform relevant people of the possible potential hazards of our UAV products and preventive measures. Privacy concerns arise from the use of cameras mounted on the UAVs, which can capture images of people without their consent. This can be particularly problematic in public spaces, where individuals have a reasonable expectation of privacy. What's more, considering this is a design task, challenge and study process, we would accept honest criticism of our UAV, acknowledge and correct errors in time as well as making statements according to reliable data [15].

5.2 Safety

Safety is another critical consideration when it comes to the use of two propeller UAVs. These drones can be dangerous if not handled properly, particularly in crowded or densely populated areas. First, when testing the aircraft, we need to be very careful of the aircraft's high-speed rotating propellers, and to do brushless motor and remote-control power-off at the moment when hands are likely to touch the propellers. Secondly, we need to do a good job of fireproofing the electronic components. Water leakage and exposed wires may lead to short circuits, so we avoid flying on rainy days until we can ensure that the system is completely waterproof. Not only that, we should also try to avoid crowds and various facilities during the flight, so as to reduce the danger caused by the plane crashing. Also, we need to do a good job of heat dissipation of the electronic components to prevent the PLA materials used to build the main part of the aircraft from melting and deforming due to high temperatures. Some of the safety risks associated with two propeller UAVs include loss of control due to environmental factors such as wind, and malfunction or failure of critical components.

To ensure the safety of individuals and property, regulations have been put in place to govern the use of UAVs. These regulations include requirements for operator training, restrictions on where and when UAVs can be flown, and the use of safety features such as fail-safe mechanisms and automatic collision avoidance systems.

In conclusion, while the use of two propeller drones has numerous benefits, the ethics and safety of their use must be given utmost considerations. Ethics and the respect of people's privacy need to be enforced to avoid misusing them, while safety standards are needed to prevent accidents, damages, and injuries they may cause. As regulations for the use of UAVs continue to evolve, it is essential to ensure that their deployment does not interfere with established ethical and safety practices.

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