System Overview for the Xawk X-4 UAS

Mississippi State University's Entry for the 2010 AUVSI Student UAS Competition

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Abstract

The 2010 Student UAS Competition, hosted by AUVSI, marks Mississippi State University's seventh 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 X-4 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 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 LT autopilot in the guidance, navigation, and control (GNC) subsystem, and a pan/tilt/zoom camera, a video IP server, and a broadband Ethernet bridge in the surveillance subsystem. The ground station subsystem includes the interface to the autopilot, camera control software, and auto-target recognition software. To improve the quality and reliability of the video link, a high-gain, directional antenna tracking system 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.

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 four mission phases: takeoff, waypoint navigation, area search, 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 last phase, landing, may occur either under manual or autonomous control. In order to obtain maximum credit, the team must complete all four phases of the mission in less than forty minutes.

II. SYSTEM ENGINEERING APPROACH

II.A OVERVIEW

Xipiter IPT has embraced a Systems Engineering approach over the years. 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 vee into sub-systems and sub-components; and then reassembles it to a final product on the right side. 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.

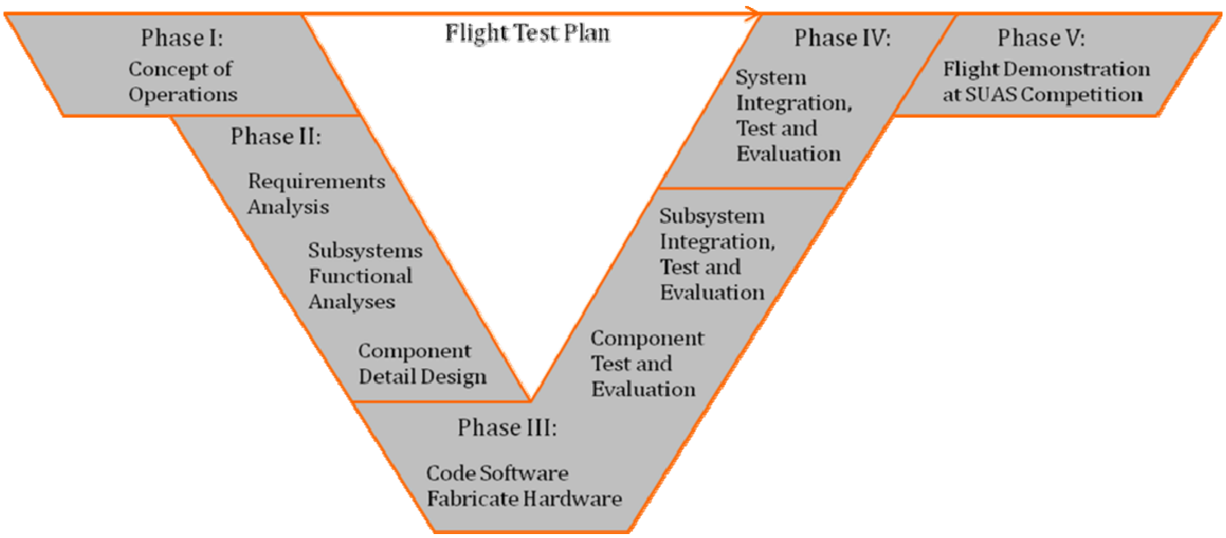


Figure 1 – Team Xipiter Systems Engineering Vee Model

II.B PRIMARY MISSION OBJECTIVES

Based on the competition rules and the mission profile presented, the following definitions represent the primary minimal objectives of the Xawk X-4 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.

II.C MISSION CONSTRAINTS

Due 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 major requirements and constraints that were determined to impact the design and performance of the 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 40 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 DEFINITION OF SYSTEM & SUB-SYSTEMS

Xipiter's solution takes a systematic approach to logical groups of components, classifies them as a sub-system, and relates them to the UAS as a whole. In the case of the Xawk X-4, the system is divided into two primary sub-systems: **Airframe** and **Avionics**. 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

Just as the Xawk X-4 airframe follows an evolutionary design, the avionics system also builds upon previous successes, and seeks to improve or redesign unsuccessful components. The essential subsystem structure remains the same: Guidance, Navigation, and Control, Surveillance, and Ground Station. Two new components, the Antenna Tracking System and the Auto-Target Recognition System, were added to improve system performance and autonomy. Also, the maneuverability of the Pan/Tilt/Zoom camera was increased by reevaluating the abilities of the camera control hardware.

III.B AVIONICS REQUIREMENTS

In addition to the requirements given for the airframe, certain stipulations exist for the avionics system as well. Xipiter has also established objectives beyond competition requirements in order to attain the best possible flight. These requirements and objectives pertain to the areas of autonomy, in-flight re-tasking, imagery, target location, and mission time.

During waypoint navigation, the system must remain autonomous, with a goal of demonstrating autonomous takeoff and landing. To account for the pop-up target, the system must be capable of re-tasking by modifying waypoints and search areas during flight. The imagery system must be able to display to the judges pertinent target information such as the shape, alphanumeric, and the corresponding colors, as well as orientation, and size. Targets must also be located within 250 ft with an objective of location within 50ft. The maximum time for the mission is 40 minutes; however, the goal is to conclude the mission within 20 minutes and deliver target identification in real-time.

Safety also plays a very important role in the mission requirements. The system must be equipped with fail-safes that allow a pilot to take control of the vehicle at any point during flight. In addition to the manual override, a flight termination system must be incorporated into the system as a precaution.

III.C SYSTEM DESIGN

The XAWK X-4 avionics system contains all hardware and software components to satisfy the requirements and objectives as stated. A systems engineering approach was used to develop the avionics system by creating subsystems based upon functionality. Figure 2 shows the full system and the interactions between subsystems.

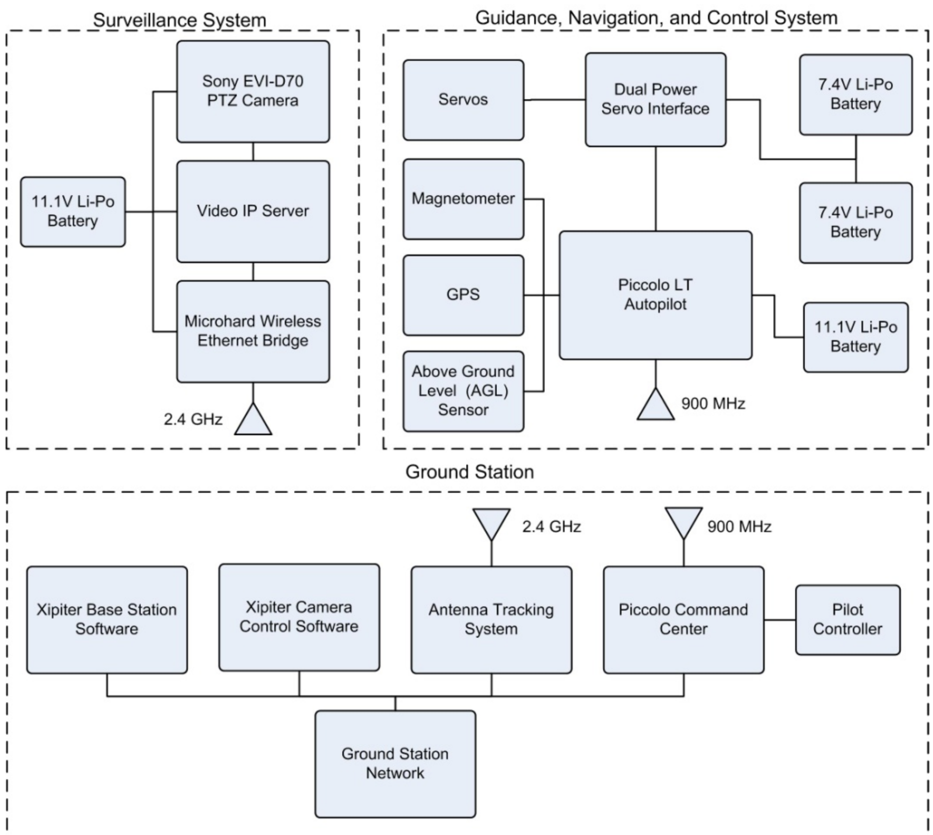


Figure 2 – Avionics Sub-systems Block Diagram

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. By clearly defining the inputs and outputs of each of the sub-systems, this approach allows for improvement within the subsystems without affecting the overall system. The following are the subsystems of the XAWK avionics and will be discussed in more detail in the subsequent sections: Guidance, Navigation, and Control (GNC); Surveillance; and Ground Station Interface.

III.D SUBSYSTEMS

III.D.1 Guidance, Navigation, & Control

At the heart of the X-4 avionics is the GNC subsystem. It is comprised of the autopilot, sensors, servos, and a data link. The autopilot, along with an external magnetometer and altimeter, 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 at the ground station as well as being used in calculations within the image processing software. The data link is a 900 MHz radio link tested up to 1-mile.

III.D.2 Surveillance

The Surveillance subsystem consists of all components necessary to scan the search area for targets, transmit the video stream wirelessly to the Ground Station Network, and view and capture images for post-processing. These components include the Sony EVI-D70 Pan/Tilt/Zoom (PTZ) camera, Axis Communications Network Video Server, and a Microhard 2.4 GHz wireless bridge.

To choose a camera, certain key features were identified. Among these features are PTZ capability, zoom features, image resolution, and method of control.

Several cameras featuring similar specifications were compared using a trade study. By setting weighted values for the importance of characteristics, the avionics team was able to choose the camera that exhibited as many of the desired characteristics as possible. The Sony EVI-D70 camera was chosen based on the results of the trade study.

Choice / Factor (Weight)	Sony D70	Toshiba IK-WB21A	Bronzepoint PTZ 270
Cost (2)	5 x 2	4.55 x 2	5 x 2
Performance (2)	4.2 x 2	3.9 x 2	3.89 x 2
Resolution (3)	3.5 x 3	5 x 3	1.78 x 3
Zoom (2)	4.2 x 2	4.07 x 2	5 x 2
Size (1)	3.9 x 1	5 x 1	2.66 x 1
Gimbal System (1)	4.2 x 1	4.34 x 1	4.75 x 1
Total	**4.42**	**4.37**	**4.20**

Table 1 – Camera Trade Study

Because the camera is an analog camera, a device is needed to convert the analog video to a digital network stream. The Axis Communications 282A Network Video Server was chosen for this task. The small size and ability to control the Pan/Tilt/Zoom function of the camera made the video server the best choice to add to the GNC subsystem.

Figure 3 – Sony DV70 Camera with Axis Communications 282A Network Video Server

The final element of the GNC subsystem is the Microhard wireless bridge, which is used for imagery transfer to the Ground Station. Though the video server was originally chosen for PTZ control of the camera, performance at the 2009 competition led the avionics team to configure the Microhard bridge to relay the VISCA PTZ commands. The design including the video server proved to be unable to relay enough control information for the camera to be controlled by a joystick. Thus, the previously unused serial port on the Microhard bridge was chosen to pass VISCA commands from the Ground Station to the camera. By changing the control method of the camera, more commands were able to be sent, and the responsiveness of the camera was greatly increased.

III.D.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 from the aircraft. The components of the Ground Station include the Piccolo Ground Station and Antenna Tracking System hardware, and the software packages Xipiter Camera Control Software (XCCS), and Xipiter Base Station Software (XBS).

III.D.3.a Piccolo Ground Station

Acting as the aircraft interface to the onboard GNC subsystem, the Piccolo Ground Station (PGS) transmits and receives telemetry and commands to and from the autopilot. The Piccolo Command Center (PCC) displays aircraft telemetry and status at the ground station. The operator is able to manage the aircraft including dynamically retasking the aircraft during flight and controlling onboard payloads and sensors. The PGS communicates to the aircraft via a 900 MHz radio link and streams data over the ground station network.

III.D.3.b Antenna Tracking System

To address past issues encountered with the video transmission link, a high-gain directional antenna was added to the ground station. The antenna tracking system (ATS) consists of the actual antenna, 2 degree-of-freedom (DOF) motion base, and an embedded control system. Connected to the ground station network, the ATS receives elevation and azimuth commands calculated from the aircraft telemetry to point the antenna at the aircraft. The embedded control system consists of a Kalman filtered PID feedback controller providing accurate tracking of the aircraft throughout flight. The ATS improves the quality and reliability of the video data link.

III.D.3.c Xipiter Camera Control Software

XCCS is the primary application in the image processing suite, a package designed to satisfy the imagery requirements for the competition. It serves two purposes, to capture imagery and control the Pan/Tilt/Zoom camera. XCCS captures the image stream broadcasted from the XAWK aircraft and the telemetry data acquired from the Piccolo autopilot. To aid a human operator in controlling the camera and identifying targets, the video stream is displayed on a user-friendly GUI. Once an object of interest is detected, XCCS captures a JPEG image from the stream and saves it, along with the accompanying telemetry data, to a folder shared between XCCS and XBS for future processing. XCCS may be controlled by either a human operator or an autonomous system, allowing for future development of a fully-autonomous system.

XCCS is programmed in Java to make use of its simple API and cross-platform compatibility. Using Java benefits Xipiter in several ways. Student participation in developing code is a large part of the avionics development. Because Java is part of the core requirements of their curriculum, students are available to easily contribute to the team’s final product. In conjunction with this, the cross-platform availability allows students to develop code whether they run a Windows, Linux, or Mac platform. The final benefit is ease of use. The Java API provides programmers with easy to use objects for developing user interfaces, spawning threads, and communicating through sockets, tasks which would be much more difficult for beginning programmers in other languages.

III.D.3.d Xipiter Base Station Software

Also a component of the image processing suite, XBS performs the necessary functions for target characteristic and location identification. Similar to XCCS, XBS is developed in Java and can be controlled either by operator or computer. In the case of operator control, XBS has a GUI for the operator to see the image displayed, determine shape and color, and click on the target location so that the GPS coordinates can be obtained. Using the telemetry data obtained from XCCS and photogrammetric calculations, XBS can determine the location, size, and orientation of the target. Other key features include a target list, which allows the operator to view previously identified targets and characteristics. This list can be exported into the competition-specified format for easy submission of mission results.

III.D.3.e Auto-Target Recognition

A new development to the Ground Station is the Auto-Target Recognition software. This software uses the MATLAB Image Processing Toolbox to identify possible targets. The process is divided into two phases, detection and recognition, first detecting the target by shape, and then recognizing the color and alphanumeric. Standard image processing techniques such as edge detection, template matching, and geometric characteristics are used to detect and recognize the targets. Currently, the software can identify 9 shapes, 9 colors, and 36 alphanumeric characters. The tables below summarize the combinations of targets that can be recognized.

Table 2 – Summary of Possible Target Combinations

Shapes		
Circle	Square	Rectangle
Triangle	Ellipse	Cross
Hexagon	Octagon	Pentagram

Colors		
Red	Green	Blue
Yellow	Cyan	Magenta
Black	White	Orange

Alphanumeric	
A-Z	0-9

MATLAB was chosen for the Auto-Target Recognition software because of its versatility. The Image Processing Toolbox provides user-friendly APIs that can simplify complex image analysis, and the Simulink tool allows for full-system simulation of the software. Using other tools produced by the Mathworks, the Auto-Target libraries can be compiled into Java, C, or other embedded languages, which allows the Auto-Target Software to interface with many different types of applications.

III.E COMMUNICATIONS

III.E.1 Imagery

The two Microhard Wireless Bridges form the backbone of the imagery data link between the aircraft and the Ground Station. The bridges operate at 2.4 GHz range using spread spectrum technology. They can operate at speeds up to 54 Mbps and are designed for wireless video surveillance, which makes them suited for the XAWK application. These bridges also offer WEP and WPA authentication to encrypt communication. Another feature that proved to be useful is the serial communications port. It can be attached to a TCP or UDP port, allowing networked applications to send serial data over the wireless network to devices onboard the aircraft. This feature, along with minor changes to the XCCS software, provides a different method of controlling the camera that is taken advantage of in the XAWK X-4's avionics design.

III.E.2 Piccolo

The GNC data link consists of a 900MHz connection. Both the autopilot's internal radio and the ground station ratio transmit at 1W. During testing this has yielded a reliable data link up to 1 mile. The link is used for transmitting commands and telemetry to and from the aircraft during flight. This allows for dynamic retasking as well as real-time monitoring of the aircraft's state and status. Also, the pilot commands to the aircraft are transmitted over this link during manual control. Employing the 900MHz data link ensures there is no interference between the GNC and surveillance subsystems.

III.F 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. Though these applications could be run at the same console, they are executed on separate computers to accommodate the human operator. As mentioned in previous sections, both of these applications can be human or autonomously controlled. This feature allows the current iteration of the Auto-Target Software to reside inside these two applications and control them, reducing the number of computers and essential personnel. This works by placing the detection portion in XCCS. Once a target is detected, a JPEG of the frame is saved and passed to XBS where the recognition phase would begin. Though Auto-Target Recognition is in the early stages of development and currently only supports detection and recognition of targets, Xipiter visualizes the possibilities of autonomous control to be endless. Implementation of this software opens up the doors for automated camera search patterns, embedded image processing, and a streamlined process from image acquisition to accurate target identification.

IV. AIRFRAME

IV.A OVERVIEW

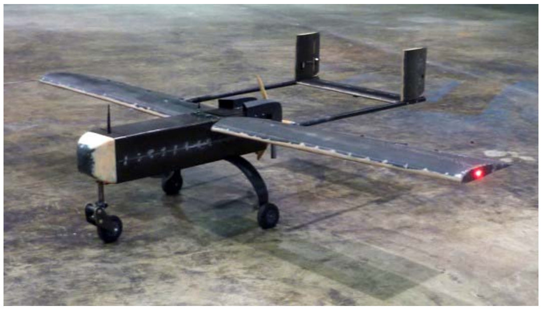


Figure 4 — Xawk X-4 UAS Airframe Fully Assembled

The Xawk X-4 airframe is derived from an evolutionary approach improving on previous flight vehicular designs presented by previous Xipiter teams. Changes this year include two degree wing dihedral, internal boom attachments, custom 'I'-beam wing spar, and twin-boom tail configuration. X-4's design is largely based on the team's successful X-2C airframe, but has undergone modifications emphasizing stability, rigidity, weight, and avionics integration. The two degrees of wing dihedral improve roll stability and cross-wind performance. The internal boom attachments solve a previous problem of possible misalignment, structural concerns, and various issues with X-2C's empennage attachment. The empennage was also modified from its previous 'pi'-tail configuration to improve structural rigidity of the entire structure and simplify connections for control surfaces. The resulting structure is not only stronger, but lighter as well. The entire vehicle with few exceptions is fabricated using preimpregnated carbon fiber composites, including the fuselage, wings, empennage, and landing gear. Composite construction successfully supports our emphasis on decreasing weight while increasing rigidity. A powerful 2-cylinder engine provides additional maneuverability during low-speed flight, increased performance in cruise, and less induced vibration. The 2-cylinder engine is mounted in a pusher configuration to eliminate residue obstructing surveillance and mitigate vibration to the avionics sub-system components. Based on flight testing from previous years, the team chose to modify the standard spring-leaf landing gear design into a 'half-moon' shape. Previous flight testing in both X-2B and X-2C showed too much bending spring-action, which is reduced by the new shape.

IV.B DESIGN

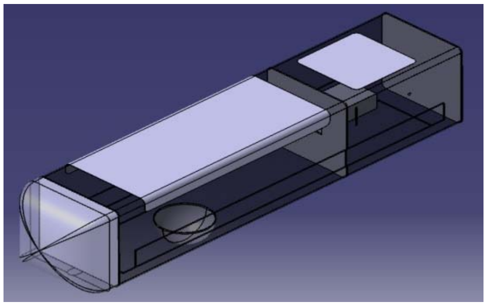
The Xawk X-4 UAS airframe (see Figure 4) is an improved design from X-2C. Although the basic airframe design is retained, modifications in size, empennage configuration, engine, air-scoop, and landing gear increase the overall performance of the X-4 UAS.

IV.C.1 Fuselage

The fundamentally sound design of X-2CThe fuselage of X-2C proved to be so structurally sound that virtually the same design was used for the Xawk X-4 fuselage. Reinforcements were added to decrease the risk of failure due to high stress landings. Specifically, the bulkheads are now composite instead of plywood, extra layers of carbon fiber have been added to create a high strength landing gear attachment point, and composite strips have been added to the corners as a safeguard against preexisting buckling tendencies. Dimensions were slightly modified, decreasing overall length to 33in, but retaining the same 9in x 9in cross-section. The total internal volume of the fuselage is 2673 cubic inches (1.55 cubic feet). While this figure is reduced from X-2C, optimization of avionics components in a shelving-configuration inside the fuselage more efficiently uses the space allowing for a shorter and thus lighter fuselage. The dimensions and drawing are shown in Figure 5.

Figure 5 — Design Components of the Xawk X-4 Fuselage

Parameter	Value
Length	33.00 in
Width	9.00 in
Height	9.00 in
Internal Volume	2673 in^3 (1.55 ft^3)

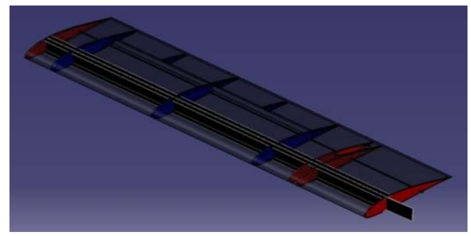


IV.C.2 Wings

X-4's wings employ a SD7062 airfoil with dimensions provided in Figure 6. Xipiter selected this airfoil, from its extensive past experience in use on its other UAS wings. This airfoil is effective in slow-flight maneuverability and highly stable in cruise. For enhanced roll stability, Xipiter added 2° of dihedral to the wings. In addition, the team modified the control surfaces to allow room for the internal boom attachments from 4in x 21in to 5in x 17in. Note the surface area of the control surface remained the same. The team also chose to fabricate its own "I"-beam spar instead of the COTS tube previously used as a spar. This enables the team to integrate the dihedral into the part and reduce weight. Finally the wings now include an internal boom attachment structure comprised of three plywood blocks, a 2-ply 3k carbon sleeve, wrapped in 2-plys of 3k carbon to support the boom. Two bolts with retaining wing-nuts secure the boom within the wing. The dimensions and drawing are shown in Figure 6.

Figure 6 — Design Components of the Xawk X-4 Wings

Parameter	Value
Airfoil	SD7062
Span	128.00 in
Chord	16.00 in
Area	2,048.00 in2
Aspect Ratio	8.00
Control Surfaces	5 in x 17 in
Wing Loading	3.80 psf
Dihedral	+2°

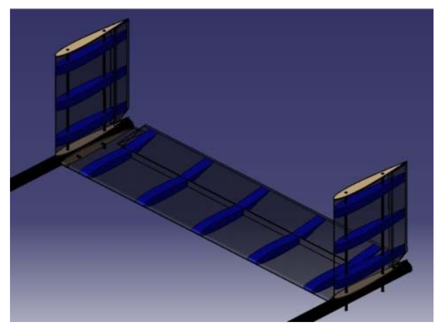


IV.C.3 Empennage

The empennage of the Xawk X-4 is mounted to the wings by twin booms and consists of two vertical stabilizers joined by a horizontal stabilizer in an 'H' configuration. The J5012 airfoil is used for all three parts. Each vertical stabilizer has a height of 12 inches, and a chord of 9 inches, giving 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, making the area 297 square inches and the aspect ratio 3.67. These specifications and drawing

Figure 7 — Design Components of the Xawk X-4 Empennage

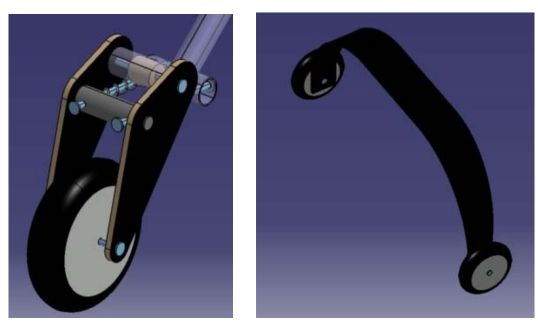
Parameter	Vertical	Horizontal
Height/Span	12.00 in	33.00 in
Chord	9.00 in	9.00 in
Area	216.00 in^2	297.00 in^2
Aspect Ratio	2.67	3.67



IV.C.4 Landing Gear

The landing gear configuration of X-4 remains the same from previous aircraft of Xipiter. The nose gear is a trailing link design comprised of a steel tube and carbon-plated mount. The main gear has been slightly modified from a standard spring leaf design and is now a "half-moon" spring leaf design. Both are depicted in figure 9. This change was to eliminate the stress concentration points found in the corners of the standard spring leaf design. Both the front and rear landing gears use 5-1/2 inch tires.

Figure 8 — Design Components of the Xawk X-4 Landing Gear



IV.C.5 Engine

The Xawk X-4 UAS saw a slight performance jump from its predecessors. A BME 115X, 2-cycle, 2-cylinder engine was chosen for its high power to weight ratio. Specifications are compiled in table 3. The engine weight is a critical factor for balancing and staying below the weight constraint discussed in Section II. Reliability and performance were also key factors in engine selection. Unintended shutdown of the engine during flight could lead to a rough landing, potentially damaging the system. The two cylinder engine minimizes engine vibration induced to the surveillance sub-system. The BME 115X uses an electronic ignition (EI) system. The EI unit uses a 4.8V battery that provides a higher spark and constant power source. This ensures that the engine starts easily, mitigating the chance of wasted valuable time during the competition and/or possible scenarios similar to the Concept of Operation. The engine is located in the aft section of the fuselage in a pusher configuration and uses a Xoar tri-blade Beachwood 24in x 10in pusher propeller. This places the thrust stream behind the engine and reduces the air that would otherwise cool the engine components. To maintain operational temperature during flight, two carbon air ducts redirect airflow to those key areas of the engine.

Table 3 — Xawk X-4 Engine Component Specifications

Parameter	Value
Type	2-cycle, 2-cylinder
Displacement	115 cc
Output Power	11.0 hp
Weight	4.6 lb

IV.D FABRICATION

Xipiter IPT has substantial experience in working with carbon composite fiber/fiberglass. This year the team combined many of its previously used methods of fabrication with some new techniques to manufacture the Xawk X-4 airframe.

IV.D.1 Fuselage

The fuselage of Xawk X-4 is comprised of two half shells, three bulkheads, two longerons, a nose cone, and various components that aid in the bonding procedure. Two half shells (figure 10) are formed instead of a single structure to ease in the manufacturing process. The upper and lower shells are made of two plies of 3k prepreg carbon with two strips added between layers to each corner as reinforcement (shown in figure 9). By using a symmetric fuselage, the manufacturing process is simplified further by allowing the use of one m old to produce multiple distinct parts. The upper shell also consists of two hatch cutouts for easy access to the payload. These cutouts are made by adding tape outlines to the mold to form indentations that allow hatch covers to sit flush on the shell. The hatch covers are made with the same specifications of the upper shell and in the same mold. The lower shell contains Nomex core for added rigidity and two additional plies of carbon as a landing gear support section.

Figure 9 — Fuselage shell formed in mold.

Figure 10 — Two shells clamped together with nosecone.

The fuselage also contains three bulkheads: forward, aft and middle. The forward and aft bulkheads are eight plies of 3k prepreg carbon. The forward bulkhead acts as a support and attachment point for the forward landing gear, while the aft bulkhead acts as a firewall and mounting point for the engine. The middle bulkhead is four plies of 3k prepreg carbon and contains a special housing for the autopilot constructed using two plies of 3k wet layup carbon. The middle bulkhead also serves as a mounting point for the wing spars and creates two distinct payload compartments. Two longerons are composed of four plies of 3k prepreg carbon in an "L" shape. They are located in the forward compartment and serve the dual purpose of support and shelving for payload.

The nosecone is made of four plies of 3k prepreg carbon in a pre-existing custom mold. A hole is cut out of the bottom of the nosecone to allow for the forward landing gear to be internally mounted. After the parts are made, the bulkheads are bonded to the lower shell using structural adhesive and using 'L'-shaped "angle stock" as added bonding area. Strips of carbon—dubbed "lap straps"— are used to bond the upper and lower shells together. Wet-layup carbon is used to secure the bulkheads to the now full sides of the fuselage. The longerons are bonded using structural adhesive. Two small pieces of angle stock are bonded to the nose cone which serves as mounting plates to attach the nose cone to the forward bulkhead.

III.D.2 Flight Surfaces

The flight surfaces of Xawk X-4 consist of the wings, horizontal stabilizer and vertical stabilizers. All flight surfaces are made using two plies of 3 k prepreg carbon fiber with a strip of Nomex core strategically positioned between to provide added rigidity, with leading edge close out pieces to bond the two skins together. Horizontal and vertical skins are made using preexisting molds, while wing skins are layed up using molds made from CNC'd MDF. The wing is supported internally through the use of a custom 'I'-beam spar, solid carbon rod aft (figure 11) of the spar, "anti-torque rod," several carbon fiber ribs, and an internal support structure for boom attachment. The ribs are made using two plies of 3k prepreg carbon fiber, with end caps having an added Nomex core for added strength. The ribs are bonded to each wing skin with a "form fitted" angle stock using structural adhesive. The anti-torque rod is run through drilled holes in the ribs and end caps and then bonded in place.

Figure 11 — Vertical stabilizer showing foam ribs and spar rods.

IV.D.3 Spar

Each spar is comprised of a web and two caps. The web is made up of two plies of 3k prepreg carbon fiber with a Nomex core. While the caps are made with five unidirectional carbon fiber strips wrapped in one ply of 3k prepreg carbon fiber. In addition, the spar connecting surface uses added angle stock on the top and bottom to add durability and allow for spars to fit tighter when connected. The spar is bonded to each wing skin using structural adhesive (seen in figure 12).

Figure 12 — Custom 'I'-beam spar used in Xawk X-4, shown bonded to lower skin.

IV.D.4 Boom Attachments

Figure 13 — Internal boom attachment.

The boom attachments for X-4 are built using drilled three plywood blocks wrapped in 3k carbon fiber, a two ply 3k carbon fiber boom sleeve, and two strategically placed ribs made with two plies of 3k carbon fiber with a Nomex core. The first wood block is bonded right behind the spar, with the others falling in behind to spread out the load along the wing. In order to increase the sturdiness of the attachment two ribs are bonded to each side of the wood blocks and to both top and bottom skins. In addition, to improve the ease of assembly and removal, the carbon fiber sleeve is bonded in place through the wood blocks.

IV.D.5 Landing Gear

The forward gear for the X-4 is a trailing link design composed of a custom made steel pipe, two carbon reinforced plywood brackets, a steel bar acting as a lower spring support, two spring wrapped bolts, and a 5 ½” wheel. The rear landing gear is made of 12 layers of 12k wet layup carbon fiber with two 5 ½” wheels.

IV.E ASSEMBLY

X-4 is designed to allow for easy assembly while ensuring the aircraft is securely fastened together. For typical assembly and disassembly the following process occurs: Firstly, the port wing is inserted into the fuselage, followed by the starboard wing, with both secured with two bolts through the spars and bulkhead and another bolt through each wing securing the end cap to the fuselage. Secondly, the booms are each secured with two bolts through the wings. Then the horizontal is attached between the two booms with four bolts. Next, insert the carbon fiber pitot tube into the starboard wing. Lastly, both hatches are secured with four screws each. Semi-permanent attachments include: nose cone, cooling ducts, landing gear, and engine.

V. SAFETY CONSIDERATION

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 our team has responded by strongly emphasizing safety in all aspects of its operations. As suggested by concepts in Occupational Safety Engineering, Team Xipiter has implemented safeguards throughout the entire system in order of maximum effectiveness first — beginning with designing hazards out of each sub-system in accordance with highest risk consequence and frequency.

V.B RISK ASSEMENT TABLES / MATRIX

Xipiter used the following risk assessment tables and matrix to identify and classify potential system and sub-system hazards through-out all phases of X-4's development.

Table 4 - Hazard Consequence

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.

Table 5 - Hazard Probability

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

Table 6 - Risk Matrix

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 AIRFRAME RISK IDENTIFICATION / MITIGATION

The primary concern with the airframe sub-system is structural integrity during flight. Loss of components in the air can potentially jeopardize the entire system, damage other sub-systems causing potential failure, 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

To mitigate risk from loss of these components, redundancies were also designed into each part. Each control surface contains a redundant hinge, each with two pins. The nose cone was fabricated slightly larger than necessary to ensure an overly snug fit, with four retaining bolts. The main landing gear is secured using four bolts, each with Loctite Threadlocker.

V.D AVIONICS RISK IDENTIFICATION / MITIGATION

Containing Guidance, Navigation, and Control (GNC), much consideration was placed into the risk analysis of the avionics sub-system. 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 autopilots with these functions. The Piccolo LT 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 two 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.

V.E FLIGHT TESTING AND MISSION SAFETY CONSIDERATIONS

As with any experimental vehicle involving multiple sub-systems and personnel, operational procedures are critical to the safe operation of the Xawk X-4 UAS. Xipiter’s Flight Test Plans uses a systems engineering mindset to flight. Flight tests are conducted with a dedicated airframe sub-system lead, dedicated avionics sub-system 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 rolls with specific checklists for each sub-system ensures that each components are 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. FLIGHT TESTING

VI.A OVERVIEW

Continuing to apply systems engineering influences, the team performs flight testing on each component and slowly "builds-up" to more advanced assessments involving multiple sub-systems in tandem. All testing requires in-depth cooperation between the airframe and avionics sub-systems.

VI.B RADIO RANGE TESTING

All radio systems were tested by simply moving the aircraft away from the ground station until radio transmission was degraded to an unacceptable level. The aircraft was on the taxiway at Starkville-Bryan Airfield, and the radio transmitters were down the taxiway. In this configuration, a significant amount of the radiated signals is dissipated by the ground; therefore, these tests will measure an attenuated signal. The results of these range checks will be closer to a worst-case scenario. 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 ground station was moved away from the aircraft while smoothly moving the surfaces of the aircraft. Jittery response was observed at approximately half a mile from the aircraft. In addition, the receive signal strength indication (RSSI) and acknowledgement ratio were observed at various distances from the aircraft. The plot of these values versus distance from the aircraft is shown in Figure 9.

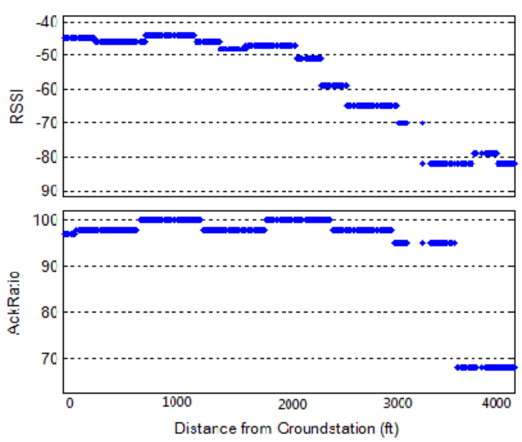


Figure 14 – RSSI & Acknowledgement Ratio

VI.C ENGINE TUNING & TESTING

With the engine change to BME 115x versus the Kroma used on X-2C, the team scheduled additional time to familiarize personnel with the engine. The engine was mounted on the airframe, and secured in the flight lab. The engine was initialized according to the manufacturer specifications and fired. After some minor difficulties with the throttle control, which was replaced with a more robust control rod, the engine was again started and trims tuned to match the throw of the throttle servo.

In addition to the engine, the safety features of the engine control system were also tested. The Xawk X-4 has two safety shut-off engine "kill switches"—one physical switch on the fuselage, and one software kill switch in the Piccolo Command Center software. The engine was fired and each switch independently tested. Both successfully disconnect the ignition module from the engine and stop the engine. These two switches also act as a safe-guard, as both must be engaged for the engine to start.

VI.D FLIGHTWORTHINESS TEST

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 and inspecting the structural integrity on the ground. Airframe stability numbers were confirmed by the pilot after takeoff and compared to prior calculated figures. Additional time for the test pilot was allocated, as he was new to the team. The flight test was performed without the surveillance sub-system. Three members of the team were required to ensure safe operation: the aircraft pilot, a spotter, and a safety officer. Prior to flight, range checks were performed again using the manufacturer's instructions.

After the personnel were briefed and checklist completed, the test was ready to begin. The pilot taxied the aircraft and performed takeoff and climb out. Once X-4 was cruising at an altitude around 300 ft, 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 gained much experience from the flight.

VI.E IMAGERY SUB-SYSTEM TEST

When testing the camera transmitter, the primary consideration for unacceptable level is loss of video signal. The RSSI value is a second signal strength parameter to consider. The camera transmitter was be tested in the same manner as the autopilot transmitter.

During a subsystem test, both the onboard and ground station components of the imagery subsystem operated satisfactorily. The time that it took the video to reach the screen on the computer was measured by waving an object in front of the camera and waiting for it to move on the computer screen. This time was less than 1 second. Also, the camera command lag was measured by sending a command to change the pan and tilt of the camera and measuring the time it took for the camera to actually move. This measurement was also less than 1 second. While flying, both of these lags were measured by sending a movement command and waiting for the change to be seen on the screen. This time was also less than 1 second. The field of view of the camera is an important characteristic, especially in the analysis of individual photographs so that size and direction can be calculated accurately. For this reason, the field of view of the camera was measured for different zoom settings by placing the camera perpendicular to a wall a known distance away. A tape measure was placed against the wall to measure the physical width of the image at each zoom setting. Basic trigonometry is used to calculate the angle spanning the perpendicular distance. Taking this angle and dividing it by the number of pixels across the measurement gives the average angle per pixel ratio. Multiplying this by the total number of pixels in a certain direction gives the field of view for that direction. Performing this calculation at many different zoom levels allows for a curve fit. The calculated pixel resolutions were plotted against their corresponding zoom settings.

VII. CONCLUSIONS

The culmination of Xipiter UAS IPT's design process is the Flight Demonstration at the 2010 Student UAS Competition. The team has designed Xawk X-4 using a systems engineering approach in the requirements, design, fabrication, testing, and integration of the components and subsystems. Full system tests have verified the flightworthiness of the airframe and performance of the GNC and Imagery subsystems. Before departing for competition on June 16, Xipiter plans to perform more tests to assess the readiness of the Xawk X-4 Unmanned Aircraft System, seen below in Figure 10.

Figure 15 — Xipiter UAS Integrated Products Team, Xawk X-4 UAS