Calvert Hall College High School

2019 AUVSI SUAS Competition

Technical Design Paper

Abstract

The Calvert Hall College High School Aerocards have designed a multirotor unmanned aerial system (UAS) to compete in the 2019 AUVSI SUAS competition. Building on previous performance and prior experience, the team set out to design an entirely new aircraft. Limited by a shoestring budget, a strict timeline, and little knowledge of engineering beyond high school the team has created an octocopter capable of completing several missions. This octocopter was the result of joint effort from 12 students of varying levels of experience with 3D design, computer programming, and electrical engineering. Throughout the development process, the team has had opportunities to test and improve aspects of the design so that the UAS is fully prepared for the competition in June.

1. Systems Engineering Approach

1.1. Mission Requirement Analysis

The mission demonstration simulates a long-range payload delivery using an autonomous system. The aircraft itself must complete the waypoints before attempting any additional missions. As a result, the aircraft's design must include sufficient battery life and payload capacity in order to carry out as many missions as possible. The UAS will primarily focus on the autonomous waypoint navigation, obstacle avoidance, and airdrop missions as those are best suited for a multirotor vehicle. The table below offers a brief summary of each aspect of the mission demonstration and the team's requirements for scoring the maximum number of points.

CATEGORY	DESCRIPTION	REQUIREMENTS
TIMELINE (10%)	• Efficient use of allotted flight time	• Must conduct mission in allotted 40 mins • One timeout may be taken in the event of
AUTONOMOUS FLIGHT (20%)	• Autonomously fly a series of waypoints	• Must travel a length of up to 4 miles and get within 100 feet of each waypoint, higher accuracy yields more points
OBSTACLE AVOIDANCE (20%)	• Avoid virtual obstacles according to given data	• Must be able to autonomously retrieve and interpret information from the interoperability server • Must be able to exchange data with GCS at minimum of 1 Hz
OBJECT DETECTION, CLASSIFICATION, LOCALIZATION (20%)	• Identifying and locating large lettered targets autonomously	• High-resolution camera with gimbal • Ability to process images with an on-board camera or rapidly transfer data to ground station computer for post-processing • Algorithm capable of detecting, classifying, and localizing targets
AIRDROP (20%)	• Deploying a UGV to carry a water bottle to a specified location	• Must have a separate autonomous ground vehicle and appropriate drop hardware on UAS
OPERATIONAL EXCELLENCE (10%)	• Operate in a professional and highly organized manner	• Be attentive to safety at all times including setup, mission demonstration, and teardown • Interact with judges and safety personnel in a highly professional manner • Maintain communication between all members of the team during the mission demonstration

1.2. Design Rationale

The team decided in the fall that the optimal vehicle design given the team's background and the mission requirements for the 2019 AUVSI SUAS competition would likely be a large multirotor vehicle or a fixed-wing aircraft. Because the team has more knowledge and experience with multirotor aircraft than fixed-wing aircraft, it was determined that a large multirotor with six or more rotors would become the basis of the design for the UAS.

The team was allotted a relatively small development budget of $3000 to create a completely new UAS. As a result, it was determined early on that many parts would need to be manufactured in-house utilizing 3D printed parts and other readily accessible components. This allowed the team to invest in new Pixhawk components to improve on the autopilot systems developed in previous years. Because of the team's limited programming experience, the team decided to focus more on the missions which required fewer software challenges, such as the waypoint navigation and payload delivery. As the requirements for the UAS became clearer, the design settled on a octocopter multirotor roughly 5 feet in diameter with an approximate mass of 9 kilograms capable of hovering in place for at least 30 minutes. These specifications vary slightly from the final drone but informed the design throughout the development process.

2. System Design

2.1. Aircraft

The UAS is an 8-rotor autonomous aircraft weighing in at roughly 19 pounds. It uses primarily off-the-shelf electronics and custom-made airframe components. A brief table of important UAS components is given below.

Specific components such as GPS and telemetry radios which have proven to be single points of failure during developmental testing have been doubled so as to provide redundancy. As single points of failure have proven to be significant challenges in the past, redundant systems hope to eliminate or at the very least mitigate some of these challenges.

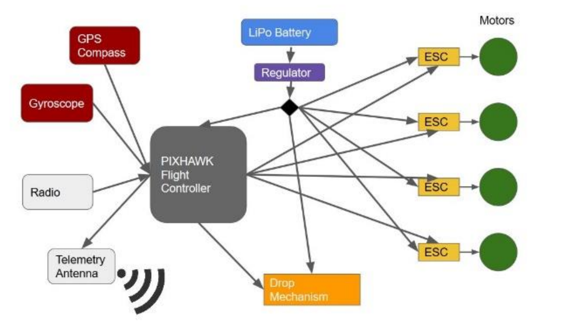
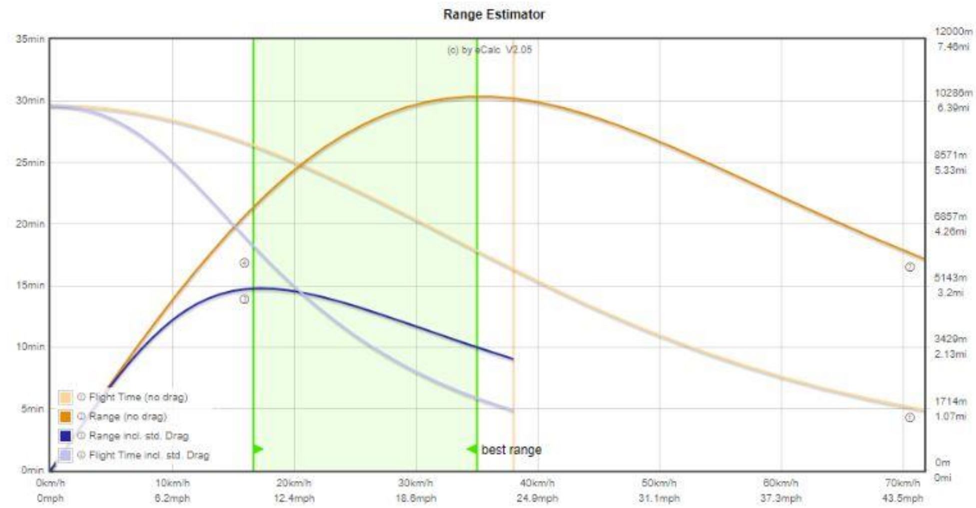


Figure 1 - Wiring Diagram for a 4 rotor UAS. Much of the wiring, apart from the motors, is identical to the 8 rotor UAS

COMPONENT	QUANTITY	SPECIFICATION
BRUSHLESS MOTOR	8	400kV
PROPELLER	8	18.5” x 5.5
6S LIPO BATTERY	2	22.2 volt 100C 15,000mAH
GPS	2	redundant
TELEMETRY RADIO	2	433 MHz

Additionally, much of the development process was informed by simulations which allowed the team to fine-tune specific aspects of the drone to better evaluate expected performance before beginning a test flight. The image below shows a graph specifying the UAS capabilities given a certain payload mass (in this case, 1 kg).



2.2. Autopilot

Because of the simple assembly and massive user-base, the Aerocards decided to use the Pixhawk 2.1 (Cube) flight controller. This replaces the Pixhawk 1 system that was used for the past two years, because the age of the component made it unworkable. The new Pixhawk 2.1 has several improvements over the older system, most conveniently in connector type- the old system was a risk for breaking the connecter every time the wire had to be removed, while this one has a lock system that facilitates removal of wires. The new system also has increased parameters. It facilitates the addition of additional motors to complete the mission tasks, and includes several redundant system features, such as GPS, telemetry, and power. The *UAS* is designed to run the MavProxy autopilot system, because it is much easier to integrate python as an interoperability language. This is a change from last year, where the ground control station software Mission Planner was used for flight planning, but still ran MavProxy for interoperability. This year, the team has been able to directly import the waypoint file from the interop server and plug it into the flight plan. Another major benefit to the ArduPilot-based systems is the fact that they are open sourced, allowing for the team to manually change the settings of the autopilot. For example, it was calculated during the design process the ideal speed for the UAS to fly for the mission to ensure maximum range and flight time, and the ground control team can set this value in order to reach the calculated effectiveness of the system.

Figure 2 - Pixhawk 2.1 Cube

Figure 3 – Ground station hardware setup for testing the UAS

The system is optimized for point control flight and object delivery, the focus of our mission plan. The system has an average waypoint accuracy of 1.5 m, and our air delivery accuracy averages at 6 ft off of the target coordinates. The ground control station will have two instances of MavProxy running during the mission, one for the UAV, and one for the UGV. The UGV will have preloaded commands, to release itself from the *UAS* once it reaches the drop point, and to drive itself to the final point.

The ground control station is a scaled-up version of last year's ground control station, with three monitors for the UGV positioning (left monitor), interoperability monitoring (central laptop), and UAV positioning (right monitor). The central laptop does all interoperability processing, receiving telemetry directly from the UAV and UGV (antennae are plugged into USB ports). The Ethernet cable (red) is representative of the Ethernet cable provided at the competition, linking the ground control station to the judge interoperability system for transmission of telemetry. This three-display setup allows for constant monitoring of the position of the UGV and the UAV while also monitoring telemetry upload rates for both, whereas in years prior one screen was shared, making it much more difficult for the team to manage everything simultaneously.

The interoperability system is the method by which the team transfer the UAV and UGV's telemetry data, including altitude, speed, heading, and geographical positioning (latitude and longitude). This is accomplished using MavProxy, a python-based GCS software. The team decided to use MavProxy because being python based, it interacts very well with other python scripts and the software team is more comfortable with python than any other programming language. This gives the team more flexibility with interacting with the interoperability server, such as custom output for the mission data and waypoints which can allow it to be accessed by MavProxy faster. By using python, the team can create custom scripts for MavProxy that allow it to automatically set itself up, reducing the time needed at startup to begin interoperability and ensuring that no parameter setups are forgotten. Essentially, the move over to MavProxy gave the team more control over the formatting and flow of telemetry.

2.3. Obstacle Avoidance

The UAV is capable of predetermined static obstacle avoidance. The location of said obstacles are determined at the same time mission waypoints are retrieved. This is done via a python script that retrieves the waypoints and obstacles at the same time and uploads them to two separate text files, one named "waypoint.txt" for waypoint locations and the other named "obstacle.txt" for obstacle locations. The obstacle coordinates are then added to the geofence coordinates file named "geofence.txt" by a second python script which are loaded into MavProxy, our ground control station (GCS), using the "fence load" command. This prevents the UAS from flying out of bounds and from flying through the obstacles, which are marked as no-fly zones. Because there are no moving obstacles this year, there is no need to constantly ask the server for the position of the current obstacle.

2.4. Imaging System

Due to the 8-propeller design of the UAS, a major constraint is battery life, heavily limiting flight time. Because of this, the Team decided that it would be more beneficial to focus development resources on other tasks such as the UGV payload delivery. As such, the team will not be attempting to collect imagery as part of the missions

2.5. Object Detection, Classification, and Localization

As discussed in the Imaging section, the primary constraint of the UAS is battery life. As such, the team has decided not to pursue the object detection, classification, and localization mission in favor of allocating battery life to other missions.

2.6. Communications

This year, the team is using a dual telemetry system that operates on two 443 MHz radios to convey information between the UAV and the computers at the ground station. The using two telemetry radios allows for increased redundancy and reliability compared to previous years. This is a change from last year, where a single 915 MHz radio was used. The 915 MHz did not have the same level of long-range reliability that the 443 MHz radios do. The UGV uses a 915 MHz telemetry radio for autonomous telemetry and data transfer.

Figure 4 - The Taranis remote

2.7. Air Drop

To deliver the payload, the team will utilize a servo to create a quick release tether. The servo will be fitted will a metal rod that will fit through a hole in the end of a bar. This bar will sit between two brackets (servo rod uses these to secure bar to frame) and attach to a hinge on the other end. When the servo is enabled, the metal rod will slide out, allowing the bar to swing free, releasing the tether. To ensure accuracy, the payload will be secured to the bar via a string, which will prevent the payload from being thrown by the bar's swinging motion. As a result, the bar will open upwards, allowing the string to slide from it unaffected. The payload itself is still in development but will likely consist of several 3D-printed components and an Arduino-based system working in tandem with an additional telemetry radio. The airdrop will be triggered manually after receiving confirmation from the judges and safety officers when the UAS has reached the appropriate location, as determined by the telemetry data.

2.8. Cybersecurity

As with any electronic system, there are several ways that the UAS can be accessed or tampered with by unauthorized sources. A major vulnerability is radio jamming on the 443 MHz frequency, which would cause a communications failure in the UAS and could cause the UAV to fly out of control posing a significant safety risk. An additional vulnerability is someone potentially intercepting radio traffic between the UAV and the GCS, altering it, and sending it back to the GCS. This could cause incorrect positioning of the UAV to be displayed to the judges, and to the GCS team. This could potentially lead to issues with flight boundaries and how the drone behaves autonomously. In the event that there are significant levels of radio interference on the 443 MHz frequency, the team still has access to 915 MHz radios for emergency use. The team will determine whether the 915 MHz radios are necessary based on ground testing prior to the flight demonstration.

3. Safety Risks and Mitigations

3.1. Developmental Risks and Mitigations

Figure 5 - A basic example of protective eyewear

A vast majority of the developmental safety risks arise from the workshop environment in which many of the UAS components are manufactured. To mitigate these potential hazards, the team was thoroughly educated about workshop safety and used tools under the guidance and supervision of an experienced advisor. In addition, basic workshop protocols were established to mitigate possible injury, such as making the use of safety glasses or other protective eyewear mandatory. Additionally, manufacturing of aircraft components is overseen by a faculty advisor with experience using a wide variety of power tools and equipment.

3.2. Mission Risks and Mitigations

Outside of the workshop, the greatest safety risks arose during developmental testing of the UAS. The most significant mission risk is the possibility of equipment failure which could result in a crash. The team has suffered multiple such equipment failures in the past three years, but there has yet to be an injury as the team has established a strict set of procedures for when the drone is in the air. Additionally, the team has learned to remain calm and focused in the event of a system malfunction. The team always conducts tests over an empty sports field, so that there is no risk of injury if the UAS or a component of it were to fall from the sky, as sometimes happens. Likewise, spectators are never allowed any closer to the drone than a member of the team, and all team members must maintain a distance as deemed necessary and proper by the safety pilot. In a usual test flight, this horizontal distance is around 20 to 30 feet, though it is increased to 50 feet when a new piece of equipment or autopilot program is being tested.

Figure 6 - Map of the testing area. The practice zone is marked in black