UTSA Senior Design II
Drone Conversion Appliances (DCA)
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Final Report
Fixed-Wing VTOL Quadcopter Conversion Module

Approvals

Title	Print	Signature	Date

Revision History

Revision	Summary of Change	Originator
X0	New Document	UTSA-ECE
X1	Formatting Fixes	UTSA-ECE

Contents

1. Executive Summary

This Final Report was put together by the Drone Conversion Appliances Team for the purpose of demonstrating and documenting the work the team has done throughout the Spring 2023 Semester. By the end of the Spring Semester, the team had created a drone that could switch between Fixed-Wing VTOL and Quadcopter modes without the use of any tools.

Although the final flight test unfortunately ended in a significant crash, the team is still proud of what they were able to accomplish during the semester, as a flight did occur. The main goal of having a drone that could feasibly switch between two separate flight modes was accomplished for the most part, and as a proof of concept the drone has exceeded our initial expectations. Specific features of the build that the team would like to point to are the carbon fiber rods added for stability, the 3D printed connectors placed at various spots on the drone to add parts such as servo motors, and the 'tilt rotor' functionality that allowed for the front two motors to rotate forward during fixed-wing flight, eliminating the need to add additional motors.

During the development of this project, it was decided that the 'Rover' functionality would be scrapped in favor of focusing solely on the fixed-wing portion of the build. This was a time-saving measure, as the team quickly determined that creating a stable fixed-wing build would take the majority of the semester, leaving little time to build a Rover module.

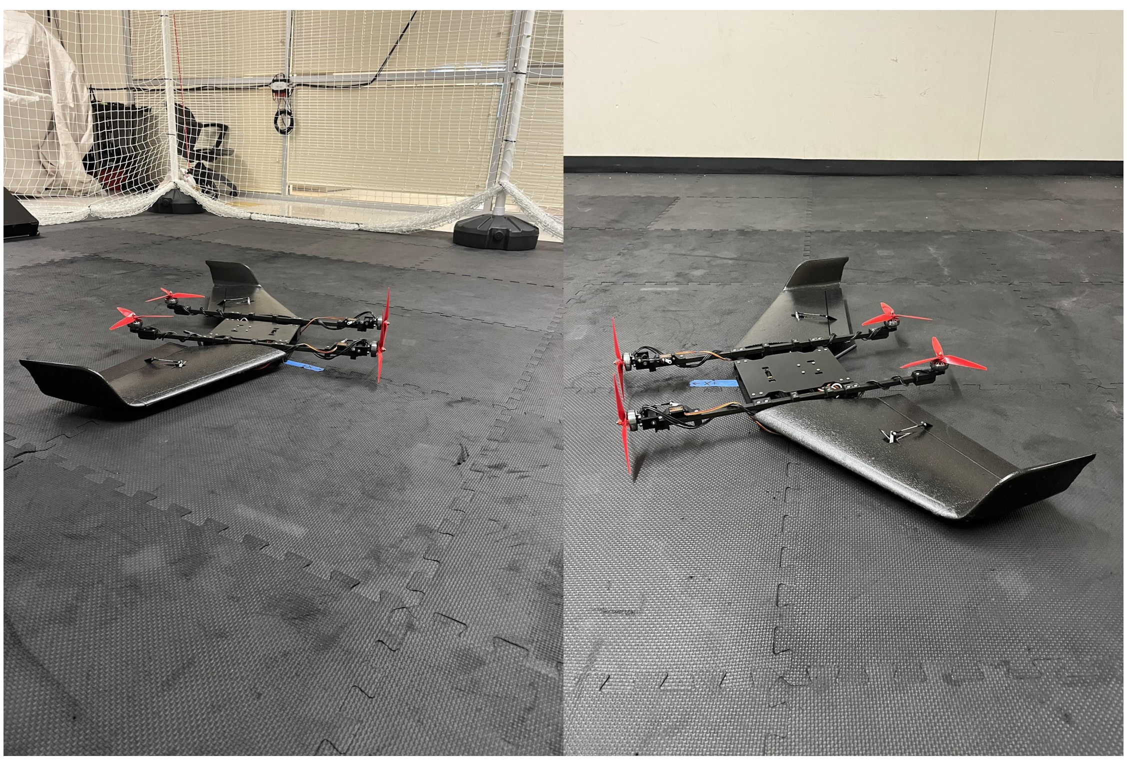


Figure 1.1 Final Fixed-Wing VTOL Module on Drone

2. Introduction

2.1 Overview

The way that a drone is designed and built has a massive impact on what roles that drone can accomplish. A drone that is built as a bicopter (such as a helicopter) will not operate the same as a drone built with the traditional four arms (also known as a Quadcopter). Neither of these drones will operate the same as a drone that is built as a Fixed-Wing vehicle (like a plane). Any applications that require the usage of multiple flight modalities leave a user with few options, and may lead to the purchase of multiple vehicles in order to fully cover the use case. This quickly becomes both costly and unwieldy.

A relatively new area of drone research has begun to provide an answer to this dilemma in the form of Fixed-Wing VTOL aircraft. This type of drone combines two of the most popular drone designs: the traditional Quadcopter and Fixed-Wing drones. This allows for users to get the best of both worlds, by having a vehicle that can hover in place, make sharp turns, and other Quadcopter-specific functions, while also retaining the ability to travel long distances due to lower battery consumption. However, even with this approach there are drawbacks, as users may not always need the full capability of a Fixed-Wing VTOL drone, and having the additional weight at all times will inevitably lead to diminishing returns. This is where the DCA team comes in.

This project is a collaboration with the ModiFly team, who have created a modifiable drone platform that significantly expanded the functionalities of a Quadcopter drone, essentially allowing users to have the benefits of multiple Quadcopter drones in one. The DCA team has added Fixed-Wing VTOL capabilities to the ModiFly drone, allowing a user to quickly and easily switch between a pure Quadcopter drone and a Fixed-Wing VTOL aircraft, all on the same vehicle. This novel concept has the potential to revolutionize the field of unmanned aircraft for years to come.

This product was designed as a proof of concept for the Unmanned Systems Laboratory, to eventually be extended into a released product on the market. The anticipated users for the eventual product would be a hobbyist drone consumer, a researcher, or an educator.

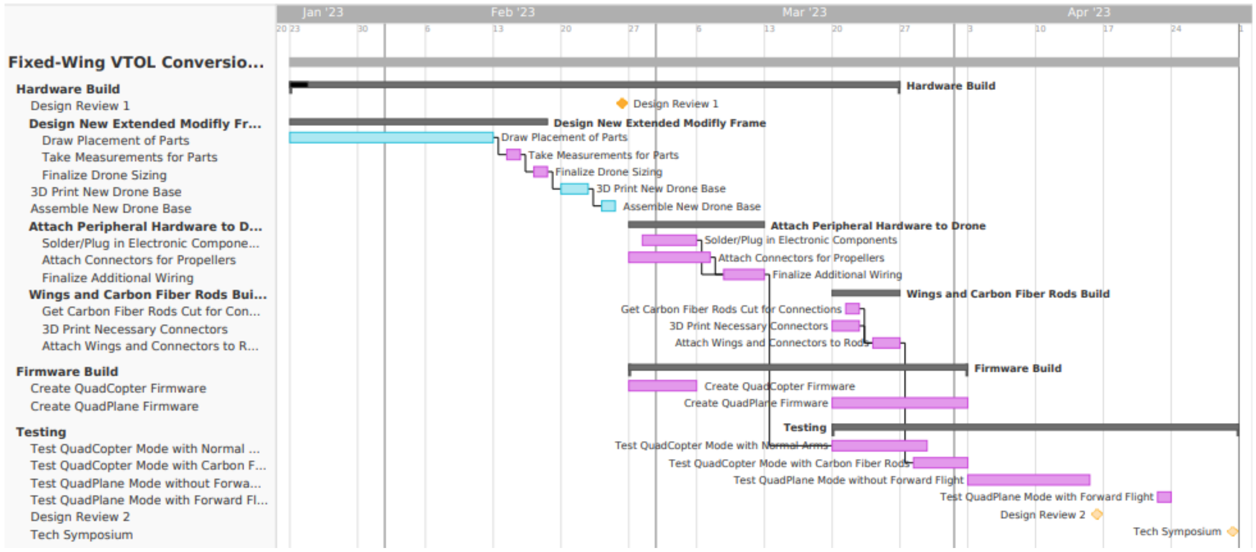
2.2 Document Introduction

This document contains the documentation and system requirements of the Fixed-Wing VTOL Conversion Module. The documentation and requirements come from the Unmanned Systems Laboratory, Ardupilot, and various FAA documents and rules for operation.

2.3 General Description

The DCA team identified three main criteria that they wanted the drone to accomplish. The drone needed to be backwards compatible with previous Modifly modules, it needed to have lower battery consumption in fixed-wing mode than previous Modifly drones, and the process of switching between the fixed-wing and quadcopter modalities needed to be quick and easy to perform by an average user.

2.4 Project Schedule



3. Need Being Addressed

The Fixed-Wing VTOL module provides a unique and versatile solution for researchers and professionals seeking a drone that can overcome the limitations of fixed-wing and quadcopter drones. With the Fixed-Wing VTOL market projected to grow by more than 500% between now and 2028, the need to have a vehicle capable of both fixed-wing and quadcopter flight is even more pronounced. [1] By having separate re-attachable modules for different movement options, operators can easily change the functionality of an unmanned system without having to purchase another system. Through the addition of a fixed-wing VTOL module, the ModiFly drone is an even more versatile and adaptable UAV that saves researchers and professionals both time and money.

4. Literature and Patent Search Results

Searching for relevant literature and patents related to this project proved to be a challenge due to the novel nature of the Modifly drone, and the added complexity of the fixed-wing module. However, one patent that helped to formulate the idea for the fixed-wing module did present itself, namely US Patent 10124890, or “Modular nacelles to provide vertical takeoff and landing (VTOL) capabilities to fixed wing aerial vehicles, and associated systems and methods.” [2] This patent was published in November of 2018 by Jaime G. and David Alejandro. The patent showcased a Fixed-Wing aircraft with an attachable VTOL module, making it somewhat the inverse of the DCA team’s project, however, it still served as a valuable source of inspiration for the module.

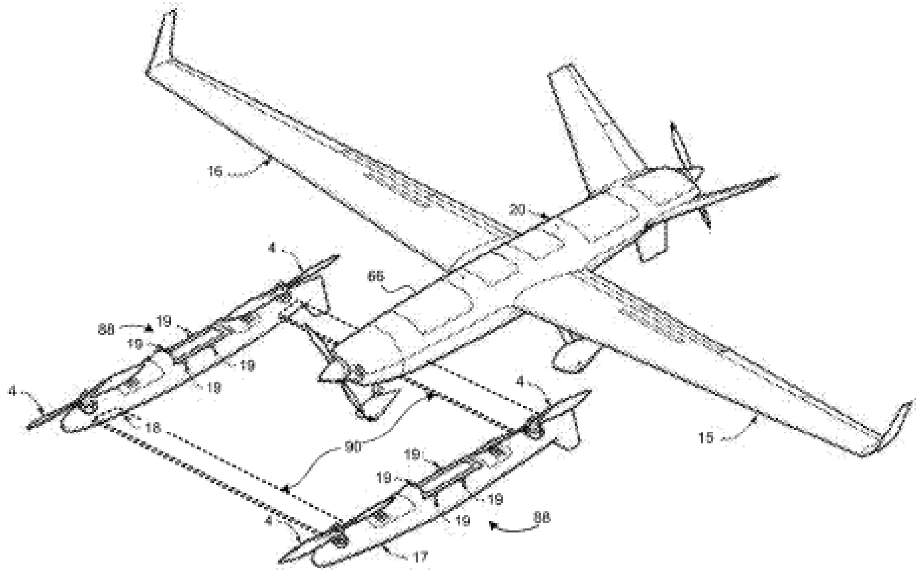


Figure 4.1 Jaime G. and David Alejandro's VTOL Module [1]

5. Marketing Analysis and Strategy

When analyzing the market around fixed-wing aircraft and drones in general, the DCA team took a few different approaches. First, the product was always meant to be a Proof-of-Concept for the Unmanned Systems Laboratory and Modifly team to expand upon in the future, as many of the necessary additions would need to be made in order to create a successful product for the market. That being said, research was still done into the market surrounding fixed-wing and quadcopter drones, and a few determinations were made. Namely, although the project was first developed with hobbyists in mind, as the 3D printed parts and low overall cost for the drone, as well as the projected rapid and significant increase expected in both the quadcopter and fixed-wing markets by 2028, the project seems more suited for research and/or law enforcement/military applications. [1] This is due to the factor of having two separate modes of transportation in one vehicle, allowing researchers as well as military and law enforcement to be able to quickly switch between the desired flight modes, without having to purchase separate systems. Therefore, the target demographic and overall marketing strategy for the product would be targeting drone researchers and government contractors looking for a versatile system with the ability to move between multiple different flight modalities.

Current competitors of this product are mainly limited to Fixed-Wing drones with VTOL attachments, as market research did not reveal any designs with a Quadcopter base and a Fixed-Wing VTOL module attachment. The competitors identified were the following:

- The OMP Hobby ZMO VTOL FPV Airplane PNF is a $1,099 USD FPV drone utilizing 3 propellers, with the front two tilting forward. Although it is a strong system, the VTOL attachments are not designed to be removed, making it a slightly different niche than the DCA project.
- The HEE WING T1 Ranger PNP-VTOL Conversion Kit takes a base Fixed-Wing drone and adds a $135.15 USD VTOL attachment. Once the VTOL portion is attached, removing it again becomes difficult. This is unlike the DCA team's Fixed-Wing VTOL Module, that can be attached and reattached freely.

6. Engineering Design Constraints

6.1 Global Constraints

Economic Constraints – Costs to make product
- Costs of prototyping unique filament
- Upcharging on American shipped parts
- Import tariffs on international components
- Fluctuating exchange rates affecting component prices

Schedule Constraints – Ability to tests prototypes
- Disruption to supply chain for drone circuitry
- Testing different frames with circuitry setup
- Availability of testing facilities
- Seasonal weather affecting outdoor testing conditions

Manufacturing Constraints – Cost of materials and setup of assembly
- Shortage of flight controllers
- Wasted filament for bad 3D prints
- Limited availability of skilled labor
- Increasing labor costs

Environmental Constraints – Battery restrictions and plastic waste
- Lithium Battery Shipments
- If the drone lights on fire, the plastic chemical emissions will be harmful to the user
- Recycling and disposal of electronic waste
- Noise pollution from drone operation

Sustainability Constraints – How sustainable is design and manufacturing

- Modularity may remove the need to buy more products once owned

- Drone identity circuit board requirement will change design slightly
- Energy consumption during manufacturing and operation
- Use of eco-friendly materials

Ethical Constraints – Designing drone to be mindful of customers

- Designs may be under designed for weight saving
- Will need to offer prop protection for younger customers
- Ensuring fair labor practices in manufacturing
- Addressing potential privacy concerns

Life-Cycle Constraints – How long is the potential life cycle of the product

- Battery degradation
- Vibrations could wear connections quicker than predicted
- Obsolescence due to rapid technological advancements
- Corrosion and wear of mechanical components

Safety Constraints – What safety concerns are present

- The drone could crash into people's property
- The drone could crash into people
- Electromagnetic interference with other devices
- Potential electrical hazards (short circuits, battery failure)

Quality Constraints – What level of quality is acceptable

- Part sourcing may change depending on shortages
- Quality of 3d prints
- Ensuring consistent quality control in manufacturing
- Warranty and after-sales support

Legal/Ethical Constraints – Legal requirements for use of product

- FAA regulations with the flight of these drones [3]
- Could someone place a weapon on the drone
- Intellectual property rights and patents
- Radio frequency spectrum regulations

6.2 Local Constraints

Economic Constraints – Costs to make product

- Costs of producing in Texas
- Taxes of manufacturing in Texas, or cost of importing
- Costs associated with local shipping and logistics
- Local labor costs and availability

Environmental Constraints – Local regulations and impact

- Compliance with local environmental regulations
- Local waste disposal and recycling facilities
- Local noise ordinances and restrictions
- Impact on local ecosystems and wildlife

7. Product Requirements/Specifications

This section of the document lists specific requirements and specifications for Drone Conversion Appliances. Requirements and specifications are divided into the following sections:

1. User requirements and specifications. These are requirements and specifications written from the point of view of end users, usually expressed in narrative form.
2. System requirements and specifications. These are detailed requirements and specifications describing the functions the system must be capable of doing.
3. Interface requirements and specifications. These are requirements and specifications about the user interface, which may be expressed as a list, as a narrative, or as images of screen mock-ups.

7.1 User Requirements and Specifications

7.1.1 User interface

The user interface will showcase each separate module's camera display allowing the user to operate each module individually through the flight controller. This is done through the pre-existing Ground Station that is compatible with Ardupilot.

7.1.2 Ergonomics

The Fixed-Wing VTOL module was designed with lift and drag in mind, as well as considerations to reduce flexing as much as possible. This was done by carefully cutting pieces such as the carbon fiber to not introduce any cracks or structural instability to the supports. The center of gravity for the drone was also determined and the components of the drone were placed with it in mind.

7.1.3 Training or Skills Required

A working knowledge of how to operate the drone in each different modular combination. There will be a need for a technical understanding of how the firmware works and how to modify different parameters to achieve desired results through Python. In addition, a basic understanding of aerodynamics and how to test 3-D models virtually. As well as training on how to use a 3-D printer will be needed. Piloting skills will be crucial as well, as a fixed-wing vehicle is difficult to control by nature.

7.2 System Requirements and Specifications

7.2.1 Physical Characteristics

- Frame with components loaded and wings attached weighs approximately 1200g
- Unloaded frame weighs approximately 900g
- Estimated payload capacity is 800g

7.2.2 Material Requirements

- Filament: Polylactic Acid, Polypropylene
- Wings: Styrofoam
- Supports: Carbon Fiber Rods
- Flight Controller/ Speed Controller/ Radio Transmitter: ArduPilot compatible flight controller

7.2.3 Electrical Requirements

- Operating voltage: 5V for Pixhawk, Radio Transmitter, Bluetooth Transmitter, Servo Motors
- Motor: 13A-40A
- BEC for connection to Flight Controller from battery

7.2.4 Abilities

- Fixed-Wing Flight
- Quadcopter Flight
- Quick attach modules for flight mode transitions

7.2.5 Limitations

- Small wingspan makes control during forward flight dubious under windy conditions
- FC may not be compatible with software other than Ardupilot and PX4
- Carbon Fiber rods may be prone to crack internally when subjected to pressure

7.2.6 Equipment or materials required to use the product

- 2.4GHz Radio Controller
- 4S LiPo Battery
- Part 107 FAA Drone Certification required for builds above 250g [3]

7.2.7 Equipment interface requirements

- Flight Controller must be loaded with appropriate firmware with parameters set

7.2.8 Handling and storage requirements
- Battery Optimum Storage Capacity 11.1V
- Battery Storage Temperature: 21°C
- Drone Storage Temperature: 21°C
- Store Drone and Batteries away from areas with excessive moisture
- Keep wings separated from drone frame when not in use to avoid damage to carbon fiber rods

7.2.9 Cleaning and Sterilization
- Components should be disconnected from battery prior to cleaning, and RC should remain off.
- Do not allow motors to spin without power to prevent electrical charge from damaging main assembly.
- Avoid touching FC/ESC/BC directly to prevent electrostatic discharge.
- Remove electrical components prior to cleaning.

7.2.10 Product maintenance and serviceability
- Prior to any flight ensure the drone's structure is not damaged.
- Prior to any flight verify that the electronic assembly is properly connected and damage free.
- Batteries must be fully disconnected prior to any maintenance.
- Remove and replace any damaged components and conduct flight tests after any installation.
- Allow components 15 seconds without battery prior to maintenance.
- Replace electronic/frame component as necessary.

7.2.11 Operating parameters
- Must comply with FAA Part 107 operating standards. [3]
- Do not operate in winds stronger than 5 MPH.
- Prevent water leakage onto any components of the drone.

7.2.12 Repeatability and reproducibility
- System may be used with no loss of features if system still has integrity and no
no physical damage to frame.
- 3D Printed parts that are damaged during operation of flight may be reprinted and replaced using the same or consistent filament.
- When replacing electrical components, attempt to use the same or similar parts. Untested components may lead to a loss of service or cause damage to the drone.

7.2.13 Reliability
- System has been tested to handle wind conditions up to 5 mph
- Degradation of frame is unlikely if maintained between 0° and 160° Celsius
- Carbon fiber rods may fail after repeated use if care is not taken to preserve the parts

7.2.14 Mechanical safety features
- Frame has been observed to handle crashes in indoor environments as well as outdoor environments with wind speeds of under 5 mph without major damage to the drone.
- Critical electrical components are housed within the frame to protect from damage upon crash.

7.2.15 Electrical safety features
- LIDAR object avoidance
- RC kill switch
- Mission Planner kill switch

7.3 Interface Requirements and Specifications

System Interface will primarily be done through the use of an open-source Ground Station called Mission Planner. A pre-existing UI is utilized for the purpose of uploading parameters for modules pre-flight.

8. Engineering Codes and Standards

The DCA team's Fixed-Wing VTOL Module was designed and built with the following standards in mind, in order to ensure all relevant safety and ethical considerations were met.

1. DO-178B/C: Software Considerations in Airborne Systems and Equipment Certification: This standard is a software safety standard that applies to airborne systems and equipment. It defines the requirements for software development, verification, and validation for safety-critical systems, including those used in aircraft. Compliance with this standard is essential to ensure the safety and reliability of the VTOL fixed-wing module, specifically in testing various features and aspects of the drone. It is the primary document by which FAA approve all commercial software-based aerospace systems and if our system is to be sold commercially as requested then it will need to meet these standards. [4]
2. IEEE 829-2008: Standard for Software and System Test Documentation: This standard specifies the requirements for documenting software and system tests, including test plans, test cases, and test results. Adherence to this standard ensured that the testing process of the fixed-wing module was thorough, consistent, and well-documented. [5]
3. IEEE 1939.1-2021 - Standard for Low Altitude Airspace Management Services: This standard defines a structure for low altitude airspace that enables safe and efficient unmanned aerial vehicle (UAV) traffic management. The standard provides guidelines for airspace design, operational procedures, and communication protocols to enable safe and efficient UAV traffic management. The DCA team's module was built with this standard in mind, to ensure all relevant design methods and communication protocols were met. [6]

9. Design Concepts

The DCA team's Fixed-Wing VTOL Module was created with a few different concepts in mind, including aerodynamic stability, ease of access, low overall cost, and easily replaceable parts. Multiple different design ideas were considered by the team before coming to a final conclusion for the prototype build.

9.1 Critical Components

VTOL Module Attachment Mechanism

- Wing stability
- Firmware
- Cost
- Module Compatibility with Drone
- Attachment process
- Propeller Attachment

9.2 Design Alternatives

1. VTOL Module
   - Multiple smaller modules
   - No Propeller
   - Control surfaces
2. Firmware Loading
   - One large firmware with different transportation modalities
   - Changing parameters as opposed to flashing new firmware
   - Have multiple firmwares already flashed on to the Flight Controller

9.3 Pugh Matrices

Pugh Matrix VTOL Module Attachment Mechanism

Critical Component	*Weight*	All-in-One VTOL Module	Multiple Smaller Modules	No Propeller	Flaps for Control
Wing Stability	15	7	3	1	10
Firmware Compatibility	28	9	3	4	10
Cost	10	8	6	10	4
Drone-Module Compatibility	13	8	3	7	8
Attachment Process	14	9	2	9	9
Propeller Attachment	20	9	10	1	9

Summary Table

Total	847	456	464	880

The findings from the VTOL Module Pugh Matrix have indicated that firmware compatibility is the most critical component, followed by propeller attachment for forward motion, wing stability, the ease of attachment process, and cost being the least significant factor. The prioritization of firmware compatibility was based on the fact that the drone will not be able to utilize the module for the VTOL Fixed-Wing mode in its absence. The propeller attachment was weighted next, owing to the need for forward motion to be provided, without which the fixed-wing attachment would only provide gliding capability, thereby decreasing flight time. The ease of attachment process was prioritized based on customer considerations, as complex attachment processes would dissuade customers from utilizing the Fixed-Wing module. Cost was ranked least important since it will generally only come into consideration with 3D printing filaments and various attachments, which will be relatively inexpensive compared to other drone components. The Pugh Matrix determined that using flaps for control marginally surpassed the All-in-One VTOL module. However, due to the prohibitively high complexity of using flaps, the All-in-One VTOL module was selected as the final choice. The no propeller and multiple smaller module options ranked poorly, as they either performed poorly in the critical criteria or did not address them at all.

Foldable Arms					
Critical Quality	***Weight***	**Fold another direction**	**Parallel Folding**	**Non Folding Wings**	**Pull Into Body**
Aerodynamics	25	10	3	1	10
Weight	15	7	7	7	6
Cost of Small Motors	5	7	6	10	7
Center of Gravity	20	8	2	2	10
Durability	10	5	5	1	9
Actual Folding Mechanism	25	10	8	1	6

Summary Table				
Total	850	500	255	815

In the Foldable Arms Pugh Matrix, the actual folding mechanism and the aerodynamics of the drone were identified as the two most significant components, followed by the center of gravity, the weight of the arms, the durability, and the cost of the small motors. The aerodynamics of the wings were deemed to be one of the most critical factors because the air flow and air pressure on the wings greatly affect drone performance. A well-designed aerodynamics system can reduce air pressure on top of the wing, leading to better speed and maneuverability. Non-folding wings can positively impact aerodynamics as they eliminate the need for an extra motor to fold the wings. The direction of the wing fold and whether they fold in parallel or not were found to have little impact on the weight and durability of the drone. Non-foldable wings provide benefits in terms of cost, aerodynamics, weight, durability, and center of gravity. The use of non-foldable wings would also eliminate the need for a folding mechanism. Pull-into-the-body wings were deemed advantageous for the durability, center of gravity, and aerodynamics of the drone. However, it would increase the drone's weight and cost as more small motors would be required to fold the wings.

Firmware Loading to Controller					
Critical Components	*Weight*	Microcontroller Loads Firmware	One Large Firmware	Change Parameters	Flight Controller has all firmware
Storage	10	9	8	3	10
Microcontroller signal to switch	30	10	0	10	0
State Control	30	10	10	10	10
Read Current Mode	15	10	10	10	10
Cost of Memory	10	9	8	3	0
Type of Memory	5	5	5	5	0

Summary Table				
Total	955	635	835	550

The Firmware Loading Pugh Matrix determined the critical components in order of importance as follows: microcontroller signals to switch between modes and state control were ranked equally as most important, followed by reading the current mode and storage and cost of memory, also ranked equally, and lastly, the type of memory used. Microcontroller signals to switch between modes and state control were prioritized because they determine the core functionality of the component, enabling the ability to switch between modes. Knowing the current mode was ranked next in importance, as it is necessary to switch between modes. Storage and cost of memory were deemed crucial in determining the ideal firmware loading method. The type of memory storage used was ranked as the least important component, as it is only relevant if the firmware flashing method fails. The top choice in the Pugh Matrix was found to be loading firmware through a microcontroller, as it addresses the most critical components. The runner-up option was to change parameters in the firmware instead of flashing new firmware. However, this option presents potential issues and complexity, as value changes, addition or removal of parameters, and proper functionality would need to be taken into account. Using one large firmware or having the flight controller hold all the firmware poses storage concerns, as the flight controller may not have enough capacity to store the firmware.

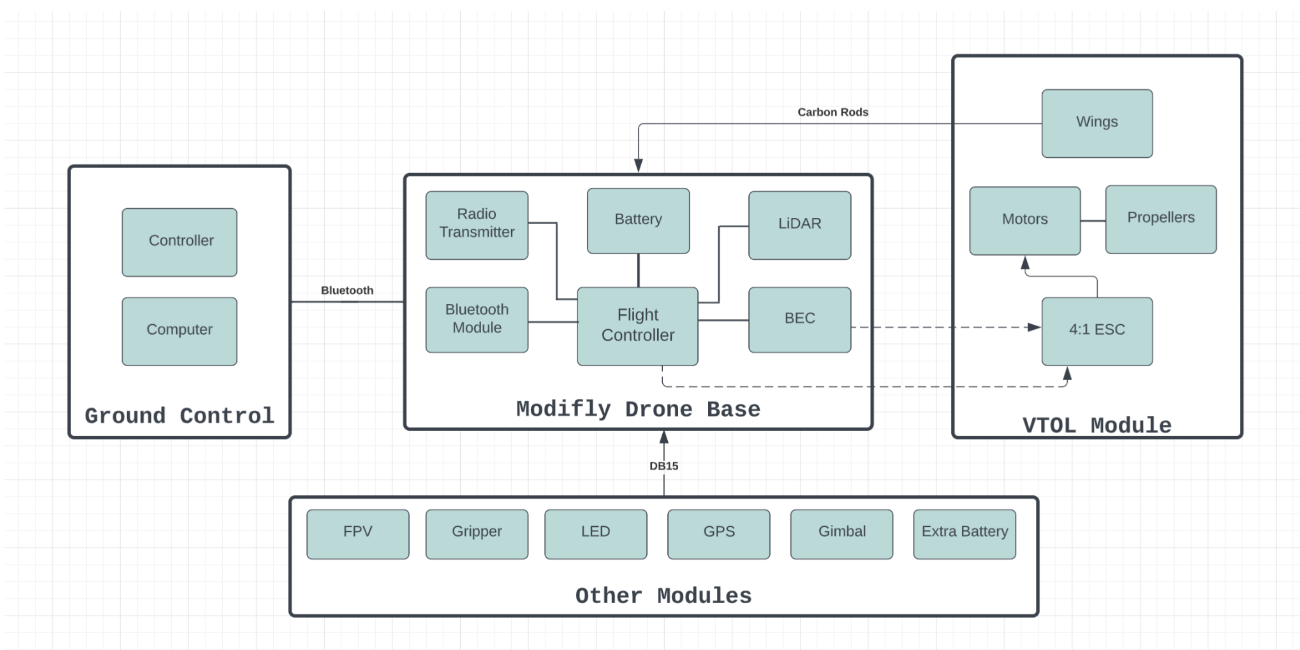
10. High Level Block Diagram

10.1 High Level Block Diagram

When developing the high level block diagram the team wanted to emphasize the critical components in our drone base and VTOL module and their connections. The components and connections highlighted in the block diagram play a large role in determining the limits of the drone. The HLBD displays the components within the drone base and their connections to the Pixhawk flight controller. It also displays the connection of the VTOL module and other modules to our ModiFly drone base.

The carbon rods were used to connect the wings of the VTOL module to the drone base while the DB15 connector allows the drone to connect to the ModiFly Drone's modules(shown as "Other Modules") which was needed to maintain reverse compatibility. The Ground control provided a mapping plan to decide how the software would work. The user can control the drone with a common radio receiver.

The HLBD is a simple diagram which shows the important connections and components involved and is a good tool for users who are familiarizing themselves with this system.



11. Major (Critical) Components

Image 1: Flight Controller

Flight Controller – PixHawk 4. The flight controller chosen for the project was the Pixhawk 2.4.8 FC. The previous flight controller from an earlier project in the lab (the Flywoo Goku F745) was determined to not have the hardware and software specifications required for the project. The Pixhawk, however, was not only already available in the lab (significantly reducing the total cost for the project), it also had the correct technical specifications needed for the project to be a success.

Technical Details:

- 32 bit 2M flash memory STM32F427 Cortex M4, with hardware floating point
- Main frequency: 168MHZ
- RAM: 256KB
- 32 bit STM32F103 back up processor
- Gyroscope: L3GD20 3 axis digital 16 bit
- Acceleration/Magnetometer: LSM303D 3 axis 14
- Acceleration/Magnetometer: MPU6000 6 axis
- Includes gyroscope, accelerometer, magnometer and barometer
- Does not include GPS
- 5 UART, one compatible high voltage, two have hardware flow control
- 2x CAN, 1x I2C, 1x SPI
- Spektrum DSM/ DSM2/ DSM-X satellite receiver compatible input
- Futaba SBUS compatible input and output
- PPM signal input
- RSSI(PWM or voltage) output
- 3.3 and 6.6VADC input
- External MICRO USB interface

Image 2: VTOL Wings

VTOL Wings – SonicModell AR WING PRO Wings. The team opted for the SonicModell AR Wing Pro wings, primarily because of their expansive wing spans and superior aerodynamic stability, which proved vital in bolstering our design's carrying capacity. Furthermore, the wings' length was deemed compatible with the current ModiFly design, further justifying our selection of this component.

Technical Details:

- Payload: (60-70g / dm2)
- SonicModell Wing Area: ~28 dm^2
- Wing Area (WA): Root Chord + Tip Chord2 x Wing Span WS
- Root Chord: 268 mm
- Tip Chord: 170 mm
- Wing Span: 1000mm
- Estimated payload capacity: 1680-1960g

Image 3: VTOL Motors

VTOL Propellors and motors: iFlight Xing-E Pro 2207 (4pcs) and 7-inch Tri-Blade Propellers (4pcs). The selection of these motors was predicated on their capacity for high-speed rotation, robust lifting capabilities, and balance, all of which were critical factors in enabling the heavier Modifly drone base to achieve liftoff.

Technical Details:
- Base Mounting Pattern: 16x16mm M3 Thread
- Motor Wire Length: 150mm / 20AWG
- Internal Resistance (Rm): 81.5mΩ
- Max Burst Current <10s: 35.22A
- Motor Dimension: 28.5x19.7mm
- Idle Current @12.6v (Io): 1.2 A
- Weight: 33.8g (150mm wires)
- Shaft Diameter: 4mm / Steel
- Max Power (W) 60s: 845W
- Magnets: N52SH Curved
- Stator Diameter: 22mm
- Configuration: 12N14P
- Bearing Size: 9x4x4
- Cells (LiPo): 2-6S

Image 4: LiDAR Module

LiDAR – The DCA team's code included obstacle avoidance functionality, which we implemented using LiDAR sensors. Specifically, we integrated the TF-Luna LiDAR single-point ranging module, which offered a low-cost solution capable of detecting objects up to a distance of 8m. This made it feasible to expand the design to incorporate the professional LiDAR module.

Technical Details:
- Detecting Range: 0.2m~8m
- Field of View: 2°
- Supply Voltage: 5V±0.1V
- Frequency: 100Hz
- Data Interface: UART/I2C
- Weight: 5g

Image 5: DB15 Connector

DB15 Connector – These connectors were previously used with the other ModiFly Drone's modules and were needed to maintain reverse compatibility.

Technical Details:
- Dimension: 39.5mm x 36.5mm x 16mm
- Wire Dimensions: 20 AWG
- Rated Current: 2A
- Rated Voltage: 24V
- Operating Temperature: -10°C~80°C

Image 6: VTOL Battery

VTOL Battery: Zeee 14.8V 4S Lipo Battery 50C 3300mAh. This battery was chosen for its small height (28mm), while still being a 4S battery. This was due to height limitations on the Modifly Drone base.

Technical Details:
- Dimension is(±2mm): 131*43.5*29mm/5.16*1.71*1.14 inch(L*W*H)
- Approx Weight(±15g): 348g/12.28oz.
- Material: Lithium polymer
- Battery voltage: 14.8V
- Configuration: 4S1P
- Capacity: 3300mAh
- Discharge: 50C
- Connector: XT60 plug

Image 7: BEC

BEC – UBEC Micro 5V/3A Adjustable BEC. The BEC was needed to provide a controlled 5V to the Pixhawk 4 serial bus in order to power the servo motors.

Technical Details:
- Output: 5V / 3A or 12V / 2A
- Dimensions: 5.1 x 4.1 x 2 cm
- Weight: 0.05 kg

Image 8: Radio Transmitter

Radio Transmitter – The transmitter chosen was the Futaba R3008SB. The transmitter uses s.bus2 protocol to exchange signals with the radio control receiver radio that will be used to control the drone when in a manual operating mode.

Technical Details:
- 2.4GHz signals
- 8/32 Channels
- Size: 0.98 x 1.86 x 0.56" (24.9 x 47.3 x 14.3mm)
- Weight: 0.36oz (10.1g)
- Power Requirement: 4.8-7.4V
- Battery F/S Voltage: Sets up with a transmitter
- Extra Voltage Port: 0 ~ 70V DC

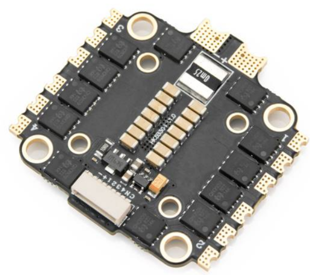


Image 9: 4 in 1 ESC

4 in 1 ESC – HAKRC 45A 2-6S BLHeli_S 4in1 ESC. The HAKRC ESC was deemed the optimal choice, given that the PixHawk 4 lacked a built-in 4in1 ESC, which was necessary for regulating the VTOL motors, a requirement that was previously met by the Flywoo Goku ESC. In addition, the HAKRC ESC has an identical mounting pattern as the PixHawk 4.

Technical Details:

- Operating Voltage: 2-6S
- Maximum continuous working current: 45A
- Maximum instantaneous working current: 50A
- Supported communication modes: DShot150/300/600 PWM Oneshot125, Oneshot42 and Multishot
- Software: BLHeliSuite
- Firmware Version: BL16.7
- Installation Hole: 20x20mm / 30.5x30.5mm
- Product Size: 44*44*5.5mm
- Net weight: 13.6g

12. Detailed Design

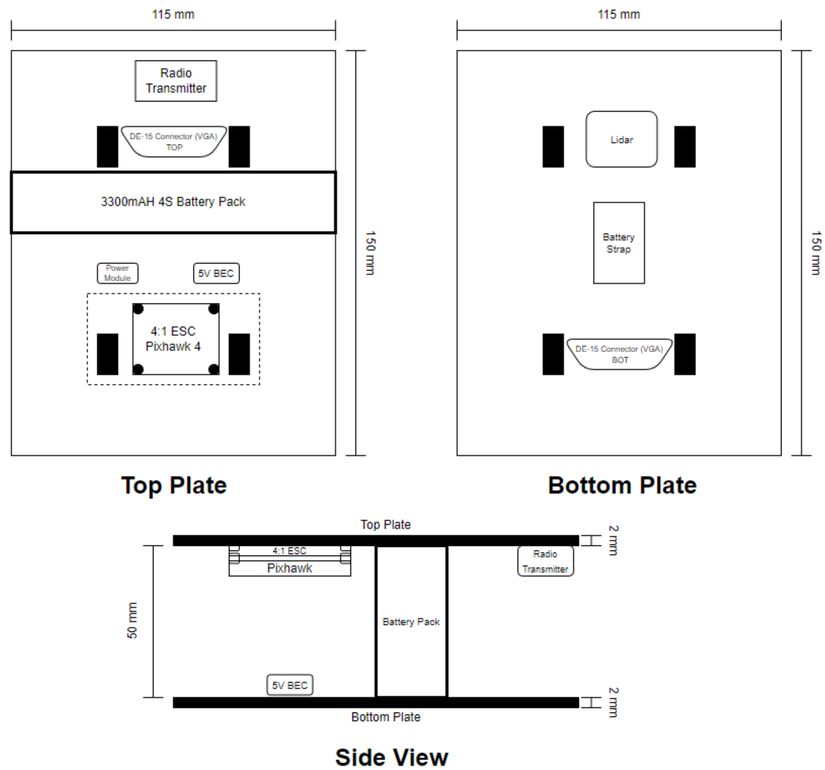
The design of the Fixed-Wing VTOL Module was done mainly through the hardware, with software being used mainly as a supplement in the areas where hardware design alone was not sufficient. Using the ModiFly drone as a base allowed the team to focus the majority of its efforts on the Fixed-Wing VTOL Module, saving much time and effort.

12.1 Hardware

Hardware design was instigated through the hard work of the DCA team, with assistance from the ModiFly team. Solidworks was used heavily in order to spur ideation within a 3D environment. This software proved to be a valuable asset, substantially accelerating the team's ideation process and streamlining decision-making regarding designs that could be printed. In addition, Solidworks' assembly function enabled the team to verify the compatibility of components and provided a comprehensive visual representation of their designs.

12.1.1 ModiFly Drone Body and Components

The drone frame was composed of four key electrical components, namely a flight controller, transmitter, Bluetooth module, and LiDAR module. During a team meeting, it was discovered that the Flywoo Goku F745 flight controller utilized in a prior project did not meet the requisite hardware and software specifications for this undertaking. However, the Pixhawk flight controller was already accessible in the laboratory, obviating the need for additional procurement expenses, and satisfying the precise technical requirements of the current project. As the team had prior experience with the transmitter, Bluetooth, and LiDAR modules from previous projects, no elaborate setup procedures were necessary to connect them to the Pixhawk flight controller. The selection of the Bluetooth and LiDAR modules was guided by their functionality and their compatibility with the ArduPilot software suite, as recommended on the ArduPilot forums. The drone frame design modifications were kept to a minimum in order to preserve backward compatibility with existing ModiFly modules and minimize production costs associated with filament consumption.



12.1.2 VTOL Fixed-Wing Module

In the development of the Vertical Takeoff and Landing (VTOL) Fixed-Wing module, the initial phase involved identifying feasible methodologies for securely attaching the wings to the existing Modifly drone base. The primary concept revolved around integrating the drone base into the fuselage of a pre-existing RC fixed-wing aircraft to optimize aerodynamics. As the team lacked comprehensive training in constructing an aircraft from scratch, this approach sought to circumvent potential challenges throughout the semester.

Upon presenting the preliminary design to the team's sponsor, they advised against utilizing an external design and recommended developing a reproducible solution in-house. Consequently, the team pivoted to employing motor mounts as the primary attachment interface between the VTOL booms and the drone base. Subsequently, Solidworks was employed to design components that were compatible with the existing wing attachments while ensuring resistance to vibrations.

A vital aspect of the module's design and positioning involved maintaining appropriate weight distribution around the center of gravity (CG). As the CG is the point at which an aircraft's weight is balanced, it considerably influences flight characteristics. To achieve the desired weight distribution around the CG, several methodologies and processes were adopted.

The initial step entailed determining the recommended CG location for the specific aircraft model, typically measured as a distance from the leading edge (LE) at the wing root. Utilizing a balancing pole, the aircraft was balanced at the recommended CG location, and its position adjusted until it remained level without tilting. This assessment facilitated the identification of nose or tail heaviness, with a preference for slight nose heaviness due to its less detrimental impact on flight behavior.

Subsequently, the team cataloged all components and their corresponding weights, strategically positioning them within the drone base to attain optimal balance. Post-adjustment, the balance was rechecked to confirm the aircraft's level position at the desired CG location. Test flights were conducted to verify stability and handling characteristics, with adjustments to weight distribution implemented as needed until optimal performance was achieved.

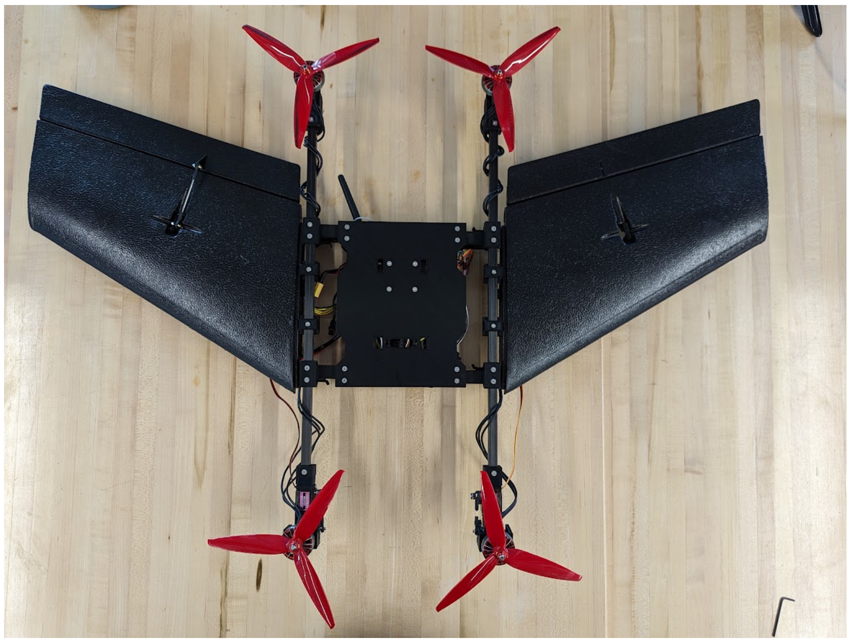
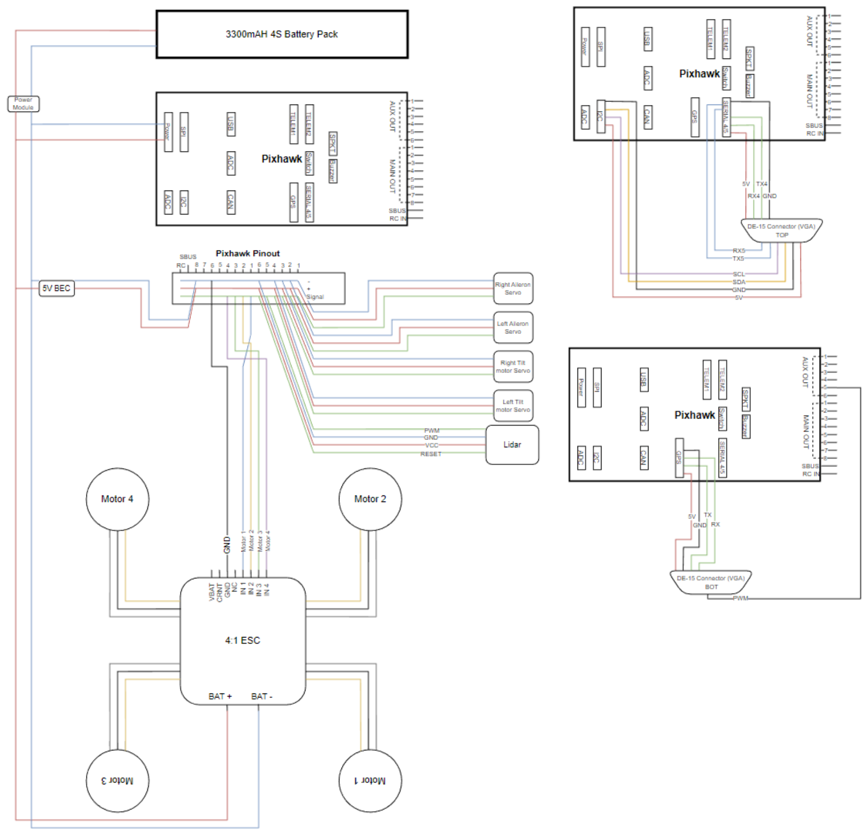


Figure 12.1 Intermediate prototype of the Fixed-Wing Module

12.1.3 PixHawk Connections



The implementation of a 4-in-1 Electronic Speed Controller (ESC) HAKRC 45A 2-6S BLHeli, in conjunction with the PixHawk 4 flight controller, was critical to ensure precise communication and motor management. The team meticulously connected each motor's threefold wiring assembly to the corresponding motor output pads on the 4-in-1 ESC through the process of soldering. The power input leads (red and black conductors) of the ESC were soldered to the power module, adhering to the specified voltage output pads (2-6S LiPo battery voltage) in alignment with the ESC's stipulations.

The HAKRC 45A 4-in-1 ESC engages in communication with the PixHawk 4 via Pulse Width Modulation (PWM) signal transmission. The ESC encompasses a singular plug with an assortment of conductors to transmit these signals. The signal conductors (one per motor) and the ground conductor were interfaced with the PixHawk 4's MAIN OUT ports (1-4, aligned with our quadcopter configuration). Subsequently, the team ensured that the signal conductors were connected to the designated signal pins and the ground conductor to the ground pin.

Before system initiation, the team executed the configuration of the PixHawk 4 and ESCs through the Ground Control Station (GCS) Mission Planner. The preliminary setup process included firmware updates, accelerometer calibration, compass calibration, and radio calibration.

The ESCs were configured in accordance with the "ESC Calibration" protocol outlined in the GCS software. This procedure ensured the ESC's ability to discern the entire spectrum of PWM signals originating from the PixHawk 4, enabling precise motor manipulation.

Following this, the team powered the system using a LiPo battery compatible with the ESC's specified voltage range and evaluated the motor rotation direction. In cases where motor rotation was erroneous, the team swapped two of the three motor conductors linked to the ESC and reevaluated. Upon completion and validation of all connections and configurations, the team finalized the assembly by securing the ESC and PixHawk 4 to the drone frame.

12.2 Software

The software design of this project mainly consisted of working with the Ardupilot firmware, and changing the appropriate parameters to allow the flight controller to work efficiently. The team did extensive research into the Ardupilot documentation in order to ensure the firmware worked correctly. Much of the research in this area focused on the Quadplane parameters, including but not limited to: determinations on the tilt rotor to choose between continuous transition and vectored yaw transition; working with the PID settings in the firmware in order to eliminate vibrations; working to get the GPS module receiving data from satellites and transmitting the data correctly to Ardupilot; and making determinations for the range of the tilt servos.

Initial parameters were set following the standard Ardupilot documentation in order to get the drone to a state where it could perform basic functions. Specifically, the team found the typical parameters for a tilt-rotor Quadplane that was built in an X-Frame configuration, and used the generic parameters given from the documentation for the initial tests. Following this, testing was done to see where the drone was performing suboptimally. Once the initial phases of testing were concluded, the team surveyed through documentation and forum posts in order to determine what parameters in the firmware were causing the poor performance. From there, the parameters were incrementally changed, then tested, to find the “sweet spot” where the drone would perform to standard.

Overall, due to the nature of the project the software was not the main focus during development, however it did serve an important purpose for the success of the drone, and appropriate consideration and time was spent on this aspect in order to limit crashes and drone failures.

12.3 Engineering Analysis and Calculations

12.3.1 ESC, Motor, and Battery Combination Analysis and Calculations

In determining the combination of ESC, motors, and battery the team examined the performance and power requirements of each component. Here is a step-by-step analysis and calculations involved:

Motor selection: Key parameters for motor selection are kV rating, motor size and weight, and efficiency. We selected the iFlight Xing-E Pro 2207 1700 kV motors with 7-inch Tri-Blade Propellers.

Motor performance calculation: With a 1700 kV rating and 14.8V battery, the motor RPM can be calculated as follows:

Motor RPM = Motor kV * Battery Voltage
Motor RPM = 1700 * 14.8 ≈ 25,160 RPM

ESC selection: The ESC must be compatible with the motors' current draw and battery voltage. We selected the HAKRC 45A 2-6S BLHeli_S 4in1 ESC.

Motor current draw compatibility: The HAKRC 45A ESC is rated for a continuous current of 45A per motor channel. The iFlight Xing-E Pro 2207 1700 kV motors have a maximum current draw of 35.22 amps (for 180 seconds). Since the motors' maximum current draw is well below the ESC's continuous current rating of 45A, the ESC is suitable for these motors.

Battery selection: The battery should provide the required voltage and capacity to power the quadcopter. We selected the HRB 4S Lipo Battery 3000mAh 14.8V 60C.

Battery compatibility: The HAKRC 4:1 ESC supports a 2-6S LiPo battery, which means it can handle battery voltages from 2S (7.4V) to 6S (22.2V). The HRB 4S Lipo Battery has a voltage of 14.8V, which is within the supported voltage range of the ESC.

Estimate motor thrust: To estimate the motor thrust, we can refer to manufacturer's data sheets, use online calculators, or conduct empirical tests.

The motors provide the following thrust values at different throttle levels:

50% throttle: 483g
60% throttle: 622g
70% throttle: 799g
80% throttle: 1051g
90% throttle: 1189g
100% throttle: 1391g

Calculate total thrust for the quadcopter at 100% throttle:

Total Thrust = Thrust per motor * Number of motors
Total Thrust = 1391g * 4 = 5564g

Determine lift capacity: For a stable flight, it's recommended to have a hover throttle level between 50-70% so that there's enough headroom for maneuvering and stability. We assumed a throttle of 60-70%, which provides 622g-799g of thrust per motor.

Lift Capacity = Total Thrust - Quadcopter Weight

Total Thrust at 60% throttle = 622g * 4 = 2488g
Lift Capacity = 2488g - 1914.3g = 573.7g

Total Thrust at 70% throttle = 799g * 4 = 3196g
Lift Capacity = 3196g - 1914.3g = 1281.7g

These values indicate that at 60-70% throttle, the lift capacity would be approximately 573.7g - 1281.7g.

13. Major Problems

During the development process, the team encountered a major issue with oscillation, which caused instability during flight. Oscillation is a common problem in drones and can be caused by various factors such as unbalanced propellers, uneven weight distribution, incorrect motor or propeller settings, poor calibration of sensors, wind or weather conditions, and pilot error. To address this issue, the team undertook a thorough investigation into the potential causes of the oscillation and implemented several measures to address the issue. Firstly, the team switched out the motors with fresh motors to help isolate the issue. They then checked the weight distribution in relation to the center of gravity and made adjustments to ensure that the weight was evenly distributed. They also calibrated the 4:1 ESC, PID controller, accelerometer, and gyroscopes to optimize the performance of the drone. The calibration involved following the instructions provided by the manufacturer and using software tools to adjust the gain settings of the PID controller and ensure that the sensors were accurately measuring the drone's orientation and movements. As a result of the measures implemented, the team was able to successfully eliminate the oscillation and improve the stability and performance of the drone. The drone was able to maintain a stable hover.

During the last part of development, a major problem was realized late enough that it could not be revised by the completion date. During the VTOL to forward flight test, it was observed that the drone was swept away by the wind after successfully flying forward for several seconds. We believe that this was due to the drone base itself being open to the air, allowing the wind to have a larger, flat, surface area to push and pull the drone. This caused loss of control of the drone, and the kill switch had to be pulled to prevent it from flying into power lines. The drone plummeted to the ground, mostly in one piece. A proposed solution is a 3D printed “cone” to attach to the front of the drone that matches the angle and curves of the wings. This would help the aerodynamic profile of the drone and make it easier to control.

14. Integration and Implementation

14.1 Initial Construction and Test Hover

Before even thinking about taking a first flight, we had to decide how to build and attach our new fixed wing VTOL module. We went through several interactions on paper such as removing the quadcopter arms and dropping the drone base as is into a larger remote control plane, and plugging it in, but ultimately decided on using the SonicModell wings and fixing them to a carbon fiber rod to start with. On the new wing module, there are corresponding plugs to simply snap and plug into where the arms would be in quadcopter mode. At the end of the carbon fiber rods, we designed and 3D printed a mechanism to affix the VTOL motors to the arms, as well as a small mechanism that will allow the front motors to tilt forwards when transitioning from VTOL to forwards flight. The drone was assembled as both a quadcopter and in fixed-wing VTOL mode so that testing could commence.

14.2 First Tests at Hovering

Once the connectors were finalized and the drone was constructed, testing began in the dedicated testing space within the USL lab. First, we attached the quadcopter arms to do a small test flight as a quadcopter drone. The drone had to pass this test, as the goal is to have a single firmware handle quadcopter mode as well as fixed-wing take off, as well as flying as a fixed-wing drone. After some adjusting of the variables within Ardupilot, we were able to tune the PID controller to achieve a stable hover while gently moving in all 4 cardinal directions. The next test was to complete the same test, but with the fixed-wing modules attached. We were able to successfully repeat the same test as above, with the same firmware.

14.3 Test Flight Outdoors

Due to space constraints, we were unable to test both transitioning from vtol to forward flight and the forward flight itself indoors. These tests had to be performed outdoors, on a day where the wind was least likely to affect the performance of the drone. The drone was placed on the ground, in a fixed-wing configuration and powered on. First we made the drone liftoff in VTOL mode to an acceptable altitude, which it did successfully, and initiated the transition to forward flight. During transition, the drone dropped in altitude but was able to successfully transition and start flying forward. Unfortunately, this is where the testing stops, after a few seconds of successful flight the wind caught the drone and control was lost. The kill switch was pulled and the drone was allowed to plummet to the ground. Only 3D printed parts and one propeller were damaged to a point of needing replacement, making repair a cheap and easy endeavor.

15. Comments and Conclusion

The project was a fun and challenging experience that gave everyone a real taste in what it can be like to work on a team designing a new product. Many ideas on how to make it to the final product were thrown around, but many never actualized themselves in a tangible manner.

None of the team had any experience beforehand in 3D modeling, and having at least 1 member who had access to the software and a printer to learn on or having previous experience would have helped speed along design and prototyping. We had outside help with much of the design and printing of our custom parts, as well as providing insight into what we wanted and whether or not that it was something feasible or even worth trying to implement.

One example of all of the above was deciding how the wings were going to be attached to the base of the drone. One idea that we had considered was placing the drone base into an airframe that had been modified with VTOL motors, and just plugging all the components into the drone base. While a novel idea, it ultimately didn't line up with the goal of the project and, if implemented, would have meant more total weight of the drone and a longer time to transition from quadcopter to fixed-wing modes.

16. Team Members

16.1 Conrad Obeng

Conrad's role in the project was to act as a liaison between the Unmanned Systems Laboratory and the DCA team. He also acted as the team's project manager, ensuring that the project moved forward at a steady pace, and was able to be completed before the 2023 Tech Symposium.

His additions to the team included work on the drone's firmware, submitting parts to be purchased by the USL, work on the drone hardware during assembly, aiding in testing and test flights, various documentation of the project, aiding in the finalized design for the project, and his previous experience with the Ardupilot software allowed him to aid in troubleshooting software issues that came up during the course of the project.

16.2 Matthew Moubray

Matthew was assigned the responsibility of guaranteeing a dependable and robust Vertical Takeoff and Landing (VTOL) Fixed-Wing Module. His contributions encompassed providing assistance and finalizing the design of the three-dimensional (3D) components for the quadcopter and VTOL fixed-wing module, implementing a 4-in-1 Electronic Speed Controller (ESC), calculating weight distribution and optimizing component placement, as well as conducting thorough testing and verification of the integrated system.

16.3 Lexi McMinn

Lexi's role in the project was to aid in the conception and design of the fixed-wing modules, as well as providing support in most facets of the project.

Her additions to the team included aiding in the construction of the fixed-wing modules and decisions involving what motors should be used in fixed-wing mode, as the increased weight of the wings was a major concern early on in the design process. She also participated in the testing of the drone and tuning of the firmware.

16.4 Mark James, jr.

Mark helped to work on th modifly drone project, where he played an integral role in both its conceptualization and building process. As part of his contribution, Mark worked on figuring out the correct parameters for ardupilot firmware, this involved carefully analyzing and adjusting the various settings that would allow the drone to function optimally, ensuring it would be capable of performing the tasks it was designed for.

16.5 Ehab Afsoonko

Ehab's role in the project was documentation lead and was responsible for the formatting and editing of the team's documentation while also working on the drones hardware assembly.

His addition to the team included attaching the VTOL fixed wing module to the ModiFly quadcopter base and connection of motors and propellers to the carbon rods. He also participated in testing of the drone and tuning of the firmware.

17. References

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