# FLY UC

## PROTOTYPE 1

## MISSION CONCEPT REVIEW
CONCEPT OF OPERATIONS
Version 1.0

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# 1. Introduction

## 1.1 Identification

This document shall serve to define the Concept of Operations[1] of Prototype 1, hereafter referred to as P1. This system is being developed with the intent to test and optimise certain aircraft systems and their functional relations for use in larger aircraft.

## 1.2 Document Overview

This document is intended to serve as a record of the expectations, objectives, goals, constraints, and success criteria for Prototype 1; as well as the team's understanding of how the system shall operate to fulfil those needs. This document is also intended as a basis for system development activities, and to familiarise new team members, and others interested, with the problem domain and the system.

## 1.3 System Overview

Prototype 1 is intended to be a modular vertical take-off and landing aircraft with take-off weight no greater than 25 kg that shall be developed to optimise and collect test data for certain aircraft design elements. It shall also serve as a baseline for understanding and documenting the processes of VTOL aircraft production at UC; this includes organisational matters such as safety protocols, department permissions, IP and other legal matters, and funding.

# 2. Referenced Documents


1. IEEE (1998). *1362 (R2007) - IEEE Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document - IEEE Standard.*
2. GoFly, (2019). *GoFly Prize | Technical Rules.* [online] Available at: https://www.herox.com/GoFly/guidelines [Accessed 16 Jul. 2019].
3. Leishman, J., & Ananthan, S. (2006). Aerodynamic Optimization of a Coaxial Proprotor. In *62nd Annual Forum Proceedings* (pp. 64-86). Phoenix, Arizona: American Helicopter Society; University of Maryland.
4. *FAA Reauthorization Act of 2018* - H.R. 302,Sec.341-384.
5. FlyUC (2019). *Roster - Summer 2019*
6. FlyUC (2019). *Roster - Fall 2019*
7. FlyUC. (2019). *Review Process (Version 1.0).*
8. FlyUC (2019). *File Sorting & Naming Convention (Version 1.0).*
9. *FlyUC Constitution & Bylaws (Amendment I)* (2019).
10. FlyUC (2019). *Meeting Programme (Fall 2019).*


[1] IEEE (1998). *1362 (R2007) - IEEE Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document - IEEE Standard.*

# 3. Current System

## 3.1 Background, Objectives, and Scope

The current system was designed by the FlyUC team (2018 - 2019) to compete in Boeing's GoFly Competition. The system was developed with technical feedback from GoFly's reviewers and Dr Shaaban Abdallah of UC CEAS and was reviewed by the UAV MASTER Lab.

## 3.2 Operational Policies and Constraints

- ❖ Able to lift 100 kg payload.
- ❖ Meet GoFly's technical regulations.[2]
- ❖ Safety clearance from CEAS required for all testing.
- ❖ CEAS and FAA restrictions for flight tests in Class G airspace.[3]

## 3.3 Description of the Current System or Situation

- ❖ Coaxial contra-rotating quadcopter with passenger payload below.
- ❖ Hollow aluminium tube frame to be outsourced for manufacturing.
- ❖ Custom battery pack and electronics that did not have enough room to operate in a safe manner.
- ❖ Struggled to obtain a 2.0 thrust-to-weight ratio required for sufficient control of the aircraft.
- ❖ No safety protocol for design and manufacturing.
- ❖ Although there were safety considerations in the design, it was unfit for a human operator.
- ❖ The estimated cost of materials without taking into account all other costs far exceeded the resources of the team. (~$350,000)
- ❖ Lack of avionics, onboard communications, flight controls and interior cabin design.

## 3.4 Modes of Operation

Designed for single passenger short-distance urban transport

- ❖ Technical modes per GoFly's rules: vertical takeoff, static hover, forward flight, vertical landing.

## 3.5 User Classes and Other Involved Personnel

- ❖ Technical Sub-teams: Structures, Propulsion, Electronics, Simulations, Controls. Operations Sub-team for organizational support.

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[2] GoFly, (2019). *GoFly Prize | Technical Rules*. [online] Available at: https://www.herox.com/GoFly/guidelines [Accessed 16 Jul. 2019].
[3] See *Appendix B*.

- Advisor: Dr Shabaan Abdallah; Reviewers: Justin Ouwerkerk, Bryan Brown.

### 3.6 Support Environment

- The University of Cincinnati College of Engineering and Applied Science.
- CEAS Department of Aerospace and Engineering Mechanics.
- Technical review by CEAS UAV MASTER Lab.
- Support environment did not include funding or a dedicated safety advisor

## 4. Justification for and Nature of Changes

### 4.1 Description of Desired Changes

- Design:
  - Partial optimisation of coax engines for one flight mode using bench-testing and CFD.
  - Integration of electronics into aircraft frame, taking into account the thermal effects of electronics.
  - Optimize and regulate power and current throughout the system.
  - Find and verify optimal battery cell for flight time.
    - Find a method of reusability as well.
  - Design battery pack with safety components in mind.
  - Design and optimize the cooling system for electronics.
  - Create a system and protocols for controls.
    - Integration of control concepts with the flight controller.
  - Integration of redundant system for electronics to ensure the safety of the aircraft.
    - Create redundancy flowcharts, fail cases, and protocols for emergencies.
  - Creating a modular design: capable of modulating the radial separation of propellers; not during flight.
  - Proper FEA and CFD for proof of the design.
- Operational:
  - Proper systems engineering
  - Adhere to the review process and create clear documentation.[4]
  - Create and adhere to a realistic extended timeline.
  - Develop safety protocols and be in close communication with the University safety advisors.[5]

[4] FlyUC. (2019). *Review Process (Version 1.0).*
[5] See *Appendix A.*

## 4.2 Justification of Changes

- Optimization of the coax system will ensure a 2.0 thrust-to-weight ratio, to provide sufficient control authority while allowing for error in manufacturing and integration.
- Optimizing the frame for electronics will allow space to account for thermal effects and wiring of motor controllers, batteries, etc.
- Optimizing power system will prevent power surges and stress on electronics
- Finding optimal battery cell will allow for longer flight time and more reliability of power
- Designing battery pack with safety components will allow the power system to be maintained for a longer period of time
- Creating a controls system will enhance safety methods for the aircraft
- In-depth plan of the safety protocols will allow the aircraft to be prepared for all situations
- Following safety protocols will allow for faster approval of the design by UC, FAA, etc.
- Proper FEA and CFD will provide proof of the design for faster approval of the design by UC, FAA, etc.

## 4.3 Priorities Among Changes

- Essential changes:
    - Structured timeline.
    - Proper systems engineering.
    - Documentation of the design and development process.
    - Battery-frame integration.
    - Develop safety protocols for designing and manufacturing.
    - Optimisation of the propulsion system.
- Desirable changes:
    - Increased recruitment and outreach to the CEAS student community.
    - Comprehensive fundraising plan and timeline.
- Optional changes:
    - None.

## 4.4 Changes Considered but not Included

- Changing aircraft type to other than a quadcopter design.
- Design capable of changing propeller separation ratio.
- Variable-pitch contra-rotating coaxial propeller system.
- Use of mechanical controls; i.e. swashplate, collective.

## 4.5 Assumptions and Constraints

- Coaxial contra-rotating propellers will produce more thrust at a given power input as compared to single propellers.

    - ➢ Estimating loss of thrust in lower propeller set; optimisation for a certain phase of flight.
- ❖ Access to sufficient funding.
- ❖ Ability to manufacture with required precision and accuracy.
- ❖ Ability to operate within the required safety protocols.
- ❖ Access to personnel with the required technical experience.
- ❖ Access to advisors in the relevant technical areas

# 5. Concepts for the Proposed System

The motivation for the proposed system comes from a desire and need to optimise VTOL systems to have larger payload-weight-to-aircraft-size ratios in order to develop VTOL aircraft ideal for urban application; as well as the need to optimise battery systems to reduce battery size and increase flight time.

The following system is also needed to understand and document the scalability of different aircraft systems in a VTOL system, such as coaxial propellers, truss frames, battery pack, and others.

Design of Prototype 1 is based on the systems and designs developed by the FlyUC team while working on the GoFly Competition (2018-2019). P1 has an objective to lift a scaled-down payload with the same volume density of a full-size human payload; with take-off weight not exceeding 25 kg. The aircraft is intended to be designed with a modular design so that flight data can be collected in different modes; providing a better understanding for optimising the flight systems in future prototypes.

Borrowing from past work done by FlyUC, a quadcopter design with coaxial contra-rotating propellers will be used to increase the amount of thrust generated in less space. Moreover, optimisation of the battery pack, along with the optimization of the propulsion system and electronics setup overall will ensure a safe craft that can be operated for a longer period of time.

## 5.1 Background, Objectives, and Scope

- ❖ Coax propeller optimization.[6]
- ❖ Use trusses to design the aircraft frame
    - ➢ Attempt to create a system for functional simulation of weldments
    - ➢ System assembly may be bolted at a smaller scale
- ❖ 5 kg payload; take-off weight must remain under 25 kg.
- ❖ Optimize payload weight-to-aircraft size ratio.
- ❖ Test relationship of different variables to set a baseline for scalability.

[6] Leishman, J., & Ananthan, S. (2006). Aerodynamic Optimization of a Coaxial Proprotor. In *62nd Annual Forum Proceedings* (pp. 64-86). Phoenix, Arizona: American Helicopter Society; University of Maryland.

## 5.2 Operational Policies and Constraints

- FAA Regulations[7]
- CEAS flight testing policy and safety protocols.[8]
- Any additional club safety protocols
- Constraints include errors in manufacturing due to access to precise manufacturing.
- Vertical take-off and landing envelope must be no greater than the size of the aircraft.
- Constrained by access to funds and time dedicated by students.

## 5.3 Description of the Proposed System

Proposed is a small Unmanned Aerial System powered by four battery-run coaxial contra-rotating engines.

## 5.4 Modes of Operation

- Flight-phases:
  - Take-off; hover; forward-flight; landing.
- Differential blockage [functional modes]:
  - Allow the frame to adjust the radial separation of propellers to set blockage at different levels to collect better test data on the effects of blockage on coax systems.
- Testing:
  - Assistance from the Drone Lab might be needed for bench-testing and flight testing.

## 5.5 User Classes and Other Support Personnel

Technical sub-teams: Structures, Propulsion, Electronics, Simulations, Controls; organizational support from Operations.[9] [10]

## 5.6 Support Environment

- The University of Cincinnati College of Engineering and Applied Science
- The CEAS Department of Aerospace and Engineering Mechanics
- The UC UAV MASTER Lab
- Support environment did not include funding or a dedicated safety advisor

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[7] See *Appendix B*.
[8] See *Appendix A*.
[9] FlyUC (2019). *Roster - Summer 2019*
[10] FlyUC (2019). *Roster - Fall 2019*

# 6. Operational Scenarios

- All testing shall be done in different functional modes per PFR and TRR[11].
- Pilot certification needed per FAA regulation for all flight operations.[12]
  - Assistance from UC UAV MASTER Lab might be required to test and operate the aircraft.

# 7. Summary of Impacts

## 7.1 Operational Impacts

- Review Process has been changed since the last aircraft design.
- New CAD file sorting system and naming convention.[13]
- A new approach to system design and system engineering.

## 7.2 Organisational Impacts

- Change in FlyUC Constitution & By-laws.[14]
- Creation of a faculty/staff advisory board.
- Informal distribution of labour amongst the presidents i.e. technical and organisational.
- Elaboration of the Operations Sub-team; including system-design overview, fundraising, media plans, safety protocols.
- Change in the team meeting programme, to increase cross-subteam interaction.[15]

## 7.3 Impacts During Development

- Development of safety protocols and parameters for design, manufacturing, and testing; collaborating with CEAS Safety.
- Documentation and possible publication of operational development process and technology.

# 8. Analysis of the Proposed System

## 8.1 Summary of Improvements

- New capabilities:
  - Modular design focusing the design on providing test data.

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[11] FlyUC. (2019). *Review Process (Version 1.0)*.
[12] See *Appendix B*.
[13] FlyUC (2019). *File Sorting & Naming Convention (Version 1.0)*.
[14] *FlyUC Constitution & Bylaws (Amendment I)* (2019).
[15] FlyUC (2019). *Meeting Programme (Fall 2019)*.

- Enhanced capabilities:
  - Optimization of the coaxial propulsion system.
  - Modular design allowing for zero blockage in the engine airflow.
  - Integration of the electronics into the aircraft frame allowing for reduction of aircraft-volume to payload weight ratio.
  - Optimization of communication and power throughout the electronics system
  - Optimize cooling system for electronics
  - Optimization of controls and safety
- Deleted capabilities:
  - Passenger capabilities.
  - GoFly technical rules.[2]
- Improved performance:
  - Not applicable; no test data for the current system.

### 8.2 Disadvantages and Limitations

- Unable to account for forward-flight speed in the design.
- Unable to estimate/ simulate noise generated by the aircraft.
- Without existing baseline test data, determining the effects of scalability on different aircraft elements will not be possible.
- Funding and fundraising.

### 8.3 Alternatives and Trade-offs Considered

- A change from a coaxial quadcopter design was considered, the alternate proposed design was a coax-copter design with two tilt-rotors on the sides.
- Change to a fuel-powered propulsion system or a fuel-battery hybrid was considered but not adopted due to CEAS safety concerns.

## 9. Notes

### 9.1 Acronyms Used:

| | | |
|---|---|---|
| 1. | CAD | Computer-Aided Design |
| 2. | CEAS | College of Engineering and Applied Science, University of Cincinnati |
| 3. | CFD | Computational Fluid Dynamics |
| 4. | FAA | Federal Aviation Administration |
| 5. | IP | Intellectual Property |
| 6. | PFR | Post-Fabrication Review |
| 7. | TRR | Test Readiness Review |
| 8. | UAS | Unmanned Aircraft Systems |
| 9. | UAV MASTER | UAV Multi-Agent Systems Technology Reseach Lab a.k.a. UC Drone Lab |
| 10. | UC | University of Cincinnati |
| 11. | VTOL | Verticle Take-Off and Landing |

# 10. Glossary:

*Separation ratio*: The ratio of vertical separation between coaxial propellers to the diameter of the propellers.

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