Calvert Hall College High School Aerocards

2018 AUVSI-SUAS Competition

Journal Paper

Figure 1- The Kolímpri

Abstract

This paper describes the Calvert Hall College High School Aerocards' process in the design, assembly, and programming aspects of constructing a multirotor UAV for the 2018 AUVSI SUAS competition. The team's intent is to combine past years of experience with new talent on a team consisting of students from all levels of science and math backgrounds in order to better address problems from previous years. In 2018, the team has chosen to take on new software-related challenges in an attempt to automate as many systems as possible. In addition, there is a greater focus on testing the various systems to ensure reliability. With new skills and ambitions, the Aerocards hope to continue to perform well.

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Team Roster

Matthew Minogue, ’19- President & Mechanical Systems Lead

Charlie Cannon, ’18- Vice- President & Safety Pilot

Braden Wolf, ’20- Autopilot Developer & Reserve Safety Pilot

Patrick Kotulak, ’20- Team Manager & Mechanical Team

Sean Beahn, ’18- Secretary & Deliverables Lead

John Nguyen, ’20- Mechanical & Drafting Teams

Brian Schwerz, ’21- Mechanical Team

Christian Post, ’20- Drafting Lead & Deliverables Team

William Bauer, ’21- Code Expert

Daniel Zimmerman, ’18- Communications Expert

Patrick Pendergast, ’20- Deliverables Team

Jack Stewart- Faculty Moderator

1 Systems Engineering Approach

Kolímpri is a reworked model of last year's design, because of the reliability and adaptability of the system. The UAS was designed to operate autonomously to gather and process information of objects on the ground, relay that information to emergency crews, and provide limited assistance to the site via an air delivery system, all with the highest accuracy, safety, and reliability.

1.1 Mission Requirement Analysis

This year's UAS is designed to complete a search and rescue mission combined with a fire control element, where a team is informed of the situation and is deployed to attempt to bring the emergency under control, particularly where it would be dangerous or inefficient for humans to traverse the area. The methods by which the Aerocards will attempt each section of the planed mission are depicted in *Table 1.*

Task	Description	Requirement for Completion
Timeline- 10%	❖ Complete mission within timeline restrictions- 80% ❖ Avoid taking a timeout- 20%	❖ Multiple practice missions ❖ Checks to ensure the functionality of the UAS
Autonomous Flight- 30%	❖ Autonomous flight- 40% ❖ Waypoint capture- 10% ❖ Waypoint accuracy- 50% ❖ Avoid flight outside flight boundaries- Loss of 10% per violation ❖ Avoid objects falling off the UAS- Loss of 25% ❖ Insure that UAS does not crash- Loss of 35%	❖ Ensure proficiency with Mission Planner Autopilot system ❖ Coding interoperability to transmit telemetry at a minimum of 1 Hz ❖ Establish that all components of the UAS are tightly secured ❖ Confirm that UAS is in complete functioning order
Obstacle Avoidance- 20%	❖ Stationary obstacle avoidance- 50% ❖ Moving obstacle avoidance- 50%	❖ Will not be attempted
Object Detection Classification, and Localization- 20%	❖ Characteristics- 20% ❖ Geolocation- 30% ❖ Actionable- 30% ❖ Autonomy- 20% ❖ Avoid extra objects- 5% per object submitted	❖ A system capable of locating objects on the ground ❖ Code that can autonomously classify images, as well as work with the UAS positioning system to locate objects
Air Delivery- 10%	❖ Accuracy- 100% ❖ Delivering 8 oz water bottle to drop site and causing it to break on impact	❖ A system that will autonomously release the package from the UAS airframe ❖ An autopilot that can function with the change of weight
Operational Excellence- 10%	❖ Communicate between members of the flight team ❖ Exhibit professionalism ❖ Precise, calm reactions to system failures ❖ Care for safety	❖ Practice each aspect of the requirements

Table 1- Mission Requirement Analysis

The UAS Kolímpri is designed around these constraints, enabling the Aerocards to operate at maximum efficiency during the mission. Due to successes last year in *Autonomous Flight*, the team confident in excelling in autonomous flight, particularly because the capability in interoperability has dramatically increased. *Object Detection, Classification, and Localization* is the focus of the team this year, and it requires complex code to identify the differences on a field of pixels. The Aerocards' ability to program systems had increased greatly between this year and last year, and the team hopes to do very well in that facet of the competition. *Air Delivery*, due to the multirotor airframe, is a simple task and will be completed easily, because its requirements of accuracy are comfortably achieved with precision. *Timeline* and *Operational Excellence* require multiple practice missions run to make the team function well together, and mesh into a single unit.

As the Aerocards' previous UAS functioned well as a first prototype, the team is utilizing that system as a base for this year's. The craft's durability and reliability were increased by installing more safety systems, particularly shock landing gear and set screws into the motor housing. The UAS's autonomy was increased by the addition of more code to perform certain tasks, such as a more reliable air delivery system.

1.2 Design Rational

Because of the team's limited experience with certain aspects of the mission requirements, the Aerocards decided to focus on improving characteristics the system lacked in 2017, such as interoperability and autonomous image recognition.

The first decision was to continue using Mission Planner as the autopilot system, due to its simplicity yet adaptability. The program is easy to learn, open-source, and capable of running the entire UAS from a single interface.

Considered second was the imagery system, due to the critical importance for the completion of the mission. Due to budget restraints and team experience, a GoPro Hero 4 was chosen to operate as the camera for the mission. The team decided to use a gimbal to counter the vibrations that the UAS causes during flight, as well as to be able to view the off-axis target. The gimbal is mounted on the front half of the undercarriage, to balance the weight from the air delivery package.

The team's third decision was object classification, because of the change to require autonomous processing during this year's competition. The team decided to use an open source image recognition program that could be modified to suit the mission requirements.

The fourth decision, about air delivery, was one of the easiest systems to develop. The team modelled this year's system on the success of the 2017 system during testing, while improving the design to increase reliability. The system is mounted on the rear of the airframe behind the gimbal, to reduce the change in balance after the drop.

Fifth, the team decided to abstain from creating an obstacle avoidance system, as they lack the members with the proper levels of experience.

2 System Design

2.1 Aircraft

The Kolímpri system is designed around a quadcopter frame, as these types of vehicles have a proven history of performance, reliability, and cost-effectiveness. With a custom-made carbon-fibre airframe and anodized aluminium support braces, the quadrotor configuration offers plenty of versatility to attach cameras, drop mechanisms, and other payloads. The changes this year include new components that are easier to replicate, and shock absorbent landing gear, for improved survivability in difficult conditions. The team has also added and modified many small components to increase the durability and reliability of the UAS.

The airframe is designed around a central fuselage of carbon fibre, with four arms on aluminium hinges for easy transportation supporting the set of four Cobra CM4510/28 brushless motors drawing from a XRotor Pro 50A ESC each. Power is provided by a 13000 mA 25C LiPo battery, and the Kolímpri can stay in flight for 25 minutes on one charge. The landing gear is PVC plastic with steel spring insert, modelled to allow hard landings with large payloads while still protecting sensitive equipment by absorbing shock. The UAS weighs 9.5 kg, with payload. *Table 2* shows the dimensions of the Aerocards' 2018 UAS.

Airframe Dimensions and Specifications		Performance	
Length (cm)	66.04	Cruise Speed (m/s)	5
Width (cm)	66.04	Flight Hours (hrs)	3.5
Height (cm)	76.2	Flight Time (min)	25
Weight (kg)	9.5	Radio Range (km)	3.5
Motor	Cobra CM4510/28		
Payload Weight (kg)	.313		

Table 2- Airframe Specifications and Performance

2.2 Autopilot

The Kolímpri uses a 3DRobotics Pixhawk Flight Controller for autonomous navigation, diagrammed in *Figure 2.* The simplicity of the wiring combined with the powerful flight computer lends the system for use by the Aerocards. The team is using Ardupilot 1.7.3 firmware, because of the many varied features that can run the entire UAS from the single interface. Through Ardupilot's Mission Planner, the Aerocards can run the Kolímpri system entirely under autonomous flight.

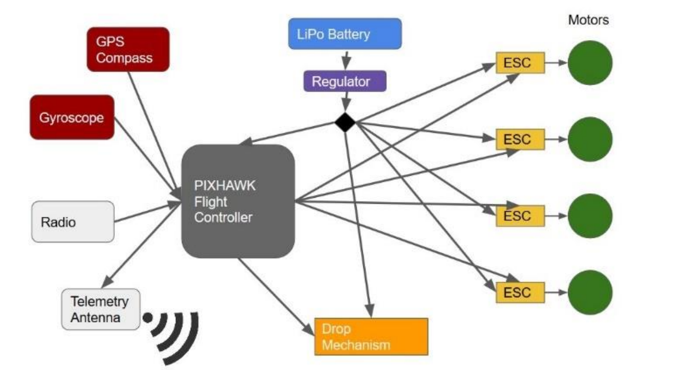

Figure 2- Pixhawk Wiring

The Ground Control Station (GCS) is the default Mission Planner interface, because the Aerocards are able to use that interface to relay information to the interoperability server while monitoring the position and status of the Kolímpri during flight. This allows for, should the UAS depart the planned flight path due to extraneous systems, for the GCS operator to tell the safety pilot and then guide the safety pilot in returning the UAS from a great distance.

2.3 Obstacle Avoidance

Due to budget and time restrictions, the Aerocards will not be attempted to incorporate a system for obstacle avoidance into the autopilot system of the Kolímpri.

2.4 Imaging System

The camera was chosen to meet a few criteria. The first criteria involved finding a camera so that would meet the drone's budget. The second criteria involved finding a camera that could obtain 4k resolution images at a given height for both user and automaton could determine characteristic features of an object. The third criteria involved sending all photos contained on the UAV en masse to the ground station during the flight to receive and ensure optimal quality of the image. After much design consideration, the team resolved to transfer the images from an on-board storage card to the ground station manually during a brief pit stop. This alleviates the need for extra telemetry gear.

Figure 3- GoPro Hero 4

Aerocards chose the GoPro Hero 4 with a wide-angle lens to capture the furthest field of view shown in *Figure 3*. The camera has 4k (3840x2160) ultra-wide camera. The GoPro Hero 4 was chosen as it is cost efficient and its ability to capture 4k resolution scenes that were sufficient for resolving targets given its resolution and field of view (FOV) characteristics shown in the equation below.

$$px/_{cm} = \frac{px}{100 * b}, where\ b\ is\ base\ in\ metres$$

$$b = 2h \tan\theta\ , where\ h\ is\ the\ height\ in\ metres\ and\ \theta\ is\ degrees\ in\ radians$$

2.5 Object Detection, Classification, Location

The images transmitted to the ground station are processed en masse with an optical character recognition (OCR) software. After this text has been extracted from the image, the image itself is cropped around the most significant disruption in the image, such as a brightly colored patch created by a potential target. Classifying the image and determining the character of the target is accomplished through an OCR program capable of scanning an image to find text. Data is collected from the program and passed along to the interop server. To determine the object's location, the time stamp of each relevant image is correlated to the location of the drone at that time via a recording of the GPS data, stored on the ground station. The time of each image is matched up with a location to determine each object's respective location.

2.6 Communications

The Kolímpri communications system sends data through three main stages. Data from the ground station is transmitted to the UAS through a Taranis R/C controller, shown in *Figure 4*. In return, the drone transmits telemetry data via the long-range antenna back to the ground station, which processes and interprets the signals before passing them on to a program which forwards all data to the interoperability server in the appropriate structure.

Figure 5 - an image of the FrSky Taranis controller

Figure 4-Radio Controller

2.7 Air Delivery

The air delivery system of Kolímpri is modelled on the system of 2017, though much more refined. The system is, quite simply, a servo that will retract a pin that supports the water bottle. The team's plan is to reach terminal velocity without placing any modifications on the delivery. This will allow the bottle to fall at a rate according to the equation:

$$V(t) = V_{max}\left(1 - e^{-\frac{Ct}{m}}\right), where\ V_{max} = \sqrt{\frac{2mg}{\rho AC}}.$$

m = mass of the object

g = gravitational force

ρ = air density

A = reference area of the object

C = Drag constant

To find the time the bottle will take to fall, the team used this equation:

$$\lim_{V(t) \to t_1} V_{max}$$

Then the team used the following integral to calculate how high to perform the delivery:

$$\int_0^{t_1} V(t)\,dt$$

The Aerocards tested two orientations of the water bottle, cap up and cap down. Data for these calculations are shown in *Table 3*.

Calculation Terms	Calculation Results
V_{max} of bottle cap up (m/s)	32.305
V_{max} of bottle cap down (m/s)	50.970
t_1 of bottle cap up (sec)	1.5
t_1 of bottle cap down (sec)	3.5
Minimum distance to fall ($\int_0^{t_1} V(t)\,dt$) bottle cap up (m)	42.22
Minimum distance to fall ($\int_0^{t_1} V(t)\,dt$) bottle cap down (m)	153.904

Table 3- Air Delivery Calculations

2.8 Cyber Security

There are fundamental vulnerabilities to using an open frequency radio to communicate between the drone and the ground team operating it. The main concern being that someone outside of the ground team could tune their radio to the same frequency and from there, either take control of the drone, or intercept radio signals coming from the drone to the ground team. This would prevent the ground team from receiving the any telemetry data from the drone, and in turn, would prevent the ground team from submitting any point garnering data to the judges. There are 4 main ways to this from happening. The first way is to simply invert the radio signal as its being transmitted to the ground team and then revert it upon its receival. This prevents someone who only looked at the antenna for the frequency from accessing our telemetry data or gaining control of the drone. Another way to prevent outside personnel from interfering with the ground team is to use hopping inversion encryption. This type of encryption causes the frequency of the radio waves to change irregularly so that it is much harder to decrypt compared to regular inverse encryption. The only downside of this encryption method is that it would take longer to decrypt than the standard inversion encryption mentioned before. Another form of inverse encryption is rolling inversion encryption which is when the radio frequency inverts at regular intervals. This makes the radio waves easier to decrypt compared to hopping inversion while keeping the radio waves more secure than leaving the radio waves unencrypted. While these forms of encryption for radio waves are useful, we decided not to use them due to time and other technical constraints concerning the other parts of the drone.

3 Safety Risks and Mitigations

3.1 Developmental Risks and Mitigations

The most significant safety risks in the development of the Kolímpri system resided in the potential misuse of power tools such as drills, saws, soldering irons, et cetera. To mitigate these potential hazards, the team was thoroughly educated on the subject of 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 goggles mandatory.

3.2 Mission Risks and Mitigations

The most significant mission risk comes from an equipment failure on board the drone which could cause it to crash. The team has suffered multiple such equipment failures in the past two years, but there has yet to be an injury as the team has established a set of procedures for when the drone is in the air, and 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- Location of Practice

4 Conclusion

During the past few months, the Calvert Hall Aerocards have devoted much time and resources into developing and testing the Kolímpri in preparation for the AUVSI SUAS 2018 competition. While the automation and programming portion of preparation have been a steep learning curve, the team is confident that the integration of these new systems will improve our score and allow the team to be more competitive as a high school in an increasingly advanced and expanding field of colleges and universities.

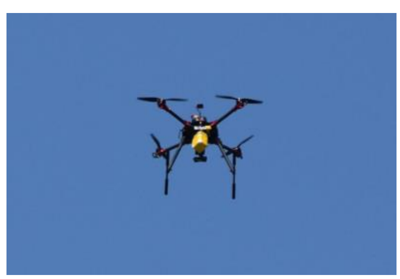

Figure 7 - Image of UAS in flight