Clark College Aerospace Team
2017 AUVSI SUAS Competition Technical Paper

Abstract

This paper describes the approach taken by Clark College Aerospace Team for the design and development of the Emperor flight system for the AUVSI SUAS 2017 competition. Our team consists of undergraduate engineering, computer science and design and manufacturing students who have worked to build a flight system from the ground up which is capable of autonomous flight as well as image detection, classification, and localization. The Emperor flight system is entirely student-designed and built with provisions for updates and improvements for future competitions.

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System Engineering Approach

Mission Requirement Analysis

Our team's primary objectives for the AUVSI competition are to achieve autonomous flight, object detection, localization, and classification, as well as obstacle avoidance. Secondary objectives, such as air delivery, are subject to time constraint. The decision to exclude air delivery from the primary objective was made for reasons of time required, budget considerations, skills of team members, and percentage of total score.

The following table (Table 1) provides the comparisons made:

Task	Time	Priority	Percentage of Score
Autonomous Flight	3 Months	High	30%
Obstacle Avoidance	1 Week	Medium	20%
Object Detection, Classification, Localization	6 Months	Medium	20%
Air Delivery	2 Weeks	Low	10%

(Table 1)

Design Rationale

Airframe budget constraints were fortunately a non-issue due to the generosity of a local company (Protech) which volunteered their time and resources to help us cast an airframe of our own design using a carbon fiber/fiberglass composite. The composite material allows us to maximize fuselage airframe strength and rigidity while minimizing weight, resulting in a strong lightweight platform capable of longer periods of flight.

Secondary to airframe design, autonomous flight was given top priority since all other objectives rely on the platform's ability to operate effectively without human input. Signal input for object detection, obstacle avoidance and payload delivery depend on stable and precise flight patterns. Because of this, both our hardware and software teams have allocated a majority of their time to achieve reliable autonomous flight.

Object detection, classification, and localization was ranked as higher priority than obstacle avoidance for several reasons. First, our programming team expressed a strong desire to experiment with the machine learning algorithms required for achieving this objective. Secondly, object detection and classification is considered by our programming team to be a more difficult task than obstacle avoidance, necessitating a larger amount of time allocated to this task.

Risk Mitigation

Risk	Possibility	Impact	Mitigation
Inability to complete on time	High	High	Detailed schedule with set deadlines
Delay in parts acquisition	Medium	High	Parts ordered early with time to spare in event of defective or delayed parts
Damage to airframe	High	Medium	Flight simulation training and spare parts on hand.
Damage to hardware	Medium	High	Fully-enclosed rigid fuselage
Unintended Malfunction of Software	High	Medium	Active backup of all files
Crew training issues	Medium	High	Crew required to complete flight sim training as well as familiarize themselves with GCS.

(Table 2)

System Design

Aircraft

The Emperor airframe is made up of a two-part polyhedral wing consisting of a balsa frame wrapped in MonoKote heat shrink, an enclosed carbon fiber/fiberglass composite fuselage, hollow carbon fiber tail boom, and a standard cruciform tail made of balsa and heat shrink. While initially the intention was to produce a custom three-part flat wing made of carbon fiber/fiberglass composite, it was replaced in favor of a conventional off-the-shelf polyhedral balsa wing. The polyhedral wing design, in addition to providing very stable flight, allows for yaw-controlled roll which reduces the control input requirements to two channels in addition to consolidation of control surfaces to the tail of the airframe. Coefficient of lift calculations were performed for a standard Clark Y and Eppler-205 airfoils and selected the Eppler-205 based on our system requirements (Fig 1).

Airframe:	Skyhunter
Span (in)	70.8
Area (sq in)	640.86
weight (oz)	88.18
Aspect ratio	7.8
Taper ratio	0.91
CL Max	1.3694

Airfoil: Clark Y	Re: 100,000					
	V (mph)	V (m/s)	CL	CD	Pro+Ind CD	Drag (oz)
Stall	18.8	8.4	1.3694	0.0401	0.116	7.490
v2	20	8.9	1.211	0.0229	0.083	6.011
v3	30	13.4	0.538	0.0181	0.030	4.902
v4	40	17.9	0.303	0.0190	0.023	6.618

Airframe:	Clark Hunter 100
Span (in)	100
Area (sq in)	892.5
weight (oz)	141.10
Aspect ratio	11.2
Taper ratio	0.62
CL Max	1.3694

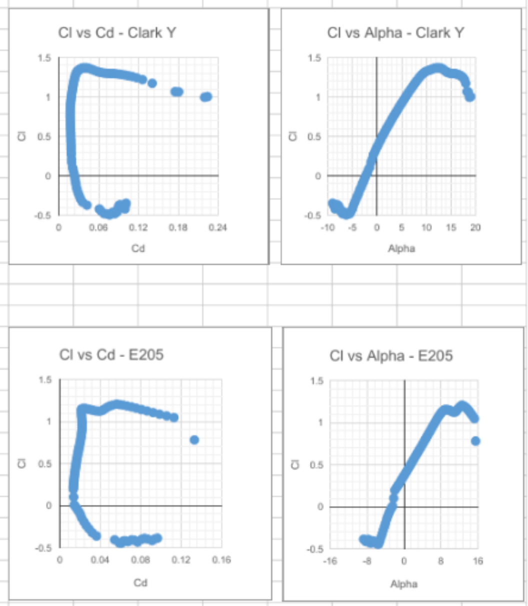
Airfoil: Clark Y	Re: 100,000					
	V (mph)	V (m/s)	CL	CD	Pro+Ind CD	Drag (oz)
Stall	20.2	9.0	1.3694	0.061	0.114	11.761
v2	30	13.4	0.618	0.018	0.028	6.500
v3	34	15.2	0.481	0.016	0.022	6.495
v4	38	17.0	0.385	0.015	0.019	6.875

Airframe:	Riser 100
Span (in)	100
Area (sq in)	1000
weight (oz)	44.97
Aspect ratio	10.0
Taper ratio	0.82
CL Max	1.2071

Airfoil: E205	Re: 100,000					
	V (mph)	V (m/s)	CL	CD	Pro+Ind CD	Drag (oz)
Stall	11.5	5.1	1.207	0.133	0.180	6.688
v2	15	6.7	0.703	0.019	0.035	2.230
v3	25	11.2	0.253	0.013	0.015	2.753
v4	40	17.9	0.099	0.014	0.015	6.598

Airframe:	Riser 100 Electric UAV
Span (in)	100
Area (sq in)	1000
weight (oz)	88.96
Aspect ratio	10.0
Taper ratio	0.82
CL Max	1.2071

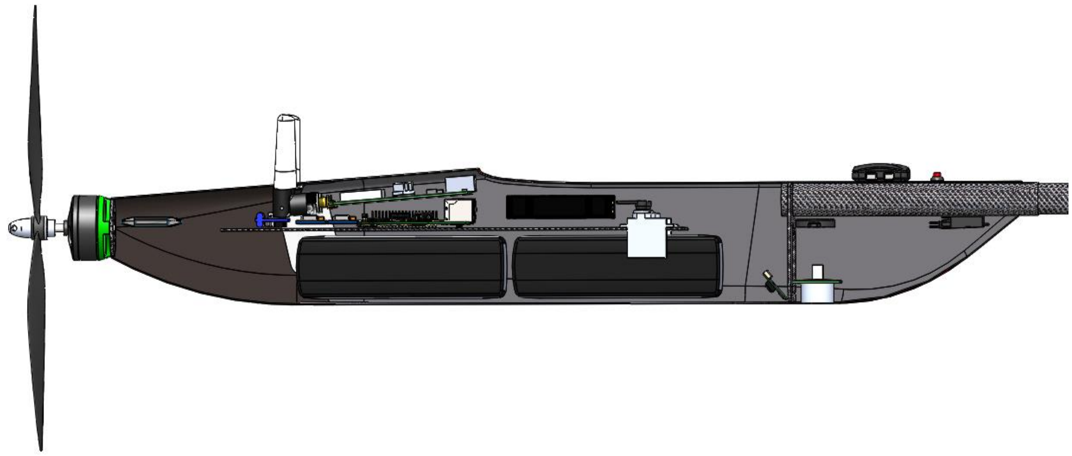
Airfoil: E205	Re: 100,000					
	V (mph)	V (m/s)	CL	CD	Pro+Ind CD	Drag (oz)
Stall	16.1	7.2	1.207	0.133	0.180	13.229
v2	20	8.9	0.783	0.020	0.040	4.524
v3	25	11.2	0.501	0.016	0.024	4.243
v4	36	16.1	0.242	0.013	0.015	5.640



(Figure 1)

The main body of the airframe is a custom-built fully-enclosed hollow carbon-fiber/fiberglass composite frame designed to house all electrical components of the flight system (Fig 2). Wings are attached to the body of the airframe with four nylon bolts which will act as a weak point in the event of a crash.

(Figure 2)



The tail of the Emperor is a standard cruciform which was selected for its simple design. Both control surfaces (rudder and elevator) are located in the tail and controlled with independent servos. All relevant airframe and flight information is presented in tables 3 and 4.

Cruise Speed	Empty Weight	MTOW
34mph	2.96lb	8.82lb

(Table 3)

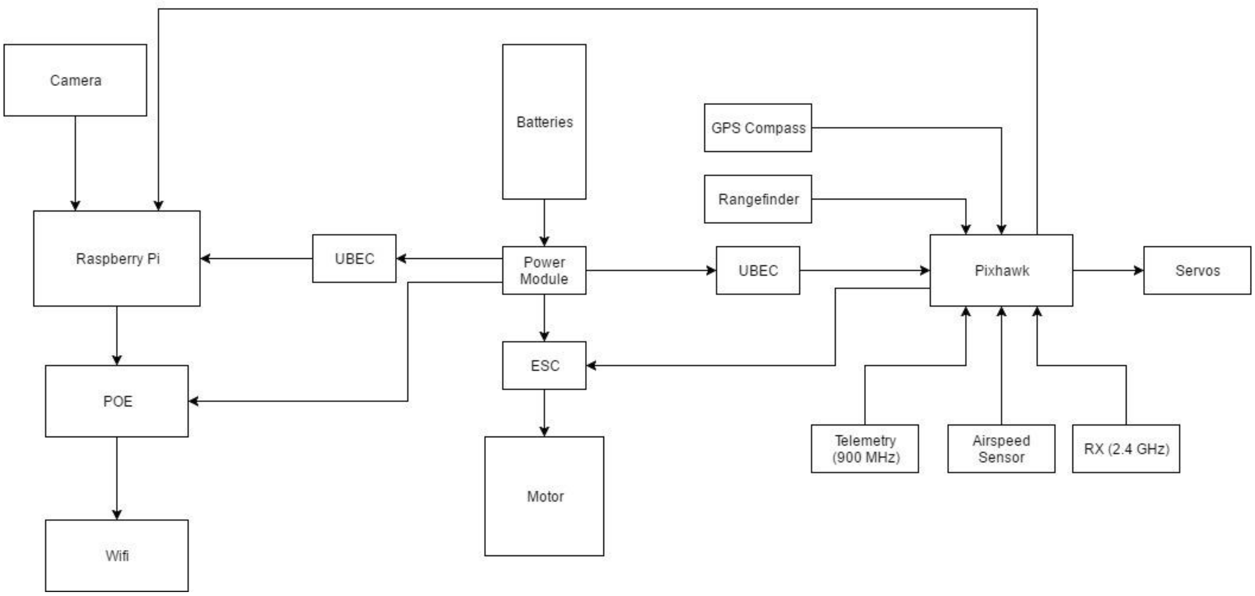
	Main wing
Root chord	11in
Tip chord	7in
Airfoil	Eppler-205
Span	100in
Area	1000in^2
Aspect Ratio	11.2

(Table 4)

Autopilot

The Pixhawk flight controller was selected due to its price, processing power, and open source nature of the software. The communication protocol of Pixhawk is Mavlink which consists of a library of commands. Pixhawk outputs these commands through a serial connection to a telemetry radio which is picked up by our ground telemetry radio. This radio is connected via USB to a laptop computer configured as a virtual comm port. Mission Planner reads this Mavlink telemetry data and uses the information to update the navigation map. Additionally, this system allows us to call for parameters from autopilot and in turn mission planner can update the flight controller parameters either on the ground or in flight. This includes updating waypoints and navigation control. Autopilot is constantly updating Mission Planner with all the data points it can perceive such as power use, voltage, current draw, airspeed, altitude, ground speed, and GPS health. Autopilot also has the capability to upload all flight controller parameters at startup and update them as they are modified at the ground control station.

Information pertaining to the flight of the aircraft is acquired through a sensor suite which was created to suit the specific design requirements of the competition. The primary sensor is the IMU which detects orientation and acceleration. A GPS sensor records position, speed, and altitude which is relayed to the ground control station. Additional sensors include airspeed and power module sensors, as well as a rangefinder used to detect precise height above ground for landing (Fig 3)



(Figure 3)

Obstacle Avoidance

As of the writing of this document no systems for obstacle avoidance have been implemented. This will be addressed if time permits, however since this has yet to become a legacy project we have made provisions for obstacle avoidance features to be added as the design evolves for future competitions.

Imaging system

The current Emperor prototype uses a Raspberry Pi camera. This was selected due to its low cost, compatibility with the Raspberry Pi, and low weight. Flight and systems testing will determine whether the resolution is adequate for image capture and whether a fixed focal length will be detrimental for our purposes. According to Mission Planner the Raspberry Pi camera can plot a grid scale of 1 in/pixel which meets the minimum criteria for our design requirements. Since our aircraft would be operating at a minimum altitude of 150 ft, achieving higher resolution would require a longer focal length which in turn would require our aircraft to fly a tighter grid in order to map an area. If the Raspberry Pi camera proves to be insufficient, our design will have to evolve to incorporate a camera such as the Samsung NX1000 which has higher resolution and a variable focal length lens. The trade-off is that of weight as well as the challenge of fitting it into our airframe.

Object Detection, Classification and Localization

The object detection, classification and localization system used is made of separate interconnected systems: an onboard data collection system, a wireless communication network, a grund image pre-processing system, and neural processing system. The data collection system consists of a Raspberry Pi 3 with the default camera module connected to a Ubiquiti Rocket M5 wifi transmission module. After system confirmation from the Python-Bash socket ground server, the camera automatically starts to take still frame images and sends it to the ground in jpg form for image preprocessing. The still frame method was selected instead of live video transmission as it allows for greater image definition and superior latency as well as already formatting it in the correct format for the image system. The ground station that the UAV connects to is a Ubiquiti NanoStation with an estimated range of approximately 15 kilometers. This in turn connects to the ground station laptop which receives the jpeg frames from the UAV. These are deposited into a folder which an OpenCv python script processes into files that may contain potential targets through image analysis and optimizes them and laces the reformatted images into another folder for neural processing.

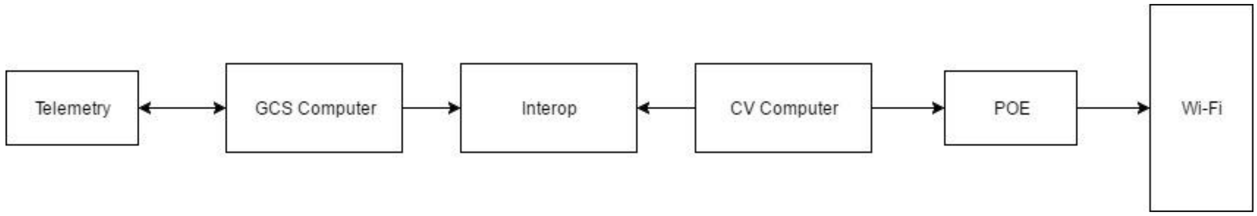
In choosing the right neural network processing algorithm it was clear that a convolutional neural network was superior to recurrent networks, autoencoders, or multilayer perceptrons due to its almost consistent success in real life applications, such as the ILSVRC. Neural networking was not the only system considered, also investigated during development were the Haar Cascade cv2 classifier as well as simple geometric analysis. But in consideration of the uncertainty of noise data or uncontrollable variables, convolutional neural networks provide the most reliable solution. With regards to the selection of which possible library to utilize for the system, Tensorflow was selected as it has a large online community and documentation as well as being the most popular choice. The system was considered to be made without the use of machine learning library with just Numpy operations, but the large amount of processing is faster with Tensorflow as it is configured for maximum efficiency and it saves considerable development time by installing a framework for dealing with neural networks. After the neural processing stage, the output data is put in JSON form. In addition to the color and object identification system, the frames are also sent to a location estimator that uses the data from the frame and Mission Planner to estimate the location of the target and appends this data with the JSON file for the frame.

Communications

Communications for the Emperor fall into three categories: radio control link, autopilot telemetry, and image capture (Fig 4). Our radio control link operates on the 2.4 GHz frequency spectrum using a FrSky receiver/transmitter combo. Frequency hopping is employed to reduce interference in the 2.4 GHz range and all communication over this frequency falls under part 15 FCC compliance. This is a standard hobby radio controlled communication system that is employed by most out of the box R/C radio systems.

Autopilot telemetry will be transmitted using 900 MHz 3DR or RFD900+ radio telemetry system, the latter being a tradeoff of increased range along with increased weight. These radios relay the MAVLink protocol telemetry data between the Pixhawk and the ground control station computer which runs the Mission Planner Software. In addition to receiving telemetry, this link allows for commands to be transmitted to the aircraft during flight.

The image capture system communicates through the Ubiquity NanoStation. The communication network uses the Ubiquiti Rocket M5 for onboard transmission and the Ubiquiti Nanostation for the ground control station with an estimated range of 15 kilometers. A wireless bridge connects two python socket servers that can transmit image data to the ground computer which is used with telemetry from Mission planner to obtain all necessary information.



(Figure 4)

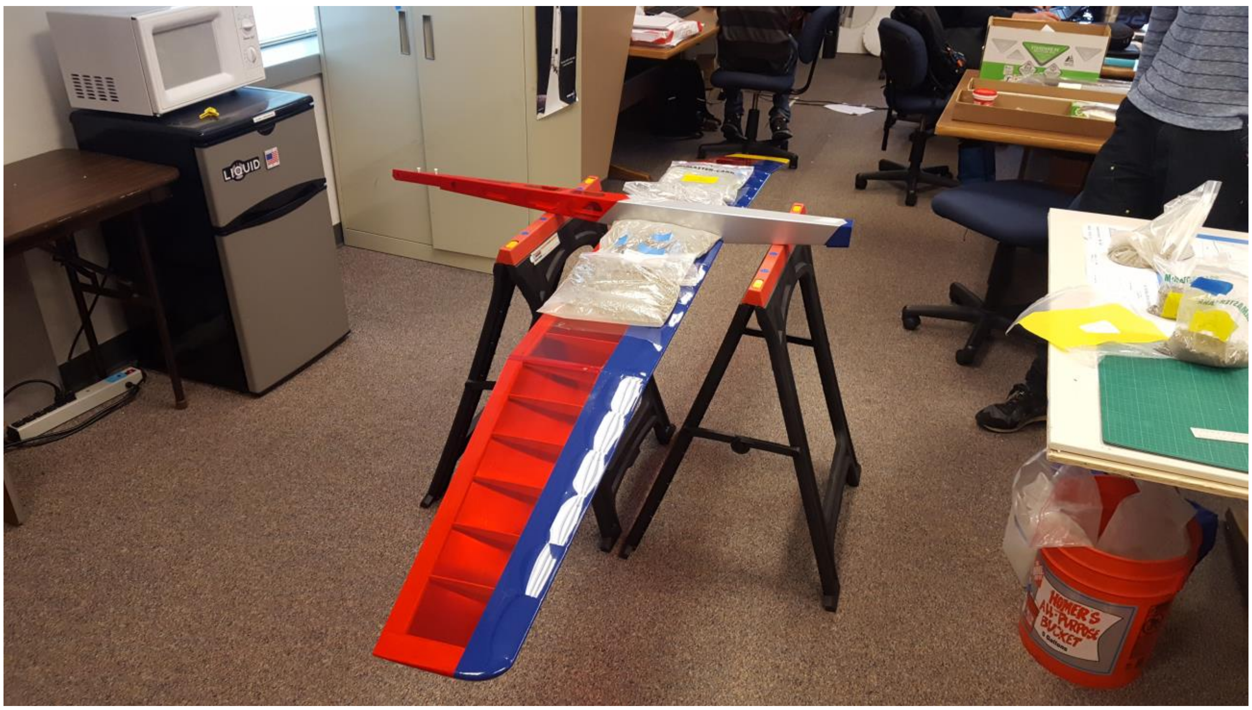
Cyber Security

The Ubiquiti Rocket M5 and Nanostation are pre-configured to encrypt messages in WPA2 so that only the ground computer can send messages up to the UAV or receive imagery data. However, the telemetry and aircraft control system is managed by Mission Planner and therefore a breach of the imaging system would not put the vehicle at risk. Mission Planner encryption is used to protect the aircraft control system.

Test and Evaluation Plan

Developmental Testing

Developmental testing consisted of wing loading and computer vision testing. Wing load testing was conducted on the Emperor to simulate a 2 G load at an approximate weight of 8 kg and was successful with minimal wing deflection. Since the fuselage has yet to be manufactured, all other testing will be completed at a later date. These tests will include flight time, static thrust, waypoint capture, takeoff and landing, altitude hold, wind correction and extensive propulsion system testing in order to select the correct motor for the aircraft.



(Figure 5)

The computer vision system can be tested in real world testing environments or in a simulated test. The real life testing environments use vehicle prototypes taking images of targets in the field and use this testing data to optimize the system parameters. Other tests are digital reproductions of the targets using cv2 that are also used for optimization. Computer vision parameters are already optimized through cross-entropy cost reduction while the BGR ranges were optimized through a custom cv2 python script.

Individual Component Testing

Three brushless electric motors will be evaluated for use in the Emperor flight system. Initial testing will take place with a Turnigy Park 430 kV motor which will be underpowered and help us in determining the minimum thrust-to-weight ratio required for climbout. After that, three motors of various sizes and kV ranges will be tested along with a variety of propellers. These flight test will be conducted for qualifying the eCalc 3 software predictions for our aircraft. Other parameters for testing include efficient cruise speeds, rates of climb as well as weight and balance.

Preliminary testing will include a simulated flight through FlightGear by connecting the Pixhawk autopilot hardware to a PC. The simulated flight will include a waypoint map based off of the 2016 competition. Any tuning or complications in the simulation will be addressed before proceeding to the next test. The secondary test will be flown using a disposable fuselage and will be performed for the purposes of verifying successful waypoint navigation, takeoff and landing, altitude holding and wind correction. The final test will be performed on the completed airframe in order to ensure that the autopilot functions as intended.

Mission planner was used to evaluate the minimum requirements for our camera and to ensure that the camera used will provide enough resolution for target recognition software to function as intended. Secondary imaging testing will be performed on the ground using 1:5 scaled targets.

Object detection, classification and localization can be tested through real and simulated training data. Real object testing will consist of using sample images from past competitions and will be used to test accuracy and for purposes of tuning design parameters in order to optimize performance. Simulated testing will take place with generated images which will also be taken from previous AUVSI SUAS competitions.

Communications system testing will take the form of static testing in order to verify that communication systems are operating correctly at the intended ranges for the mission requirements. In particular, image transmission via the 802.11 Wi-Fi band will be tested in order to determine processing time and range.

Mission Testing Plan

Multiple flight tests will be conducted in order to establish the readiness of the Emperor flight system. Flight tests will measure the performance of the flight system as development progresses. The primary categories of our missions will include takeoff and landing, waypoint navigation, object detection, location and classification, obstacle avoidance and interoperability. Additionally, emergent task testing will take place as well as automatic flight termination in order to ensure the robustness of our failsafe system. The flight system will also be tested in adverse conditions which include high winds and low visibility.

Safety, Risks and Mitigations

In order to minimize the possibility of human error multiple checklists were employed for both the Emperor aerial system and ground control station. Detailed inspections are carried out before and after each flight and any issues present have to be cleared by the team lead and safety officer before operations can continue.

Developmental Risks and Mitigations

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Because mishandled LiPo batteries also present a possible risk, measures were taken to mitigate this risk. Batteries are charged using a Turnigy Accucell 6 battery charger which can be powered by either a 12 volt portable source or a 110 volt wall outlet. Batteries are checked prior to each flight for correct and even charge across all cells and charge is actively monitored during flight. Special LiPo bags are used for transportation and batteries are only shipped via ground transport. At least one fire extinguisher is required to be present at all times.

Care was also taken to make construction of the airframe safe. To prevent inhalation of toxic fumes no highly toxic materials were used. Construction took place in a large, well ventilated room to prevent any buildup of gases. Gas masks were also worn if any particulates were present. Cutting tools and heated tools were handled with all the proper safety procedures. All tools, adhesives and other chemicals were kept locked in cabinets when team members were not using them.

Mission Risks and Mitigations

Since the UAV itself presents a notable risk to people in the general vicinity of the aircraft, such as during takeoff and landing, team members are required to wear safety goggles during all flight operations. Additionally, in order to minimize any damage to property all flight testing was performed away from private residences and areas with high vehicular traffic. Team members are also required to pay attention at all times so as to be aware of incoming hazards. A first aid kit was also carried during all field tests.

Operational Risks and Mitigations

Autopilot malfunction presents a large risk since an out-of-control UAS can be quite hazardous to both people and property. In the event that the autopilot does not perform as intended, a manual override is installed and a safety pilot is always on hand and ready to take over the flight controls.