System Overview for the Xawk 5 UAS

Mississippi State University's Entry for the
2013 AUVSI Student UAS Competition

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Abstract

The 2013 Student UAS Competition, hosted by AUVSI, marks Mississippi State University's tenth year of participation. The Xipiter Integrated Product Team (IPT) has taken a systems engineering approach to accomplish mission objectives involved with gathering and delivering real-time actionable intelligence, surveillance, and reconnaissance (ISR). The Xawk 5 UAS couples a robust student designed and built airframe with a combination of commercial off-the-shelf (COTS) hardware and student-designed software components into a dynamic system capable of gathering imagery of targets of interest and network interface during fully autonomous flight. The airframe is fabricated using preimpregnated carbon composites and is capable of carrying a payload of up to 25lbs. The onboard avionics include: a Piccolo SL autopilot in the guidance, navigation, and control (GNC) subsystem, a digital camera, a single-board computer, and a broadband Ethernet bridge in the surveillance subsystem. The ground station subsystem includes the interface to the autopilot, and camera control software. To improve the quality and reliability of the video link, a high-gain, directional antenna has also been integrated into the ground station. This system has been designed to meet the mission requirements set out by the Student UAS Competition.

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I. 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 search 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 network interface phase consists of orbiting a directional antenna while connecting to a network on the ground to download data. 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.

II. SYSTEMS ENGINEERING APPROACH

II.A. OVERVIEW

Xipiter IPT 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.

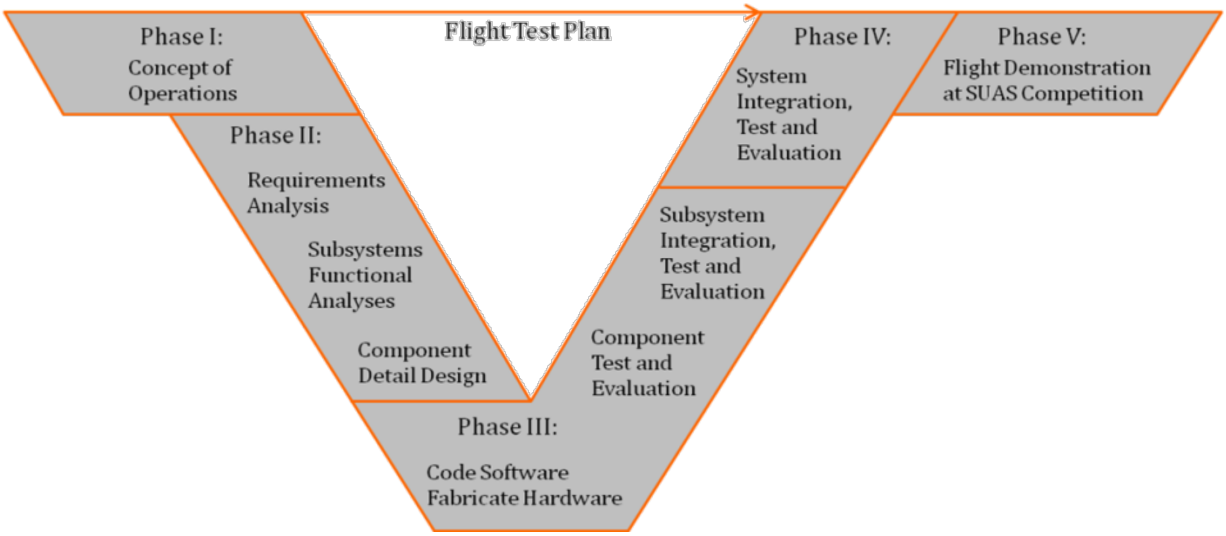

Figure 1 – Xipiter UAS Integrated Products Team's Systems Engineering V-model

II.B. PRIMARY MISSION OBJECTIVES

Based on the competition rules and the mission profile presented, the following core statements define the primary baseline objectives of the Xawk 5 UAS:

- The system shall be capable of autonomous flight.
- The system shall be capable of real-time imagery.
- The system shall be capable of target identification.
- The system shall be capable of safe operation.
- The system shall be capable of network interface.

II.C. MISSION CONSTRAINTS

Due to safety concerns and regulations, Xipiter's system is restricted based on the following constraints adopted from the competition rules and Aircraft Modelers Association (AMA) regulations. The primary constraints determined to impact the design and performance of the Xawk 5 UAS are listed below:

- The system shall be capable of avoidance of the competition specified no-fly boundaries.
- The system shall be capable of remaining in flight between 100 – 750 MSL.
- The mission shall be completed in a maximum of 30 minutes.
- The system shall have a maximum gross takeoff weight of 55 lb.
- The system shall have a maximum airspeed of 100 knots.
- The system shall be capable of operating within specified environmental conditions.

II.D. MISSION FULFILLMENT DESIGN

In response to the statement of work (SOW), Xipiter UAS IPT developed three major system design objectives to provide results ideal for mission fulfillment, shown in Table 1 below.

Table 1 -- System Design Objectives.

System Design Objective	Result
Maximize flight vehicle size within SOW constraints to minimize effects of environmental conditions.	Stable airborne surveillance platform
Maximize surveillance equipment resolution, while minimizing weight and size.	Clear, crisp photos for best image processing results
Minimize UAS assembly / disassembly complexity	Rapid deployment in the field

II.E. DEFINITION OF SYSTEM AND SUBSYSTEM

Xipiter's system design groups supporting components into subsystems and relates them to the UAS as a whole. In the case of the Xawk 5, the system is divided into two primary subsystems: Avionics and Airframe. These are further divided analytically within this paper. By categorizing the UAS, Xipiter can methodically analyze the Primary Mission Objectives and appropriately design, fabricate, and fly within the Mission Constraints.

III. AVIONICS

III.A. OVERVIEW

The Xawk 5Avionics System is comprised of the following subsystems: Guidance, Navigation, and Control (GNC), Intelligence, Surveillance and Reconnaissance (ISR), and Ground Station. The GNC subsystem maintains a Piccolo SL autopilot with associated telemetry sensors and servos, while the ISR subsystem includes an onboard computer for data processing, a high resolution camera, and a high-reliability network bridge. ISR subsystem antennas have been moved to a location below the fuselage for consistent communications to the ground. The Microhard wireless bridges have been selected in order to maximize transmission reliability while using the Imperx Bobcat camera. Within the Ground Station, Xipiter Camera Control Software and Xipiter Base Station Software have been modified for better mission performance. Finally, a limited Automatic Target Recognition process has been added to the Xipiter Base Station Software, which enables enhanced autonomy in the surveillance procedure.

III.B. SYSTEM DESIGN

The Xawk 5 avionics system contains all hardware and software components to satisfy the requirements and objectives as stated. There are a few important changes that allow for increased mission performance over previous designs. The most notable differences are the use of high-reliability wireless bridges and a more robust software package running at the ground station and on the Xocelot onboard computer. Figure 2 shows the full system and the interactions between subsystems.

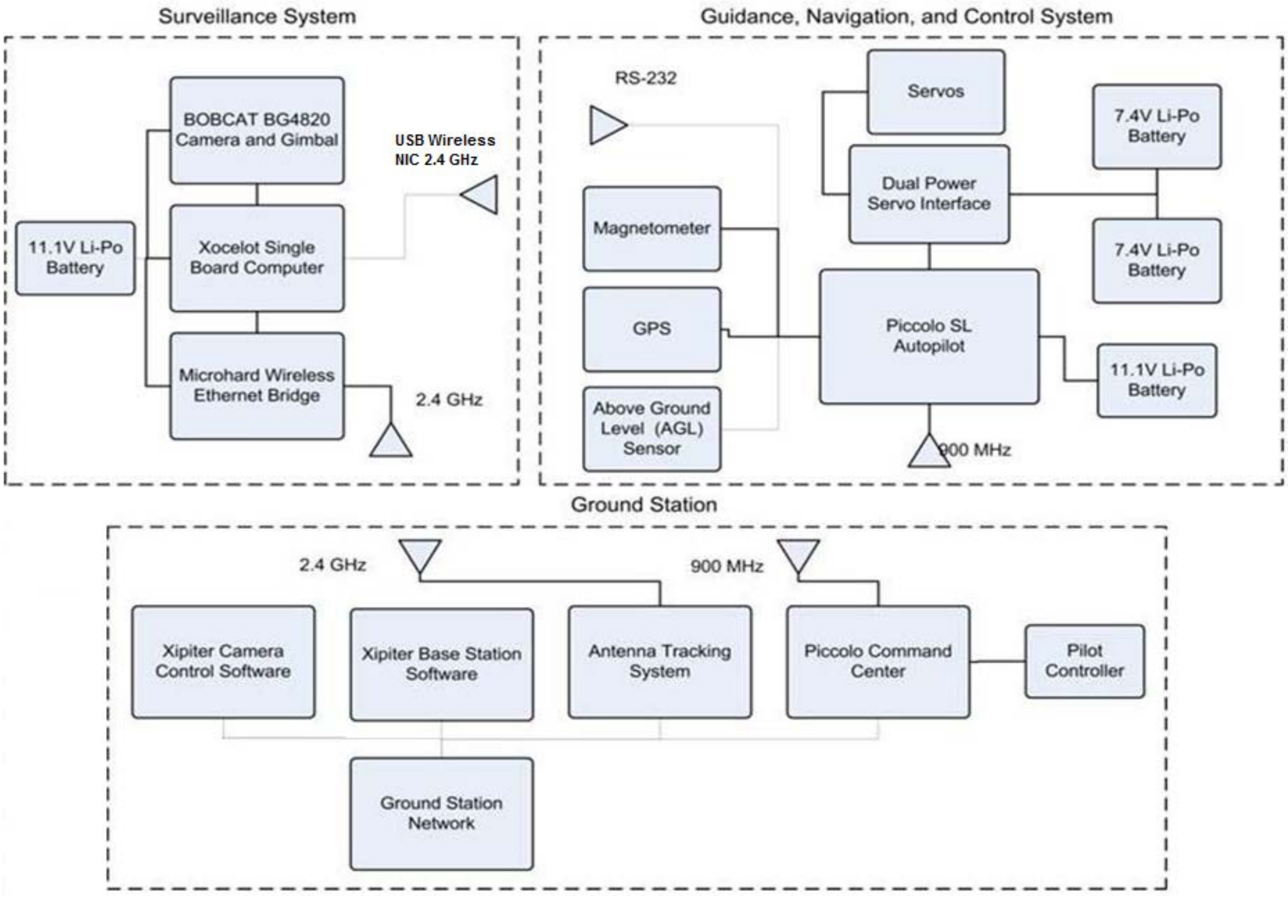

Figure 2 – Avionics Subsystems Block Diagram

These subsystems allow for small-scale development and testing before integration into the system. This ensures that each component functions properly and safely, and reduces the amount of time spent in the debugging phase. The following are the subsystems of the Xawk 5 avionics and will be discussed in more detail in the subsequent sections: Guidance, Navigation, and Control (GNC); Intelligence, Surveillance, and Reconnaissance (ISR); and Ground Station Interface.

III.C. SUBSYSTEMS

III.C.1 GUIDANCE, NAVIGATION & CONTROL

The base component of the Xawk 5 avionics is the GNC subsystem. It is comprised of the autopilot, sensors, servos, and a data link. The autopilot, along with various sensors such as an external magnetometer, static port, pitot tube, and laser altimeter, accompanying an internal three-axis gyro, interfaces with the aircraft subsystem to provide autonomous control during flight. The servos are redundantly powered via two lithium-polymer batteries independent of the main GNC battery. In constant communication with the ground station, the autopilot also delivers real-time telemetry which is displayed and logged locally as well as being used in calculations within the image processing software. The data link is a 900 MHz radio link ground tested up to 1.127 statute miles.

III.C.2 SURVEILLANCE

The Surveillance subsystem consists of all components necessary to scan the search area for targets, transmit the image stream wirelessly to the Ground Station Network, and view and capture images for post-processing. These components include an Imperx BOBCAT IGV-B4820 camera, VersaLogic Ocelot VL-EPMs-21b Single Board Computer, and Microhard 2.4 GHz wireless router. Additionally, a TP-LINK TL-WN722N wireless network card has been included which enables the subsystem to connect to remote wireless networks.

III.C.2.a CAMERA

Xawk 5 uses an Imperx BOBCAT IGV-B4820 16 megapixel camera shown in Figure 3. This camera produced very effective results during test flights from the previous year, and remained the most desirable candidate for use with the present system. The camera’s most prominent capabilities are image resolution, ease of installation, communication rate, and interfacing options. The Imperx BOBCAT IGV-B4820 camera features can be seen in Table 2.

Table 2 – Camera Specifications

Features	Imperx IGV-B4820
Resolution	4872 X 3248
Interface	GigE
Frames / second	3.2
Size	45x45x51mm
Weight	365g

The camera has an excellent digital shutter to capture images ranging from 1/500,000 seconds to more than 16 seconds with max resolution of 4904 x 3280 pixels. This will enable Xawk 5 to capture fast moving images while maintaining excellent quality. An Ethernet interface enables the Xocelot computer to communicate with and control the camera.

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Figure 3 -- Imperx BOBCAT IGV-B4820 camera

III.C.2.b OCELOT EMBEDDED SINGLE BOARD COMPUTER (XOCELOT)

The Ocelot Embedded Single Board Computer (Xocelot) in Figure 4 runs the Debian 6.0.5 operating system making for a stable, modular, and embedded computer to run anything needed for an imagery subsystem, including software to interface with other systems, the ability to collate data for re-use across the system, and shell scripting to start and operate separate components. The Xocelot is a self-contained controller for the imagery subsystem as well as a microcontroller derived computer; it can survive a full systems failure and reboot the imagery subsystem without the need for landing the aircraft.

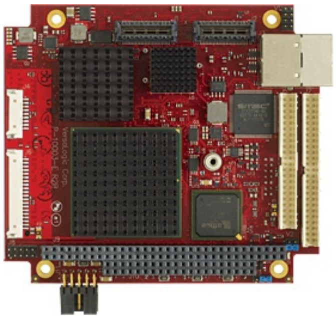


Figure 4 -- Ocelot SUMIT-104 SBC by VersaLogic Corporation

III.C.2.c LINUX ENGINE for OPTICS (LEO)

The primary software running on the Xocelot, called the Linux Engine for Optics, directly interfaces with the Imperx IGV-B4820 camera and the Ground Station. After linking the two parts of the system, the software takes pictures streamed from the camera's ethernet GigE connection and compresses them into a much smaller jpeg format for efficient transmission to the ground. Additionally, the software provides a simpler and more useable interface to the camera through command line arguments and configuration files. This enables the ISR operators to quickly reconfigure the software to send larger pictures, change the size of the video link, or change precisely how to connect to the Ground Station.

III.C.3 GROUND STATION INTERFACE

The Ground Station Interface is the central hub for monitoring and controlling mission progress. The responsibilities of this subsystem are to facilitate the operation of the airborne systems by processing and responding to the data offloaded over all wireless links from the aircraft. The components of the Ground Station include the Piccolo Ground Station and 2.4 GHz Microhard wireless router, the Xipiter Camera Control Software (XCCS), and Xipiter Base Station Software (XBS).

III.C.3.a PICCOLO GROUND STATION (PGS)

Acting as the interface from the Piccolo Command Center (PCC) software to the onboard GNC subsystem, the Piccolo Ground Station (PGS) transmits and receives telemetry and commands to and from the autopilot. All telemetry data about the aircraft is accessible through PGS during flight and is archived for viewing after a flight. Based on this data, the operator is able to manage the aircraft including dynamically retasking the aircraft during flight and controlling onboard payloads and sensors. While the plane flies autonomously, individual flight characteristics such as altitude and airspeed can be limited or manipulated with PGS. Finally, in the event of a serious safety concern, PGS can be used to send a kill engine, abort flight, or return-to-home command to the aircraft.

III.C.3.b XIPITER CAMERA CONTROL SOFTWARE (XCCS)

The student-designed and -written XCCS program is used to control camera operations from the ground station. Once connected to the onboard computer, the operator can request an image from the camera for a complete analysis. An ever-present image stream is sent from the onboard camera down to XCCS to facilitate target identification. This stream sends quarter-resolution images (1200x800 pixels) to reduce data transmission costs on the network without significantly degrading image quality. Once an object of interest has been identified within the streaming channel, XCCS can save and store that image for further analysis. This image is saved along with corresponding telemetry data to a shared network storage drive and the image's unique identification number is queued for processing. Flight data is received at regular intervals from the Piccolo Command Center on the ground (Figure 5), and the camera's tilt value is received from the gimbal system whenever a tilt adjustment is made.

As an additional service, XCCS acts as a server for distributing images to and collecting and consolidating all target data from any connected XBS clients. Any number of XBS clients can connect to the image distribution server found in XCCS and request a full-resolution image from the queue for analysis. XCCS also receives the information of validated targets from XBS clients and compiles a list of all identified targets. At any time, the XCCS operator can edit the target list for duplicates or unacceptable target data. When complete, the target list can be exported to a formatted text file and submitted to the competition judges.

III.C.3.c XIPITER BASE STATION SOFTWARE (XBS)

The XBS program, also student-written, is in charge of analyzing captured images from the onboard camera. After connecting to the image distribution server run by XCCS, XBS can request an unprocessed picture for analysis. The XBS interface will display the image along with the Xawk 5's flight data at the time of image capture. At this point, the XBS operator can search the image for any previously undetected targets, including any emergent targets. If found, clicking on the center of the target will cause a second screen to appear where the operator can enter in identifying features of the target (i.e. shape, background color, alphanumeric character, character color). There is also an option to determine the orientation of the target by clicking on the bottom and top of the target within the image. XBS can then calculate the orientation and exact location of the target with this information, the telemetry data, and photogrammetric equations. Once all information on a target has been recorded, XBS sends the new data back to XCCS for consolidation. XBS can then request a new image for analysis, edit, or remove previously submitted targets.

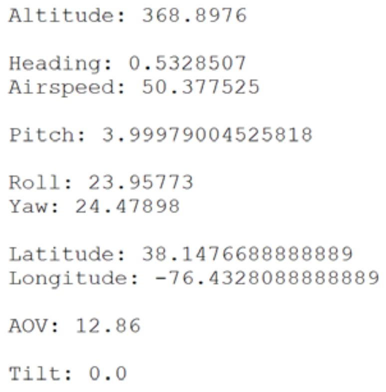
The design of XBS facilitates a simple integration of automatic target recognition software. This year, a limited target recognition process is being used that can autonomously queue targets and describe some of the target characteristics before being verified by the operator.

III.C.3.d GROUND STATION DATA PROCESSING

Data processing in the Ground Station is mainly performed by two applications, XCCS and XBS. These applications comprise all the necessary functions to process incoming imagery data, although these applications could be run at the same console, they are executed on separate computers to accommodate the human operator, and to bring more than one operator and/or CPU into the loop of processing the incoming data. As mentioned in previous sections, both of these applications support easy integration of autonomous control for target acquisition and analysis. The current iteration of Auto-Target Recognition Software resides inside XBS, automatically detecting targets, and thereby reducing the number of essential personnel and analysis time required. Though Auto-Target Recognition is in the early stages of development, Xipiter visualizes the possibilities of autonomous control to be endless. Implementation of this software allows for future use of automated camera search patterns, embedded image processing, and a streamlined process from image acquisition to accurate target identification.

III.C.3.e AUTOMATIC TARGET RECOGNITION (ATR)

During the development of the ATR program, several tests were performed to compare the actual capability of the main program to the desired capability. The main program was tested to the standards set forth by the competition before further integration. From previous flight tests and competitions, several pictures that were taken by the same camera used in the current system with a known lens were chosen as test images. Pictures, both with and without targets, were used to calibrate the system to not only identify targets in an image but also to not identify false positives. This was the earliest and most often performed test. Shapes identified by ATR are indicated to the operator with a red box (Figure 6). The shape recognition program was independently written and tested, and based on a program developed by Mathworks. The code was tested against high resolution, high contrast computer generated images and modified to make the program more robust. Using these images, the program was tested on its ability to identify the following shapes: square, rectangle, pentagram (star), cross, triangle, hexagon, circle, semi-circle, ellipse, octagon, and unknown. The images used contained examples of all these shapes, and the program demonstrated an ability to correctly identify all of them. Due to the complexity of identifying colors by their RGB values, the color recognition program was developed from a test rather than tested after development. That test divided the 0 to 255 range of each color value into 26 segments and used a program to generate 17,576 color samples. Each sample was assigned one of the following color names: red, green, blue, yellow, orange, purple, pink, brown, black, white, or grey. The color recognition program was an attempt to match the recorded data to the assigned name. Test results showed that the program corresponded closely to the original data. This shows that the methodology utilized by this program is at least as good as a human operator at determining the color of an object.



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Altitude: 368.8976

Heading: 0.5328507
Airspeed: 50.377525

Pitch: 3.99979004525818

Roll: 23.95773
Yaw: 24.47898

Latitude: 38.1476688888889
Longitude: -76.4328088888889

AOV: 12.86

Tilt: 0.0
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Figure 5— Telemetry Data Used By XBS

Figure 6—Target Identified Using ATR

III.D. POWER SYSTEMS

Supplying power to the various components onboard the aircraft for a sustained period of greater than forty minutes reliably is made possible by six different batteries installed within the aircraft. These include five Lithium-Polymer batteries running at 11.1 volts, and 5.9 volts, and one Nickel-Metal Hydride battery at 6.0 volts. Even with multiple high milliamp batteries, the question of if there was enough power to continually run these devices arose. The lights systems and the autopilot both running on their own 11.1 volt battery had been proven to run continuously in the previous year and in previous test flights. The Imagery subsystem, with its high-performance camera and new components, was where any new issues would arise. Through testing and a few calculations, the subsystem was discovered to run for about 2.51 hours, as shown in Table 3.

Table 3 -- Component Power Consumption Analysis.

	Xocelot	Microhard Bridge	Camera
Specs	6.5W, 12V	12V	5.8W, 12V
Amps	0.542	1.5	0.483
		Total	2.525 Amps
		Battery Life = 6.35 Ah / 2.525A	2.51 Hours

III.E. COMMUNICATIONS

III.E.1 SURVEILLANCE

The backbone of the imagery data link is formed by two Microhard wireless bridges (Figure 7) -- one mounted in the aircraft and another at the Ground Station. The communication bridges operate on the 2.4 GHz range. They can operate at speeds up to 54 Mbps and have been optimized for use with the Xawk 5 ISR subsystem.

Figure 7 – Microhard VIP2400

III.E.2 SRIC WIRELESS NETWORK CARD

One of the newer mission objectives is to connect to a Simulated Remote Intelligence Center (SRIC) and retrieve a team-specific file. To facilitate this objective, a 2.4 GHz TP-LINK TL-WN722N wireless network adapter (Figure 8) was added to the Xocelot onboard computer. While flying within range of the SRIC's directional antenna, this network card will enable a user at the ground station to remotely access the SRIC network and search for the appropriate remote file.

Figure 8 -- TP-LINK wireless network adapter

III.E.3 GNC

The GNC's 900 MHz data link is a direct connection between the autopilot and PGS, transmitting at 1W. In practice this has yielded a reliable data link up to approximately 1.1 statute miles. The link is used for transmitting commands from the pilot and his controller, as well as the PCC software and telemetry to and from the aircraft during flight. It also allows for dynamic retasking and real-time monitoring of the aircraft's telemetry and position, along with the ability for the pilot to take command of the aircraft seamlessly.

IV. AIRFRAME

IV.A. DESIGN AND FABRICATION

The Xawk 5 airframe is a student designed and student built aircraft and is an improvement over the previous X-4 series in several notable ways.

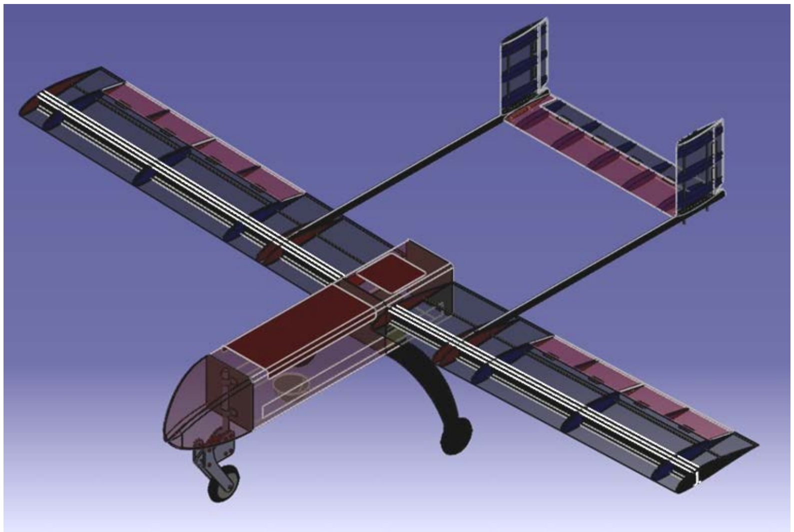

Figure 9 -- CATIA model of Xawk 5 UAS

IV.A.1 DESIGN MODIFICATIONS FROM XAWK X-4

The Xawk 5 airframe (see Figure 9) is the next step in the iterative method utilized by Xipiter. It is a modification of the Xawk X-4 airframe, with design changes focused on manufacturability, reliability, and weight. Major changes from the Xawk X-4 airframe include: a streamlined nose cone, an improved nose landing gear, C-channel wing spars (main and aft), foam wing ribs, and interchangeable engine mounting plates. The nose cone has been reshaped to allow for nose gear control to be mounted internally rather than below the nose cone. It also can provide housing for batteries and the pitot tube. The new nose landing gear has been redesigned to address a flaw in the previous design that prevented the gear from adequately absorbing shock. By using C-channel spars and foam ribs, Xipiter has been able to produce molds and hotwire patterns that allow for exact part shapes to be manufactured. This precision has led to a decreased need for reworks and patch fixes, leading to a lighter and stronger aircraft. The engine mounting plates serve a dual purpose. First, they allow for easy engine swapping should the need arise due to engine reliability issues. Secondly, they provide a way to further isolate the engine from the firewall, reducing the transmitted vibrations from the engine to the fuselage and subsequently the ISR system.

IV.A.2 FUSELAGE

The fuselage, which is 55 inches long and has a payload volume of 2430 cubic inches, of Xawk 5 is composed of two half shells, three bulkheads, two longerons, and a nose cone consisting of two shells. The upper shell of the fuselage features two hatch cutouts providing access to the main payload compartment and the aft payload compartment. The lower shell of the fuselage is reinforced near the middle bulkhead to provide extra strength for the main landing gear. The forward bulkhead acts as a support structure and an attachment point for nose landing gear and nose cone. The middle bulkhead contains a special housing for the autopilot and serves as a mounting point for the main wing spars. The aft bulkhead serves as a connection point for the engine mount plates and subsequently the engine. The longerons are bonded into the main payload compartment and serve a dual purpose of providing structural support and shelving for avionic components.

IV.A.3 WINGS

The Xawk 5 airframe’s wings employ the SD7062 airfoil. Xipiter selected this airfoil due to the team’s experience with the airfoil on previous airframes. This airfoil is designed for stability and control in slow, low Reynolds number flight. For enhanced lateral stability, the Xawk 5 airframe has 2° dihedral in the wings. The internal structure of each wing consists of a C-channel main spar, a C-channel aft spar, and foam ribs.. Additionally, the wings feature internal boom attachment structures, which will be discussed in Section IV.A.5. All flight surfaces are composed of two skins and a leading edge close out piece. All skins are made using Divinycell core sandwiched between two layers of carbon fiber for added structural strength.

IV.A.4 EMPENNAGE

The empennage of the Xawk 5 airframe is a twin boom, H-tail design. The booms attach to the wings through the use of carbon fiber sleeves. These carbon fiber sleeves are secured to the wing at wooden hard points inside the wing. On both sides of the hard point is a pair of carbon fiber reinforced plywood ribs that are bonded in to provide additional reinforcement. The J5012 airfoil is used for each vertical stabilizer and the horizontal stabilizer. Each vertical stabilizer has a height of 12 inches and a chord of 9 inches, resulting in a total area of 216 square inches and a combined aspect ratio of 2.67. The horizontal stabilizer has a span of 33 inches and a chord of 9 inches, resulting in an area of 297 square inches and an aspect ratio of 3.67.

IV.A.5 LANDING GEAR

The landing gear of the Xawk 5 airframe is in a tricycle configuration. The nose gear is a trailing link design comprised of a carbon tube, carbon fiber mounting plates, and springs mounted to be in tension. The main gear is a “half-moon” spring leaf design. The landing gears are designed to simultaneously provide enough support to the aircraft, but also to have enough give to damp impact forces from landings to protect the avionics payload. Both landing gears use 5 inch tires.

IV.A.6 POWERPLANT

The Xawk 5 aircraft uses the Desert Aircraft DA-120, 2-cycle, 2-cylinder engine. This engine was chosen previously for its excellent power to weight ratio and its reputation of being a reliable engine. Using a 2-cylinder engine versus a single cylinder engine minimizes engine vibrations transmitted to the ISR system. The engine is mounted to the aft bulkhead in a pusher configuration and uses a Xoar tri-blade beech wood 26 in x 12 in tractor propeller. The engine is in a pusher configuration to eliminate exhaust fumes over the camera, a tri-blade propeller is used to reduce propeller diameter, and the engine’s rotation has been reversed as tractor propellers are much less expensive and are more accessible than pusher propellers. A disadvantage to this configuration is that there is a lack of air flow over the engine to cool it in flight. This was resolved by adding a pair of custom made cooling scoops mounted on the fuselage to redirect the airflow over the engine.

V. SAFETY CONSIDERATIONS

V.A. OVERVIEW

Safety is a primary concern in operation of any aircraft and perhaps even more important with unmanned vehicles. The AUVSI Student UAS Competition Rules clearly indicate the importance of safety, and Xipiter UAS IPT 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.

V.B. RISK ASSESSMENT TABLES / MATRICES

Xipiter used the risk assessment tables and matrix (presented in Table 4) to identify and classify potential system and subsystem hazards through-out all phases of Xawk 5's development.

Table 4 -- Risk assessment tables 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	🟦	🟦	🟦	⬜	⬜

🟦 I - Acceptable Task/Action
⬜ II - Semi-acceptable Task/Action - requires authorization or pre-approval
🟨 III - Unacceptable Task/Action - risk reduction required.

V.C. 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, or cause injury to ground personnel and/or observers. All removable parts represented the primary interest of hazard, followed by actual airframe structure. The team identified the following components as removable in a standard field operation:

- Wings
- Two booms (with vertical stabilizers to remain attached)
- Horizontal stabilizer
- Hatches

To mitigate risk from loss of these components, multiple fastener redundancies were designed into each part. In the wing attachment, there are two extra bolts through the port and starboard sides of the fuselage. For the boom attachment, each boom has two bolts that extend through the entire wing and are confirmed secured both visually and tactilely. The horizontal stabilizer was secured using four bolts that extend through the entire boom to ensure a secure attachment. Hatches were fabricated slightly smaller to ensure a tight "squeeze" around the sides of the fuselage, in addition to four retaining bolts.

The team also identified the following components as removable in an extensive disassembly of the airframe:

- Control surfaces
- Nose cone
- Landing gear
- Cooling Scoops

To mitigate risk from loss of these components, redundancies were also designed into each part. Each control surface contains a redundant hinge, each with a securing cotter pin. The nose cone was fabricated slightly larger than necessary to ensure an overly snug fit, with six retaining bolts. The main landing gear is secured using four bolts, each with Loctite Threadlocker. Cooling scoops, secured with three bolts each, maintain air flow over the engine during flight to keep engine temperatures within safe operating conditions.

V.D. AVIONICS RISK IDENTIFICATION / MITIGATION

V.D.1 ADEQUATE WIRING

Electromagnetic interference (EMI) is always a concern when building electrical systems. Noise can be improperly interpreted as commands, and it can distort proper commands into something unrecognizable by the system. As such, the use of correctly shielded wiring is essential.

Faulty wire connectors are also points of failure; if a device loses power or signal, the results could be catastrophic. In order to resolve these potential hazards, high grade connectors and power switches are used in the Xawk 5.

V.D.2 SURVEILLANCE DATA SECURITY

As is the case in real world systems, security is always a major concern, if not the most important. In the case of the avionics subsystems, multiple points in the system are secured against external control or data interception. The first component of the overall security protocol is formed by requiring physical access to shut-down or take control of both the GNC and Imagery subsystems. SSH remote login is enabled, but basic security features have been put into place such that the system ignores many harmful commands such as the ‘halt’ command to shut down the system. Furthermore only pre-approved programs can be run by any one of only three team members who have access to the computer aside from the root administration account, which can only be accessed via physical access to the system. Other basic security measures built into the system include network access encryption with a 24-character mixed alphanumeric WEP key, custom packet structuring for imagery data sent between aircraft and ground station (rendering any data intercepted completely useless), and password protection on the Piccolo autopilot itself.

V.D.3 AUTOPILOT

Pertaining to Guidance, Navigation, and Control (GNC), much consideration was placed into the risk analysis of the avionics subsystem. The overall approach was to have a design that incorporated as many of the Student UAS Competition Requirements as possible into a single unit. In searching for an autopilot, Xipiter sought options that met these requirements. The Piccolo SL autopilot selected by Xipiter satisfies a large percentage of the requirements on its own. The main map window displays a graphical representation of the aircraft’s three dimensional position, the aircraft’s elevation, and the latitude and longitude coordinates, satisfying the requirement stating, “The system shall provide sufficient information to the judges to ensure that it is operating within the no-fly/altitude boundaries on a continuous basis.” The autopilot system also allows the user to take manual control of the aircraft. This is achieved through the use of a standard RC aircraft transmitter and console cable which links the transmitter commands to the Piccolo autopilot. Pilot manual override assures that unintended inputs from the autopilot can be mitigated and prevented.

VI. FLIGHT TESTING AND MISSION FULFILLMENT

VI.A. OVERVIEW

As with any experimental vehicle involving multiple subsystems and personnel, operational procedures are critical to the safe operation. Xipiter's Flight Test and/or Mission Plans use a systems engineering approach, applied to flight operations.

VI.B. OPERATIONAL PROCEDURES

VI.B.1 APPROVED TESTING LOCATION

Team Xipiter performs all flight operations at Champion Field at the Camp Shelby Joint Forces Training Center in Hattiesburg, MS. Range Control is contacted 15 minutes prior to launch and when the aircraft is airborne, and the aircraft must maintain an altitude of at or below 1000-ft AGL and visual line-of-sight contact at all time. When traffic is present, the aircraft must land immediately, and the engine must be set to DISARMED position.

VI.B.2 PERSONNEL REQUIREMENTS

The Xawk 5 UAS requires a minimum of nine people to safely perform flight operations. Figure 10 below represents a typical flight operations chain of command for Xipiter. Yellow tabbed 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.

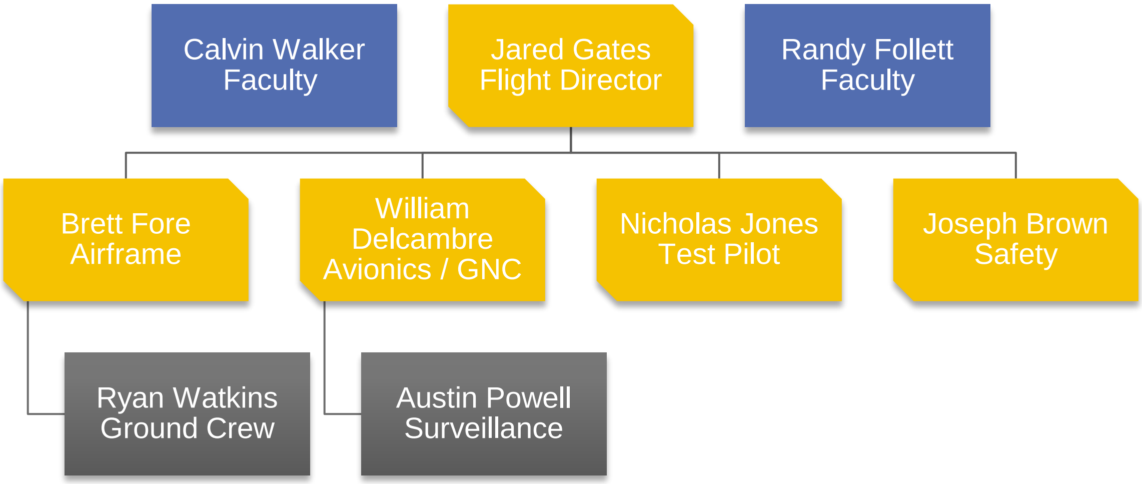

Figure 10 – Flight operations chain of command

VI.B.3 PRE-FLIGHT CHECKLISTS

Flight tests are conducted with a dedicated airframe subsystem lead, dedicated avionics subsystem lead, and a dedicated safety officer. All three have separate checklists that are referenced when directed from a master flight procedure checklist by the team lead. Several key values are again checked prior to flight, and verified by the safety officer and team lead. Defining role with specific checklists for each subsystem ensures that each component is analyzed, verified, and brought together as a whole system. The check values by the team lead allows a quick go/no-go analysis, combined with other environmental and traffic data, as well as input by advisors to make an informed flight decision.

VI.C. TESTING

VI.C.1 AVIONICS

VI.C.1.a RADIO RANGE / DATA TRANSFER RATE

All radio systems were tested by simply moving the aircraft away from the ground station until radio transmission was degraded to an unacceptable level. In this configuration, a significant amount of the radiated signal is dissipated by the ground; therefore, these tests measure an attenuated signal, meaning that the results of these range checks are closer to a worst-case scenario. Even in this case of withering signal strength, loss of line of sight, and a distance of one mile, the link rate between ground station and autopilot never dropped below 35%. In the case of the backup radio transmitter, an attenuator was also used, as it was available for this transmitter. Unacceptable levels were different for the different radio systems. For the autopilot system, the primary consideration for an unacceptable level is loss of manual control. The aircraft was moved away from the ground station while smoothly moving the surfaces of the aircraft. Jittery response was observed at approximately half a mile from the aircraft. The imagery system maintained a transmit/receive time of below 50 milliseconds (10 Kbps or better) for approximately half of a mile, and a time below 200 milliseconds (2.5 Kbps or better) up to the maximum distance tested.

VI.C.1.b SOFTWARE / HARDWARE TESTING

The current iteration of the Xipiter software package has been tested at each stage of development: first as individual software applications on developmental hardware, then as a complete software system before being installed on the UAS hardware. As a result, each piece of software was slowly built up part by part to guarantee that the stability and reliability of the complete software package was maximized. Basic functionality was first written in the code, to build a proof of concept, and then on top of that more and more complex algorithms and functions were added and then tested to ensure expected functionality. Next, interconnection of the programs and the processes that were to run alongside them across the system network was verified. Once the complete software package was finished and ready to be fully tested, the hardware systems that had not been already systematically introduced through necessity were installed to fully test the avionics subsystem.

VI.C.1.c IMAGE CAPTURE TESTING

Initial testing of the camera performance was promising but presented several problems that would have to be corrected when designing the imagery software. The camera outputs a 60 megabyte .BMP image file by default, which was found to take almost 10 seconds to transfer to the ground station for analysis. Because this system performance would not adequately meet the mission objectives, the image stream was routed through the onboard computer before being transmitted. Dedicated software was written that would compress and convert the image to a .JPG file roughly 10 kilobytes in size. With this modification, images were being transmitted at a rate of about one image per second. Further testing was performed to find a satisfactory balance between image quality and frame rate. The most recent testing has shown that 3 megabyte images being received every 2-3 seconds is the most efficient combination for properly covering the entire search area. Additionally, some variations were observed in the image brightness and color correctness during test flights. To resolve these issues, functionality to adjust the camera gain, shutter speed, and color filters from the ground during flight was implemented. Further testing of these features resolved the issues at hand.

VI.C.2 AIRFRAME

VI.C.2.a POWERPLANT SAFETY TESTING

In addition to essential engine testing, the safety features of the engine control system were also tested. The Xawk 5 has three safety shut-off engine “kill switches”—one physical switch on the fuselage, one physical switch on the safety pilot controller and finally one software kill switch in the Piccolo Command Center software. The engine was started and each switch independently tested. All three successfully disconnected the ignition module from the engine and stopped the engine. These three switches also act as a safe-guard, as all three must be engaged for the engine to start.

VI.C.2.b TAXI TESTING

The taxi testing ensures the plane tracks straight during ground roll prior to take-off. From past attempts it was found that the automatic takeoff program requires that the nose wheel be precisely trimmed to hold the centerline during takeoff otherwise the autopilot will abort the takeoff. During this test, the nose wheel is trimmed to roll straight with engine off for a rough trim then with the engine on during a simulated takeoff under the control of the safety pilot. After the simulated takeoff roll the plane is then allowed to roll to a stop which tests the landing roll. During both of these simulations, the plane is observed for unusual vibrations which would indicate misaligned wheels or a nose wheel shimmy. After the simulated landing, the safety pilot taxis the plane at his discretion to gain a feel for plane’s taxiing turns.

VI.C.3 FULL SYSTEM TESTING

Xipiter prepared a comprehensive full system test plan strategy to follow prior to competition. Each test plan builds upon previous plans and is designed to be performed sequentially. As of the publish date of this paper, all Flight Test Plans with the exception of 6 and 7 (detailed in Section VI.C.3.g) have been completed, however Flight Test Plan 6 is scheduled to be complete prior to competition.

The evolutionary project lifecycle of the Xawk series provides years of test data to draw from, applicable to this class of aircraft and many of the subsystem components. Because the team draws in new members each year, “tribal knowledge” is able to be passed on from older members to newer members before they graduate. Both team characteristics provide continuous data from year-to-year and allow a much more efficient and compressed testing strategy.

VI.C.3.a FLIGHT TEST PLAN 1, FLIGHTWORTHINESS TESTING

The primary objective of the first flight test was to demonstrate flightworthiness, evaluate airframe stability and control, and allow time for the test pilot to familiarize himself with the aircraft. Flightworthiness was determined by balancing the location of the center of gravity, inspecting the structural integrity on the ground, and performing a control surfaces check. The flight test was performed without the surveillance subsystem. Prior to flight, range checks were performed again using the manufacturer’s instructions.

With personnel briefed and the checklist completed, the pilot taxied the aircraft and performed takeoff and climb out. Once Xawk 5 reached an altitude around 300ft, the pilot trimmed the controls while flying simple rectangular patterns. In accordance with the test plan, a few controlled approaches were flown before the actual landing attempt. The pilot landed the UAS successfully and the pilot controls were trimmed for future flights (Figure 11).

Figure 11 – Xawk First Flight

VI.C.3.b FLIGHT TEST PLAN 2, AUTOPILOT FLIGHT FOLLOWING

Flight Test 2 followed the same flight path as Test 1. The main objective of this test was to monitor and track the Xawk 5 UAS with Piccolo SL Autopilot, and verify data accuracy, strength, and quality while still under manual control. The aircraft flew for approximately 20 minutes, in which the pilot was allowed multiple attempted passes for landing to provide him with further experience. Reported airspeeds from Piccolo for approach speeds, cruise speeds, flaps-down cruise speeds, and other parameters were noted during this flight. Throughout the flight, the aircraft was successfully tracked, flight data was verified, and signal strength and quality were maintained.

VI.C.3.c FLIGHT TEST PLAN 3, AUTOPILOT COMMAND

The objective of this test was to demonstrate the mid-air control of the Xawk 5 UAS from the Piccolo Autopilot. The flight consisted of a manual take-off, and a minimum of one complete pattern circuit to ensure proper flight handling characteristics, at which point the aircraft was turned over to the Piccolo SL Autopilot to command the aircraft in continuing flight in the pattern circuit. The aircraft was then turned back over to manual control for manual landing by the pilot.

Upon reviewing the telemetry data for this test, the aircraft was able to hold altitude within 10ft of the commanded altitude and within 5 knots of the commanded airspeed. The aircraft successfully tracked waypoints and the GNC operator was able to retask the aircraft in-flight.

VI.C.3.d FLIGHT TEST PLAN 4, SURVEILLANCE SUBSYSTEM TESTING

This test demonstrated the basic functionality and communications of the surveillance subsystem. The flight consisted of a manual take-off, manual flight of a minimum of one full traffic-pattern circuit and was turned over to the Piccolo SL Autopilot for autonomous control within the traffic-pattern circuit. The surveillance team had approximately 20 minutes of test time, at which point the aircraft was manually landed.

The surveillance team was able to continuously receive images throughout the flight with only minor drops in signal strength when the aircraft was in a bank in the traffic-pattern circuit. The images from the aircraft were slightly darker than anticipated due to a poor camera aperture setting (Figure 12). With aperture settings adjusted, the test was performed once again, this time resulting in high quality images with appropriate brightness being received throughout the flight (Figure 13).

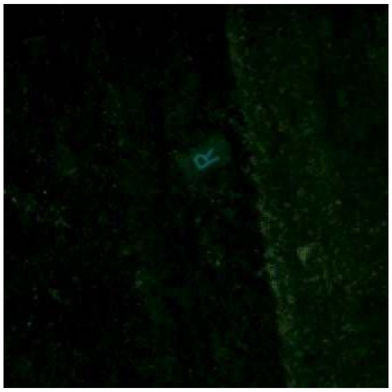

Figure 12 -- “R” Target Before Camera Adjustment

Figure 13 -- “T” Target After Camera Adjustment

VI.C.3.e FLIGHT TEST PLAN 5, SURVEILLANCE AND SRIC TESTING

This test demonstrated the basic functionality and communications of the surveillance subsystem and network interface capabilities. The flight consisted of a manual take-off, manual flight of a minimum of one full traffic-pattern circuit and was turned over to the Piccolo SL Autopilot for autonomous control within the traffic-pattern circuit. The Piccolo SL Autopilot was then commanded to orbit over a replica SRIC, allowing for network interface. The aircraft was then to be landed under manual control once a max of 20 minutes flight time was reached. However, once the aircraft entered the orbit it began to lose altitude and the test pilot was forced to retake control at which time the aircraft was landed. Upon reviewing the telemetry data, it was found that the Piccolo SL Autopilot was not allowing the aircraft to pull more than 2G’s due to a previously unknown mission limit resulting in the loss of altitude. This setting was increased to 4G’s to allow the aircraft to bank tighter, while maintaining altitude. With this setting adjusted, the test was performed once again, this time the aircraft successfully orbited the SRIC, which allowed the surveillance team to connect to the SRIC.

VI.C.3.f FLIGHT TEST PLAN 6, FULL MISSION SIMULATION

This test will demonstrate the complete system capabilities of the Xawk 5 UAS. Careful attention to simulation of a full mission will be followed, and simulated targets and a replica SRIC will be placed in the field. The flight will begin with the aircraft searching for five targets scattered about a simulated search area, with the aircraft later being later retasked to orbit the SRIC. Once the simulated mission time is reached the flight will conclude with a manual landing.

VII. SYSTEM APPLICABILITY TO STATEMENT OF WORK

The Xawk 5 UAS is a culmination of Xipiter UAS IPT’s systems engineering process, considering the requirements, design, fabrication, 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 IPT presents the Xawk 5 UAS as a solid answer to the Statement of Work issued by the Seafarer Chapter of the Association of Unmanned Vehicle Systems International (AUVSI) Student Unmanned Aerial System (SUAS) Competition.