XIPITER
Unmanned Aircraft Systems

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System Overview for the XawkEye-2 UAS

Mississippi State University's Entry for the
2018 AUVSI Student UAS Competition

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Abstract

The 2018 Student UAS competition, hosted by AUVSI, marks Mississippi State University's sixteenth year of participation. The Xipiter team continues to take a systems engineering approach to designing an unmanned aerial system (UAS) capable of safely and efficiently accomplishing mission objectives. These objectives involve gathering and delivering real-time actionable intelligence, surveillance, and reconnaissance (ISR). The XawkEye-2 UAS couples a robust, student-designed airframe with an array of commercial hardware and student-developed software components. This enables a dynamic system capable of producing 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 high powered compact 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's design and testing has proven to meet the mission requirements set forth by the Student UAS Competition.

Table of Contents

1.0 Introduction

The AUVSI Undergraduate Student UAS Competition is an international collegiate competition that requires participating teams to submit a journal paper, submit a video flight readiness review, 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, however, the flight portion of the competition must be fully autonomous. After takeoff, the UAS must climb to a cruise altitude between 100 feet and 750 feet 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 using GPS coordinates. The air delivery task involves delivering a plastic water bottle to a specified location, ensuring that the bottle remains mostly intact. 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 position of the UAS. This data is then cross referenced against the known coordinates of the virtual obstacles to determine if the aircraft has successfully avoided the obstacles.

2.0 Systems Engineering Approach

Xipiter has embraced a systems engineering approach over the years and is best represented by a V-model. The V-model is a commonly applied representation for project lifecycle development, which is shown in Figure 1. The team examines the given tasks, 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 into 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.

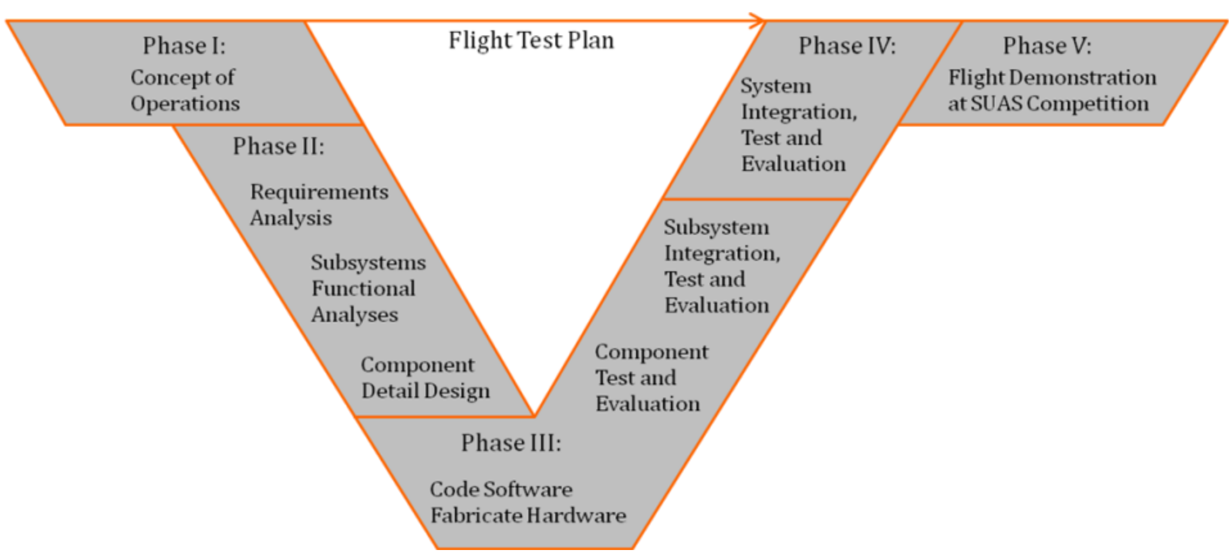

Figure 1: Xipiter's V-Model

2.1 Mission Requirements Analysis

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 , Search Area, Sense Detect and Avoid (SDA), Actionable Intelligence, Emergent Target, Air Drop 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 70 knots. **(AMA)**
- The system shall be capable of operating within specified environmental conditions. **(AUVSI)**
- The system shall be capable of autonomous flight, including 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, SDA)**
- The system shall be capable of network interface. **(Interoperability, Search Area)**
- The system shall be capable of carrying a droppable load under the starboard wing **(Air Drop Task)**

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 Design Rationale

In order to achieve the design objectives, the team elected to design a custom fixed-wing, electric propulsion aircraft. An off-the-shelf airframe would allow the team to spend more time on the software and electronic systems development, but the added limits of retrofitting hardware into an existing airframe (weight, size, etc.) outweigh the increased manufacturing time. While a rotorcraft is capable of completing the mission, the team decided that the benefits of increased sustained forward flight efficiency and decreased power system complexity outweigh the vertical takeoff and landing/hovering benefits of a rotorcraft. For increased lateral stability, ease of manufacturing, and less launch/landing risks, XawkEye-2 has a high-wing, conventional tail design. A high wing aircraft is inherently more stable, but less maneuverable, than a mid or low-wing aircraft. In this mission, the aircraft will not be required to perform any maneuvers that require a high roll rate, so a high-wing design is more favorable. A low-wing design with the same lateral stability characteristics would require dihedral, which adds unneeded manufacturing and assembly complexity. A high wing design was ultimately selected, as it satisfies all of the design objectives the team has set.

To satisfy the autonomous flight requirement, an autopilot system is required. Due to the development time costs, the team decided that designing and building a custom autopilot was not feasible. Because data from the flight controller board is required to complete other mission tasks effectively, an open-source system is necessary. The hardware must also be relatively low-cost and have a small form factor as to not induce any unnecessary performance or manufacturing burdens. The team selected the Pixhawk and ArduPilot Mega firmware, as it satisfies all the requirements, and the team also has previous experience with this package.

The Point Grey Flea3 8.8MP camera was selected for this aircraft due to its small form factor and high pixel density. This is the same camera that has been used in the past, and our imagery team is familiar with its software development kit. The old 16mm lens was switched with the Tamron M118FM08 8mm lens this year. The 8mm lens was chosen because it provides a wider angle of view. This decreases the chances of missing a target if it was out of frame due to being in between search area passes. The increase in viewing angle did decrease the resolution of the targets, but this was not seen as an issue due to the high pixel density of the Flea3.

2.3 Risk Identification and Mitigation

In order to mitigate risk, the potential risks must first be identified. Table 2 shows the risks that team Xipiter has identified and their mitigations.

Table 2: 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

3.0 XawkEye-2 UAS Design

Xipiter UAS used a systems engineering approach throughout the development of the XawkEye-2 UAS. A combination of commercial-off-the-shelf components and custom designed hardware/software is used in the system.

3.1 Aircraft and Supporting Systems

The XawkEye-2 platform is a custom built airframe with a electric propulsion system. The platform uses the assistance of a pneumatic propulsion catapult to assist in reliable takeoffs every flight.

3.1.1 Airframe

The airframe of XawkEye-2 is a student designed and built aircraft that is catapult launched and belly landed as opposed to a conventional runway takeoff and landing. This configuration allows the team 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 and also 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, to which all components are attached to, is an off-the-shelf carbon tube. The payload bay is made of a four ply fiberglass composite with a 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 machine to cut out the desired shape from polystyrene foam, which was then used to complete the associated lay-ups.

The wings, horizontal, and vertical tail are manufactured using fiberglass composites with carbon fiber spars and a 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 a single ply of fiberglass which added rigidity as well as surface protection from debris. Table 4 shows the geometric specifications for XawkEye-2.

Table 4: XawkEye-2 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	6 ft	-	-

3.1.2 Payload and Gimbal

While the outer mold line of XawkEye-2 is relatively the same as XawkEye-1, the team made significant changes in the internal payload structure and gimbal design. The internal payload structure was changed to allow easier maintenance access as well as a more modular construction. The design consists of an upper level shelf attached to the top section of the payload which serves as a base for the Pixhawk and flight computers. The lower half of the payload houses the batteries that power both flight systems and imagery systems with fiberglass bulkheads that stabilize the batteries. These bulkheads may be adjusted to allow the team to easily change the location of each component for ease of access and to manipulate the center of gravity. This internal structure is entirely independent of the outer shell, allowing all of the electronic components to be easily removed for maintenance. An edge connector facilitates the connection between the upper shell and the wing assembly, reducing complexity and the need to plug/unplug parts when assembling and disassembling the system. A new gimbaling system for the E/O camera was also designed. The team elected to design a gimbal system that is custom fit and optimized to the aircraft. The gimbaling system uses two servos to allow stabilization in the pitch and roll axes. For the physical components, the team chose to fabricate them out of completely 3D printed parts. A custom 3D printed fairing was designed to protect the gimbal and camera from any in-flight debris and to reduce the overall drag of the system. The fairing allows for 60 degrees of roll in each direction, 10 degrees pitch down, and 20 degrees pitch up.

3.1.3 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 of being hand-launched, a catapult system will provide a smoother launch sequence and will perform consistently 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 is then 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 sideways 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 helps 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 6.

Figure 6: XawkEye-2 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, 12V DC power outlet, and 12VDC-120VAC power inverter were added to the box.

The solenoid used is an 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 to launch is requested and granted independently by all personnel. 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 7 and 8.

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 130 psi used for launch. The lowest pressure rated components used are the air-tank and solenoid valve which are rated to 200 psi working pressure. Also a 200 psi pressure release valve 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.

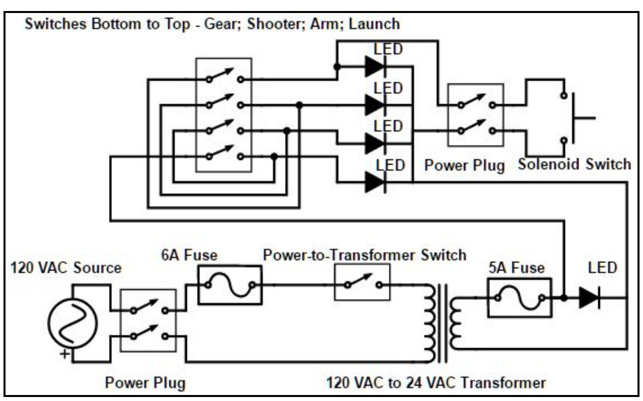

Figure 7: Launch box wiring schematic

Figure 8: Launch box

3.1.4 Propulsion System

In order to promote safe, efficient, and user-friendly control an electric propulsion system was adopted. For XawkEye-2 the team elected to continue using the same motor, ESC, propeller, and battery combination that maximizes overall flight time to 35 minutes and keeps the propulsion system weight to a minimum. The motor selected is an 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 16000 mAh, 6 cell LiPo.

3.2 Avionics Systems

The XawkEye-2 UAS is a system of systems. To ensure mission success, the system is discretized into two subsystems: Guidance, Navigation and Control (GNC) and Intelligence, Surveillance and Reconnaissance (ISR).

3.2.1 Guidance, Navigation, and Control (GNC)

The Guidance, Navigation, and Control (GNC) operator monitors and directs the aircraft for autonomous flight. This system is comprised of a ground control station that instructs XawkEye-2 in the predetermined flight path and to relay corrective waypoints to the flight controller in order to avoid obstacles. The GNC operator is also responsible for arming and directing the drop of the water canister.

3.2.1.1 Autopilot

Team Xipiter decided to use a combination of a custom built ground control station running mission planner paired with the 3DR Pixhawk autopilot system. 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 ASRock BeeBox computer running at 2.08 GHz. The team selected this computer for its low cost and small form factor which makes it ideal for the ground control station's limited space. The UAS community developed software Mission Planner interfaces with the Pixhawk to upload flight plans as well as tune the system, giving autonomous flight. A block diagram of the control system is shown in Figure 9.

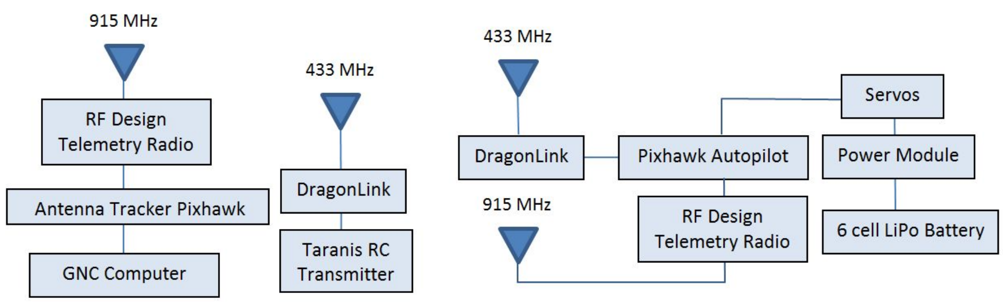

Figure 9: Aircraft Control System

3.2.1.2 Obstacle Avoidance

Sense, detect, and avoid (SDA) uses several techniques and different pieces of software to try to dynamically pull several different bits of data into something usable for the aircraft. The most important piece of software that helps tie everything together is Unity. Unity is a software suite designed for video game developers. Because of this, it comes shipped with several different problems already solved. The most important of these is representing real world coordinates in cartesian 3D screen space. An ECEF (Earth-centered, earth-fixed) cartesian coordinates system is used to convert latitude and longitude coordinates into something usable for Unity. Simply representing raw latitude and longitude as a 32 bit floating point will not work because 32 bit does not provide enough precision. This is where the ECEF comes into play. It converts raw latitude and longitude coordinates into something useable by the computer. Now that it is possible to accurately represent objects in computer 3D space, it is now possible to dynamically pull coordinates from the judges interop server to represent obstacles in Unity. Another useful feature of Unity is raycasting and collision detection. Raycasting is used to determine how far the aircraft is from an obstacle if it is within range. Once a potential collision has been detected, potential fields is used to determine how the aircraft will avoid obstacles. Potential fields is implemented using sudo magnetic fields around obstacles and the aircraft to determine aircraft trajectory in real time. Two different types of fields are used, rejection potential fields around the aircraft and attraction fields around the obstacles. For ground testing, dronekit-sitl is used to simulate the Pixhawk. The closest waypoint related to avoiding the obstacles is then sent to the Pixhawk to let the auto pilot determine how to fly the aircraft. Once the obstacle has been avoided, the next waypoint for the mission is then set as the next waypoint.

3.2.2 Intelligence, Surveillance, and Reconnaissance (ISR)

The Intelligence, Surveillance, and Reconnaissance (ISR) system is comprised of many smaller systems working together to locate and classify targets in the search area of competition. This is a robust system that blends in human intellect with the help of some autonomous background processes to give the highest chance to locate and identify targets while staying in flight.

3.2.2.1 Imaging System

The imagery system is comprised of multiple computers, a gimbaled PointGrey Flea3 8.8MP with a Tamron M118FM08 lens hooked to the ODROID-XU4 computer. The ODROID-XU4 was chosen for its high computing power in a manageable package that fits inside the payload. This computer handles images coming from the camera at a rate of two frames per second and stores them on board for later retrieval and acts as a backup in the event of data link loss. Two frames per second was deemed as an acceptable frame rate based on the size of the imagery sensor, the focal length of the lens, the average altitude (300 ft), and the average speed(35 kts) of the aircraft. This gives us a few frames of overlap to ensure proper area coverage. Flight data is obtained by the Pixhawk and sent through a USB connection for live telemetry. This data gets stored alongside the frame for later retrieval in case there is a break in the data link or in the event that the ground portion of the ISR system becomes inoperable. The system is set to transmit one frame per second. This has proven to not tax the data link and provide ground overlap between frames so the entire search area will be covered. Pre processing is done on the images before they get sent down to the ground to shrink the image to a size that is manageable and then the telemetry data gets appended to the package for retrieval by the preliminary monitor on the ground.

3.2.2.2 Object Detection, Classification, Localization

Team Xipiter created both an automatic target recognition method and a manual detection method. The automatic target recognition method was developed using Tensorflow, Python, and convolutional neural networks, a machine learning technique. One script was written that will build a target recognition model, teach the model, evaluate the accuracy of the model, and finally save the model for use in a GUI classification program. The model consists of a total of six layers: two convolutional layers, two pooling layers, and two dense layers. The final output layer is a total of 63 neurons, 62 for all alphanumeric possibilities (excluding symbols) and one for human features. The model was trained using a combination of old flight images and the open source MNIST image data set. Using this dataset an accuracy of 98.8 percent was achieved. From this, it can be determined that the model is good for ideal data. Training will be approved over time with test flights and the use of the GUI manual detection method to compile training data. For this reason, a manual detection graphical user interface (GUI) was created. It can be used to create a repository of images and labels. It can also serve as a backup, in the event the data isn't sufficient for accurate detection or the MNIST trained model does not suit the needs of a flying image capturing system. The idea is to load the model into the GUI to act as a preliminary target detector with human input as a backup. This way, team Xipiter will have an image classification system either way. The GUI will work by linking with the image streaming software that has already been developed to pull images along with location characteristics. It will then pass through a SURF filter to isolate any potential targets, if it fails it will put the image into a second folder that can be processed at a later time. Once an image passes through SURF it will pass the image to the neural network model. The output from this model will be displayed in the characteristics fields that the user can then edit for accuracy; this is the manual detection aspect. Each final image will have a human in the loop to verify or correct target information and send it off via an http interface that packages together the image, location, and target characteristics.

3.2.3 Communications

Air-to-ground and ground-to-air communications are handled using multiple systems. Direct control of the Pixhawk is done over the RF Design 900x telemetry modems using 900 MHz. This is used to connect to Mission Planner to view live system health information from the aircraft and perform preflight checks such as programming the provided flight path through mission planner. Mission planner is ran on a Asrock Beebox that serves as the GNC computer. A flight computer is installed on the aircraft and communicates with the PixHawk over a serial connection and with the imagery computer via USB. Communications between ground and air for the flight computer are handled over a Ubiquiti rocket system. This system uses the 5.8 GHz frequency using the 802.11ac protocol to communicate to the ground station ISR computer. This communication sends packets of data that are interpreted as the standard TCP/IP protocol stack. This communication link is used to communicate with the aircraft to get telemetry, receive live video feed from the onboard camera, and get mission data for interop. The rockets ground antenna outputs communication over wire as Ethernet and is connected to the team's router to be routed to the ISR computer. The ISR computer is a custom built rig that handles all of the imagery information and interoperability. This computer communicates with the flight computer via the rockets and to the judges server via an ethernet connection.

3.2.4 Air Delivery

The air drop system was developed to emphasize safety, repeatability, and reliability. The air drop structure consists of a plate and hook that attaches to the underside of the port wing for ease of usability. The plate has a cutout for a servo that actuates a pin through the hooks on the plate. The airdrop payload is held by a hose clamp and its own hook that allows the pin mechanism to feed through for easy release. To ensure that the payload is relatively stationary and stable in flight, stabilization arms are attached to the plate that keep the payload in place and prevent it from moving.

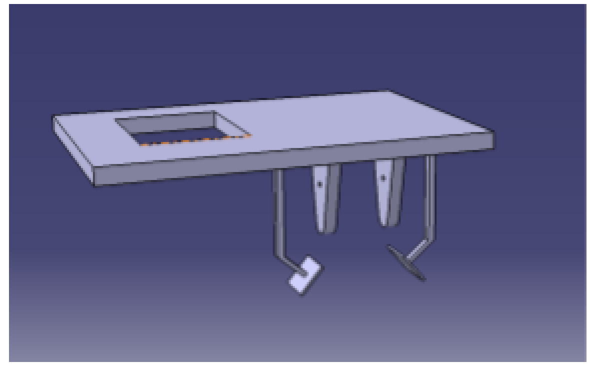

Figure 10. Airdrop Plate

The approach used to determine the optimal drop time is done by developed algorithms that use airspeed, altitude and heading to calculate the optimal drop position using GPS coordinates. When the correct distance between target location and aircraft location is met, the system activates the servo, the pin is pulled, and the payload is released. The autonomous airdrop is the prefered method, but there is a manual override if the system fails to drop the payload. This sub-system was tested apart from the overall system. The test showed that from a regular standing height, the payload bursted upon ground impact. The airdrop system was then integrated into the aircraft upon successful completion of initial ground testing. Flight testing of the system will be performed in the summer.. The design of the airdrop plate is featured in Figure 10.

3.2.5 Cyber Security

Cyber security is taken very seriously in the design of the communication systems. Any data that is sent over the ubiquiti rockets are encrypted using HTTPS/TLS encryption. Any connections made to the rocket are monitored constantly for any potential break-ins. All data that is sent over HTTPS will use TCP/IP protocol stack which ensures that incoming packets are received in order and that any data contained in the packets have not been tampered with. In addition to TCP's checksum, all data is also verified before being processed using HTTPS/TLS encryption which uses certificates to verify if data received is coming from the aircraft and is accurate. If it is detected that data has been tampered with then that packet is dropped and if it believed to have been caused by an intruder, ground control is then notified to make an appropriate decision. In addition to the TCP/IP protocol stack, all data sent through the system will have encryption determined by the server program with the only decrypter being the clients with a hard coded decryption algorithm.

If a break in is detected and ground control then determines the degree of the attack, different actions may be taken depending on the level of attack. Information is also gathered about the intruder and attack to determine the level of invasion. The level of invasion determined by ground control determines how to protect the aircraft. If the attack is determined to be a mild attack, the aircraft will be instructed to make an emergency landing over Mission Planner's GUI. If the attack is considered moderate, the aircraft may be hand piloted in to avoid any possible circumstances that could arise from an invasive attack. If the attack is considered invasive and has infected on-board equipment, the aircraft's flight computer, autopilot, and any other wireless communications hardware besides what is required to manually land the aircraft will be remotely shutdown to avoid any possible damages that could arise from an invasive attack.

4.0 Test and Evaluation Plan

Team Xipiter follows a rigorous test and evaluation plan for each part of our overall system. Each individual component is tested to verify performance before combining components to form subsystems, and each subsystem is then tested in isolation. Once each subsystem’s performance is verified, system integration tests are performed. This incremental process ensures that each component, subsystem, and system performs as expected during the mission.

4.1 Developmental Testing

The XawkEye family of aircraft was developed using an iterative approach. Each year, a new aircraft is designed and fabricated based on the previous year's designs. XawkEye-2 has the same outer mold line as XawkEye-1, but some modifications were made in order to reduce airframe weight and allow higher performance electronics. During development, a new wing design to be implemented next year was tested and reduced overall airframe weight even further. The team also discovered a way to completely eliminate one of the three onboard computers, reducing system complexity and weight. Team Xipiter is confident after field tests that Xawkeye-2 will be a competitive platform this year at competition and will be able to accomplish the mission.

4.2 System Testing

Each onboard system component will be tested in isolation to verify that they perform as expected. This ensures that any anomalies found in a component will be corrected before integration to its respective subsystem, reducing the risk of subsystem failure and higher financial burden.

4.2.1 RF Interference Testing

With the change in the rules that allowed all teams to broadcast on 900 MHz, the team was interested in the effects of potential RF interference from nearby teams. In order to test this, the team used the standard ground station and pixhawk combination paired with the 900 MHz telemetry radios. Since many teams are using the exact same radios, this test will use two pairs of the RFD900 radios. The team tested the connections using several different configurations in order to simulate the scenarios faced at competition. Once a connection was formed, GPS data was used to verify that the connection was made to the correct pixhawk and not the pixhawk simulating the other team(s). A summary of the results is shown in Table 7.

Table 7: RF Testing Results

Configuration	Distance	Connection	GPS Data
Side-By-Side	0 feet	Yes	Nominal
Flight Line	50 feet	Yes	Nominal
Flight Line – Mid Flight	100 feet	Yes	Nominal
Pits-Mid Flight	200 feet	Yes – 2 second delay	Nominal

4.2.2 Autopilot testing

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.

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 launches. After four successful autonomous hand launches, and seven 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 including takeoff, a rectangular pattern, and landing. 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 four successful autonomous missions were completed with no further damage to the airframe.

4.2.3 Communications Tests

In order to verify the performance of all data transmission equipment, a communications test will be performed. Each system will be tested in isolation out to a competition range of 1500 feet, ensuring that a strong connection with minimal latency is achieved. After the imagery, telemetry, and RC control links are verified in isolation, the systems were tested together (out to the same range) in an incremental fashion. The first test consisted of RC control and Telemetry being powered, while imagery is turned off. The final test will be a full-up system communication test with all three data links transmitting. This incremental approach proved that all three data links have satisfactory performance at competition ranges.

4.2.4 Imaging Tests

Imagery tests were conducted through the use of painted wooden targets. These targets consisted of many different shapes, colors and alpha-numeric values. These targets resemble those used at the competition. Targets were placed in the flight field and known GPS locations so as to test accuracy of the localization aspect of the software system. The Xawkeye-2 aircraft completed its regular simulated mission over North Farm (team Xipiter's flying field) all while capturing images. Unfortunately, the full automatic target recognition system did not work as planned and manual detection was necessary.

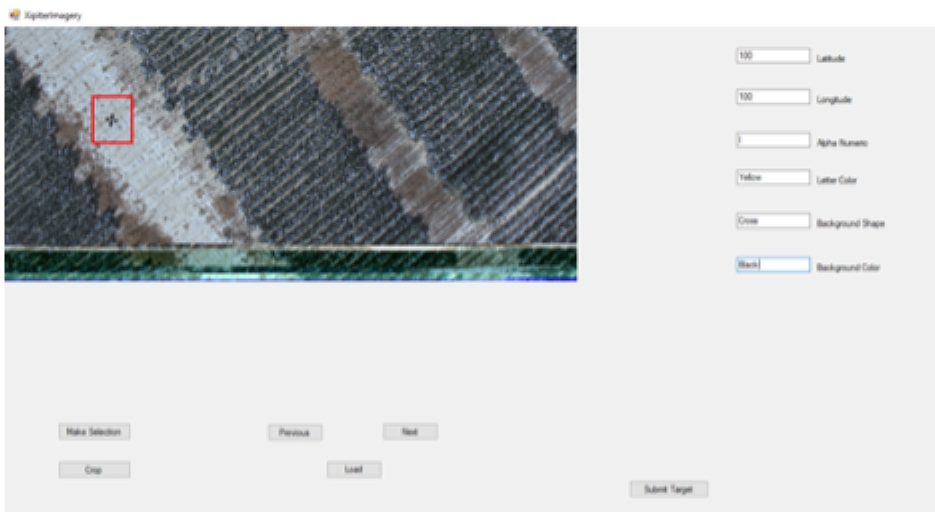

Figure 11. SURF Detection

However, looking at Figure 11, the surf detection algorithms implemented in the manual detection method successfully isolated a target out in the field. The imagery system will be continuously tested all summer with the goal of compiling enough flight test imagery data to train the neural network model with enough data to successfully detect targets automatically.

4.2.5 Air Delivery Test

In order to ensure the safe operation and successful execution of the Air Delivery task, a series of tests will be performed in the summertime. With ground testing completed that verified the system operates as designed, the next phase of testing will focus on synchronization with full system testing. The first series of tests will be conducted in the air during a routine autonomous mission test. A safe drop location, far from any hazards will be selected and added as a waypoint. A high-visibility background will be placed on the ground at the drop location. The GNC and ISR operator will monitor the aircraft's position relative to the drop location, and will provide the Pilot with a best-guess drop time. A ground crew member will time the drop from actuation until the bottle hits; this data will be used to model the drop and ultimately develop the autonomous drop timing algorithm. After the aircraft has landed, ground crew personnel will recover the bottle and measure the distance between the intended drop target and the bottle location and will also verify the bottle burst upon impact as intended. The second series of tests will be a fully autonomous drop in order to validate the accuracy of the model. Multiple drops will be performed and the accuracy of the drop will be measured, allowing the model to be improved and updated to be as accurate as possible.

4.3 Mission Testing Plan

Full mission testing will be conducted in a similar iterative manner as previous tests. After the aircraft has been successfully manually trimmed and tuned, a fully autonomous flight mission, including takeoff, a search pattern, and landing, will be conducted. This will ensure that the aircraft and control system are still performing as expected. During this test, imagery targets will be placed afield and images will be captured just as they would be in the competition mission. After the aircraft has successfully flown at least 3 autonomous missions, the air delivery system will be attached and tested as discussed in section 4.2.5. This will ensure that the bottle remains attached to the aircraft during the tight turns required in a search pattern and will verify the performance of the autonomous drop timing algorithm. During all of these tests, the system will be interfacing with a dummy interoperability server to ensure that the data is being transmitted and received correctly.

Once the interoperability data has been verified, the Sense, Detect, and Avoid system will be tested in a shorter mission. The flight plan will deliberately pass the aircraft through the locations of the virtual obstacles, and the GNC operator/Pilot will be closely monitoring the behavior of the aircraft. Once the aircraft has successfully avoided the stationary obstacles, moving obstacles will be tested. The moving obstacles will be set up to cross paths with the aircraft during the flight, and again the GNC operator/Pilot will closely monitor the behavior of the aircraft. After the aircraft has successfully avoided moving obstacles, the two obstacle types will be combined and the test will be repeated. If the aircraft completes at least 3 successful SDA missions, full-length mission tests will then be conducted with obstacles. The team plans to complete as many full-length mission tests as possible before competition.

5.0 Safety, Risks & Mitigations

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 strongly emphasizes 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 Development Risks & Mitigations

Since the team fabricates a custom aircraft, there are many safety risks involved throughout the process. During composite lay-ups, prolonged exposure to release compound, resin, and hardener can cause health problems. To prevent this, each member performing a lay-up wears appropriate PPE (personal protection equipment) for the situation, including gloves, eye protection, and face masks. Each new member is also trained by experienced personnel, so everyone involved in the process understands the inherent safety risks and knows the proper procedure to avoid them. XawkEye-2 also contains metal parts that are traditionally machined, which pose their own safety risks. Traditionally machined parts are only fabricated by personnel who have been trained and have previous experience with traditional machining tools such as the lathe, drill press, and mill. Proper PPE such as gloves, eye protection, and hearing protection are worn at all times during the machining process.

The development of the electronic systems also pose safety risks, such as short circuits, electrical fires, and potentially explosive Lithium Polymer (LiPo) batteries. To mitigate the short circuit/electrical fire risk, all new avionics subteam members are trained by a senior member on proper soldering and wiring technique while wearing the proper PPE (heat-resistant gloves and eye protection). No member is permitted to plug any system into shore power or another system without clearing the procedure with the avionics hardware lead. Lithium polymer batteries pose significant safety risks such as overcharging, over discharging, or improper polarity and can cause thermal runaway scenarios resulting in fires and potentially dangerous explosions. To prevent this, all batteries are charged with a high-grade balance charger that monitors the voltage of each individual cell and charges at the correct current. To prevent over discharging, the voltage of each battery is checked before plugging into any system. If the voltage readout is less than 95% of the rated nominal voltage(i.e. a 3-cell, 11.1V nominal battery that drops to below 10.5 volts), that battery is not permitted to be used until it is charged. The same low voltage cutoff is used for any flight testing; if a battery is below 95% nominal voltage, the battery must be changed until a final GO is given. A summary of the developmental risks and their mitigations are shown in Table 8.

Table 8: Developmental Risks and Mitigations

Risk	Mitigation
Chemical exposure during composite lay-ups	PPE, Personnel training, MSDS
Traditional machining injury	Personnel training, PPE
Incorrect soldering/wiring, soldering injury	
Lithium Polymer batteries: overcharge/discharge	High-grade balance charger, low voltage cutoff procedure

5.2 Mission Risks & Mitigations

The biggest risk associated with the mission is the fact that the vehicle is autonomous and is airborne, making loss of components a severe safety risk. To combat the team implements, a robust system of reduncies to ensure the aircraft stays intact. The flightline duties of Safety, GNC, and Safety pilot also monitor the flight so if something goes awry, manual control can be taken instantaneously.

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 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
- Horizontal tail
- Lower payload shell
- Flight battery, power over ethernet injector, and on board computer

To mitigate risk from loss of these components, structural redundancies were designed into each part. The wings are secured using two fiberglass plates on the upper and lower surface, four nylon bolts, and two aluminum spar carry-through rods. The payload is bolted along the lower line to ensure it is secure in flight. The avionics tray is secured using six fasteners 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 fasteners to dampen vibration as well as provide mounting redundancy. 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 slightly undersized in reference to the boom, which adds friction lock to ensure the part will not move during flight.

The second largest risk during the mission is the loss of the RC control link between the aircraft and the safety pilot. If this occurs at any time, a multi-step fail-safe system is implemented. After first loss of link, the aircraft will enter an autonomous Return to Launch (RTL) mode for up to 30 seconds. The safety pilot and GNC can also activate the RTL mode independently, via a switch on the RC transmitter or changing the flight mode within Mission Planner. The RTL mode navigates the aircraft to the location where it was first armed, and circles that point. If the link is not established within those 30 seconds, the aircraft will enter the flight termination mode. This mode is designed to bring the aircraft to a stall and ultimately to the ground with zero throttle, full up elevator, full right rudder, and full right aileron. Once the flight termination mode has been activated, it cannot be overridden.

5.3 Operational Risks & Mitigations

XawkEye UAS requires a minimum of ten people to safely and adequately perform flight operations. Figure 12 represents the flight operations chain of command for Xipiter. Red 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 supersede all flight operation decisions made by the team. Each person on the flight line has a specific role that they are responsible for during mission execution.

The mission roles and corresponding responsibilities are detailed in Table 9. 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.

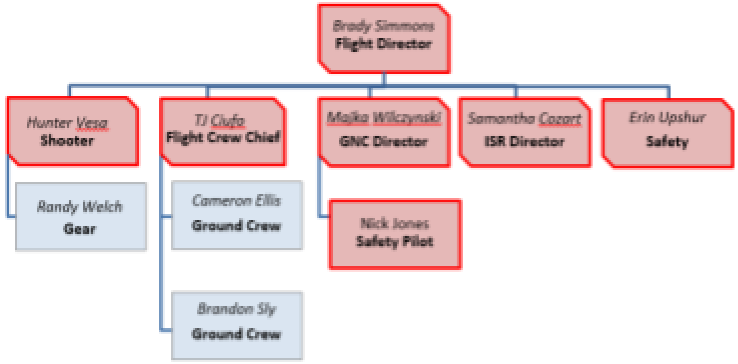

Figure 12. Flight Operations Chain of Command

The Crew Chief, GNC, and Shooter all have checklists 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.

Table 9: 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

6.0 Conclusion

The XawkEye-2 UAS is a culmination of Xipiter UAS' systems engineering process which considers 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-2 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.