Fixed-Wing VTOL Design Document

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Date: 14 October 2022

Overview

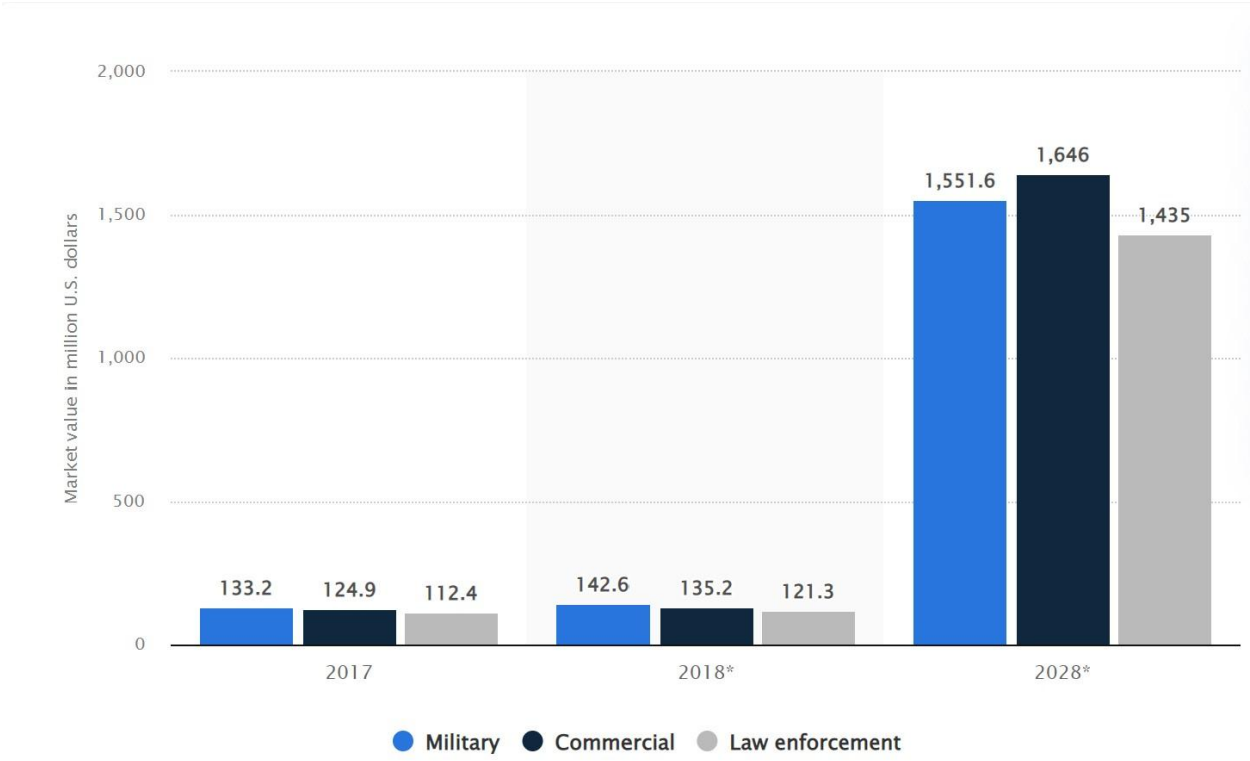
This document is intended to describe the process of creating the VTOL Fixed-Wing module for the ModiFly Drone system. This is meant to be utilized by the members of the D2R team, the members of the ModiFly and USL teams, and any other related persons looking for an overview of the Fixed-Wing module design. This document assumes base level familiarity with QuadCopter/QuadPlane systems and the associated Autopilot, however a brief appendix is maintained at the end of the document, as well as a section for FAQs.

Problem

Currently, the ModiFly drone only has QuadCopter capability. This is the design that has 4 arms with a motor at each end. Although this design allows for vertical take-offs and landings, as well as fast turning and hovering capabilities, the QuadCopter design limits the length of flights, specifically through battery life constraints. For a significant portion of high-level applications, longer range flights with similar battery life consumption is a crucial factor when end-users are considering which drone system to proceed with. However, maintaining the advantages of the traditional QuadCopter design is still important in order to cover applications requiring fast turning and/or smaller airspaces.

Business Justification

The VTOL Fixed-Wing UAV hybrid market is expected to grow by over 1000% by 2028, according to a forecast analysis from BIS Research.



Size of the global fixed-wing hybrid vertical take-off and landing (VTOL) UAVs market from 2017 to 2028, by end-user

Requirements

The proposed solution should:

- Allow for flight times longer than currently available in the QuadCopter arm design.
- Retain vertical take-off and landing functionality.
- Not irrevocably alter the existing drone design.
- Be relatively easy for an end user to implement.
- Allow for a payload or other module to be attached to the drone.

Out of Scope

This design will not:

- Replace the existing QuadCopter design.
- Retain the fast turning and hovering of the QuadCopter functionality.
- Require the usage of a secondary drone.
- Have the ability to be implemented in real time during a flight.

Success Criteria

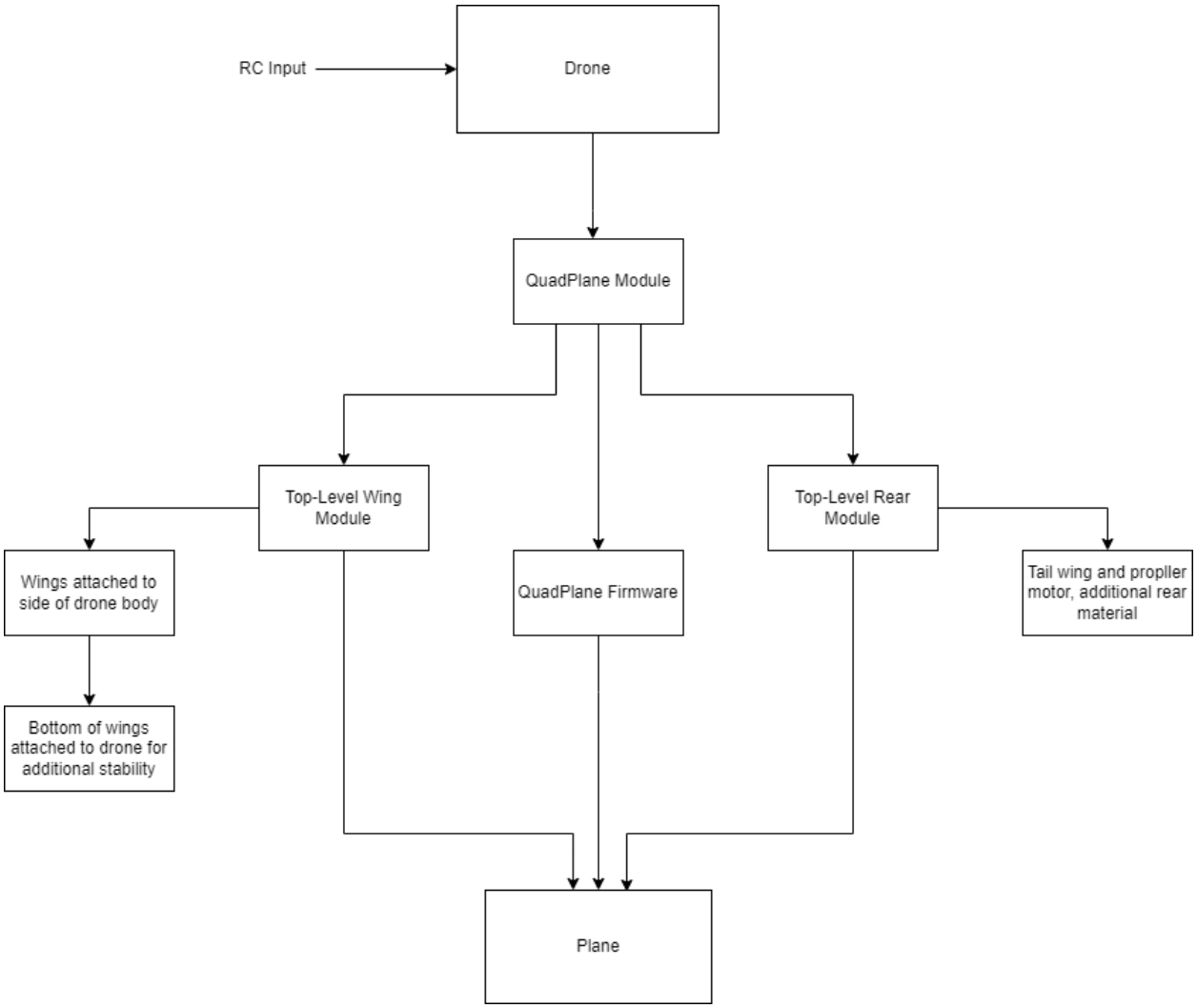
- Battery consumption reduced by a minimum of 10%.
- Flight time increased by a minimum of 10%.
- Added weight constrained to under 30% of maximum drone load capability.
- Consistent flight (minimal crashing/stalling).

Architecture

The proposed solution will be implemented as a top-level module on the ModiFly Drone. The side wings will sit just below the quadcopter arms, and a tail wing with a rear propeller will be attached to the backside of the drone body. According to the Ardupliot website the existing Flywoo Goku board used for Quadcopter flight will be compatible with the Plane module. The eCalc website will be used for determining aspects such as the length of the wings required, as well as the length of the tail, and motor requirements.

High-Level Design

- Top-level module with side connectors for the wings, as well as a rear connection for the tail wing and propeller motor.
- Quadcopter arms for vertical take-off and landing capabilities.
- Functionality allowing for firmware switch from Quadcopter to Quadplane.
- Attachment at bottom of the wings to drone to provide additional stability for the wings.
- Sufficient power in the quad motors.
- Full clearance above and below disk area of quad motors.
- Parameter setting for Quadplane.
- Flight controller.
- Sufficient side wing and tail wing length.



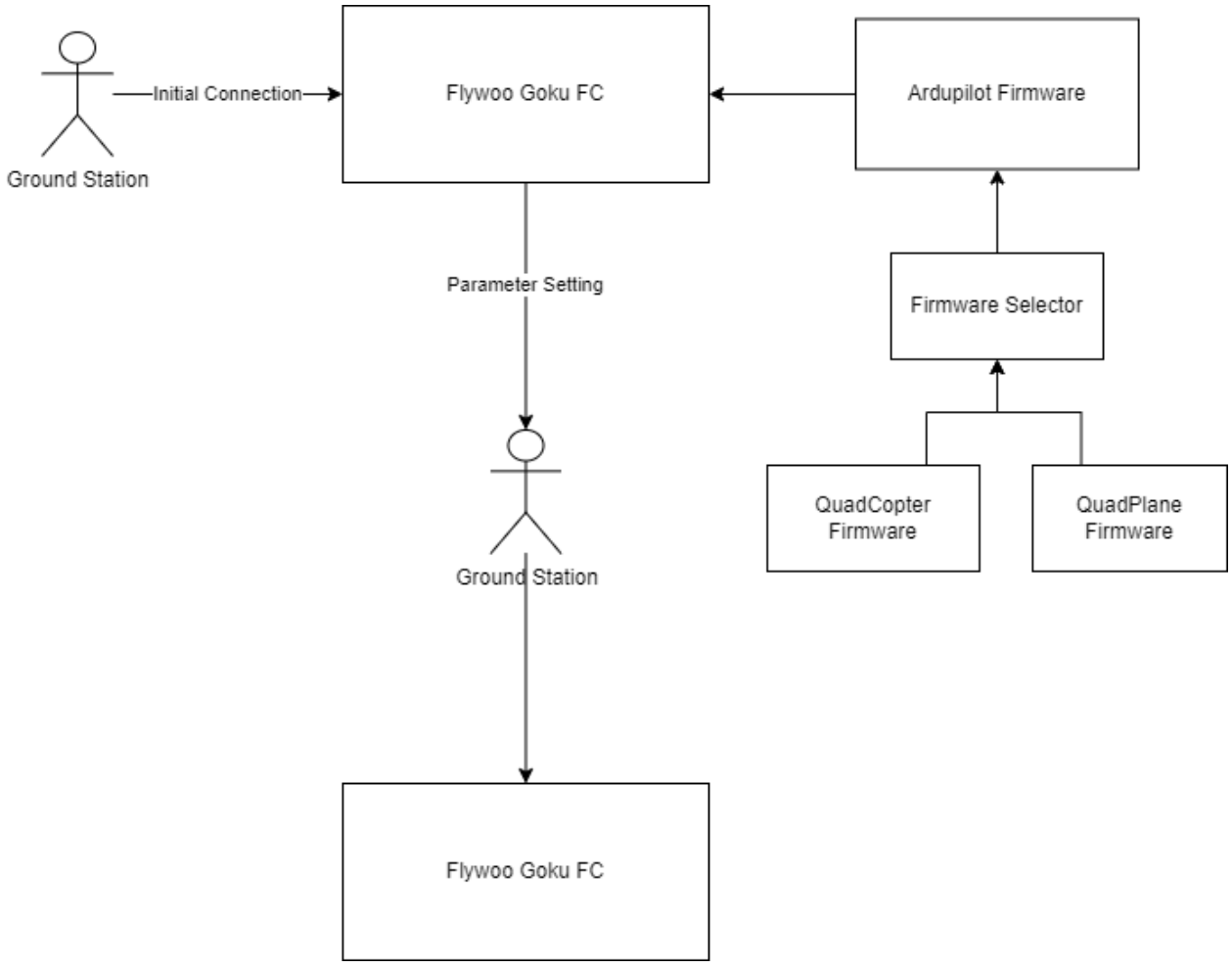
QuadPlane High-Level Design

Software Component-Level Design

Ground Station:
Mission Planner is compatible with the QuadPlane design and Ardupilot. Since familiarity with this system has already been established through previous work on the ModiFly drone in Quadcopter format, continuing the usage of Mission Planner will be the most time efficient method, specifically for testing. The UI developed for the ModiFly drone should be kept up to date with any QuadPlane requirements until implementation.

Firmware:
All of the Quadplane parameters start with ‘Q_’, and are generally similar to the Quadcopter parameters. Q_Enable will need to be set to 1, then parameters should be refreshed.
The Frame Type will be Quad (1) and the Frame Class will be X frame (1). Motor order and output will remain the same as the Quadcopter firmware, however the output channel numbers will start at 5 rather than at 1.

Parameters:
Q_Enable = 1 (refresh parameter list)
Q_M_PWM_MIN = PWM range of quad motors
Q_M_PWM_MAX = PWM range of quad motors
Q_A_RAT_RLL_P = Important tuning parameters
Q_A_RAT_PIT_P = Important tuning parameters
Q_M_SPIN_ARM = Correct level of motor output in quad mode
Q_OPTIONS bitmask



QuadPlane Software Component-Level Design

Hardware Component-Level Design

- Side Wings (Fixed-Wing Frame): The side wings will need to be long/wide enough in order to maintain lift, as well as be securely fashioned to the side of the drone. In order to maintain stability, these may have to attach to the side of the drone, which would require slight modifications to the original ModiFly design. More testing will be needed to determine whether this will be the case.

- Tail Wing: The tail wing is generally seen to be a critical component for plane design, and will be added to the rear of the Fixed-Wing module.
- Rear end/Forward Propeller: The forward propeller will be used to help move the drone after take-off. Using the single propeller instead of the four used for take-off and landing will reduce the battery consumption.
- Battery: The existing batteries should be more than sufficient for the design, as the main goal of this module is to reduce the existing battery consumption. If a longer lasting battery is to be required, the design will need to be revisited.
- Flight Controller: The current Flywoo Goku F745 Flight Controller already being used for drone functionality is said to be compatible with the Arduplane firmware.

The final design will need to take into consideration aerodynamics. The existing drone has a rectangular shape that will need to be worked around in order to allow for lift, while also reducing drag as much as possible. This will require extensive research, which should be initiated as soon as possible.

Dependencies

The two software dependencies interacted with here are Ardupilot and Mission Planner. Mission Planner may only be used for testing. In this case, the Mission Planner Ground Station would be replaced with the custom UI being worked on by the ModiFly team. Because Mission Planner/the custom UI will only be used for parameter setting and other pre-flight checks, we do not rely on these systems for actual flight. After flight, the Ground Station may be interacted with for flight-logging purposes. The Ardupilot firmware will be utilized during flight. From previous experience, the firmware does not tend to have issues during flight, so assumed risk is minimal. The hardware dependency is the existing ModiFly drone. Because of the modular nature of the drone, it is ideal for this project. However, since it is a relatively new product, documentation is not at a robust level, making troubleshooting difficult.

Alternatives Considered

Splitting the module into several different parts (i.e. one for the side wings, one for the tail, and one for the propeller) was discussed, but was determined to not be worth the increased cost, as it would remove little weight from the drone.

Failure Modes

Potential failure points include:

- Stalling
- Wing breakage
- Inability to achieve lift

Cost Analysis

Component	Cost	Analysis
Ardupilot	N/A	Open-Source Platform
Mission Planner	N/A	Open-Source Platform
Side Wings		
Tail Wing		
Rear Propeller (Forward Motor)		
Quad Motors		
Battery		Existing Battery to be utilized
Flight Controller		Existing Flight Controller to be utilized

Non-Functional Requirements

Scalability

The modular nature of this design will allow for future improvements to wing length and the propeller motor. Due to this, it may be worthwhile to investigate having detachable wings and propellers.

Testing

The eCalc software will be used for initial testing/designing of the Fixed-Wing module. After the hardware has been designed/built, testing will need to be done in an open area. This will most likely require obtaining a permit for flying an Unmanned Aerial Vehicle.

Success Metrics

Success will be determined by:

- Ability for Drone to achieve Vertical Take-off.
- Ability for Drone to achieve Vertical Landing.
- Flight time greater than currently possible with Quadcopter design.
- Reduced battery consumption over same flight length as Quadcopter design.

Concerns

The existing ModiFly drone has a rectangular shape. Converting this into a QuadPlane design may be difficult, as the plane design requires a wide front and narrow tail. Having the four motor arms remaining on the drone will add dead weight to the drone, so battery life constraints may still be an issue.

Future Improvements

FAQs

Appendix A: ModiFly Drone

Appendix B: Ardupilot

Appendix C: QuadCopter and QuadPlane

Glossary

- Ardupilot - Open-source autopilot system with support for multicopters, fixed-wing aircraft, rovers, submarines, antenna trackers, and helicopters.
- Flight Controller - ‘Brain’ of the drone that holds parameters, gets RC inputs, and in general takes care of flying.
- Firmware - Software loaded into the non-volatile memory of the flight controller that remains even if the power is removed, and determines what and how the autopilot works.
- Fixed-Wing - A machine that is heavier than air that is able to fly through the use of lift generated by the shape of the wings and the machine’s forward momentum.
- Ground Station - A software application on a ground computer used to communicate with the drone.
- Mission Planner - Open-source Ground Station compatible with Ardupilot.
- ModiFly - Name of existing drone system.
- QuadCopter - Type of helicopter utilizing four motors.
- QuadPlane - Combined fixed-wing and MultiCopter aircraft
- UAV - Unmanned Aerial Vehicle, a flying system that has no on-board users.

- VTOL - Vertical Take-off and Landing, drone can take-off and land from a stationary position.

References

- Ardupiliot: https://ardupilot.org/plane/index.html
- QuadPlane FCs: https://ardupilot.org/plane/docs/common-autopilots.html
- Building a QuadPlane: https://ardupilot.org/plane/docs/quadplane-building.html
- QuadPlane Parameter Setup: https://ardupilot.org/plane/docs/quadplane-parameters.html
- QuadPlanes: https://ardupilot.org/plane/docs/quadplane-support.html
- QuadPlane Frame Setup: https://ardupilot.org/plane/docs/quadplane-frame-setup.html
- QuadPlane Flying: https://ardupilot.org/plane/docs/quadplane-flying.html#quadplane-flying
- eCalc: https://ecalc.ch/
- https://www.statista.com/statistics/939183/global-fixed-wing-hybrid-vtol-uav-market-size-end-user/
- https://bisresearch.com/industry-report/global-fixed-wing-vtol-aircraft-market-2028.html?utm_source=Statista
- https://www.statista.com/statistics/939183/global-fixed-wing-hybrid-vtol-uav-market-size-end-user/