Senior Design Project:

Modular Coupling Drones

University of Central Florida
Fall 2018 - Spring 2019
Department of Electrical & Computer Engineering

Group 11

Brandon Cuevas (EE & CpE)
Nicholas Omusi (EE & CpE)
Garett Goodale (EE)
Nicholas Peters (EE)
Dr. Chung Yong Chan (Mentor)

1 Project Description

1.1 Project Motivation and Goals

The purpose of our project is to accelerate adoption of multirotor drones for rapid online purchase delivery by increasing the range and payload capacity of shipping drones. Linking multiple drones together minimizes costs while increasing the flexibility of deliveries. Heavy or long-range deliveries are made possible by increasing the number of drones in a delivery cluster with added mid-flight breakaway capability for smaller packages when necessary. Smaller packages can be assigned an appropriate amount of transport capability to avoid excess and utilize waste caused by mismatching inappropriately large shipping drones to small packages. Reducing the variety of drones that need to be purchased and maintained also capitalizes on economies of scale. This benefit compounds when repairs can be completed via replacement of standardized components.

The primary benefit of the coupling drone is that it allows companies to simplify their respective drone fleets. Rather than having to maintain larger and smaller drones for different package sizes and delivery ranges, they will quickly link together the proper number of drones for a specific payload and delivery distance. The development team is comprised of multiple highly-driven individuals sharing experience in automation, robotics, electronics, and software engineering. There are clear logistical and economic benefits to this system and a proof of concept will be constructed to demonstrate full-scale possibilities.

1.2 Objectives

Our objective is to create three drones that can operate individually or link together to cooperate on heavy or long-range deliveries. When linked, the drones will communicate over a radio link to coordinate control. Physical structures will be based on hexagonal chassis having connecting blocks at the end of the propeller support arms, with the connection made by a combination of locating pins in a 3D printed part and a polymagnet that can rotate to unlink the drones. In this scenario, a drone will be elected as the "master" to take command of the other drones' motors. Depending on the delivery mission profile, the drones will unlink mid-flight to fulfill their individual objectives, and the "slave" drones will reassume control of their flight systems. The number of drones forming a cluster can vary, with flight control systems adapting accordingly.

The very nature of dynamic linking lends itself to several advantages compared to what may be achievable via the utilization of multiple drone variations or additional docking stations, which increase fleet complexity and have limitations when extending service to areas in non-ideal locations. The proof of this concept, illustrated by Figure 1. Modular delivery concept, will be completed as follows:

- Three packages will be delivered by three drones simultaneously to demonstrate dynamic cluster linkage: one large package and two smaller packages
- The weight of the largest package will exceed the maximum payload of an individual drone to demonstrate increased capacity in numbers
- The largest package will be initially delivered by all three drones, with one drone returning to base upon completion to demonstrate flight control reassignment
- The two remaining drones will break away, each individually delivering a smaller package to demonstrate improved flexibility and delivery range over individual units

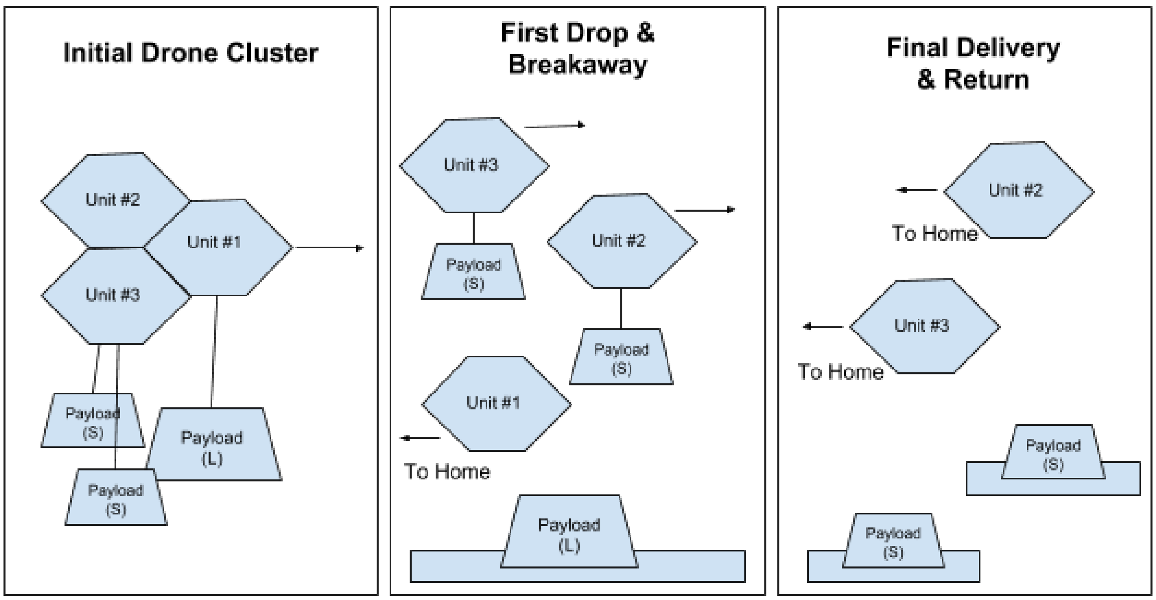


Figure 1. Modular delivery concept

Due to the cost of building the drones, a reduced version of this project would be built around two drones with the same linking ability. The two drone mission would be similar to the three drone mission where the two drones would start by delivering a shared payload, then would unlink and deliver small individual payloads before returning to base.

1.2.1 Increased Payload

Increased payload is a major component of delivery drone performance. Market research indicates that drones can generally transport a maximum payload of approximately half of their weight. Increasing the power and size of a drone is a clear way to deliver large packages, however, it adds drone fleet type complexity and decreases efficiency with varied package types. Coupling drones provide increased payload capabilities without these issues. Consider a drone of weight **D** capable of carrying a maximum payload of weight **P** some distance. Transporting a payload of weight **2P** would require a drone with a weight of approximately **2D**. The alternative is to use two drones of approximately weight **D**. Convenience is key, as these drones would need to be standardized to optimize availability, while still performing the same task. This concept is illustrated in Figure 2. Illustration of increased payload capabilities via coupling.

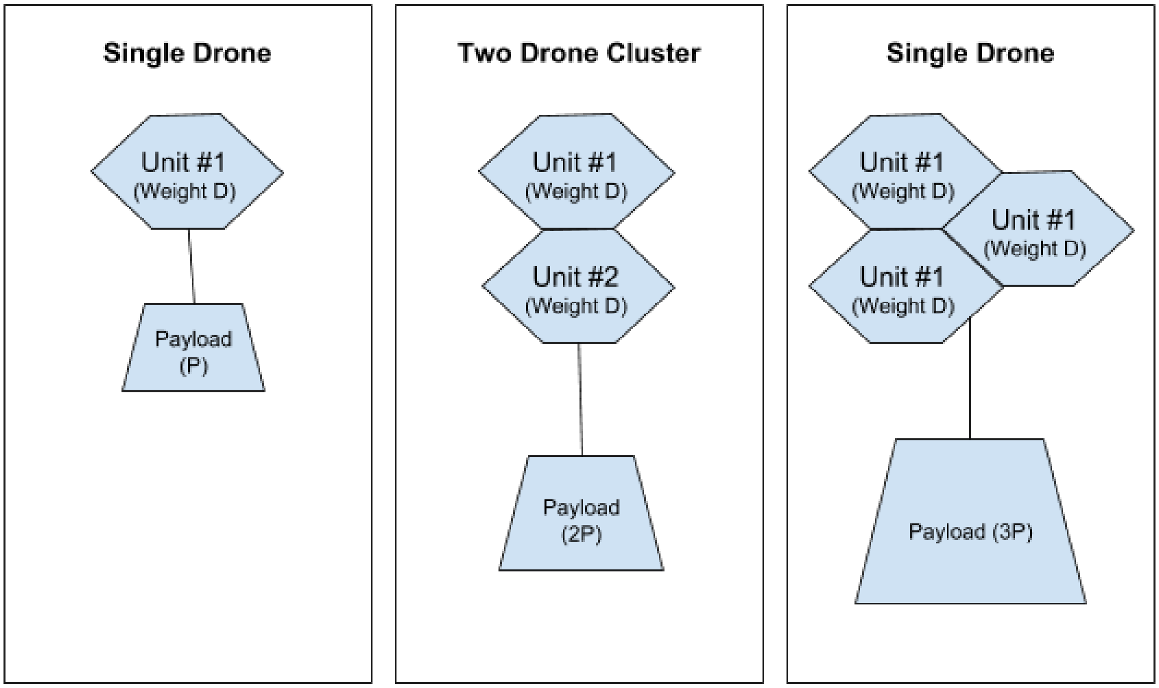


Figure 2. Illustration of increased payload capabilities via coupling

1.2.2 Range Extension

Range extension is crucial to optimize delivery algorithms and expand service area. This advantage is also highly beneficial for making deliveries to unreachable locations, particularly in emergency situations. If a drone of weight **D** is capable of carrying a payload a distance **L**, a similar case can be made for more expensive, higher performance drones increasing delivery range. However, this same benefit can be accomplished if two standardized modular drones are utilized. While two drones can be used to carry packages a full extended distance, an alternate method can be used where one drone returns to base after traveling a portion of the delivery distance and expending the majority of its energy. The other drone is able to reduce power consumption, completing an extended delivery with the saved energy. This concept is illustrated in Figure 3. Illustration of increased range via mid-flight decoupling.

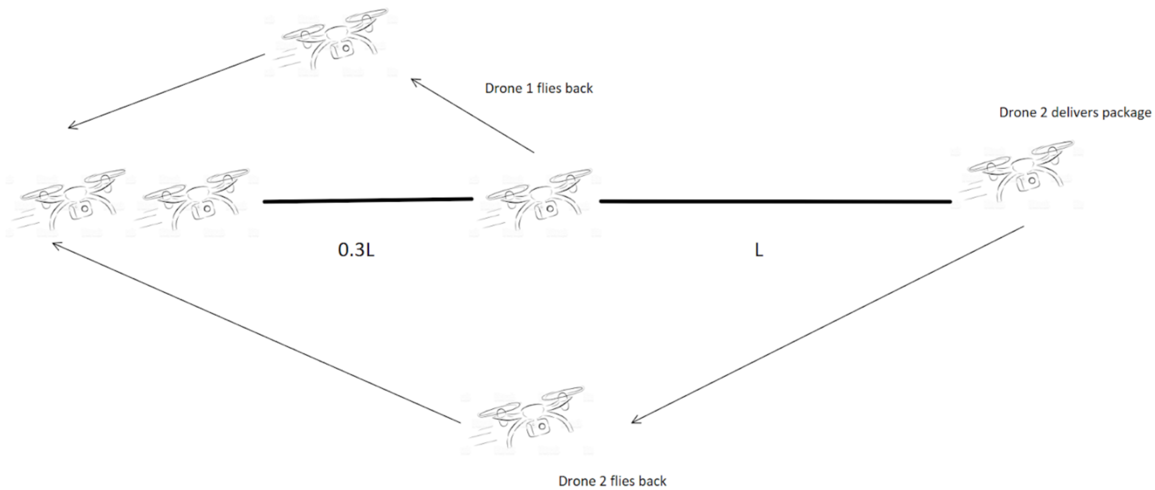


Figure 3. Illustration of increased range via mid-flight decoupling

1.2.3 Reduced Overall Operation Costs

These attributes share a common benefit that is innate to the modularity of standard linkable drones: economy of scale. Reduced drone fleet complexity not only optimizes and simplifies delivery algorithms, but also greatly reduces purchase and maintenance costs. These benefits compound when considering reduced training necessary for drone service, and the ease of stockpiling replacement parts for repairs when necessary. Simplicity and convenience is a key objective that results in higher performance and efficiency once initial capital research investments are made.

1.3 Requirements Specifications

1.3.1 Project Requirements

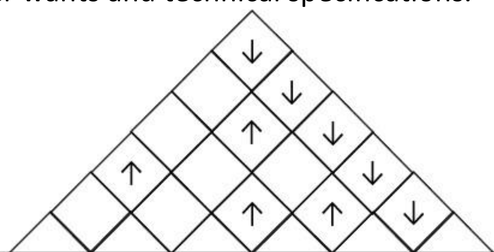
The drones must:

- "Couple" meaning to maintain a static physical bond and fly as a single unit. The coupling bond must:
  - Supply 15 N of force in the horizontal axis (driven by magnetic limits)
  - Supply 30 N of force in the vertical axis (Weight of the drone)
  - Sustain a torque of 15Nm for 1s or less (approximate torque applied to a linked drone if it supported the other drone's weight)
- "De-couple" meaning both drones move apart and fly individually
- Communicate between each other
  - Bandwidth requirement (this will be decided once we know more about the software)
  - Communicate at up to 100m
- Autonomously fly a preprogrammed route of 1 km of less, at an altitude at or above 5m
- Autonomously drop a payload within a 10m by 10m area
- Lift a payload(s)
  - Individually lift a payload of 30% of the drone weight

- Coupled lift a payload of 20% of the combined weight
- Be able to be coupled in less than 5 minutes

1.4 House of Quality Analysis

Figure 4. House of quality analysis of modular coupling drones provides an analysis of the relationships between various customer wants and technical specifications.



		Drones Per Unit	Payload Per Drone	Range Per Drone	Links Per Drone	Payload Adapters	Cost Per Drone
		+	+	+	+	+	-
1) Delivery Range	+	↑↑	↑	↑↑	↓	↓	↓
2) Max Payload	+	↑↑	↑↑		↓	↓	↓
3) # of Drone Variants	-				↓	↓	↑
4) Operation Costs	-	↑	↑	↑	↓	↓	↑
Targets for Engineering Requirements		2+ in unity flight	>30% of drone weight	1+ km	1+ links to other drones	2+ adapters per drone	<$1,000 per drone

Figure 4. House of quality analysis of modular coupling drones

1.5 Existing Similar Projects and Products

This project is unique in the sense that no one has produced drones that can link or couple together. However, the core concepts of our project are not new. Drone delivery is a new but expanding field that many large companies such as Amazon and Fedex are exploring. These companies are investigating solutions such as remote recharging stations or hybrid “quad-plane” drones, but recharging stations have limited capacity and take a long time to charge, and quad-plane drones have substantial extra aerodynamic and mechanical complexity.

2 Related Standards and Realistic Design Constraints

2.1 Standards

2.1.1 Communications Standards

UART- a way of sending data back and forth from different devices without a clock

SPI- a way of transferring data between devices with a clock and provisions for using multiple devices on a bus or chain

I^2C – A protocol for transferring data between a master device and up to 127 slave devices on a bus needing only 2 wires for all devices

2.2 Realistic Design Constraints

2.2.1 Economic and Time

The project is not currently sponsored, so the cost of 2 or 3 drones should be kept below ~$1000.

The project must be built in 2 semesters, so having drones link in the air is not feasible.

2.2.2 Environmental, Social and Political

The FAA has restrictions in place on sUAS (small Unmanned Aerial System) that affect where and how we can fly, so we must take this into account when designing and testing.

2.2.3 Ethical, Health, and Safety

- The rotors on an sUAS can be hazardous if they are spinning while someone is working on the drone
    - The flight controller should be programmed to not start the rotors without an arming sequence from the controller and audible alarms from the drone
    - The flight battery should be disconnected whenever it is unnecessary to avoid accidental rotor spin up.
- LiPo batteries can be hazardous if misused
    - Only charge at a rate specified as safe by the manufacturer
    - Only charge with LiPo chargers
    - Visually inspect the battery for damage before use
    - Ensure the battery won't be hit by moving parts of the sUAS

2.2.4 Manufacturability and Sustainability

The group is composed of electrical and computer engineers, so the drone design should avoid requiring complex machining and use laser cutting and 3D printing where possible instead.

2.3 Regulations

2.3.1 FAA Regulations

The FAA regulates all aircraft in the united states. The FAA recently published guidelines for UASs which is the proposed drone qualifies as. The FAA stipulates the following:

- The drone must be under 55 lbs.
- Flown within visual-line-of-sight*
- Not flown near other aircraft or over people*
- Not flown in controlled airspace near airports without FAA permission*
- Flown only during daylight or civil twilight, at or below 400 feet*
- Flown at or under 100 miles per hour
- Flown in class G airspace

* These rules are subject to waiver, sourced from FAA.gov

3 Hardware and Software Design

3.1 Initial Design Architectures and Related Diagrams

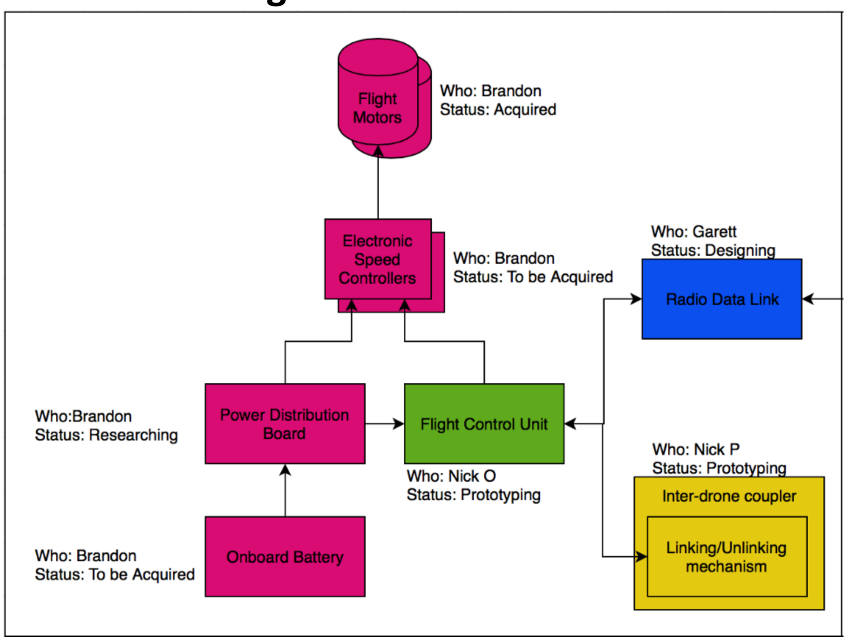


Figure 5. Diagram of electric systems showing responsible personnel and status

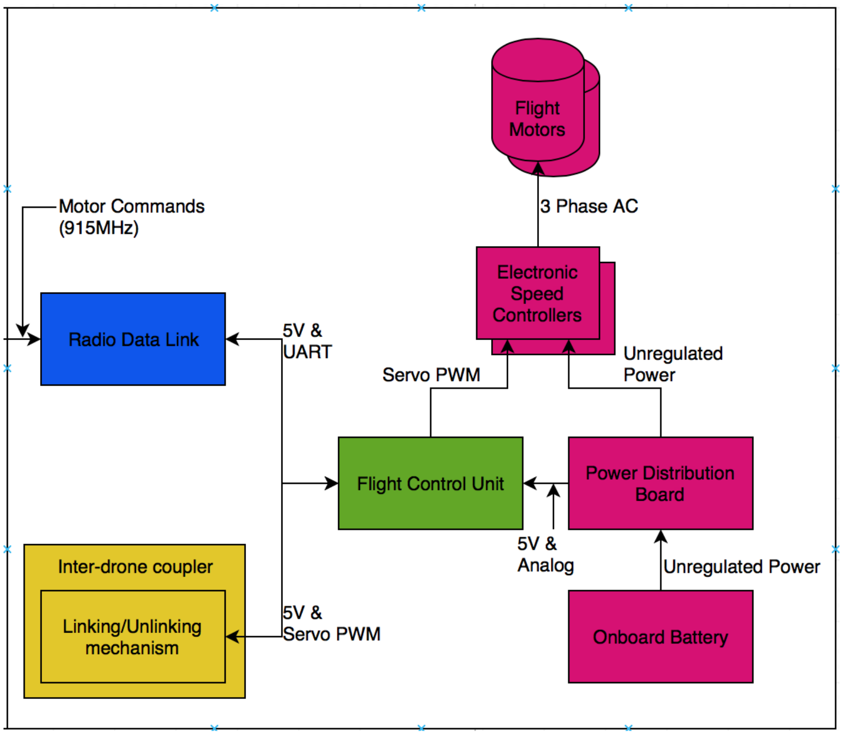


Figure 6. Diagram of electric systems showing inputs and outputs

The diagrams in Figure 5 and Figure 6 show the electrical components of each drone. The onboard battery is a LiPo pack that supplies power to the drone at approximately 11V and up to 175A, with 5Ah of storage capacity. The power distribution board connects all motors to the battery through a current and voltage sensor and provides a regulated 5V for the flight control system. The flight control unit (FCU) has sensors which determine the UAS's state (including orientation, position, and battery level) and drives the actuators with this data to follow a programmed mission. The radio data link allows multiple FCUs to communicate so that linked drones can cooperate. The inter-drone coupler provides a mechanical connection between two drones, and there may be multiple couplers per drone. The linking/unlinking mechanism is a part of the inter-drone coupler that has a servo controlled by the FCU which controls the connection between two drones, allowing them to be connected on the ground and disconnected in flight.

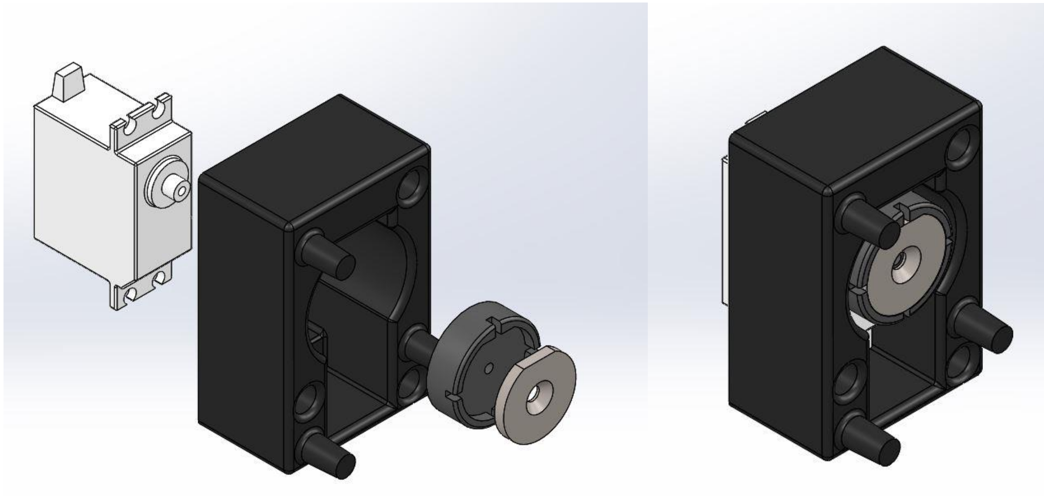


Figure 7. Isometric, exploded, and assembled views of prototype drone connector

The connector pictured above uses a polymagnet and a system of pegs to mechanically hold the drones together. A polymagnet is a magnet which has had multiple magnetic poles of different polarities printed on it in a pattern which gives it special properties. In this case, the polymagnets attract when the flat spots are aligned and repel when they are twisted around their central axis. Using a polymagnet here allows us to create a simple connector with one moving part and no complex geometry. The connector is also designed to be genderless, so that any side of any drone can be linked with any other side of any other drone. The pegs and holes take most of the forces and torques while the magnets pull the connectors together.

4 Administrative Content

4.1 Project Milestones

- Single drone teleoperated flight
- Single drone autonomous flight
- Ground test of mechanical link
- Ground test of data link
- Second drone autonomous flight
- Mechanical and data coupling between drones
- Ground integration test of drones and mechanical/data links
- Flight test of two drones linked in flight
- Flight test of two drones separating in flight
- Delivery of payload by two drones flying in unity
- Delivery of multiple payloads after unity flight and separation

4.2

4.3 Budget and Finance

Table 1. Bill of materials for one drone

Item	Cost Per Unit	Quantity Needed	Total Cost
Frame	$100	1	$100
Brushless motor	$15	6	$90
Beaglebone blue	$82	1	Donated by TI
uBlox m8n GPS	$26	1	$26
Brushless ESC	$20	6	$120
5Ah 3S LiPo battery	$60	1	$60
Polymagnet Pair	$12	1	Donated by Correlated Magnetics
Hitec HS-422 Servo	$12	2	$24
3D printed link housing	$3	2	$6
10x4.5” Propellers	$1	6	$6
Teleoperation Radio Receiver	$20	1	$20
Data Radio	$30	1	Donated by TI
Spare Parts	20% of total		$90
Total Cost			$542