Mississippi State University
Team X-ipiter
$X^{2.5}$

2007 AUVSI Undergraduate Student UAS Design Competition

Mississippi State University's Entry for the 2007 AUVSI Undergraduate Student UAS Design Competition

Savannah Ponder — Team Lead
Nathan Ingle — Air Vehicle Lead
Joshua Lassienge — Systems Lead

ABSTRACT

The $X^{2.5}$ Unmanned Aerial System (UAS) is Mississippi State University Team X-ipiter's entry into the 2007 Association for Unmanned Vehicle Systems International (AUVSI) Undergraduate Student UAS Design Competition. $X^{2.5}$-ipiter (whose name is derived from the Latin word for "hawk") is a short-range, robust UAS designed to perform fully autonomous flight through use of the global positioning system (GPS) and capture high-resolution imagery of all targets acquired during flight. Team X-ipiter has taken an evolutionary approach to designing and fabricating a UAS to perform Intelligence, Surveillance, and Reconnaissance (ISR) missions. $X^{2.5}$, a student-designed and fabricated UAS, carries a 10-15 pound payload that withstands both vibrations and environmental conditions. The payload consists of the following commercial off-the-shelf (COTS) hardware: the MicroPilot 2028[g] autopilot, a digital video camera capable of live feed video in addition to still-shot images, an analog video transmitter, and radio modems. Student-designed software is used in conjunction with the X-ipiter base station for target identification and localization.

TEAM DYNAMICS

The sixteen members of Mississippi State University's Team X-ipiter (fifteen undergraduate students and one graduate student) are seeking degrees in various fields including Aerospace Engineering, Mechanical Engineering, Electrical Engineering, Computer Engineering, Computer Science, Biological Engineering, Kinesiology, and Geography. The incredible diversity of these majors sets Team X-ipiter apart by utilizing the wide range of academic disciplines available on campus and allowing each student to contribute to both the component of the $X^{2.5}$ system for which he or she is best suited and the system as a whole. This diversity creates an optimal environment for both design and trouble-shooting.

STUDENT MEMBERS:

Marty Brennan – SR, ASE
Chris Brown – Grad, EE
William Cleveland – SO, CPE/ASE
Sam Curtis – SR, ASE
Chris Edwards – JR, EE
Jonathan Fikes – SR, ME
Mike Hodges – SR, GR
Nathan Ingle – JR, KE, Air Vehicle Lead
Richard Kirkpatrick – SO, ASE
Brandon Lasseigne – SR, ASE
Joshua Lasseigne – SR, CPE, Systems Lead
Brittany Penland – SR, ABE
Savannah Ponder – JR, ASE, Team Lead
Trent Ricks – SO, ASE
Wade Spurlock – FR, ASE
Daniel Wilson – SO, CPE

ASE – Aerospace Engineering
EE – Electrical Engineering
CPE – Computer Programming Engineering
ME – Mechanical Engineering
GR – Geography
KE – Kinesiology
ABE – Agricultural and Biological Engineering

FACULTY ADVISORS:

Dr. Randolph Follett, Electrical and Computer Engineering, Assistant Professor
Calvin Walker, Aerospace Engineering, Senior Flight Test Engineer

MISSION

The AUVSI Undergraduate Student UAS Design 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 100 and 750 feet mean sea level (MSL). The waypoint navigation phase consists of flying over waypoints provided at competition while remaining outside off all no-fly zones. During the third phase, area search, teams use their UAS surveillance capabilities to locate targets positioned within the specified search area and identify the color, size, shape, alphanumeric color, alphanumeric height, and alphanumeric thickness 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.

AIR VEHICLE

The $X^{2.5}$ airframe utilizes an evolutionary approach improving upon previous years' designs. Changes include increased size, a pusher engine configuration, and the addition of flaps. The basic design is based on that of X^2 but has undergone modifications with emphasis on stability and integration of systems. The larger wing span and addition of flaps allow the plane to fly more slowly at cruise and landing. The longer fuselage gives more internal space for and easier access to the systems. The airframe is fabricated using preimpregnated carbon fiber for the wings and empennage, COTS tubes for the spars and booms, preimpregnated fiberglass for the fuselage, and dry carbon fiber cloth for the landing gear and attachments. The 2-stroke engine is mounted in a pusher configuration to eliminate residue obstructing surveillance.

EVOLUTION

Team X-ipiter has used an evolutionary approach to developing a reliable UAS, not only for competition, but for use in real world applications. Air vehicles from previous years include Telemaster, X^1, and X^2, and for this year's competition, $X^{2.5}$.

Team X-ipiter began working on unmanned aerial vehicles (UAV) 2004 in preparation for the 2004 AUVSI Undergraduate Student UAV Design Competition. The airframe used for this competition was an off-the-shelf model of a Telemaster (Figure 1), which made construction easy. This particular plane had a tail dragger configuration with a high wing and a split horizontal stabilizer. The engine was placed in a tractor configuration, and it used glow fuel. The team concluded that, despite easy construction, the Telemaster had insufficient internal room for the payload, so a larger airframe was necessary.

Figure 1 Telemaster

For the 2005 AUVSI Competition, Team X-ipiter designed X^1 (Figure 2). This airframe was fabricated using fiberglass and a wet lay-up fabrication technique. X^1 had a tricycle landing gear configuration and a high wing placement; the engine was placed in a tractor configuration and used gasoline. X^1 airframe had a much larger internal capacity than Telemaster, which increased the amount of payload. However, new challenges surfaced with the X^1 airframe. For example, with the engine mounted on the front of the airframe, the size of the access hatches was limited, making it difficult to access the payload area. This placement also interfered with camera surveillance because engine exhaust obstructed the camera view.

Figure 2 X^1

The X^2 airframe (Figure 3) was used in the 2006 AUVSI Undergraduate Student UAS Design Competition and addressed the problems associated with the X^1 air vehicle. The airframe was constructed out of preimpregnated carbon composites using student-built carbon fiber molds. These molds simplified the manufacturing process encountered in building X^1 and helped decrease the gross weight of the airframe. A pusher engine configuration was used for X^2 to eliminate surveillance interference from engine exhaust and the structural issues encountered with placing the engine in a tractor configuration. However, the X^2 airframe had a high cruise speed, making surveillance difficult and leading to the design of $X^{2.5}$, which is entered in the 2007 AUVSI Undergraduate Student UAS Design Competition.

Figure 3 X^2

The $X^{2.5}$ UAS airframe (Figure 4) is an evolutionary design from the X^2 UAS. Improvements include a decreased minimum flight speed and an increased internal volume in the fuselage. Brakes, updated camera software, and reinforced connectors were also added to the $X^{2.5}$ UAS airframe.

Figure 4 $X^{2.5}$ UAS

DESIGN

The $X^{2.5}$ UAS uses an SD7062 airfoil and has a sixteen-inch chord, the same used previously by X^2. Adding flaps and increasing the wing span increased both the area and aspect ratio of the wing from 6.75 to 8 (Table 1) to enhance the slow-flight characteristics of the air vehicle. This change increased the span to 128 inches and the wing area to 2048 square inches. Figure 5 provides a planform view of a wing.

Table 1 Design Components of the $X^{2.5}$ Wings

Span	128.00 in.
Chord	16.00 in.
Area	2048.00 $in.^2$
Aspect Ratio	8.00

Figure 5 Planform View of a Wing

The fuselage of $X^{2.5}$ increased to 45.00 inches from X^2's 39.00 inches. The fuselage length and height remained the same, both 9.00 inches. The total internal volume of the fuselage is 3645.00 cubic inches (2.11 cubic feet). The dimensions of the fuselage are shown in Table 2.

Table 2 Design Components of the $X^{2.5}$ Fuselage

Length	45.00 in.
Width	9.00 in.
Height	9.00 in.
Internal Volume	3645.00 $in.^3$ (2.11 ft^3)

The empennage of the $X^{2.5}$ UAS is mounted to the wings by twin booms and consists of twin vertical stabilizers joined by a horizontal stabilizer in a pi configuration. The airfoil used for the vertical stabilizers is the J5012. Each vertical stabilizer has a height of 7.00 inches and a chord of 9.25 inches, giving a total area of 129.50 square inches and an combined aspect ratio of 1.51. The horizontal stabilizer uses the same airfoil section as the vertical stabilizers. The horizontal stabilizer has a span of 32.25 inches and a chord of 9.00 inches, making the area 290.25 square inches and the aspect ratio 3.59. The dimensions for the empennage are presented in Table 3.

Table 3 Design Components of the $X^{2.5}$ Empennage

	Vertical	Horizontal
Height/Span	7.00 in. (each)	32.25 in.
Chord	9.25 in.	9.00 in.
Area	129.50 $in.^2$ (total)	290.25 $in.^2$
Aspect Ratio	1.51 (total)	3.59

The center of gravity (CG) of the $X^{2.5}$ UAS is located at twenty percent of the wing chord, placing it 37.50 inches from the nose, thirty-nine percent of the overall length of 97.00 inches. Figure 6 shows the CG location of $X^{2.5}$.

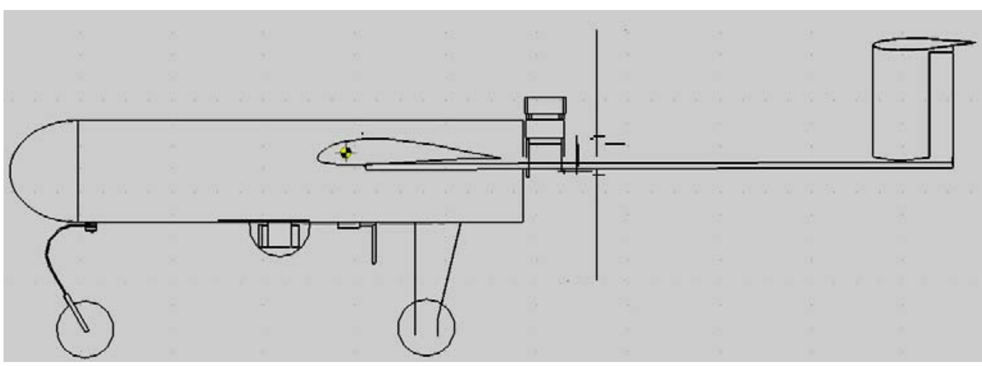

Figure 6 CG Location of $X^{2.5}$

PROBLEMS SOLVED THROUGH THE EVOLUTIONARY APPROACH

The $X^{2.5}$ UAS is the solution to many of the problems encountered over the past three years in Team X-ipiter's UAS design and fabrication. The $X^{2.5}$ UAS is robust due to its composite airframe, has a large payload area with easy accessibility, and pusher engine configuration which prevents engine residue from interfering with the camera. Also, engine vibration on the camera has been reduced by using engine vibration isolation mounts and suspending the camera using a spring dampener system. The $X^{2.5}$ airframe is easier to build than previous airframes because of previously manufactured molds coupled with the use of preimpregnated composite materials. The high minimum cruise speed has been lowered by increasing the wing span and adding flaps. This makes the $X^{2.5}$ UAS the most reliable airframe Team X-ipiter has constructed for the AUVSI Undergraduate Student UAS Design Competitions.

FABRICATION

Each of the wing ribs is made from polyurethane sandwiched between layers of preimpregnated carbon fiber. The upper and lower wing skins are made from carbon fiber that is formed using a previously manufactured mold. The wing spar is composed of a 1.50-inch inner diameter carbon tube and is placed at the quarter chord of the wing. The anti-torque is a 3/8-inch solid carbon rod and is placed 9.50 inches from the leading edge of the wing. The spar has been reinforced at the root of the wing by inserting a solid nylon rod. Leading edges for the wings are made from preimpregnated carbon fiber and are formed using previously manufactured molds. The underside of the wing at the boom attachment is reinforced using a wet lay-up construction of fiberglass and Divinycell. This construction supplies additional structural rigidity at the high stress location of the boom attachment.

The fuselage of the $X^{2.5}$ UAS is made from a sandwich construction of fiberglass and Divinycell. The construction is formed using previously manufactured molds. Each of the three hatches and the nosecone are composed solely of preimpregnated fiberglass. The two bulkheads that separate the main payload compartment, the Micropilot compartment, and the rear compartment are composed of a sandwich construction of Birchwood and preimpregnated carbon fiber. The forward most bulkhead, separating the nosecone from the main payload compartment, is composed of a sandwich construction of honeycomb and preimpregnated carbon fiber. A hole was cut in the forward most bulkhead in which a wet lay-up fiberglass box was inserted as a protective case for the power supply of various electronic components. Two wing-fuselage attachments (Figure 7), one placed on the second bulkhead and the other on the third bulkhead, secure the wings in the fuselage. These wing-fuselage attachments were fabricated using a wet lay-up method of carbon fiber.

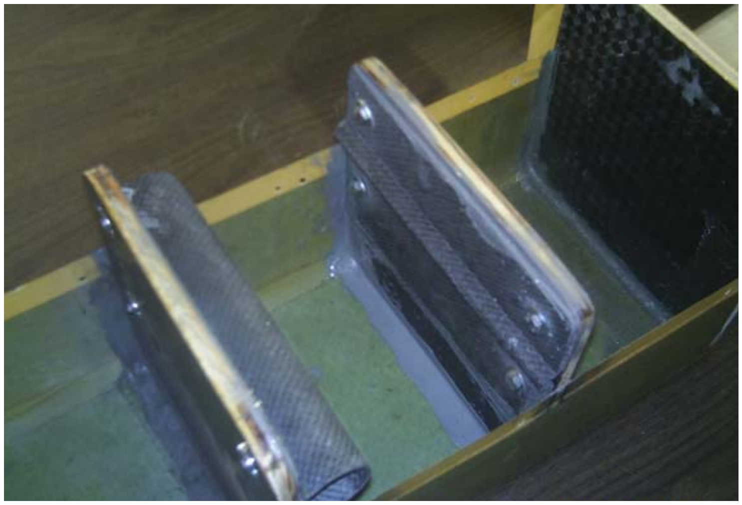

Figure7 Wing-Fuselage Attachment

The empennage, composed of twin vertical stabilizers and a horizontal stabilizer (Figure 8), is attached to the aircraft by two carbon booms. The ribs of the vertical stabilizers and horizontal stabilizer are made from balsawood sandwiched between layers of preimpregnated carbon fiber. The skins of the stabilizers are made similarly to those of the wings, using the previously manufactured vertical and horizontal stabilizer molds. The booms are purchased ¾-inch inner diameter carbon tubes. Each vertical stabilizer is bolted onto a boom with steel bolts, and the horizontal stabilizer is bolted to the vertical stabilizers in a pi configuration using nylon bolts and washers.

Figure 8 Empennage of $X^{2.5}$

The landing gear of the $X^{2.5}$ UAS is set in a traditional tricycle configuration. The nose gear and main gear of $X^{2.5}$ were constructed using a wet lay-up technique with carbon fiber. The nose gear (Figure 9) was designed by Team X-ipiter for use on X^2 and is being used again on the

$X^{2.5}$. It features a built in shock absorption design. The main gear (Figure 10) was constructed using a Spring Leaf Type Gear made of 6061 aluminum as a mold.

Figure 9 Nose Gear of $X^{2.5}$

Figure 10 Main Landing Gear of $X^{2.5}$

ENGINE

A Fuji BT-64EI 2-stroke engine (Table 4) was chosen for its high power output and low weight. The engine weight was a critical factor because the weight of $X^{2.5}$ was nearly 50 pounds.

Table 4 Engine Specifications

Displacement	3.85 cubic inches (63.1 cc)
RPM range	1,100 – 9,000
Output	5.7 hp @ 9,000 rpm
Weight without muffler	3.8 lbs (1.8 kg)

Reliability and ease of use were also important factors in selecting an engine. An unintended shutdown of the engine during flight could lead to a rough landing, potentially damaging both the aircraft and the equipment on board. Fuji engines are designed specifically for model aircraft, delivering the robust performance required for the $X^{2.5}$ UAS. Team X-ipiter's previous experience with similar Fuji engines on X^1 and X^2 has also proven their reliability and flight integrity.

The Fuji BT-64A used for the X^2 UAS in 2006 has a magneto ignition source, which made starting the engine difficult. The Fuji BT-64EI uses an electronic ignition (EI) system. The EI unit uses a 4.8V battery that provides a higher spark and a constant power source. This change ensures that the engine starts easily, minimizing the chance of wasting valuable time during the competition.

Fuji engines require a mixture of gasoline and 2-stroke motor oil, which significantly reduces the cost of fuel compared to the expensive glow fuel required by the Telemaster aircraft used in 2004. Gasoline is also more accessible than glow fuel.

The engine, placed in the rear of the aircraft in a pusher configuration, uses a 22-inch x 10-inch wooden pusher propeller. This places the thrust stream behind the engine, reducing the air that would otherwise cool the engine components. To maintain an operational temperature in this reduced airflow environment, the Fuji BT-64EI has large heat sink fins that allow the engine to cool under the lower airflow environment.

SYSTEMS

The design of an unmanned aerial system consists not only of the air vehicle but also the integration of the autopilot and reconnaissance systems, facilitated through the use of telemetry and power systems. The autopilot system provides control capability through the autopilot, the remote control (R/C) receivers, the Dual Power Servo Interface (DPSI) Twin, and the servos. The reconnaissance system consists of the camera, camera control software, and the X-ipiter Base Station (XBS) Software, which includes the X-ipiter Photogrammetry Calculator (XPC). The telemetry system includes radio modems, an R/C transmitter, a video transmitter, and a camera controller. The power system consists of two 7.4-volt Lithium Polymer (LiPo) batteries for the DPSI and two 14-volt LiPo batteries for the autopilot and reconnaissance systems. These systems must work together to have a fully functioning unmanned aerial system. The overall systems layout is depicted in Figure 11.

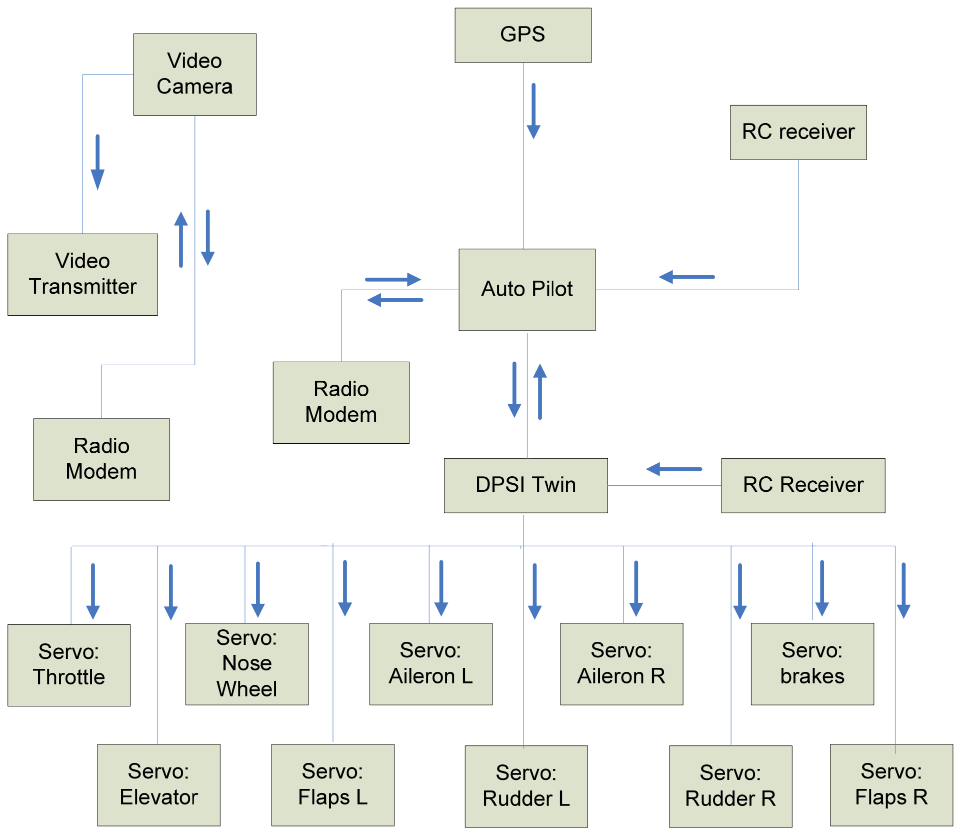

Figure 11 Overall Systems Layout of X$^{2.5}$.

AUTOPILOT

The X$^{2.5}$ UAS aircraft is controlled by a MicroPilot 2028^{g} (Figure 12). This autopilot is responsible for autonomously piloting the vehicle between given waypoints and keeping the X$^{2.5}$ stable in flight. The MicroPilot 2028^{g} weighs twenty-eight grams, is ten centimeters by four centimeters, and supports twenty-four servos. The MicroPilot 2028^{g} can support complete autonomous operations including takeoff, flight, and landing. In order to land accurately, the MicroPilot must be connected to an above ground level (AGL) sensor board (Figure 13), which gives accurate altitude readings while close to the ground by using sonar.

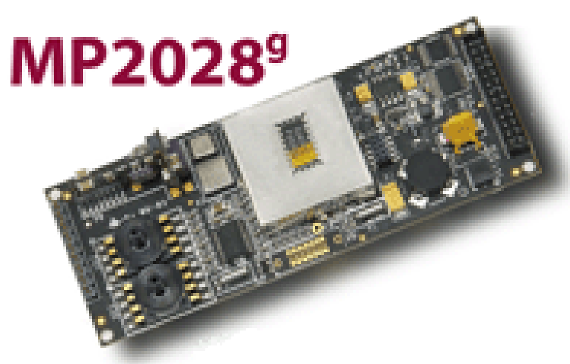

Figure 12 MicroPilot 2028^{g}

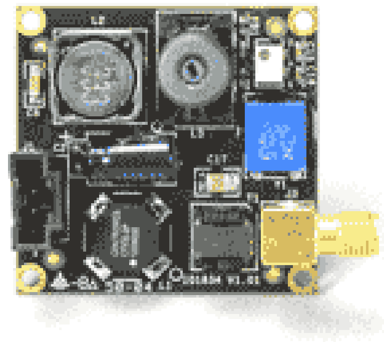

Figure 13 AGL Board

The MicroPilot 2028[g] takes input from the user in the form of waypoints through Micropilot's Horizon software interface (Figure 14). Horizon creates .fly files which are sent to the plane via wireless transmissions. The MicroPilot interprets the .fly files while in flight. These files also contain other information about the desired airspeed and altitude for the plane at any point in time. Waypoints can be modified in Horizon to generate a new .fly file which is sent to the plane. This allows for dynamic re-tasking of the MicroPilot system while it is in the air. The global positioning system (GPS) receiver is responsible for tracking position and airspeed.

Figure 14 Horizon Ground Control Software

In order to maintain steady flight, the MicroPilot system uses PID (proportional plus integral plus derivative) control loops during flight to coordinate the movements of the aircraft. Each of these PID loops must be configured individually while a remote operator remains in control of the aircraft to obtain optimal performance by the UAS. Once each loop is set, the system can navigate between waypoints autonomously. Programming these loops is relatively straightforward, although time consuming, and requires following a guide that is packaged with the MicroPilot 2028[g].

CAMERA

The camera in the $X^{2.5}$ UAS is a Sony EVI-D70 (Figure 15). This is a 950-gram color video camera; its dimensions are 132 mm x 144 mm x 144 mm. The camera has two video output formats, RCA and S-Video. The camera follows the VISCA protocol for commands, meaning it can also be connected to a network of up to seven VISCA devices. Commands sent to the camera can change the pan, tilt, zoom, and focus.

Figure 15 Sony D70 Pan/Tilt/Zoom Camera

The camera control software was developed by Team X-ipiter for use on the $X^{2.5}$ UAS and contains three different components: video, communication with the camera, and the user interface through the camera controller. DirectX is used to gather the imported video and display the gathered video inside the camera software program. Communication with the camera is accomplished via the VISCA protocol, which provides the specific commands necessary for changing the pan, tilt, zoom and focus for the camera. The remaining component is a COTS two-axis, four button camera controller (Figure 16). Through the use of this camera controller, the ground station specifies how the camera should move, and then the camera control software uses the inputs taken from the camera controller and translates them into VISCA commands. These commands cause the camera to pan left and right up to 340 degrees, tilt forward and backward 120 degrees, zoom in and out 18 times optically and 12 times digitally, and change the focus of the camera. Communication with the camera using the VISCA protocol is achieved through the use of 900 MHz Max Stream Xtend serial radio modems. Using all of these components together, still-shots can be taken from the video stream when the operator sees something that warrants further analysis, through the use of the trigger on the camera controller. This picture is then saved with an associated timestamp, which can be used later for further analysis. When a still-shot is saved, another file containing the pan, tilt, and zoom coordinates is also created and saved with the same name as the still-shot images to simplify data analysis.

Figure 16 Camera Controller

X-IPITER BASE STATION

The X-ipiter Base Station (XBS) software (Figure 17) is a student-written application used for target identification and characterization. XBS is designed to be extremely easy to use and flexible in high stress situations, such as competition. The XBS software user interface is implemented using National Instruments' LabVIEW, which provides an appealing and easy-to-use process for working with the pictures gathered by the $X^{2.5}$ UAS.

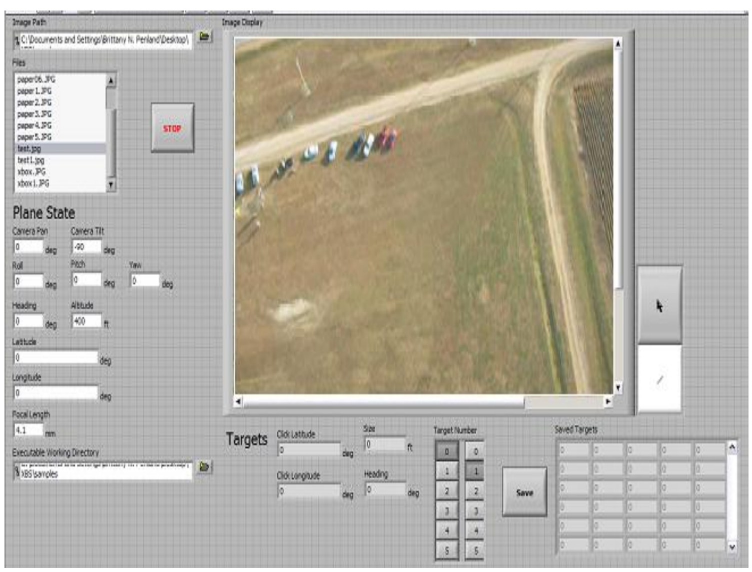

Figure 17 XBS Software

A target is identified from a picture taken by the onboard camera and loaded into the LabVIEW-based program. This picture can then be selected from a list containing all of the images available in the shared folder between the XBS laptop and the video laptop. Once a target is selected by the user via a cursor and line tool, information about the target, such as GPS coordinates, length, and heading, can be derived from the picture using the plane state data obtained by the MicroPilot 2028[g] at the time the picture was taken. Finally, this information can be accessed later for analysis by designating the target with a unique number and saving the data.

Many factors come into play when dealing with the complex calculations used to derive information from the picture. From information about the position of the aircraft such as roll, pitch, and yaw, as well as camera characteristics such as pan, tilt, and zoom, the coordinate system of the plane and camera can be transformed into the coordinate system of the picture allowing for accurate measurements. Standard photogrammetric techniques were studied in order to develop the proper algorithms for this software.

The X-ipiter Photogrammetry Calculator (XPC) is the calculation core of the XBS software. It is written in the Python 2.4 programming language with the associated third-party NumPy add-on module, primarily due to execution speed and ease of programming. XPC operates in both a positioning and a scaling mode, each using the same core features. The mathematics behind XPC are based on the science of photogrammetry, the science of obtaining information about the real world based on photography and other measurements, and follow the derivations in Wolf's *Elements of Photogrammetry*.

PERFORMANCE

To determine the basic performance of the $X^{2.5}$ UAS, first a drag build-up calculation was performed. This entailed determining the zero-lift drag coefficient of the air vehicle, which is 0.0329. Given the zero-lift drag coefficient and the power available from the engine, the maximum possible speed of $X^{2.5}$ is 92 knots. This is shown in the power polar in Figure 18.

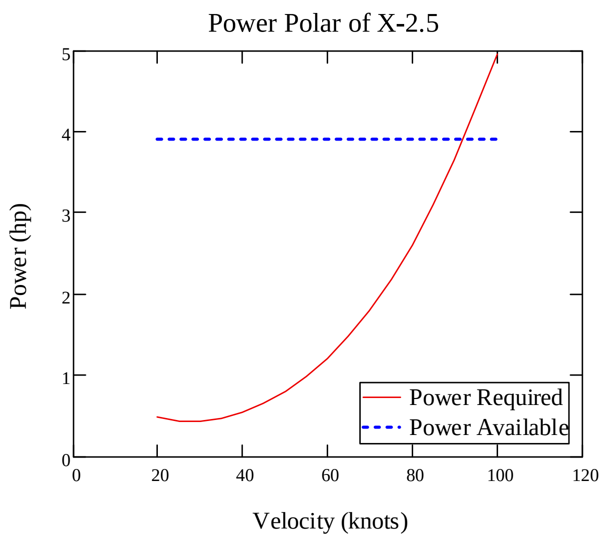

Figure 18 Power Polar of $X^{2.5}$

When $X^{2.5}$ is in search mode, the maximum loiter speed is 40 knots with the minimum loiter speed with flaps deployed is 32 knots. The cruise speed is 55 knots. The approach speed and landing speed, both with flaps deployed, are 30 knots and 28 knots, respectfully.

The maximum rudder deflection is ±20°, and the maximum aileron deflection is ±20°. For an 11-knot crosswind and the aircraft landing speed (no flaps) of 32 knots, the aileron deflection and rudder deflection needed to fly the airplane are 1.51° and 17.41°, respectively. This indicates that the maximum crosswind velocity is 11 knots at 20.26°.

With the CG located at twenty percent of the mean aerodynamic chord, the longitudinal static parameter is $C_{m\alpha}$ = -1.35 rad^{-1}. This gives a static margin of 25.77 percent; thus the airplane is longitudinally statically stable. Figure 19 shows the simulated response of the airplane after a -5° elevator input. This figure shows that the aircraft is statically and dynamically stable, and the airplane returns to its equilibrium (trimmed) condition. With $C_{l\beta}$ = -0.0091 rad^{-1} and $C_{n\beta}$ = 0.0466 rad^{-1}, the airplane exhibits lateral-directional stability. The handling quality of the $X^{2.5}$ UAS is Level 1 for all modes (phugoid, short period, dutch roll, roll, and spiral).

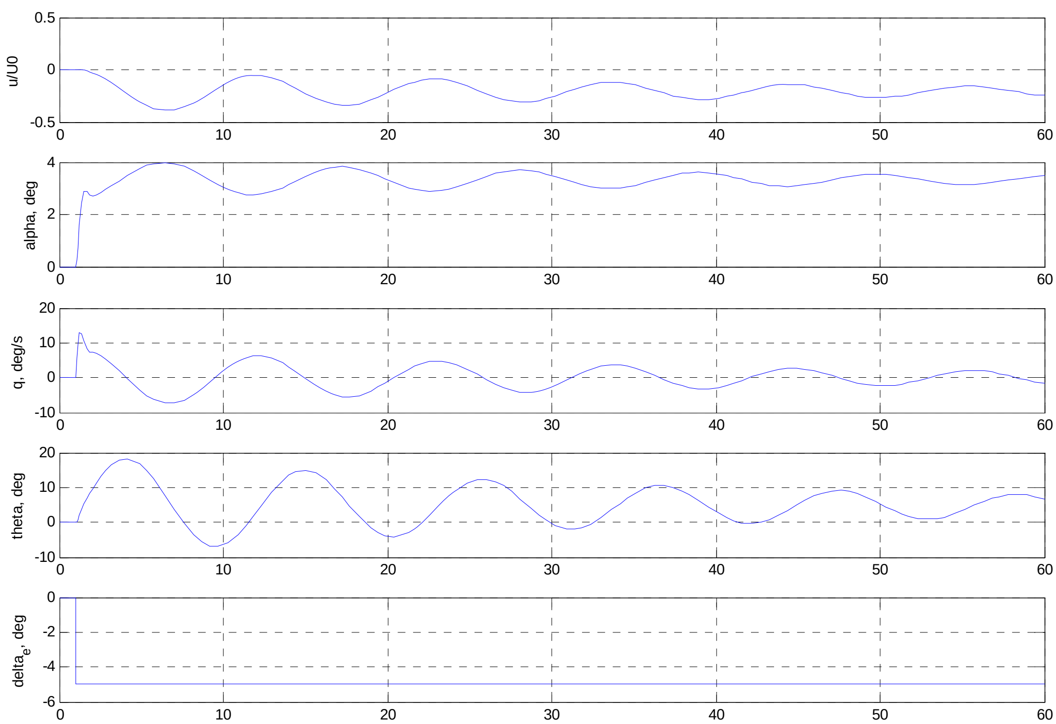

Figure 19 Longitudinal Response of $X^{2.5}$

TESTING

Team X-ipiter's step by step progressive approach to testing entailed testing components on the bench top before transferring those components to the plane. The camera, XBS software, camera control software, MicroPilot 2028[g] autopilot, and the $X^{2.5}$ UAS bare air vehicle were all tested using this methodology. The camera was tested in conjunction with the XBS software by determining the size of known objects with the software when the plane was stationary. These results showed a less than five percent error with maximum zoom. Camera control software testing showed satisfactory motion and zoom level via the camera controller. The MicroPilot 2028^{g} was tested by a computer simulation mission in Horizon. In addition, the team also has three years of experience with Micropilot 2028^{g}in the field. The $X^{2.5}$ UAS bare air vehicle was tested to determine its flight characteristics. Figure 20 shows $X^{2.5}$ in flight.

Figure 20 $X^{2.5}$ UAS during flight

SAFETY FEATURES

The $X^{2.5}$ UAS has two safety features designed into the systems components of the UAS: through the autopilot and through the twin DPSI. In the event of an emergency, the MicroPilot 2028^{g} remembers the position of $X^{2.5}$ during takeoff. The autopilot will automatically fly back to the home position should anything happen to the plane, such as radio transmission errors. In the event of a failure, information from the flight is recorded in a log file. This log file allows for future analysis. If the autopilot is unable to regain control over the UAS, there is a second receiver installed in $X^{2.5}$ as part of the DPSI twin. This second receiver allows the remote operator to regain complete control over the UAS without interference from the autopilot by taking the MicroPilot 2028^{g} autopilot out of the control loop. The DPSI twin also provides redundancy for the power supply in the event of a power failure.

ACKNOWLEDGMENTS

The many strides Team X-ipiter made this year would not have been possible without the generosity of our sponsors. We sincerely thank the Bagley College of Engineering, the Department of Aerospace Engineering, and the Department of Electrical and Computer Engineering at Mississippi State University. We especially appreciate the contributions of American Eurocopter, Freewave Technologies, Inc.; Microhard Systems, Inc.; Miltec Corporation; and 5-D Systems, Inc.