Calvert Hall College High School

Towson, MD, USA

Technical Design Journal Paper for 2017 AUVSI Student UAS Competition

Abstract

This paper will be a description of the process the Calvert Hall Aerocards followed to design, build, test, and fly the unmanned aerial system for the 2017 AUVSI SUAS Competition. The main phases of the process are the design and construction of the airframe, the programming of the flight controller and ground station, and the flight testing and troubleshooting. The team consists of high schoolers from all four grade levels. Our main goal for the this year is to plan and compete more effectively, by including a more comprehensive journal paper and plotting a more efficient autonomous flight plan, including an attempt to complete more mission tasks. This year, the Aerocards present a quadcopter with a aluminum reinforced carbon fibre body, designed to excel at autonomous flight and aerial photography. This system features a custom design CNC machined airframe, improved durability, and an efficient air delivery system.

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1. TEAM ROSTER

<u>Leadership:</u>
Jack Cannon ’17
-Team Captain
Steve Zhu ’17
-Vice President
Charles Cannon ’18
-Safety Pilot
<u>Advisor:</u>
Mr. John Stewart

<u>Competition Students:</u>
Connor O’Shea ’18
John Brezinski ’18
Andrew Lynch ’18
Sean Beahn ’18
Matthew Minogue ’19
Rishibrata Biswas ’19
Braden Wolf ’20
Patrick Kotulak ’20

<u>Dev. Team Guests:</u>
Daniel Zimmerman ’18
Jonathan Nguyen ’20
Graham Foley ’20

2. SYSTEMS ENGINEERING APPROACH

2.1 Mission Requirement Analysis

The mission requires that the drone fly over waypoints autonomously, find a hiker and the clues set to find him, and deliver him an 8 oz water bottle. Each section of the mission demonstration will be graded on accuracy of data, and the accuracy of the drone itself.
The design which would best fulfill these requirements is a quadcopter. The quadcopter, although slower than a fixed wing or helicopter, will provide more stability and mobility, allowing measurements to be taken more precisely and helping the team win more points for accuracy.

1. Autonomous Flight
    - Objective: Achieve controlled autonomous takeoff, flight, and landing
    - The team anticipates being able to fly the entire mission autonomously
    - All navigation will take place slightly above the 100ft threshold to ensure that no autonomous points are revoked.
    - The team will familiarize itself with the no fly zones at the field and continue appropriately.
2. Waypoints
    - The team will program a flight plan with considerable accuracy of the waypoints.
    - The 3DR GPS will help keep the drone's flight path as accurate as possible.
3. Obstacle Avoidance
    - While not a high priority, the team plans to have an obstacle avoidance system for stationary objects
4. Object Detection, Classification, Localization
    - The team anticipates completing this task with as much accuracy as possible, due to our unfamiliarity with autonomy in data delivery. We also anticipate proper submission of all collected data through the Interoperability system. We believe our focus on accuracy will outweigh the possible inconsistencies of autonomy in data collection and transfer.
5. Air Delivery
    - Every attempt will be made to incorporate the air delivery task into our mission, however, the team has not made this task a priority. Air Delivery will be accomplished via a gripping mechanism involving one or two servo motors.

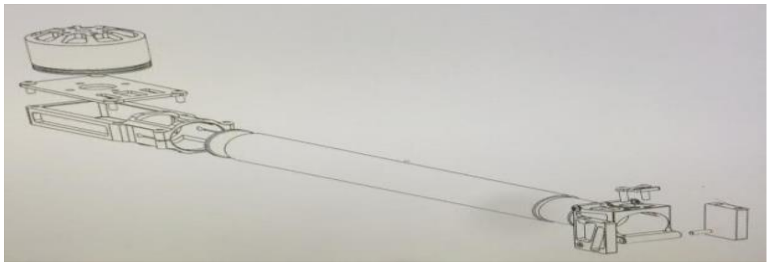
2.2 Design Rationale

Though the team had great success with the mission back in 2015, we wanted something more suited to the demands of the competition due to the weaknesses of the old airframe. These weaknesses were brought about by retractable landing gear, and loose frame supports. There were limited budget restraints while developing the new airframe.

1. Airframe: This year, one of our team members designed the airframe using Solidworks software. A diagram of the airframe can be found below. (See figure 2.2)
2. Electrical System: On the electrical side, much of our system has remained the same, with the addition of internal wiring through our PCB glass fibre plate. The team has decided to continue to utilize our Pixhawk system, due to the large expense required to

obtain a newer system, especially when considering the few additional benefits a new system would provide.

3. Mechanical System: The team invested in a Futaba t7c controller, as our previous safety pilot, who owned a similar controller, learned of a conflict which does not allow him to attend the competition. The team specifically selected Cobra CM-4510/28 Multirotor Motors, Kv=420, to accompany our rigid airframe.
4. Imagery System: The team will continue to use a GoPro Hero 3+ Black camera, but decided to upgrade from a 2-axis gimbal to a 3-axis gimbal. We have selected a tarot T4-3D gimbal, which has wider functionality, and a sleeker look than our previous option.



(Figure 2.2 - Expanded image of quadcopter arm)

2.3 Programmatic Risks & Mitigations

Risks	Mitigations
mechanical failure	• extensive testing of the completed system • individual testing of each motor
electrical failure	• Ensure all connections are soldered properly • Extensive testing of the completed system • Individual current testing and endurance testing of each ESC, telemetry module, motor, and the Pixhawk system as a whole
pilot error	• allowing multiple pilots the opportunity to practice • gaining more than the minimum hour requirements as necessary to complete the safety pilot log

Some identifiable risks are mechanical failure, electrical malfunction, and pilot error. The risk of mechanical and electrical failure can be reduced by flying drone in many different environments and situations as practice prior to the competition. The team can minimize human error by practicing basic maneuvers and flying mock missions prior to the competition, in both manual and autonomous modes.

3. SYSTEM DESIGN

3.1 Aircraft

The team chose a quadcopter design over a helicopter or fixed-wing design because the quad provides more stability, puts less stress on each motor, and saves battery power, gaining crucial mission time. The quadcopter format also requires less landing/takeoff space.

The aesthetics of the drone are as follows

1. Each of the 4 motors are attached to a 25mm carbon fibre tube using a 6061-aluminum case. Each tube is reinforced with 7075 aluminum on the inside, to minimize stress on both the motors and airframe during takeoff and rapid direction changes.
2. The aluminum pieces are produced using a CNC machine, to keep the metal from conducting electricity. For ease of transportation, the arms are connected to a hinge, which is sandwiched between a PCB glass fibre plate on the bottom and a carbon fibre plate on the top.
3. All the components are connected via the internal wiring in the PCB glass fibre plate. The centerpiece sits on two 25 mm tubes, which are each connected to one 14 mm carbon-fibre tube, facilitating landing gear.

The drone's electrical system components include:

1. Motors: The 4 motors are Cobra brand, with Kv = 420.
2. ESCs: The motors are each regulated by an XRotor ESC
3. 12000 MAH LiPo Battery (22.2 V)
4. Pixhawk flight controller and 915MHz telemetry radios
5. Electricity flow is controlled by the PCB board.
6. The power module regulates the current and supplies the pixhawk with the proper allowance of power from the battery

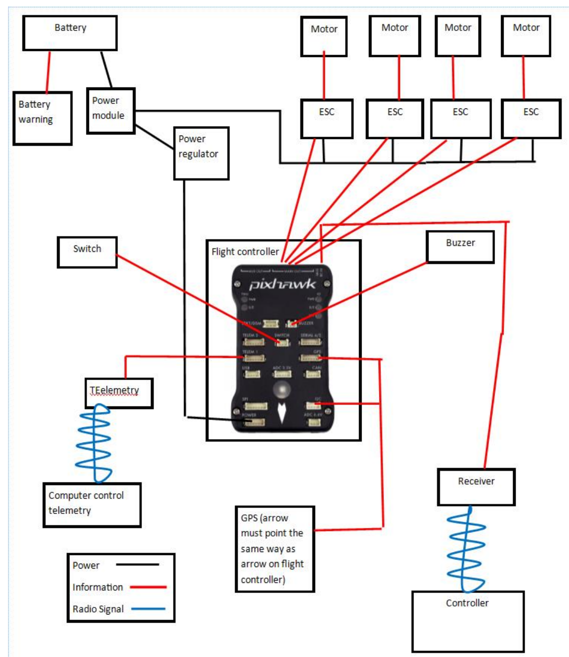


Figure 3.1: Diagram of the Pixhawk System & Wiring

3.2 Autopilot

The team will be using Mission Planner 1.3.45 to design the various flight paths and write waypoints to the quadcopter. The flight plan will be drawn to pass over waypoints based on latitude and longitude. Ideally, the drone will only fly this sequence once, as a retry will cost the team autonomy points. Once the team is satisfied with the performance of the system regarding telemetry of waypoints, we will transition to navigation of the search area via the use of polygons. The quadcopter's field of view and the shape of the search area will determine the shape of the polygons required to most efficiently scan the search area in the allotted time. If our systems are properly in place at the time of the competition, the team will proceed to the additional mission tasks such as Air Delivery. Additional tasks will also be contingent on available mission time remaining.

3.3 Obstacle Avoidance

All stationary obstacles will be entered into the Mission Planner flight plan before takeoff. In this way, the autopilot course will be altered before any obstacles are encountered. Obstacles significantly below the drone’s altitude will be disregarded. Obstacles above 100ft will be processed without regard to exact height so that all obstacles are given equal priority. Moving obstacles will not be treated as a priority, however, the team will further investigate proper handling of these obstacles prior to traveling to the competition.

3.4 Imaging System

GoPro Hero 3+ 	• Video Quality: ○ 1080p, 30fps ○ 960p, 48 fps ○ 720p, 60 fps ○ WVGA, 240 fps • 11MP photo capture with 10 frames per second burst • 197-Feet / 60m Waterproof Housing
Tarot Mount 	• 88.6 mm attachment • 49.45 mm from bottom of attachment to middle of camera • Rotation: ○ 140-degree axis of y-axis rotation ○ 90-degree axis of x-axis rotation • Brushless Motor to move
Futaba R617FS 	• 600 mhw • 5 dBi (very broad signal) • 5.8 GHz
Receiver 	• 14 dBi

The GoPro is connected to a Futaba R617FS transmitter. The transmitter is also connected to the battery. The antenna on the transmitter transmits at 5.8 Ghz, so that it does not interfere with the 2.4 Ghz signal for the motors. Its signal is transmitted to a receiver, which transmits a small-range signal. All this is connected to a separate Taranis controller, which which will control the gimbal’s brushless motors as the team performs the object tasks.

3.5 Object Detection, Classification, Localization

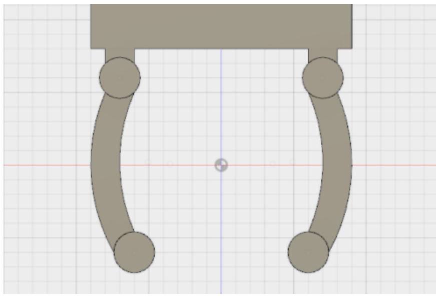
The quadcopter will fly over the search area in pre-defined polygons with one camera, a gopro hero 3+, controlled by the gimbal. As the quadcopter flies over the search area, it sends a continuous stream of data to the ground station computer for processing. One or more team members will keep track of the current data and forward any images containing possible target objects to another team member for further analysis. At this point, the team member(s) locate the object and crop the image accordingly. Finally, each cropped image is joined with its respective GPS data in the Object File Format and sent to the judges via the interoperability system.

3.6 Communications

1. Onboard Equipment:
   The Pixhawk system works hand in hand with 3dr radios operating on 915MHz, complying with U.S. FCC standards.
2. Ground Station:
   Our controller, a Futaba 7c, operates on the 2.4 GHz frequency, so the team used the 5.8 GHz frequency for the telemetry radio antennae. The Drone's autonomous mode is facilitated through a computer, using the latest version of the mission planner software.

3.7 Air Delivery

Due to time and resource constraints, the team has decided that the air delivery task will not be a priority. The system, if completed, will use a combination of two servo motors attached to a gripping mechanism. The motors will connect to the central Pixhawk controller, which can be accessed via the telemetry system. The mechanism itself will grip the payload and release it by moving the two servos outward when it receives a signal.



3.8 Cyber Security

There are 3 main cyber-threats to any drone, and all of them involve sending the drone. There can be thousands of files, one big file, or a fake packet to either overload the drone, or gain control of it.
Protecting the Ground Controller is a good first step, because when hacked, it becomes an access point for the drone. Antivirus and VPN are two types of software which keep the Ground Controller from being hacked. Antivirus protects the Ground Controller from malware, while a VPN encrypts the drone's internet connection. If all these measures fail, then the drone can be manually flown to safety. The drone's connection to the Ground Controller can also be intercepted. The only way to counter this is to monitor the location of the drone and use redundancy features like the return to home program.

4. TEST & EVALUATION PLAN

4.1 Developmental Testing

During our final phase of development, we encountered several small issues which delayed our ability to get the aircraft flying, due to long shipping timelines. Mainly, we discovered defects in parts we ordered previously, and several parts that had been used prior to construction of our current project.

Test	Result	Design Change
Initial power up of main power module	power module overheated	reduced load current and replaced power module
Telemetry test	no communication between system and ground station due to a defective antenna	replaced telemetry system
Power test	Discovery of internal wiring high voltage problem	Add resistors

4.2 Individual Component Testing

Component Test	Description
Current Test	using multimeter, compare current readings under normal operating conditions to those specified by manufacturer
Propeller static balance test	use a propeller balancer to calibrate propellers individually
motor balancing test	Compare the values given from the pixhawk and telemetry
autonomous flight	after working out mechanical issues with other components, a simple autonomous flight path will be tested. The team has previous experience with autonomous flight, and we do not anticipate any major problems in navigation
imaging	the cameras and imaging system have already been tested and function fully in action
communications	the telemetry system will be tested in different circumstances to ensure the system is able to navigate safely
air delivery system	not yet completed

4.3 Mission Testing

After all components and systems have been tested and reliability is established, the team will begin the process of mission testing. Our first test will involve a simple waypoint capture test. With this, the team will be able to test multiple aspects of the autonomous flight mission, including the autonomous flight systems and waypoint capture accuracy. As the team has completed this successfully in the past, it should not be the most challenging aspect of the mission tests. Shortly after the autonomous flight is tested, the team will integrate obstacles into the flight plan, building on the initial autonomous plan. This will prove slightly more challenging. Lastly, the team will conduct the object detection, classification, and localization tests. This may prove to be the most complicated challenge, as it will involve the coordination of the various drone systems as well as the communication and accurate analysis from multiple team members in order to be successful. The procedures will vary as the team gains more experience and practice. Once the team is able to locate target objects efficiently, additional practice will be necessary to optimize the workflow and ensure that all missions can be completed within the time constraints.

To ensure the safety of all individuals, the team has taken the time and carefully calculated the risks of conducting flights at our location. (Figure 4.3)

Figure 4.3

5. SAFETY, RISKS, & MITIGATIONS

5.1 Developmental Risks & Mitigations

There are some inherent risks in developing an aircraft. In the interest of safety, the team has attempted to enumerate the most critical risks as well as the steps taken to mitigate them.

Risks	Mitigations

burns from soldering iron or heat gun	• using basic safety procedures
	  ○ never directly touching the hot end of a soldering iron
	  ○ never
	• unplugging soldering iron and heat gun when not in use

electric shock from power supply	• using only insulated wires • unplugging devices when not in use • never touching a soldering iron to a live circuit • ensuring that all electrical equipment will be able to handle the power being supplied
cuts from propellers	• the creation of a safe area around the drone before taking off. • limited use of full throttle

5.2 Mission Risks & Mitigations

During the mission the team is also taking precautions to reduce the risks that will most likely be encountered while the team is performing the mission.

Risks	Mitigations
motor failure	• Testing the motors several times before it is taken it out of the workshop
loss of communication	• Programed the drone to return to the landing pad if the controller loses communication
loss of control in wind	• testing the drone under mild wind conditions • avoiding high winds
power module failure	• extensive testing in a safe location
battery depletion	• Programed the drone to return to the landing pad once battery level reaches a critically low point

5.3 Operational Risks & Mitigations

During its operation, there are always risks regarding the battery and control systems. The team has established plans and backup systems in order to counteract these possibilities. The subject of drone control and crashing are the first areas of concern. Crashes are usually the result of system failures or human error which cause to drone to stop functioning. These failures experienced by the team include transmitter failure, flight controller failure, and propeller shattering. Transmitter and flight controller failure are caused by electrical failures like shorting or drawing too much current. Propeller shattering is due to either faulty production or propellers not suited to the load placed upon them. In order to protect personal safety, we will complete all testing in a location where danger is limited in the event of a crash.