System Overview for the XawkEye UAS

Mississippi State University's Entry for the
2016 AUVSI Student UAS Competition

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Abstract

The 2016 Student UAS competition, hosted by AUVSI, marks Mississippi State University's thirteenth year of participation. The Xipiter team continues to take a systems engineering approach in order to design an unmanned aerial system (UAS) capable of safely and efficiently accomplishing mission objectives involving the gathering and delivering of real-time actionable intelligence, surveillance, and reconnaissance (ISR). The XawkEye UAS couples a robust, student designed and constructed airframe with an array of commercial hardware and student-developed software components. This enables a dynamic system, capable of gathering images and locations of targets of interest during autonomous flight. The airframe is fabricated using fiberglass composites with foam and balsa wood cores. The onboard avionics system includes: the 3DR Pixhawk autopilot in the guidance, navigation, and control (GNC) subsystem; a digital electro-optical camera, a single board computer, and a broadband ethernet bridge in the imagery subsystem. The ground station includes the interface to the autopilot, camera control software, and image processing software. This system has been carefully designed and rigorously tested, proving to meet the mission requirements set forth by the Student UAS Competition.

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1.0 Introduction

The AUVSI Undergraduate Student UAS Competition, an international competition for colleges and universities, requires each participating team to submit a journal paper, conduct an oral presentation, and demonstrate the flight capabilities of the team's UAS. The flight portion of the competition is composed of five mission phases: takeoff, waypoint navigation, area search, network interface, and landing. The first phase, takeoff, may be manual or autonomous, but the flight portion of the competition must be fully autonomous. After takeoff, the UAS must then climb to a cruise altitude between 100ft and 750ft MSL. The waypoint navigation phase consists of flying over waypoints provided at competition while remaining inside the given flight area. During the third phase, area search, teams use their UAS surveillance capabilities to locate targets and identify the shape, background color, orientation, alphanumeric, and alphanumeric color of each target. The team must identify a minimum of two of these target parameters. In addition to the target parameters, teams must also identify the location of the target via GPS coordinates. The last phase, landing, may occur either under manual or autonomous control. In order to obtain maximum credit, the team must complete all five phases of the mission in less than thirty minutes. Secondary objectives include automatic target recognition, interoperability, sense-and-avoid, and network interface. The interoperability and sense-and-avoid tasks involve connecting the aircraft to the judges network to verify the UAS position. This data is then cross referenced against the known coordinates of the virtual obstacles to determine if the aircraft has successfully avoided the obstacles. The network interface task consists of orbiting a directional antenna while connecting to a network on the ground to download and upload data.

2.0 Systems Engineering Approach

Xipiter has embraced a systems engineering approach over the years, best represented by a V-model. The V-model is a commonly applied representation for project lifecycle development, which is shown adapted in Figure 1. The team examines the given task, goals, and requirements presented; develops a solution; breaks down the details on the left side of the "V" into subsystems and sub-components; and then reassembles it to a final product on the right side. The "V" stands for verification and validation, incorporating testing throughout the entire process. The fundamental design process reflects those requirements outlined in the AUVSI Student UAS Competition Rules and embraces the Concept of Operations presented by the Seafarers Chapter.

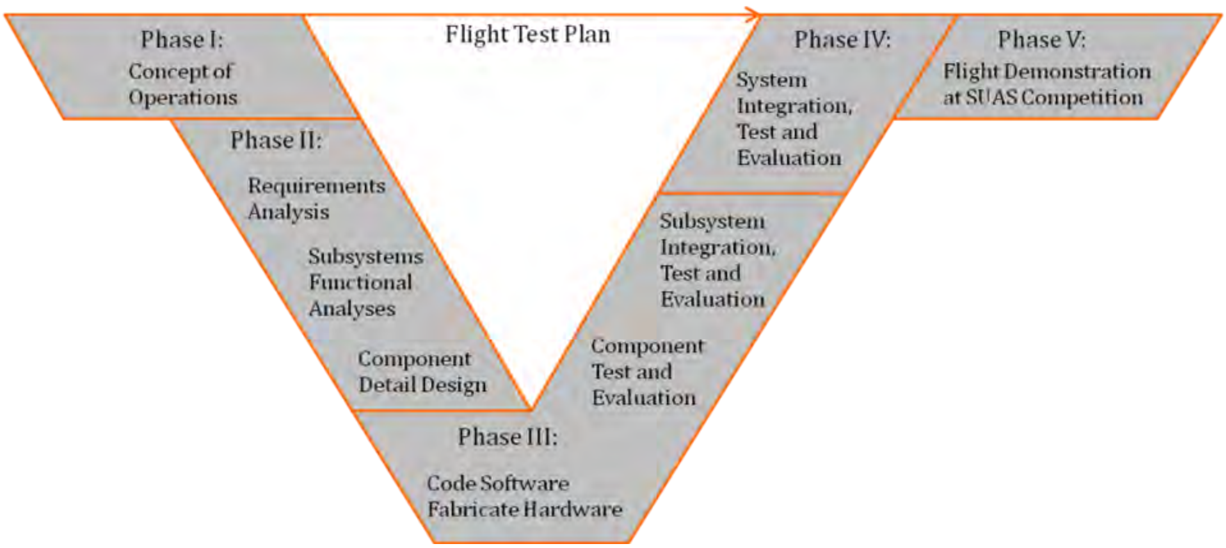

Figure 1: Xipiter's V-Model

2.1 Mission Requirements Analysis and Design Rationale

Based on the competition rules, relative score weight, and implementation-feasibility of the mission tasks, Team Xipiter has chosen to attempt the following: **Autonomous Flight (primary), Search Area (primary), Simulated Remote Information Center (SRIC), Actionable Intelligence, Emergent Target, and Off-Axis Target**. To successfully complete the planned tasks and to ensure all rules and regulations are followed, the team has identified mission requirements as follows.

- The system shall be capable of remaining in flight between 100 – 750 MSL. **(AUVSI)**
- The flight portion of the mission shall be completed in a maximum of 30 minutes. (**AUVSI)**
- The system shall not exceed a maximum gross takeoff weight of 55 lb. **(AMA)**
- The system shall have a maximum airspeed of 100 knots. **(AMA)**
- The system shall be capable of operating within specified environmental conditions. **(AUVSI)**
- The system shall be capable of autonomous flight, takeoff, and landing. **(Autonomous Flight task)**
- The system shall be capable of real-time imagery. **(Actionable Intelligence task, Off-Axis Target task)**
- The system shall be capable of target identification. **(Search Area Task)**
- The system shall be capable of dynamic retasking **(Emergent Target task)**
- The system shall be capable of network interface. **(SRIC task and Interoperability requirement)**

From these mission requirements, team Xipiter has developed 5 unique system design objectives to ensure mission fulfillment, as shown in Table 1.

Table 1: Design Objectives

System Design Objective	Result
Minimize flight vehicle size but maximize stability to reduce effect of environmental conditions	Stable airborne surveillance platform, better maneuverability within search area, easier transportation of the aircraft
Maximize surveillance equipment resolution while minimizing weight and size	Clear photos for best image processing results
Minimize UAS assembly/disassembly complexity	Rapid (5 minute) deployment in the field
Catapult Launch / Belly Land	Safe and repeatable launch sequence / no runway required
Modular construction	Rapid deployment, ease of maintenance, interchangeable parts

2.2 Risk Identification and Mitigation

Xipiter used the risk assessment tables and matrix presented in Table 2 to identify and classify potential system and subsystem hazards throughout all phases of XawkEye UAS development.

Table 2 -- Risk assessment used for analyzing impact of potential hazards.

Rank	Severity Class	Description
1	Minor	Results in minor system damage or minimal/negligible first-aid required personal injury.
2	Major	Results in repairable system damage or first aid required personal injury

3	Critical	Results in non-repairable system damage or personnel injury requiring medical attention beyond first-aid, personnel exposure to harmful chemical or radiation, or fire or release of chemicals
4	Catastrophic	Failure results in major injury or death of personnel.

Rank	Class	Description
1	Very unlikely	Has not occurred, but within possibility
2	Remote	Has occurred once or twice in the past
3	Occasional	Occurs once per month
4	Probable	Occurs once a week
5	Frequent	Occurs multiple times in work session

Frequency & consequences	1 Very unlikely	2 Remote	3 Occasional	4 Probable	5 Frequently
Catastrophic					
Critical					
Major					
Minor					

In the table above, a blue cell represents an acceptable task, a grey cell represents a semi-acceptable task, and a yellow cell represents an unacceptable task. With safety as the foremost concern, a semi-acceptable task, authorization or pre-approval from superiors is required. For unacceptable tasks, risk reduction is required before implementation.

In order to mitigate risk, the potential risks must first be identified. The risks that team Xipiter have identified and their mitigations are shown in Table 3.

Table 3: Risks and Mitigation

Risk	Mitigation
Power system failure	High-grade wire and connections and test-proven system
Loss of control link (RC)	Return-to-Launch functionality, flight termination
Launcher system failure	Safety bleed valves, shielded wire, removable hose, remain below 60% of component ratings.
Loss of telemetry link (Autopilot)	Safety pilot takeover
Irregular autopilot control (control system failure)	Safety pilot takeover

2.3 Mission Planning

Planning for each mission begins at least one day prior to the mission. Due to the system endurance of XawkEye, in order to remain within safe levels of battery charge, total flight time of the system will be hard limited to 20 minutes despite testing that shows it can last for 35 minutes. This time limit will ensure that the battery will not reach low capacity, and also allows maximum post processing time while still giving enough time to complete the planned primary and secondary tasks. Since the primary tasks are worth substantially more than the secondary tasks, at least 70 percent of the flight time will be allocated to completing the autonomous flight, waypoint navigation, and search area tasks. Due to potential weather events, such as high winds, contingency planning for autonomous takeoff and autonomous flight are prepared. Multiple landing approaches in at least three directions are planned before each mission, to account for changing wind direction and prevent a crosswind/tailwind landing whenever possible. To ensure system safety, if the reported surface winds are above 15 knots sustained, the autonomous flight objective will not be attempted; a manual landing will be performed instead. To plan the search area mission, the geometric area of the search is first calculated. By knowing the search area, the altitude the aircraft is flying, and the speed the aircraft will be flying, the number of passes required to sufficiently cover the search area can be calculated.

The secondary tasks will only be attempted if the team successfully achieves at least threshold level on each primary task. After each primary task is achieved to at least threshold level, the secondary tasks can be attempted. Due to the relative scoring weight of each secondary task, certain task attempts may be omitted due to the time constraint. Since the Actionable Intelligence task is weighted higher than the other tasks, this task will be attempted first. If time allows, the emergent target and SRIC tasks will be attempted based on the Flight Director's final call. Since the Off-Axis target does not require deviation from the planned flight path, this objective will be attempted in every scenario. If time remains after completing all primary and secondary tasks to at least threshold level, and the off-axis target has not yet been identified, the aircraft will be retasked to the off-axis target area to begin the search again.

3.0 XawkEye UAS Design

Xipiter UAS used a systems engineering approach throughout the development of the XawkEye UAS. A combination of commercial-off-the-shelf components and custom designed hardware/software is used in the system.

3.1 Airframe

The XawkEye airframe is a student designed and built aircraft. The aircraft is catapult launched and belly landed as opposed to a conventional runway takeoff and landing. This configuration allows us to maximize flight test time before competition, as getting clearance to fly on a runway can be time consuming - instead we are able to fly within the confines of a remote field. The modular design of the aircraft greatly decreases assembly complexity and deployment time. Further, it allows for rapid maintenance and repairs as necessary.

XawkEye's fuselage combines commercial off the shelf parts and custom fabricated parts. The main fuselage boom, which all components are attached to, is an off-the-shelf carbon tube. The payload bay is made of fiberglass composites, with balsa wood core for added stiffness and two plies of Kevlar for abrasion resistance. The brackets that attach the fuselage, wings, and tail to the boom are custom designed 3D printed ABS plastic. To fabricate the payload bay, a positive mold was created by using a CNC hot wire to cut out the desired shape from polystyrene foam, which was then sealed to lay-up on.

The wings, horizontal, and vertical tail are manufactured using fiberglass composites, with carbon fiber tube spars and insulation foam core. The foam core was cut using a CNC hot wire that allowed the team to achieve the desired airfoil and taper shape of the wings and tail. Once the foam core was cut and the spars were bonded, the entire assembly was covered in light fiberglass which added rigidity as well as surface protection from debris. The tail surfaces use carbon-fiber strips in the spanwise direction that act as spars. Geometric specifications for XawkEye are shown in Table 4.

Table 4: XawkEye airframe specifications

Component	Span/Length	Area	Aspect Ratio or Volume
Wing	8 ft	7.12 ft^2	9
Horizontal Tail	2.33 ft	1.42 ft^2	3.8
Vertical Tail	1.2 ft	1.11 ft^2	1.4
Payload Bay	3 ft	-	0.52 ft^3
Fuselage Boom	5 ft	-	-

3.1.1 Launch system

Due to the size of the airframe, the team elected to design a catapult launch system to provide safer, more repeatable and reliable launches. While the aircraft is capable and has been hand-launched, a catapult system will provide a much smoother launch sequence and perform exactly the same for each launch, as opposed to hand launches. The system consists of a middle-split, 12’ long launch rail, fabricated using off-the-shelf 5”x5” extruded aluminum square tubing. Inside the launch rail, a 2.5” PVC piston is housed within a 3” outer diameter PVC pipe. The piston is attached to the carriage by a 840 lb rated nylon-cased steel cable which runs over a 5” pulley at the front of the launcher. In order to energize the system, an air storage tank is pressurized independently from the launcher itself, and then that tank is connected to a solenoid valve by a 1” diameter hose. When the tank is pressurized and the system is cleared to launch, the solenoid valve is opened, releasing the air pressure into the PVC cylinder. This pressure accelerates the piston toward the aft end of the launcher, which in turn accelerates the aircraft toward the front of the launcher. Pressure bleed holes are drilled near the rear of the launcher to mitigate the instantaneous deceleration of the carriage to avoid damaging the launcher; once the piston passes each bleed hole, the pressure behind decreases and therefore the acceleration on the piston and carriage is slowed.

The carriage was manufactured using custom-machined aluminum parts. To hold the aircraft on the carriage, aluminum rods were placed in the payload such that the center of gravity of the aircraft is near the center of the two holding points. These rods then sit in custom designed arms which prevent the aircraft from tipping backwards or sidewards while on the launcher; however, the arms are free to rotate forward to avoid a tail strike at launch. At the end of the launch rail, four high-strength compression springs are attached to aluminum L-brackets. This inertial damping system help dissipate the remaining kinetic energy of the carriage system which prolongs the work life of the individual components. The aircraft on the launcher system is shown in Figure 2.

Figure 2: XawkEye and Launch System

Integral to the safe operation of the launch system is the actual launch switch box and solenoid subsystem. The box consists of a main power switch, 4 covered switches, two in-line fuses, and a voltage transformer. The solenoid is powered using 24 VAC at less than 1 A; however, the transformer is included in the box to allow for 120 VAC input. Further in order to allow for launching in locations without power, a 12 V 1250 mAh LiPo battery, 12 VDC power outlet, and 12VDC-120VAC power inverter were added to the box.

The solenoid used is a open-only-when-energized type which mitigates any safety risks associated with power failure. The solenoid is not tethered to the box until all personnel have cleared the launch area and permission has been granted from the flight director. Upon approval to tether the solenoid, a shielded cable is used to prevent any electromagnetic anomalies. Once the solenoid is tethered, permission must be requested and granted independently by all personnel - final Go/No-Go. Further, the launch sequence requires the depression of specific safety covers and switches independently by Gear and Shooter. An electrical schematic and picture of the launch box are shown in Figure 3 and 4.

Again, in order to maintain a high level of safety for the crew, bystanders, aircraft, and launch system, high quality parts are used and all components' working pressure rating is well above the 110 psi which is used for launch. The lowest pressure rating components used are the air-tank and solenoid valve, which are rated to 200 psi working pressure. Also a 200 psi pressure release valve, which has been tested to work, is located on the air-tank to ensure that the system can never be over-pressurized. This system has proven to be safe, robust, and fully-successful.

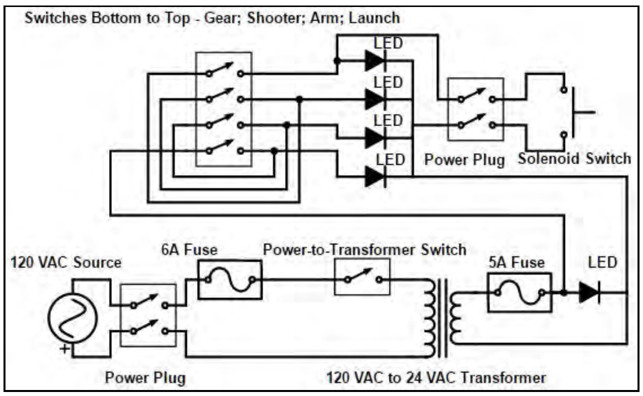

Figure 3: Launch box wiring schematic

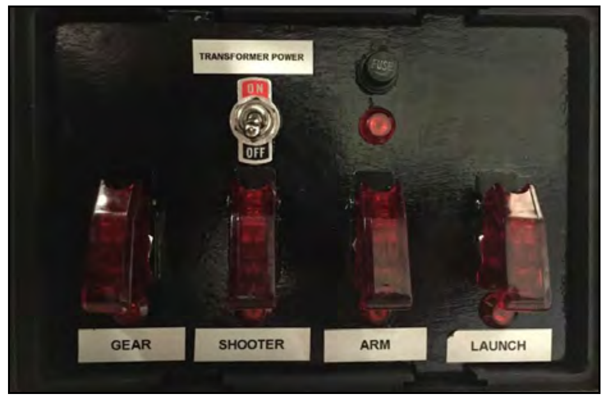

Figure 4: Launch box

3.1.2 Propulsion System

In order to promote safe, efficient, and user-friendly control an electric propulsion system was adopted. Team Xipiter has used Glow, gasoline, and electric propulsion systems through the years, and have become most comfortable and impressed with electric propulsion due to the simplicity of set-up, maintenance, storage, and its overall reliability. For the 2015 SUAS competition season, due to financial constraints the propulsion system was composed of cheaper, less-efficient components and led to less-than-ideal mission performance, primarily flight time. For XawkEye it was decided to invest in a better propulsion system; though still limited financially, a motor, ESC, propeller, and battery combination were found that increased overall flight time by 50% to 35 minutes and reduced the propulsion system weight by 10%, while the cost increase was over 400%. The motor selected is a Axi 5320/18 V2; the ESC is a Castle Creations Phoenix Edge 100, the propellers (2x) are Aeronaut CamCarbon 18x11 folding propellers, and the battery is a 12000 mAh, 6 cell LiPo.

3.2 Systems

The XawkEye UAS is a system of systems. To ensure mission success, the system is discretized into four subsystems: Guidance, Navigation and Control (GNC); Intelligence, Surveillance and Reconnaissance (ISR); Simulated Remote Information Center (SRIC), and Interoperability.

3.2.1 Ground Control Station

To facilitate successful mission performance, and easier logistics, a custom all-in-one ground station was designed by Team Xipiter. The ground station is composed of two computers: one to run the guidance, navigation, and control (GNC) system, and a second to run the intelligence, surveillance, and reconnaissance (ISR) system. The GNC computer is an off-the-shelf ASRock BeeBox single board computer. The team selected this system due to prior experience as well as the low cost, as this system does not need to have higher than average performance graphics or processing power. Since the ISR computer will be processing large image files, the team elected to build a custom computer that can be upgradable to suit the team's future needs. This all-in-one solution for the ground station will drastically reduce mission set up time, and increase the overall deployment time of the system.

3.2.2 Guidance, Navigation, and Control (GNC)

To satisfy the competition requirement of autonomous flight, Team Xipiter has selected the 3DR Pixhawk flight controller due to its proven reliability, previous experience with the system, and inexpensive cost compared to other systems. The GNC system has two parts: the ground station and the onboard flight controller.s. Team Xipiter has elected to use the DragonLink 433 MHz UHF module attached to the RC transmitter to increase the remote control range well past visual line of sight. A block diagram of the control system is shown in Figure 6.

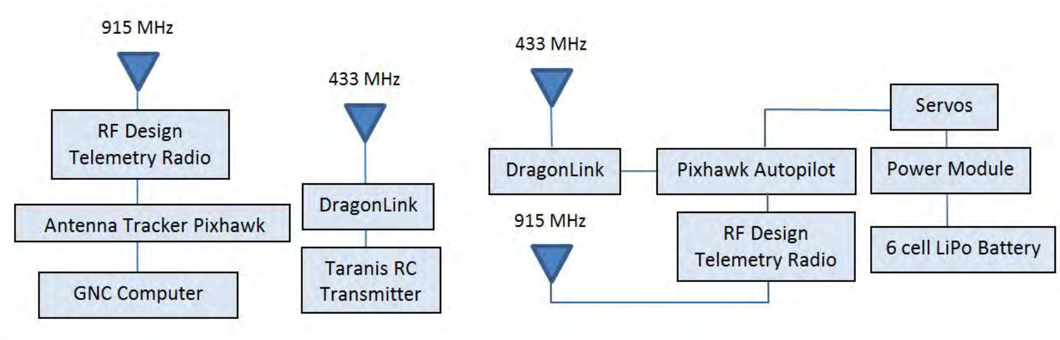

Figure 6: Aircraft Control System

3.2.2 Intelligence, Surveillance and Reconnaissance (ISR)

To fulfill the Search Area, Actionable Intelligence, Emergent Target, and Off-Axis Target mission requirements, an intelligence, surveillance, and reconnaissance system is on board. This system will allow the operators to view real-time imagery, as well as point-and-click geolocation both during and after the flight.To achieve this, a combination of commercial-off-the-shelf hardware and custom software was implemented. The ground based section of the ISR system consists of a Ubiquiti RocketAC connected to an airMAX 70 degree beamwidth antenna. This antenna is attached to a servo-controlled antenna tracking system, which uses a second Pixhawk with the available antenna tracking firmware, and automatically points the antenna at the aircraft. The onboard hardware for the aircraft consist of the PointGrey Flea3 8.8MP camera, ASRock BeeBox single board computer, and Ubiquiti RocketAC 5GHz wireless ethernet bridge. To power the ISR system, a switch is connected to the battery leads, allowing the system to be turned on independently of the flight system from outside the aircraft. The voltage from the battery is stepped down to 12 volts to power the on board computer,. To power the Rocket, the battery voltage is fed into a self-regulated power-over-ethernet injector, which takes anywhere from 9 to 35 volt input and outputs 24 volts. The camera is mounted on a custom 2-axis servo actuated gimbal to allow manual control of the camera orientation using the telemetry data link. A joystick is interfaced with the GNC computer, which sends commands over the telemetry link to the Pixhawk, which then sends out the corresponding servo signal to change the pitch and roll of the camera. The gimbal will also be automatically stabilized using the Pixhawk's built-in gimbal stabilization functionality. A CAD model of the gimbal system is shown in Figure 7. The gimbal arms, camera shaft, and rear plate are manufactured with 3D printed ABS plastic, and the gimbal fairing is a fiberglass composite shell. The fairing is removable for easy camera access if needed.

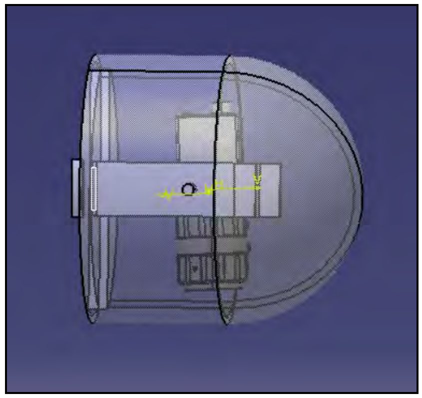

Figure 7: Gimbal model

The software consists of three components, Xipiter Imagery System (XIS), Xipiter Camera Control Software (XCCS) and Xipiter Base Station (XBS). XIS runs on the aircraft, which grabs the images at a specified rate/resolution, and sends them down to XCCS. XCCS allows the user to view the video stream and select images to be saved locally on the ground that could potentially contain targets. When the user sees a possible target in the video stream, a button is pressed in the GUI that saves that image locally along with its corresponding telemetry data. XCCS also hosts a server that multiple clients of XBS can connect to, allowing two or more operators to process potential targets while still in flight. As a backup, the onboard computer will also save images locally at 5 frames per second. This will serve as backup images in case the images sent over the datalink become corrupted, and also allow the image analyst to review images for potentially missed targets during the flight. Xipiter Base Station allows the user to request new images from XCCS, which are packaged with a text file of the current aircraft position and attitude. Once the image and corresponding telemetry data have been imported, the user can click on any point in the image and XBS will output the GPS (latitude/longitude) location of that pixel. The user can then input the target characteristics (shape, alphanumeric, shape color, alphanumeric color, and heading of alphanumeric) into the GUI and select the “Add Target” button. This button compiles the data and outputs the characteristics into a spreadsheet that is in the required format. The GUI’s for XCCS and XBS were developed using the Flask library within python, which creates a web-based user interface. The XBS GUI can be seen in Figure 8, and a block diagram of the imagery system is shown in Figure 9.

Figure 8: XBS GUI

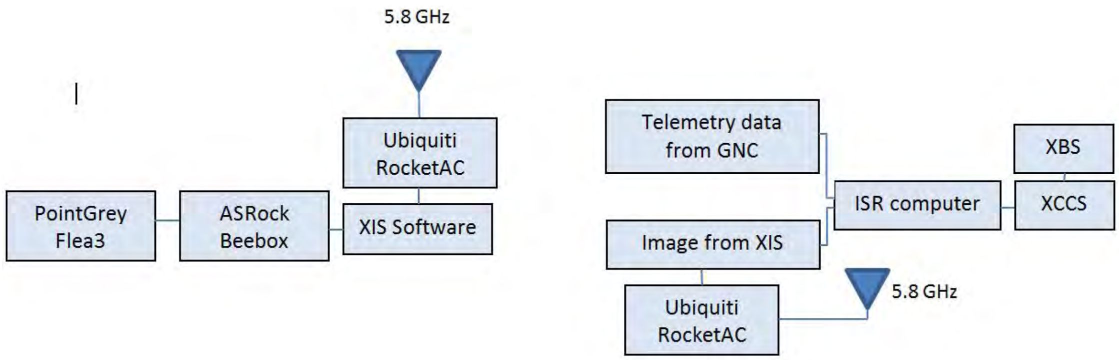

Figure 9: ISR System Diagram

The QR Code reader script is based on the open source qrtools python library. It takes an image from any location and decodes the QR code in the image and prints out what the QR Code represents. The team tested the QR Code reader by generating a QR code from qrstuff.com, printed out the QR Code image, took a picture of it at various sizes and used as input into the script. It successfully decoded the QR Code at various angles and sizes.

3.2.3 Interoperability

The interoperability subsystem is built on top of the basic Mission Planner-backed (MP) implementation provided by the competition. This system is composed of two parts: a script running within Mission Planner and a script running without which interacts with the judge server. The script running within MP sends information to the external script at 24Hz including the vehicle's current latitude, longitude, altitude, heading, and other orientation information. The external script is responsible for establishing an authenticated session with the judge server. Once it receives information from the internal script it updates an internal information store before sending the data on to the judge server. The internal script also regularly queries the external script for information from the judge server including the current server time and special string. This information is displayed in a simple window within MP.

In addition to fulfilling requirements for the interoperability related tasks, the system is also used to provide a centralized vehicle telemetry hub for other subsystems which might need access to the information, most particularly the ISR subsystem. The external script runs a Flask server in a separate thread which provides a series of HTTP endpoints. These endpoints can be used by other services to ask for telemetry information or submit data to be sanitized and sent on to the judge server. This simplifies interprocess communication and allows an arbitrary number of external processes and subsystems to have up-to-date telemetry from the craft without threatening the stability of the ground control software.

3.2.4 SRIC

The Simulated Remote Information Center is constructed of two scripts, both written in Python. One script, titled SRICAC runs on the aircraft, and the other titled SRICGS runs of the ground station. The both use the following libraries; socket, sys, json, os, subprocess, time and ftplib.

The ground station Script runs as follows:

1. Setup the sockets that are to be used
2. Gather/input login info, SSID, passkey, and the ip address of the FTP server
3. Create the network scheme
4. Connect to the aircraft via tcp sockets
5. Send configuration info as a JSON object, send network scheme, send secret file
6. Listen for connection
7. Receive the file the aircraft downloaded from the FTP server
8. End

The aircraft script runs as follows:

1. Set up the sockets that are to be used
2. Listen for connection
3. Receive configuration info, network scheme, and secret file
4. Setup the wireless network configuration via the network scheme
5. Wait until a successful connection is made
6. Upload the secret file from the FTP server
7. Download the target file
8. Connect to the ground station
9. Send the target file
10. End

4.0 Test and Evaluation Results

4.1 Surrogate Airframe: Finwing Penguin

In order to test the capabilities of the Pixhawk flight controller before the final airframe was produced, a surrogate off-the-shelf airframe was used. The team selected the Finwing penguin aircraft due to its small size, durability, and prior experience with the airframe. Since the airframe had been tuned previously, there was no need to use the AUTOTUNE feature to re-tune the aircraft.

The main purpose that the Penguin was used for was autonomous takeoffs and landings; since these mission objectives carry a large amount of risk to the airframe (potential hard landings, unsuccessful launches, etc), the team elected to use the Penguin first to gain more experience with the autonomous takeoff and landing set up and procedures. Autonomous takeoff testing was first performed using a hand launch, which was used to evaluate how responsive the flight controller was to abrupt changes in acceleration that occur during both hand and catapult launches. After four successful autonomous hand launches, and seven successful autonomous catapult launches, the performance of the autonomous takeoff capability was deemed acceptable.

After successful autonomous takeoff was achieved, the next step was to complete full autonomous missions, including takeoff, waypoint navigation, and landing. To achieve this, a simple mission was programmed as shown in Figure 10. After two unsuccessful autonomous landings, the team learned that the distance between the last navigation waypoint and landing waypoint needed to be much longer than originally thought. Lengthening the final approach fixed the issue, and 4 successful autonomous missions were completed with no further damage to the airframe.

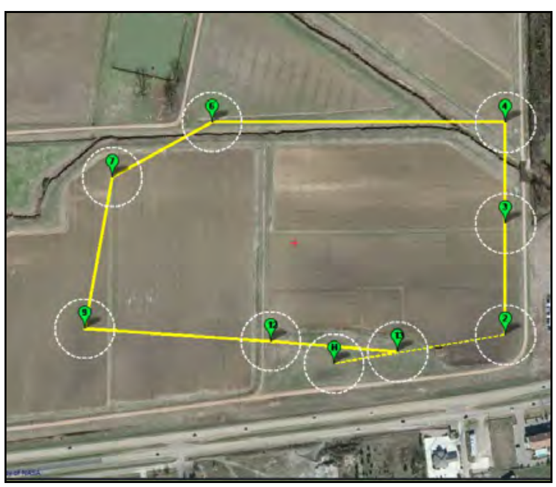

Figure 10: Autonomous Mission Plan

4.2 XawkEye testing

To verify that the system can achieve the required mission objectives safely and consistently, a combination of ground testing and flight testing was performed. Each subsystem was tested independently before integration to ensure functionality.

4.2.1 Ground testing

To mitigate potential risk, each subsystem was first tested on the ground. This ensures that any anomalies in the systems are found early in the process, as any issues while the system is in flight produce compounded safety risk.

4.2.1.1 Payload and Autopilot Performance: Communications range testing

To ensure that both the ground and aircraft based radio transmitters have adequate range for the mission, a range test was performed. The aircraft was equipped with all transmission equipment that will be on board for the flight mission demonstration: Ubiquiti RocketAC Lite wireless ethernet bridge with two 5 dBi omnidirectional antennae, DragonLink 433MHz UHF receiver, and RF Design 900 MHz long range telemetry radio. The ground station was equipped with the required transmitting counterparts: Ubiquiti RocketAC Lite with airMAX sector antenna, RC transmitter with DragonLink UHF module, and RF Design 900 MHz long range telemetry radio.To test the range, the aircraft was driven predetermined distances from the ground station, and the reported signal strength of each radio communications link was noted. The team believed the telemetry radio would be the biggest range limiter, so careful attention was paid to the telemetry data link strength. All data links were strong (70% signal strength or better) at a distance of 1 mile from the ground station, which is approximately two times farther than the aircraft will ever be during the flight mission demonstration.

4.2.1.2 Payload Performance: Simulated Remote Information Center (SRIC)

To test the performance of the software that was written for the Simulated Remote Information Center task, two ground tests were performed. The first test procedure used three computers to simulate the aircraft, the AUVSI FTP server, and the ground station, while the second procedure used the actual system (actual aircraft on board computer, actual ground station computer, and one computer to run the FTP server.). The test procedures are detailed below.

Supplies:

- 3 Computers (one to run in the aircraft, one to run as the ground station, and one to host a ftp server)
- 2 Wireless Routers
- 1 Wireless antenna so two separate networks can be established on the aircraft (which already has a built in wireless device)

Procedure:

1. Connect the ground station to the aircraft via a wireless network.
2. Populate the proper ip addresses and ports in the scripts
3. Run the SRICGS.py script on the ground station and the SRICAC.py script on the aircraft
4. Populate the information for the connections on the ground station side and send it to the aircraft
5. The Scripts will run automatically at this point, transferring a file from the ftp server to the aircraft then upload a file to the ftp server. Then finally delivering the downloaded ftp file to the ground station.

Expected Results:

- The aircraft should be able to establish two network connections and manage them correctly
- There should be a total of two files on the ftp server, the ground station and the aircraft, one originating from the ftp server and one originating from the ground station

Results:

The data was successfully ported from the ground station computer to the aircraft computer. The aircraft computer successfully made a connection automatically.. The aircraft computer successfully downloaded the desired file and uploaded the “secret” files. The downloaded target file was successfully sent to the ground station.

To verify that the actual system will perform the same way as the simulated system, the same procedure was repeated with all subsystems running (ISR, flight system, and SRIC were running simultaneously). We successfully sent the data from the ground station computer to the aircraft computer. The aircraft computer made a connection automatically to the network the FTP server was on. The aircraft computer successfully downloaded the desired file and uploaded the “secret” file. The downloaded target file was then successfully sent to the ground station.

4.2.1.3 Mission Task Performance: Propulsion System Testing

In order to select the most efficient propulsion system for XawkEye, a trade study was conducted. The team compared 8 potential motor candidates based on cost, maximum power rating, maximum current rating, weight, and maximum rpm. The larger pool of motors was narrowed down to the best two candidates, the Axi 5320/18 V2, and the Hacker A60 5XS. Due to financial constraints, a RC electric propulsion calculator was used to compare the performance of the two motors, and it was determined that the Axi 5320/18 V2 is the most efficient while providing the highest power rating.

After selecting the Axi 5320/18 V2 outrunner motor, the team began propeller tests. All propellers tested were of the Aeronaut CamCarbon folding family. Specific sizes tested were: 16x10x2/3, 16x13x2/3, 17x9x2/3, 17x10x2/3, 17x11x2, and 18x11x2 - where the last number indicates the number of propeller blades. A selection of the static thrust tests are shown in Table 5.

Table 5: Static Thrust Test

16x10x3	Throttle, %	Current, A	Power, W	Thrust, lbf
	25	1.8	40	1
	50	6	140	2
	65	11	260	2.7
	85	27	600	6.6
	100	52	1100	9

17x9x3	Throttle, %	Current, A	Power, W	Thrust, lbf
	25	1.7	40	2.05
	50	6	140	3.3
	65	17	400	6.2
	85	45	1020	10.2
	100	75	1700	13.7

17x11x2	Throttle, %	Current, A	Power, W	Thrust, lbf
	25	1.3	31	2
	50	5.6	130	3.5
	65	14.9	330	5.3
	85	42	890	8.6
	100	61	1200	10.7

	Throttle, %	Current, A	Power, W	Thrust, lbf
17x11x3	25	1.7	39	1.7
	50	7	160	3.6
	65	20	650	6.4
	75	38	820	9
	100	87	1800	13

18x11x2	Throttle, %	Current, A	Power, W	Thrust, lbf
	25	1.3	31	2
	50	10	230	5
	65	18	380	7
	85	44	950	10.3
	100	72	1680	14

Excellent
Okay
No Good

It was determined that the 17x9x3 and 18x11x2 both provided comparable thrust at similar power consumption. It was decided to use the 18x11x2 for design simplicity and slightly better results..

The next aspect tested was endurance. Once the aircraft was fully assembled and ready for flight tests, a series of 10 minute flights were conducted. It was determined that every 10 minutes of flight requires approximately 3200 mAh. This data was easily recorded through the use of a data-logging ESC and was easily viewed using its proprietary CastleLink software. Further, it was found that only about 50% throttle and thus only 35% overall thrust was required for typical cruise flight conditions and maneuvers. The results of the propulsion system testing assure that performance will be more than adequate for competition flight-time requirements and weather conditions.

4.2.1.4 Mission Task Performance: Launch System Testing

In order to ensure that the catapult launch system works as intended, and will operate safely, several ground test launches were conducted. The first test consisted of a dry fire of the pressure system, with no carriage attached to the piston. This test was showed that the system would accelerate the piston as intended, and the team found that pressure bleed holes were necessary to prevent damage to the system. The second test used a dummy load that simulated both the geometry and mass of the aircraft; the shape of the payload bay was cut out of foam and ballast with lead to simulate the total weight of the aircraft (19 pounds) and the interaction between the payload geometry and carriage. A total of 8 successful launches of the dummy load were completed, at 40,50,60,70,80, 90, 100, and 110 psi. These tests proved the system was capable of safe, repeatable launches of the aircraft, without adding the risk of launching the actual aircraft for proof-of-concept testing. Tests were then conducted using the Penguin test aircraft. 10 launches were performed at 50 psi due to lesser weight of Penguin. These launches were performed under both manual and autonomous control. After only successful testing with Penguin, it was deemed safe to launch XawkEye using the catapult. Initial manually controlled launches were performed at 90 and 100 psi; however, it was determined that 110 psi should be used to ensure a margin of safety whether the wind speed increase or decrease at launch - the launch speed of the aircraft in zero winds is approximately 1.4x stall speed or 17 m/s. Manual and autonomous takeoff was then successfully performed using the catapult and XawkEye at the prescribed pressure.

As of the finalization of this document, the launch system has had over 25 successful launches, including test launches with test aircraft. The launch system has successfully launched XawkEye 8 times as of May 15. The in-house designed and built catapult launch system has proven to be a safe and reliable launch platform.

4.2.2 Flight testing

To ensure the aircraft can successfully take off, navigate, and land in a controlled manner, several fully manual flight tests were completed. These tests consisted of a hand-launched takeoff (one instance) or catapult-assisted takeoff (all other instances) under manual control, manual pattern flight to trim the aircraft, and a manual landing. This test proved that the aircraft is stable and controllable in all flight regimes. After the aircraft was proven to be stable, autonomous flight testing began.

4.2.3.1 Autopilot Performance: Control and Navigation tuning

As a prerequisite for autonomous navigation tuning, the control gains of the aircraft were tuned using the AUTOTUNE feature of the Pixhawk flight controller. The AUTOTUNE feature automatically tunes the proportional, integral, and derivative gains for each axis of control. To tune the aircraft, a manual takeoff and one manual pattern were completed, and the system was then switched into AUTOTUNE mode. To tune the roll axis, the safety pilot gave full left and full right roll inputs in quick succession. During the first few passes, the aircraft had a very sluggish response as the AUTOTUNE mode uses very low control gains initially. On each successive pass the aircraft became more responsive in roll until the pilot was comfortable with the roll response. The same procedure was performed to tune the pitch axis until the desired pitch response was achieved. Next, to tune how much elevator the controller gives in turns to keep the nose level, the PTCH2SRV_RLL parameter was tuned. To achieve this, the pilot holds full left aileron with no elevator in fly-by-wire mode (fly-by-wire mode controls pitch in turns). If the aircraft gained or lost altitude during the turn, the parameter needed to be decreased or increased, respectively. The aircraft successfully held altitude during both left and right turns.

To tune the autopilot navigation, a rectangular waypoint path was used. The Pixhawk flight controller uses the L1 navigation controller, which can be tuned by changing the period and the damping ratio. These parameters control how aggressive the control system is in turns. The aircraft performed a manual catapult launch, and manual pattern flight to trim the aircraft. Once the pilot was comfortable, the aircraft was switched into autonomous navigation mode and allowed to navigate the rectangular waypoint pattern. On the first pass, the aircraft was swinging too wide on each turn, therefore it was not being aggressive enough. Tuning the period and damping of the navigation controller resulted in more aggressive turns and the aircraft followed the waypoints much better than the previous pass. The flight path with respect to waypoint location after the tuning is shown in Figure 11. The green balloons represent the waypoints, the yellow lines represent the path between waypoints, and the purple lines are the actual flight path of the aircraft. (The smaller pattern loops were under manual control of the safety pilot.)

Figure 11: Autopilot Tracking After Tuning

4.2.3.2 Payload System Performance: ISR

To ensure the onboard ISR system could effectively identify targets, the system was flown onboard XawkEye to simulate the full up flight mission demonstration. Five plywood targets similar to those detailed in the rules were placed afield at known locations, and the aircraft was flown over these locations both autonomously and manually. The characteristics of each target are shown in Table 6.

Table 6: ISR test target characteristics

Target	Shape	Alphanumeric	Shape Color	Alphanumeric Color	Primary shape dimension (feet)
1	Star	A	Yellow	Blue	4
2	Cross	I	Black	Yellow	6
3	Square	V	Blue	Red	4
4	Triangle	B	Brown	Orange	2
5	Circle	D	Green	Yellow	2

Three out of five targets were successfully identified at objective level, and one target was identified at threshold level, meaning the team was able to successfully identify four out of five targets. In flight images are shown in Figure 12. Each image was taken at an altitude of 300 feet AGL.

Figure 12: Targets identified

4.2.3.3 Mission Task Performance: Mission Rehearsal

To verify that the aircraft could successfully fly a search grid pattern, a simulated mission waypoint path was prepared. This mission included an autonomous takeoff, followed by a rectangular waypoint navigation path, followed by an autonomous search grid and a manual landing. The rectangular waypoint path before the search grid simulated the required waypoint navigation that the system must perform during the flight mission demonstration. The mission plan is shown in Figure 13.

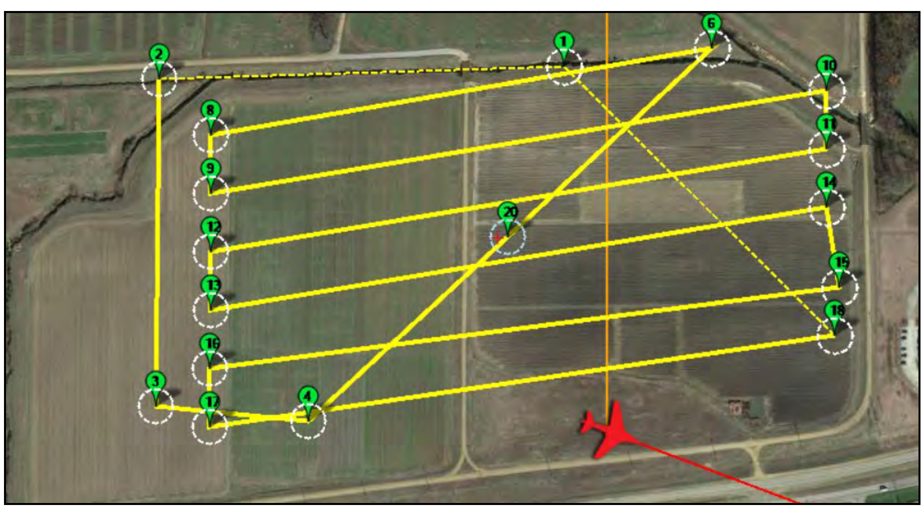

Figure 13: Simulated mission plan

The aircraft was able to successfully takeoff and navigate through all the waypoints autonomously, verifying that the system will be able to achieve objective level in the autonomous flight tasks. During the mission, waypoint number 20 was added as an emergent target "last known position" waypoint, and the aircraft was allowed to loiter. The team was able to successfully identify the emergent target as a woman in a pink shirt jogging with a dog, shown in Figure 14.

Figure 14: Emergent Target

4.3 Expected Mission Task Performance

After the testing and evaluation that was performed, Team Xipiter is very confident that XawkEye UAS will achieve at least threshold level on all planned mission tasks. The vehicle was able to take off autonomously, successfully navigate waypoints within 50ft accuracy, dynamically retask to a new waypoint to search, identify imagery targets, interface with the remote information center, and safely land.

5.0 Safety considerations and approach

Safety is a primary concern in the operation of any aircraft and is perhaps even more important with unmanned vehicles. The AUVSI Student UAS Competition Rules clearly indicate the importance of safety, and Xipiter UAS has responded by strongly emphasizing safety in all aspects of its operations. As suggested by concepts in occupational safety engineering, the team has implemented safeguards throughout the entire system in order of maximum effectiveness, beginning with designing hazards out of each subsystem in accordance with highest risk, consequence and frequency.

5.1 Operational safety

XawkEye UAS requires a minimum of ten people to safely and adequately perform flight operations. Figure 15 represents the flight operations chain of command for Xipiter. Yellow boxes represent personnel required for a "GO / NO-GO" decision. A "NO-GO" status from any of these members will halt all operations. The faculty advisors shown in blue boxes supersede all flight operation decisions made by the team.

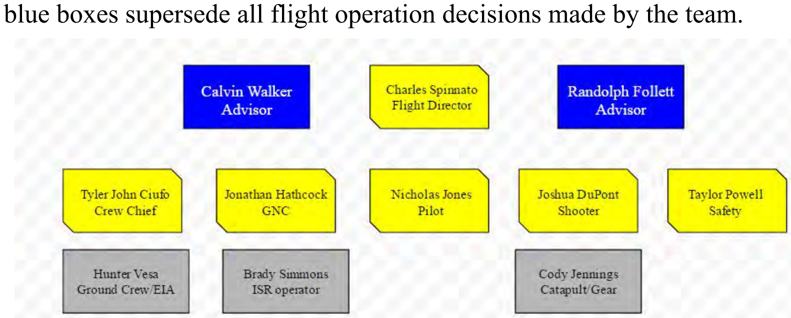

Figure 15: Flight operations chain of command

Each person on the flight line has a specified role that they are responsible for during mission execution. The mission roles and corresponding responsibilities are detailed in Table 7. Before each flight mission, a mission brief is conducted by the Flight Director. This brief informs all personnel and bystanders of every aspect of the mission so each person understands his or her role, enhancing overall operational safety.

Table 7: Flight mission roles and responsibilities

Role	Mission Responsibilities
Flight Director	Preside over flight operations, final GO/NO-GO calls
Crew Chief	Aircraft assembly, preflight inspection, and recovery
GNC	Systems preflight inspection.Auto navigation waypoints, monitor aircraft position and attitude.
Pilot	Control the aircraft during all non-autonomous modes, take over control if required
Shooter	Aircraft launch procedure, catapult preflight inspection
Safety	Monitor weather and traffic conditions, ensure overall operational safety
Ground Crew/EIA	Assist chief. Perform image data analysis
ISR operator	Operate ISR payload, identify possible targets
Gear	Catapult assembly and preflight inspection

The Crew Chief, GNC, and Shooter all have checklists that are used to evaluate system readiness for the mission. Each checklist has items that are specific to each subsystem to ensure that the system will operate smoothly and safely. For example, the Crew Chief checklist includes a visual and tactile inspection of all structural components of the aircraft, the GNC checklist includes a battery voltage and wiring polarity check, and the Shooter checklist includes a visual, tactile, and mechanical inspection of the launch system. These checklists are then passed on to the flight director so he or she can make an informed decision for flight operations. If any item on the checklist is not satisfactory, that particular system is a NO-GO until the issue is mitigated.

The team also has a multitude of safety equipment on site during all flight operations should any safety incident occur: a B-C class fire extinguisher for liquid and electrical fires, sunscreen for flight personnel, bug spray for flight personnel, emergency communication devices, and a first aid kit. This equipment ensures that all personnel and surrounding spectators are safe during all flight operations.

5.2 In-flight safety

The primary emphasis of the team's in-flight safety plan is to ensure sufficient system redundancies to guarantee integrity of the most critical structural and functional components. Loss of components in the air can potentially jeopardize the entire system, damage other subsystems, and cause injury to ground personnel and observers. All removable parts represent the primary interest of failure prevention followed by the actual aircraft structure. The team identified the following components as removable in a standard field operation:

- Wings
- Payload side hatch
- Payload rear hatch
- Avionics tray
- Flight battery, power over ethernet injector, and on board computer
- Autopilot access hatch

To mitigate risk from loss of these components, structural redundancies were designed into each part. The wings are secured using two fiberglass plates, one on the upper surface and one on the lower surface, four nylon bolts, and have two aluminum spar carry-through rods. The payload side hatch is secured with four fasteners and locking nut plates to mitigate potential loosening due to flight vibrations. To prevent the rear payload hatch from opening in flight, four fasteners are used (two redundant fasteners). The avionics tray is secured using six fasteners, three on each side, with locking nuts to prevent the tray from shifting forward in flight. Each component on the avionics tray, the flight battery, power over ethernet injector, and on board computer, are secured in at least two ways. The flight battery is secured from moving longitudinally by fiberglass L-brackets that prevent fore-aft motion, in addition to being secured by a velcro strap across the top and high-strength interlocking fasteners (Scotch DualLock) on the bottom. This mounting system ensures that the battery will not shift position during flight. The power over ethernet injector is secured in the same fashion as the battery. The onboard computer is mounted using four sets of nylon standoff bolts, in addition to two strips of high-strength interlocking fastener to dampen vibration as well as provide mounting redundancy. The autopilot access hatch is secured using four fasteners in addition to friction fitting to ensure the hatch does not depart the aircraft. All components that were identified as non-removable, such as the wing brackets, payload brackets, tail brackets, and motor mount, use locking fasteners with threadlocker. The brackets are also slightly undersized in reference to the boom, which adds friction lock to ensure the part will not move during flight.

6.0 Conclusion

The XawkEye UAS is a culmination of Xipiter UAS' systems engineering process; considering the requirements, design, fabrication, maintenance, testing, and integration of the components and subsystems. With each subsystem and its components detailed, the flight operations and safe-handling outlined, and the flight testing agenda presented, Xipiter UAS presents the XawkEye UAS as a superior response to the Statement of Work issued by the Seafarer Chapter of the Association of Unmanned Vehicle Systems International Student Unmanned Aerial System Competition.

Appendix A: System Security

The XawkEye system is designed to be resistant to cybersecurity attacks such that operators can be confident that it will not be compromised by a malicious entity before, during, or after operation. This appendix details the measures involving software and hardware security used by the team during the design and deployment of the system.

The system consists of two primary components which are in communication with each other throughout mission execution: the ground station and the craft. These components communicate over two different channels: telemetry radios which carry information concerning vehicle telemetry and control and a data channel which carries imagery data.

Of particular concern is the security of the data channel. This channel is composed of a WiFi bridge formed by two Rocket 5GHz AC Lite devices. The ground station side Rocket acts as an access point broadcasting a wireless network secured by WPA2-AES with a cryptographically strong passphrase. The vehicle-side Rocket connects to this network and is locked not just to its SSID but also to the Access Point's MAC. In the event of an entity attempting to spoof the network's SSID, the vehicle-side Rocket will still only connect to the expected network.

All independent devices composing the system (the ground station terminal computers, the on-board vehicle computer, the Rockets themselves) are secured with unique usernames and cryptographically secure passphrases. The vehicle can be manually controlled via a standard RC aircraft controller. The receiver on the vehicle feeding into the flight controller and this RC controller are bound to each other such that the receiver will not respond to controls from other controllers.