Mississippi State University
2006 AUVSI Undergraduate Student Competition

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Mississippi State University's Entry for the 2006 AUVSI Undergraduate Student Competition

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1.0 Abstract

Team X^2ipiter is Mississippi State University's entry into the Association for Unmanned Vehicle Systems International (AUVSI) Undergraduate Student Unmanned Aerial Vehicle (UAV) Competition. X^2ipiter, a modification of the Latin term for hawk, is a short-range, heavy duty UAV designed to perform autonomous flight via Global Positioning System (GPS) coordinates, provide real time flight imagery, and return high-resolution photographs of any target designated during the time of flight. The approach is to use a student designed and fabricated UAV to perform an Intelligence, Surveillance, and Reconnaissance (ISR) mission. The design is built to carry a 10-15lb payload that is insensitive to vibrations and heat. The payload consists of one digital video camera capable of live feed video as well as still imagery pictures, a Micropilot 2028g autopilot, low bandwidth wireless transmission capabilities, and analog video transmitter. Many of the electronic components are commercial off the shelf (COTS) parts to allow for simple software modification in the event of a component failure, or a component upgrade is needed. A student-designed power supply unit (PSU) is utilized to power all of the onboard electronic components.

2.0 Introduction

Team X^2ipiter is a multidisciplinary team composed of 21 undergraduate students from Aerospace Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Computer Science and Engineering. The team was formed to provide undergraduate students with experience in UAVs and to serve as a foundation for UAV research at Mississippi State University. The 2006 AUVSI Undergraduate Student UAV Competition features both autonomous flight and visual reconnaissance. These fields are crucial for both civilian and military applications alike for numerous reasons. By holding this competition, AUVSI allows undergraduate students to gain experience with new technology in both aircraft and electronics, develop new applications for existing equipment, and acquire hands-on experience; three aspects crucial to all aspects of engineering.

Per competition rules, X^2ipiter is designed to perform fully autonomous flight, including take-off and landing, fly at low altitudes and within GPS marked boundaries, and provide visual reconnaissance of short-time framed pre-determined data. While in flight, X^2ipiter can provide both high resolution video and still imagery on demand, and is capable of being dynamically re-tasked. X^2ipiter is able to perform such operations through custom-built and COTS equipment and software.

Components include:
900 MHz Max Stream Xtend Radio Modem
Micropilot 2028g Autopilot
Sony D70 Pan/Tilt/Zoom (PTZ) Camera
Custom-built DC Power supply
Custom-built signal router
NiMH battery power supply

The airframe is a nearly all composite structure, made from carbon fiber. By competition rules, the plane cannot weigh more than 55lbs, as such the aircraft has been built to be durable, handle the weight of the components, and remain under this limit. Its simple design and molded construction allows for fast repair in the event of catastrophic failure. The 2-stroke engine provides enough power to perform the mission.

Airframe components include:

Carbon/Divinycell Sandwich Core Wing Skins
Carbon/Divinycell Sandwich Core Fuselage
Twin carbon booms and vertical stabilizers
Carbon Wing Spar
Carbon/Plywood Sandwich Core Firewall
Carbon Landing Gear
2-Stroke BT-64 Engine
High-torque servos and PCM Controller

Using this configuration, X^2ipiter will transmit in real-time to the ground station all GPS coordinates, airspeed, height, bank and pitch angles, along with high resolution video imagery. High resolution still imagery can be captured from video at any time. The MP2028g software, Horizon Micropilot (MP), controls all avionics, while custom-built Labview software controls image display and data gathering.

3.0 System Overview

The X^2ipiter UAV System consists of four electrical areas: avionics, reconnaissance, transmission and power. Below is an overall schematic of the X^2ipiter UAV System (Figure 3.1).

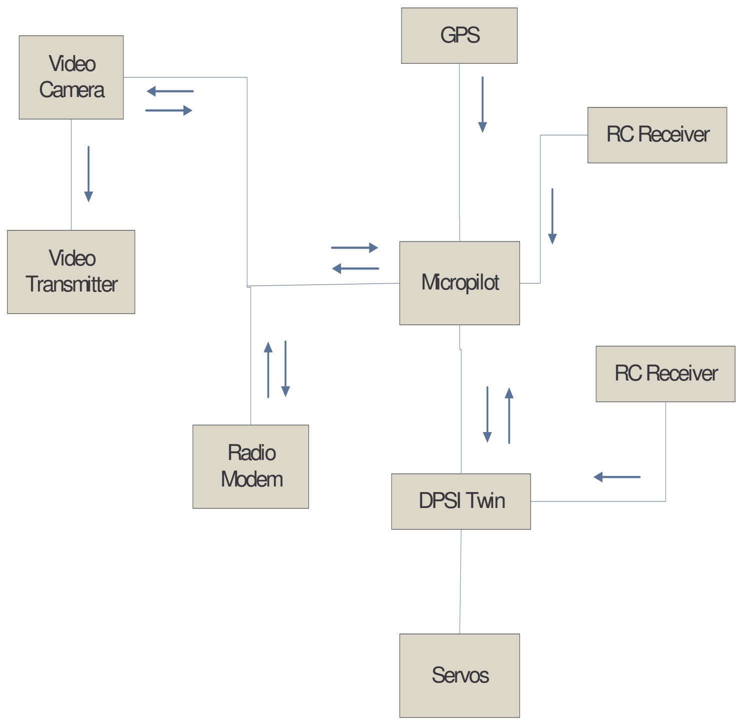

Figure 3.1: X^2ipiter UAV System

3.1 Avionics

3.1.1 Micropilot 2028g

X^2ipiter is flown completely autonomous through the use of the Micropilot 2028g miniature autopilot system. This system is ideal for a UAV of X^2ipiter's size due to its small footprint and weight and its ability to coordinate with a standard R/C aircraft setup. The MP2028g includes onboard controls for all servos in the X^2ipiter, airspeed and altitude pressure transducers, and a standard serial connection for easy transmission of data. The MP2028g includes the ability to take-off and land using the associated AGL sensor. The MP2028g also allows for in-air re-tasking when FIXED commands are used.

3.1.2 R/C Control

R/C Aircraft (Manual Control) is performed via Futaba 9C Radio System which includes the Futaba transmitter and 9-channel receiver. This system also includes Futaba and HiTech high torque servos. By using standard R/C control, manual flight can take place in the event of autopilot failure. In addition it provides a good control platform for testing autopilot and reconnaissance controls. A second level of flight control redundancy is provided by the Emcotec DPSI twin. This provides for a second power source for flight controls that is completely separate from that of the remainder of the systems along with a second R/C receiver that is completely isolated from the autopilot. In the event of complete autopilot failure, an emergency mode can be entered into that removes the autopilot from the control loop, allowing uncontested manual control.

3.2 Reconnaissance

3.2.1 Camera

X^2ipiter must be able to provide visual reconnaissance of any unknown target at any time. The targets will have assigned GPS coordinates along the flight line, or within a diameter given by GPS coordinates. Due to these circumstances, prior knowledge of any target becomes nearly impossible, and initial recognition is easiest when done visually. To accomplish visual confirmation of targets, a Sony D-70 pan/tilt/zoom (PTZ) camera has been located in the fuselage. This camera can transmit full motion analog video at television resolution. In addition to providing target visuals, the camera also serves as an in-plane monitor to determine if the aircraft is responding as programmed. The internet camera may be seen in Figure 3.2.

Figure 3.2: Sony D70

Once X^2ipiter has located a given target, a screen capture utilizing a video analog to digital converter is performed to provide still imagery. This high resolution image is processed to provide GPS location and orientation of targets. The still imagery capability provides an ideal solution for conducting detailed visual reconnaissance of given targets.

3.2.2 Controllers

A student built signal router is being utilized to minimize the number of communications links required. Both the Micropilot 2028G and the Sony D70 require the use of an RS-232 communication device, namely the Max Stream radio modem, in order to receive commands. In order to eliminate a communication link and possible source of interference the signal router was designed and used. This system combines the RS-232 signals from two ground station laptops to use a single radio modem then splits the signals to the appropriate device on the UAV. The router also works in reverse allowing down linking of relevant data from the UAV to the ground.

3.2.3 Transmission

Two data links are utilized for command, telemetry and control. The first is a 900MHz radio modem and the second is a 2.4GHz analog video transmitter. The 900MHz radio modem is used to provide both upstream and downstream data communications for the Sony D70 camera and the Micropilot 2028G. Upstream data includes control of the PTZ capability of the Sony D70 along with in flight reprogramming of the Micropilot 2028G. Downstream data includes camera PTZ state information as well as autopilot telemetry data. The 2.4GHz analog video transmitter is used to provide real time transmission of airborne video for ground station analysis and still imagery capture.

3.3 Supplementary Systems

3.3.1 Power System

The power system consists of a custom designed power conversion unit along with NiMH battery supplies. The power conversion unit also has the capability for the addition of a generator system but do to time constraints and interference problems this capability is not currently being used. The power conversion unit takes a twelve volt input and has six adjustable voltage outputs rated at five amps each. This is the main power system for the aircraft and provides all but emergency flight control power.

3.3.2 Interference Suppression

The X^2ipiter UAV was designed from the start with electromagnetic interference in mind. Twisted shielded wiring was used in all instances. Carbon composite cases were constructed for components deemed especially susceptible to either emit or receive interference. These cases were then electrically tied to ground. The carbon composite of the airframe was also electrically connected to the ground of the power system to enable it to act as an additional level of shielding.

3.3.3 Ground Control

The ground control station comprise of three computers as seen in Figure 3.3. Two computers are linked to the 900MHz radio modem for use in controlling the Sony D70 camera and the Micropilot 2028G. Additionally the video laptop is linked to the A/D converter for capturing video and still images. Finally a third dedicated laptop is utilized for dedicated image processing and is linked to the video laptop.

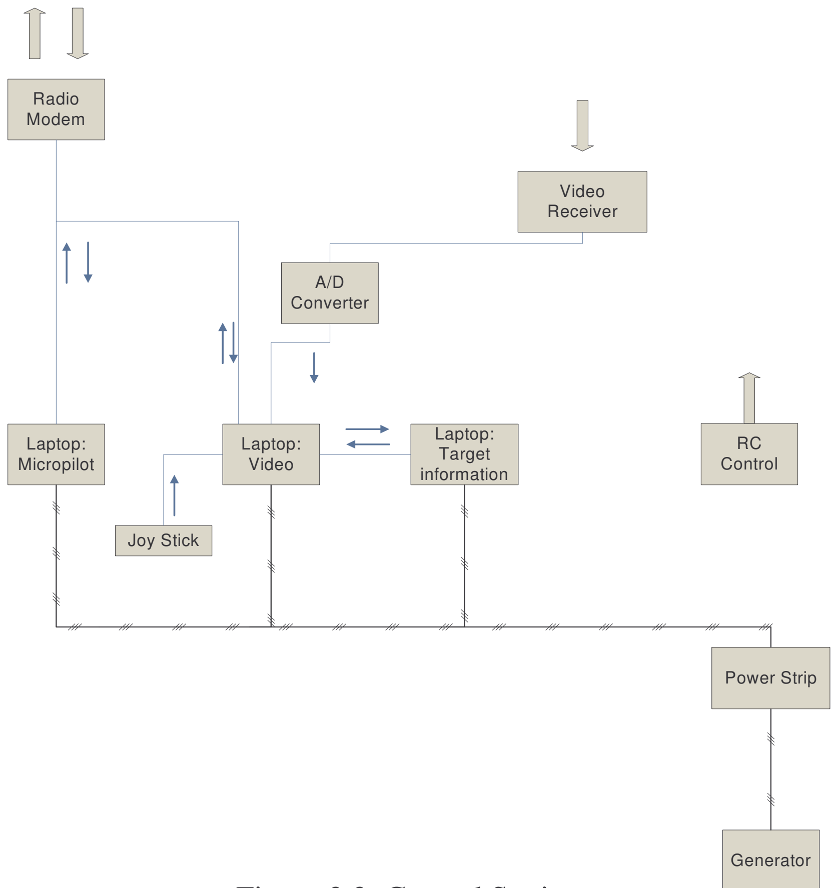

Figure 3.3: Ground Station

3.3.4 Camera Control Software

Cameral control software includes the software utilized with the custom signal router. This software takes the input from a standard PC joystick and converts it to commands for the Sony D-70 camera to include the PTZ capability along with image capture control. This also contains the capability for pulling PTZ state from the camera and aircraft telemetry information from the autopilot for target location.

3.3.5 Photogrammetry Software

Given the current system design of an autopilot, a maneuverable video camera, and a series of processing stations on the ground, it is clear that there must be a system dedicated to receiving this data and extracting from it the specific information needed by the team, including number of targets, target locations, target sizes, etc. In our design, this is accomplished by a base station software package that is in turn made up of two components: the X^2IPITER Photogrammetry Calculator (XPC), the calculation core of the system, and the X^2IPITER Base Station (XBS) (Figure 3.4), a user-friendly shell.

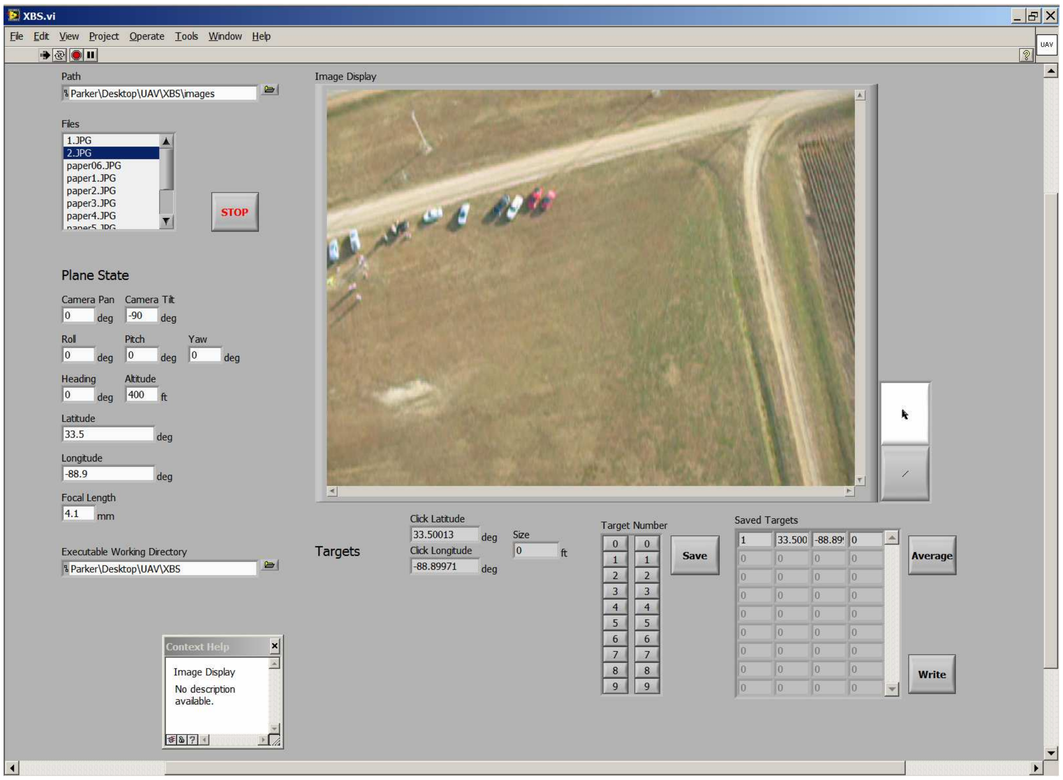

Figure 3.4: XBC Ground Station Software

XBS was designed to be flexible and extremely easy to use in time-critical situations such as in competition. It was written with National Instruments' LabVIEW 8 and the associated Vision Development Module 8 primarily due to the ease of use of that system in creating complex user interfaces. XBS serves three primary goals. The first is to accept photography and data from the aircraft through the primary camera control software on a separate ground station system and to allow the user to easily select the photograph and data set in which he or she is interested. Once the data is selected, the next goal is to allow the user to easily pick out any targets or points of interest in the photograph and extract the required data, including position and size. The final goal is to allow the user to process that data and save it for later analysis or for submission at the end of the allotted time.

To accomplish the first goal, XBS continually monitors a shared folder between the XBS laptop and the camera control laptop. When a new image arrives in the folder, it detects its presence and adds it to the list of available images on the XBS interface. When selected, XBS loads the requested image into a large display area and reads the associated flight data into memory. This data includes the camera pan and tilt angles, the aircraft attitude (roll, pitch, yaw), the aircraft heading and altitude, the aircraft position (latitude and longitude), and the active focal length of the camera lens, all at the moment the photograph was captured, as delivered by the camera control laptop.

Once the photograph is loaded into the display window, XBS allows the user to use a pointer cursor to click on points of interest on the image, such as a target. It also allows the user to use a line tool to draw a straight line on the image to measure distances, such as the dimension of a target. The system detects these actions and delivers the appropriate data to XPC for calculations. For simple pointer clicks, this data includes the on-screen coordinates of the mouse click. XPC uses these coordinates to calculate the corresponding real-world latitude and longitude coordinates of the point of interest, and returns those values to the XBS interface. In the case of a line drawn on the image, XBS supplies XPC with the average on-screen x and y coordinates, and XPC returns the scale of the image at that average point. XBS uses that scale and the on-screen length of the line to calculate the real-world length it represents. Both the position and the distance data is shown on the interface for the user to check. If acceptable, the user can then type in the target number, if available, and click a "Save" button, which saves the number and the associated data to a visible list.

After the flight is complete and a full set of targets have been identified and saved to the on-screen list, an "Average" button is available for post processing. When pressed, the Average button combines all data sets corresponding to the same target number and averages the data, giving one final result for each target. Assuming multiple observations are made in which the user can identify the target by number, any numberless data sets are discarded as unnecessary. Once processed, the resulting list can be saved to the computer as a CSV file by clicking a "Write" button. This works for both averaged and non-averaged data, so if the previous assumption is incorrect, the raw data can be saved for later processing.

The X^2IPITER Photogrammetry Calculator (XPC) is the calculation core of the base station software. It is written in the Python 2.4 programming language with the associated 3rd-party NumPy add-on module, primarily due to ease of programming and considerable experience on the part of the developer. XPC operates in both a positioning and a scaling mode, though both share the same core features.

The mathematics behind XPC are based on the science of photogrammetry, or the science of obtaining information about the real world based on photography and other measurements, and are based on the derivations from Wolf's *Elements of Photogrammetry*. XPC begins by establishing a series of six coordinate systems that fully describe the position and orientation of the aircraft and the camera. The coordinate systems are, in the order used in the program, a local ground-parallel system with axes parallel to the standard directional axes (North, East, etc.), an aircraft wind system that takes into account heading, an aircraft body system that uncovers roll, pitch, and yaw, a camera base system for pan, a camera body system for tilt, and a final photograph system with the x-axis out the right side of the image and the y-axis out the top of the image for the photogrammetric calculations themselves. All systems are assumed to originate at the center of gravity of the aircraft. A series of five three-dimensional coordinate transformation matrices are developed by calculating a series of sequential omega, phi, and kappa rotation angles from one coordinate system to the next. These matrices are then multiplied together to give a single resultant transformation matrix from the ground-parallel system directly to the photograph system. Since all photogrammetric calculations in Wolf are in terms of the angles of tilt, swing, and azimuth, a second set of calculations are done to convert the resultant omega, phi, and kappa angles to the final tilt-swing-azimuth system.

The other parameters given to XPC from the XBS interface (besides the angles) are the lens focal length, the on-screen image resolution in pixels, the on-screen coordinates of the click action (or averaged coordinates in the case of a line), and the horizontal and vertical dimensions of the camera CCD in meters. XPC uses these parameters to transform the click coordinates from a photograph system with the origin at the center to one with the origin at the nadir point, or the point representing the direction straight down from the aircraft to the ground.

In the case of the positioning mode, XPC then performs another set of calculations that give real-world coordinates of the ground point in relation to the aircraft position. It then calculates these distances in terms of degrees of latitude and longitude, adds them to the absolute aircraft position, and reports the result back to the XBS interface as the absolute real-world position of the point of interest. In line mode, XPC skips these last two steps and directly calculates the scaling factor based on the given parameters and reports this base to the XBS interface.

A limited amount of testing has been done, but when complete, it should be possible to assign error bounds to the XPC calculations and adjust the reported results accordingly. Sources of error include the assumption that the coordinate systems originate at the aircraft c.g., inaccuracies in the conversion from distances to degrees of latitude and longitude, and general numerical inaccuracies propagated through the system.

4.0 Airframe Overview

For the 2006 AUVSI Student UAV competition, X^2ipiter UAV Airframe consists of five areas: Justification behind building a new airframe as opposed to utilizing the previous airframe, airframe, performance and stability, and transceiver, receiver, and servos.

4.1 Justification behind new opposed to the old airframe

In the initial design meetings, it was determined that the airframe team had to decide between utilizing airframes from previous competitions or design a new airframe. After performing a trade study it was decided it would be beneficial to design a new airframe. The previous airframe had adequate payload room and capacity but was plagued with weight distribution and electronics access problems. A new airframe was designed to address these issues as well as providing designed in interference suppression.

4.2 Airframe

In designing the aircraft, the team determined the following features as the main design criteria:

- High wing aircraft for stability
- Maximum empty weight of 45 lbs
- Lift-Drag ratio
- Useful volume
- Manufacturability
- Strength
- Fuel consumption

After reviewing several possible concepts, the team decided that X^2ipiter (Figure 4.1) should be a high wing twin-boom pusher with tricycle landing gear. When considering what materials to fabricate the aircraft from, there were two options considered: a fiberglass composite structure or a carbon fiber composite structure. Both composite construction techniques provide large internal payload volume. Fabricating the airframe from carbon fiber composite allows the team to get the needed strength and structural integrity, while maximizing internal volume for the payloads and maximizing interference suppression. X^2ipiter is designed to perform the mission, but also has expandability built into the airframe. It has enough useable volume and is strong enough to hold future, and possibly heavier, payloads. The airframe is built utilizing a pre-preg carbon lay up on prefabricated molds (Figure 4.2-4.3). These molds were constructed through a wet lay up procedure using 12K carbon cloth.

The wing uses a Selig-Donovan 7062 airfoil shape. This airfoil is a low Reynolds number, high-lift airfoil providing acceptable lift and drag characteristics. Other high lift airfoils were considered; however, the SD7062 was chosen due to its thicker shape and thicker trailing edge. These two facts allowed for easier fabrication of the wings. Due to the size of the aircraft, the team decided to use symmetric airfoils for the tail surfaces. The airfoil chosen is the J5012. Aircraft specifications are presented in Table 4.1.

Figure 4.1: X^2ipiter

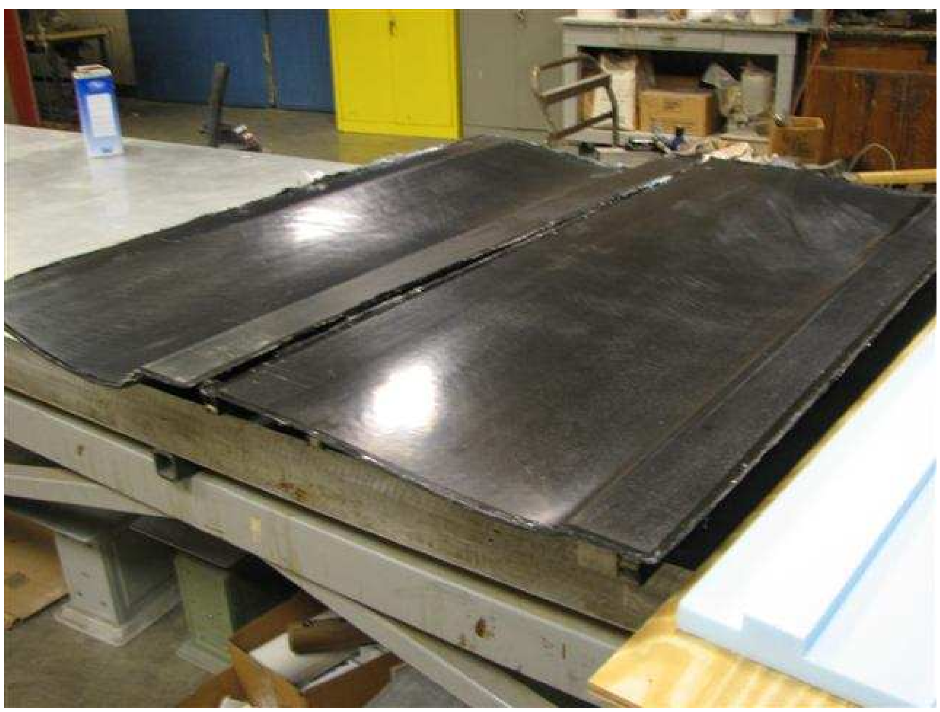

Figure 4.2: Composite Molds

Figure 4.3: Unfinished Components

X^2ipiter has the following specifications:

Wingspan	108 in
Wing Area	1728 sq in
Wing Loading	3.7 lb per sq ft
Aspect Ratio	6.75
Wing Airfoil	SD7062
Empennage Airfoil	J5012
Weight – gross	53 lb
Weight – empty	51 lb
Weight – airframe	47 lb
Weight - systems	4 lb
Engine	Fuji BT-64A
Propeller	22 in diameter
Length	65 in
Number of Servos	5
Radio	Futaba 9CA

Table 4.1: Aircraft Specifications

4.3 Performance and Stability

The team designed X^2ipiter to not just be able to structurally carry future loads, but to also be able to fly these payloads and perform future missions. The aircraft has enough power to fly the mission well above its stall speed of 32 mph and its cruise speed of 45 mph. additionally, it has enough available power to fly heavier payloads at its cruise speed.

The primary reason the team decided to use a high-wing pusher aircraft is that it provides a very stable aircraft to be used as a sensor and reconnaissance platform. According to X^2ipiter's longitudinal stability analysis, the team has succeeded in designing and building a very stable platform. The airplane's CG range is 2 inches.

4.4 Engine

A Fuji BT-64A gasoline engine as shown in Figure 4.3: Fuji BT-64A Engine powers the X^2ipiter UAV. This particular engine has the following specifications:

- 1200 – 9000 rpm
- Output of 5.7 hp @ 9,000 rpm
- Weight of 5.7 lb
- 3.85 cu in capacity

Figure 4.3: Fuji BT-64 Engine

4.5 Transmitter, Receiver, and Servos

The transmitter is the Futaba 9CA transmitter. This is a 9-channel PCM transmitter that is fail-safe configurable. The receivers built into the X^2ipiter UAV are Futaba R138DP with the following specifications:

- 8 channels
- 72Mhz band
- Operating voltage range of 3.5-6.0V
- 6000+ ft. range
- Weight of 1.75oz.

4.6 Emergency Control System

The X^2ipiter UAV is designed with an emergency control system. The Emcotec DPSI Twin (Figure 4.4) allows for both redundant R/C receivers and redundant power systems.

Figure 4.4: DPSI Twin

This allows the Micropilot 2028G along with its associated receiver to be connected to one receiver input and a bare R/C receiver to be connected to the other. In the event of Micropilot failure, an emergency mode can be entered into that completely bypasses the autopilot and its receiver allowing uncontested control of the aircraft. In addition, two power input allow flight control power to come from both the onboard power system of the aircraft as well as a backup battery supply. In the event of an aircraft power system failure, the backup supply automatically takes over and allows the aircraft to be manually returned to base.

5.0 Testing

The aircraft demonstrated both static and dynamic stability both under manual and automatic control. The level of stability was sufficient for ISR.
Electronic systems have been thoroughly bench tested, and all major goals have been met.
In testing autonomous flight, the Micropilot was found to achieve its waypoints with reasonable accuracy and respond well to in-flight re-tasking.

Figure 4.5: X^2ipiter in flight

Acknowledgements

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