



The University of Texas  
at Arlington  
Autonomous Vehicle Laboratory



## 2006 AUAVSI Student UAV Competition

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## ABSTRACT

This paper describes the implementation of our system to perform autonomous reconnaissance in preparation for the AUVERSI 2006 Student UAV Competition. Within a predetermined, confined area, the aircraft autonomously takes off and navigates to specific GPS waypoints. While in flight, with the utilization of its photogrammetric payload and with the assistance of ground imagery software, the aircraft creates a “controlled digital mosaic”. The stitched photo imagery yields a complete aerial view of predetermined area of the mission. Once the aerial overview is obtained, a series of targets are manually assessed and categorized.

The success of this project relies on the utilization, implementation and integration of commercial off-the-shelf (COTS) components to create a reliable autonomous reconnaissance system. Specifically, success depends on proficiently controlling mission elements including; autonomous takeoff and landing, autonomous control, waypoint navigation, mission flexibility (the ability to change missions before and during flight), and target interpretation.

Discussed in this text are the rationales, architectures, components, and description of processes involved in achieving these goals. Additionally, Safety features such as structural reinforcements, the ability to switch to manual control at anytime during the flight, and safety specific engineering processes are addressed.

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## NOMENCLATURE

<u>Abbreviation</u>	<u>Definition</u>
AAV	Autonomous Aerial Vehicle
AGL	Above Ground Level
AMA	Academy of Model Aeronautics
ARF	Almost-Ready-to-Fly
CG	Center of Gravity
COTS	Commercial Off-the-Shelf
GCS	Ground Control Station
GPS	Global Positioning System
GUI	Graphical User Interface
IPD	Intelligent Pulse Decoding
Li-Poly	Lithium Polymer (battery)
MP	MicroPilot autopilot system
Ni-MH	Nickel – Metal – Hydride (battery)
PID	Proportional, Integral, Derivative (control loops)
TO	Take Off
USB	Universal Serial Bus

## INTRODUCTION

Ever since man first experienced the thrill of flight, he relentlessly devised ways to improve the efficiency of aircraft and maximize their capabilities. A century after man's first flight, a new era of unmanned automated aviation has emerged where the pilots have been removed from the cockpit thereby removing the limitations imposed by the human physique. We are now living in a new aviation era, the era of the Unmanned Aerial Vehicle. This has opened a new world of possibilities. It gives the ability to gather information and/or data without risk to human life and the need for constant human control. These platforms provide a functionality limited only by the capabilities of the specific airframe, control system, payload, and our imagination. This technology has widespread military and commercial applications; and the 4<sup>th</sup> Annual AUVSI Student UAV Competition gives students the chance to work in this frontier. The UAV under consideration is required to

be capable of autonomous flight, photo reconnaissance, and performance under a time constraint. This paper describes the development of a fully-functional system that meets those parameters.

## MISSION REQUIREMENTS

The aircraft is required to take off from a paved runway and climb to above 50 ft AGL either by autonomous or radio controlled means. It must then autonomously navigate through a pre-selected corridor to several GPS waypoints and photograph the ground in order to identify targets. Finally, the aircraft must land either autonomously or manually. The system performance is evaluated based on accuracy of target interpretation, completion time of mission, and ability to stay within the bounds of the course. Extra value is placed on autonomous take off and landing.

## AIRCRAFT FLIGHT REQUIREMENTS

1. Flight Duration: 20 minutes minimum
2. Take-Off and Landing: 150 ft. with no obstacle.
3. Design vehicle Take-Off weight: 12 lbs. max
4. There is no minimum or maximum speed.
5. Flight Altitude: Minimum 50 ft. AGL  
Maximum 500 ft. AGL

## MISSION STATEMENT

The entire mission is to be fully autonomous including takeoff and landing. This is to be accomplished by improving on the previously successful system which met the mission requirements of the 3<sup>rd</sup> Annual AUVSI student UAV competition.

### **Rationale:**

The focus of the competition is autonomous flight. The team's energy was directed in perfecting autonomous flight while providing reliable aerial reconnaissance. Within this

consideration, it was decided to retain last year's competition aircraft configuration and method of autonomy. The driving factor for the selection of the components to be integrated in the airframe was reliability and simplicity.

## GENERAL DESIGN

The system is based on a SIG Kadet Senior airframe which houses an auto-controller and payload in the form of a video camera/transmitter. After an autonomous takeoff, the controller will guide the plane to the designated search area and fly level patterns across the region with banking done on the outside. Still images will be captured from the video stream and used along with the telemetry in creating a controlled digital mosaic of the search area using the custom built "Hawkeye" software. Targets will be analyzed using this photo mosaic and the software will allow the printing of the description of these targets.

The full design is explained in the following categories.

1. RC aircraft
2. Auto controller
3. Ground control station
4. Data link
5. Photogrammetry
6. Safety

### **1 RC Aircraft**

#### 1.1 Airframe Selection Parameters

As of last year, this year's RC platform was chosen to be the SIG Mfg. Kadet Senior. The Almost Ready to Fly (ARF) airframe was chosen due to its short building time, ample internal room for payload, and reliable proven airframe.

##### *1.1.1 Aircraft Rationale-modifications*

The SIG Mfg. Kadet Senior's stock flying weight is 6 – 6.5 lbs with the recommended

engine and 8 oz fuel tank, leaving as much as 6 lbs for additional avionics and payload for a total of a 12 lb total flying airframe.

A few modifications had to be performed to suit the mission at hand. A larger 16 oz fuel tank was accommodated in order to increase endurance. To account for the larger engine than was suggested by the manufacturer, the firewall was increased from  $\frac{1}{16}$  inch to  $\frac{1}{8}$  inch plywood thickness. A 3 inch by 3 inch Plexiglas access hatch was added on the bottom of the fuselage for the on-board camera. A double-fork nose-gear as well as a tensile steel cross wire (connecting the main gear between the wheel axles) was added in order to provide additional support and lateral stability on the ground roll. These modifications were necessary in order to compensate for the increased aircraft weight. Additional supports and harnesses were added internally in order to accommodate the onboard electronics. The nine-channel receiver for the manual radio control system along with a multiplex board and a signal filtering device was placed in an integrated box. Then, the electronics enclosure was placed on vibration mounts and then installed in the rear midsection of the fuselage on a  $\frac{1}{16}$  inch plywood mounting tray.

The manufacturer designed the engine to be placed at a negative  $3^\circ$  thrust angle, but this caused the plane to pitch up at every increase in throttle, causing pitch instability. This non-zero thrust angle was removed. Also, a quick refueling port and fuel filter were added to the system to increase reliability and ease of operation.

At the end of each modification, the aircraft's weight and balance was readjusted according to the manufacturers suggested center of gravity (CG) located at 3-7/8" back of the leading edge of the main wing.

You can find the finalized aircraft specifications and dimensioned 3-view drawings in Appendix I.

## 1.2 Engine Selection Parameters

The OS FX 0.61 in<sup>3</sup> engine was chosen to power the Kadet Senior airframe. This engine has developed a reputation of reliability, power and consistent operating performance.

### 1.2.1 *Engine Rationale*

With a 13 x 6 blade propeller, the engine produces about 9 lbs of static thrust. This gives the aircraft a power to weight ratio of 0.75.

The engine burns 15% Nitro-Methane concentration glow fuel, and can operate with a 16 oz fuel tank at  $\frac{3}{4}$  throttle for about 30 minutes.

A lighter, after-market muffler was used in order to minimize the total aircraft weight. In order to minimize vibrations, the engine was mounted on rubberized vibration absorbers.

## 2 Auto-Controller

### 2.1 Selection Parameters:

It was determined that the autopilot system must be capable of navigating and piloting the aircraft safely and accurately, while at the same time being compact and light. It must be affordable and have communication with a ground control station for tracking and data collection. It must also be capable of being re-tasked in flight.

### 2.2 Rationale:

Autonomous flight is governed by the MicroPilot MP2028<sup>g</sup> autopilot subsystem. The MicroPilot uses rate gyros and accelerometers, GPS data, ultrasonic and pressure altimeters, and an airspeed pressure sensor to determine the aircraft attitude, position, and velocity in flight. Using the

sensor data Proportional, Integral, Derivative (PID) control laws the MicroPilot controls the actuation of the control surfaces and the throttle.

The embedded flight control software MicroPilot can execute the following flight tasks: airspeed hold, altitude hold, coordinated turn, GPS navigation as well as autonomous launch and recovery.

### 2.3 Autopilot Component Descriptions:

#### 2.3.1 *MP2028g Autonomous Control System and Avionics:*

The MP2028<sup>g</sup> weighs only 1 oz with dimensions of 3.9 inch by 1.5 inch (see figure 1). Extensive data logging and manual overrides are also supported. All feedback loop gains and flight parameters are user-programmable and feedback gains are adjustable in-flight. This means that the PID gains can be experimentally fine tuned while the aircraft is in flight. The MP2028<sup>g</sup> also includes a ground control station software (HORIZON<sup>mp</sup>) for mission creation, parameter adjustment, flight monitoring and mission simulation.

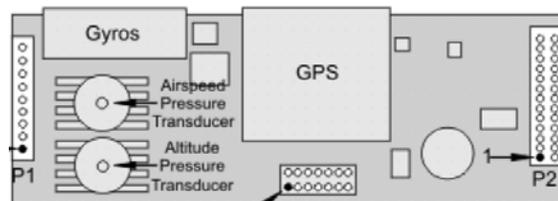


Figure 1: MP2028g Layout 1

#### 2.3.2 *Acoustic Altimeter:*

The ultrasonic altimeter is a 2.23 by 1.78 inch separate PCB board unit that interfaces a piezoelectric ultrasonic sensor to the MP2028 (see figure 2).

The ultrasonic transducer is a 0.6 oz., 1.7 inch diameter device that is mounted on the bottom of the port wing facing down.

The Acoustic Altimeter setup operates as the AGL measuring device. The AGL unit provides high-resolution relative altitude information up to an altitude of 15 feet. The AGL is an essential component for autonomous takeoff and landing.

The connection between the transducer to the board consists of a shielded coaxial cable.



**Figure 2: AGL Board and Transducer**

### 2.3.3 GPS Module:

The MP2028<sup>g</sup> comes standard with a Trimble Lassen® SQ GPS module. The unit has 8 channels and an update rate of 1 Hz. However, this unit was upgraded with the Ublox TIM-LP GPS that has 16 channel receiver and 4 Hz update rate (see figure 3). The upgrade provides a 5 times faster cold start acquisition time than the original unit as well as more precise positioning.



**Figure 3: Ublox TIM-LP GPS module**

### 2.3.4 GPS Antenna:

The MP2028<sup>g</sup> is fitted with a San Jose Navigation Inc. MK-4 Mini GPS antenna that provides a standard 24 dB overall gain (see figure 4).



**Figure 4: MK-4 Mini GPS Antenna**

### 2.3.5 Airspeed Pitot Pressure Sensor:

The MP2028<sup>g</sup> calculates relative wind velocity through a Pitot tube extending from the leading edge of the starboard wingtip. A flexible hose connects the Pitot tube to the MP2028<sup>g</sup> board, allowing it to calculate the airspeed.

### 2.3.6 Static Pressure Sensor:

The MP2028<sup>g</sup> obtains static pressure readings from a port located inside the aircraft's fuselage in order to determine pressure altitude (un-pressurized fuselage).

### 2.3.7 Proportional, Integral, and Derivative Control Loops:

MicroPilot uses a set of the PIDs to achieve a pre-specified flight plan in a satisfactory manner. The gains of each PID loop can be adjusted through HORIZON<sup>mp</sup> (GUI provided by the MicroPilot Company). The set of PID loops consist of:

1. Aileron from Desired Roll
2. Elevator from Desired Pitch
3. Rudder from Y-accelerometer
4. Rudder from Heading
5. Throttle from Speed
6. Throttle from Glide Slope
7. Pitch from Altitude
8. Pitch from AGL Altitude
9. Pitch from Airspeed Altitude
10. Roll from Heading
11. Heading from Cross Track
12. Pitch from Descend

### 2.3.8 Servo Control Board:

The servo control board is a component of the MicroPilot system. All control output from the

autopilot is ultimately sent through the Servo Control Board which acts as a signal demultiplexer. When the signal leaves the demultiplexer it gets re-routed to a Bypass Switch. In case the autopilot becomes inoperative, the switch redirects the radio control transmitter signal directly to the servos bypassing the autopilot. More information about the Bypass System can be found in Appendix III-Chart A.

### 3 Ground Control Station (GCS)

#### 3.1 Ground Control Station Requirements:

The GCS must be capable of direct communication with the UAV whether in autonomous or radio controlled flight. The GCS must provide continuous reliable telemetry information to the operator. Additionally, the GCS need to be able to work as a mission programming interface

The comprehensive ground station solution must account for photogrammetric processing capability (see section 5).

#### 3.2 Rationale:

Two-way radio modem devices provide the communication and exchange of data between the aircraft and the ground station for control, reprogramming, and the monitoring of UAV and its systems. A programmable radio transmitter provides additional manual flight control. A notebook computer along with proprietary software facilitates the data transfer and control to the UAV. A two-way CB radio facilitates voice communication between the ground station operator and the pilot of the UAV.

#### 3.3 Ground Control Station Description:

The GCS consists of two entities; the Data and Avionics notebook computer and the Pilot Operated Remote Control Transmitter. In flight, the UAV and GCS will communicate through two discrete communication systems

using 900 MHz-band radio modems. Additionally, the 72 MHz-band Pilot Operated Remote Control Transmitter can communicate with the receiver onboard the UAV.

The GCS notebook computer can use two applications to communicate with the autopilot: the HORIZON<sup>mp</sup> graphical user interface software included in the autopilot purchase and HyperTerminal emulation software to make real-time adjustments to the onboard computer.

#### 3.4 Ground Control Station Components:

##### 3.4.1 *Radio Control Hardware:*

The remote control transmitter and receiver are a synthesized Multiplex Royal Evo 9 channel transmitter and synthesized Multiplex IPD 9 channel receiver (see figure 5). These were chosen for their reliability, quality, and versatility (all channels on this particular radio system are user-assignable). The transmitter provides automatic fail-safe and information update in IPD mode when fail-safe is triggered by a loss of signal. The “intelligence” takes the form of a micro-processor which analyzes the signals picked up from the transmitter, processes them (where necessary) and then passes them on to the servos. The received signals are not simply passed on directly to the servos, as with conventional FM/PPM receivers, but are checked for interference and validity. (Ref. 8)



**Figure 5: Synthesized Multiplex Transmitter and Receiver**

##### 3.4.2 *Notebook- Dell:*

The second hardware component of the GCS is a Dell XPS Gen 2 laptop with which data is exchanged via radio modem. The Horizon

software is used as an interface to monitor the avionics on the UAV.

### 3.4.3 MP2028g HORIZON<sup>mp</sup> Software:

The MP2028<sup>g</sup> package includes a graphical interface and programming software named HORIZON<sup>mp</sup>. This software allows for the implementation of the mission creation, parameter adjustment, flight monitoring as well as mission simulation.

The software also acts as a setup tool for configuring the MP2028<sup>g</sup>. Its main function is to allow the user to observe and interact with the UAV either in flight or on the ground. Communication is possible via an RS-232 cable on the ground, or a 900 MHz radio modem while in flight. Example screen shots of the horizon software can be seen in figures 6 and 7.

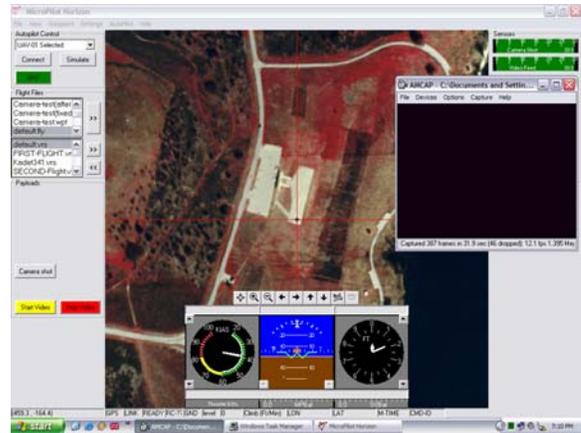


Figure 7: Active Horizon GCS Example

### 3.4.4 Microsoft HyperTerminal software:

The Microsoft HyperTerminal software, communicates with the MicroPilot's onboard computer via an RS232 cable just like the HORIZON<sup>mp</sup> software does. Through HyperTerminal, you can perform diagnostics, system changes, as well as interface text commands between the PC and the autopilot's data link port.

## 4 Data Link

### 4.1 Requirements:

Data must flow between the ground station and the UAV whether it is on the ground or in flight.

### 4.2 MaxStream Xtend Radio Modems:

The Xtend is a long-range, low-power wireless OEM module (figure 8). This modem was chosen for its brand name reliability and long range coverage. During our testing, the modems communicated reliably at ranges of over 5 miles. The modem manufacturer claims 20 miles.

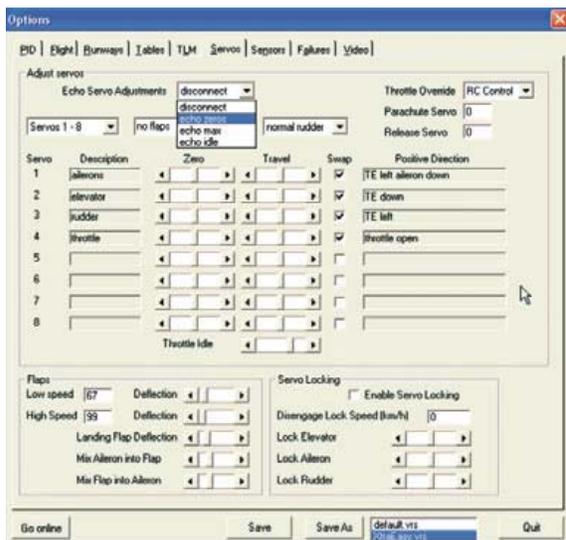


Figure 6: Horizon Servo Limits Adjustment Example



**Figure 8: MaxStream Radio Modem**

## 5 Photogrammetry (Payload)

### 5.1 Requirements

While the UAV is in autonomous flight, the photogrammetric system needs to automatically take and store aerial pictures of the designated mission area for further processing. While the UAV is enroute, the orientation and position of the captured picture-targets needs to be identified as well.

### 5.2 Rationale

The image processing unit needs to autonomously take pictures while in flight and store the processed images so that they can be viewed at the end of the mission. The photogrammetric process needs to be concurrently initiated with the start of the autonomous flight.

### 5.3 Payload Hardware Components

The payload consists of a high-resolution camera, a 1 Watt 2.4 GHz video transmitter and a 11.4 Volt power source.

#### 5.3.1 *Video Camera Selection Parameters and Rationale*

The picture resolution and clarity needs to be good enough so that if a captured image is zoomed-in, very little clarity is sacrificed and a 4 by 4 feet image can be clearly identified (for picture of camera see Appendix II).

#### 5.3.2 *Video Transmitter Selection Parameters and Rationale*

A powerful transmitter within legal limits needed to be implemented so that a video

signal could be reliably transmitted within at least a 2 mile radius for the purpose of the 2006 AUVSI competition (for picture of video transmitter see Appendix II).

### 5.4 Photogrammetric Ground Station

#### 5.4.1 *Second Notebook -Compaq*

The second notebook of the ground station will provide image support and processing capabilities.

#### 5.4.2 *Photogrammetric Software*

The Photogrammetric software (Hawkeye) will aid in the image processing, categorization, location and orientation of the acquired aerial targets.

## 6 Safety

Safety is an important part of engineering design. Thought and planning has to go into safety ensuring that personnel, equipment, and software are well-protected before, during and after the missions.

In this project, safety was stressed from the beginning of the project and throughout the daily operation of the equipment in the Autonomous Vehicles Laboratory.

The utilization of checklists and strict adherence to the lab operational rules were common daily practice at the AVL in order to prevent or minimize chance of injury. We characterize safety considerations in two sections: Procedures for Accident Avoidance and Hardware Handling.

### 6.1 Procedures for Accident Avoidance

The general operation guidelines are:

- The airplane must be de-fueled after each flight.
- Two team members are involved in the starting of the airplane's engine. One secures the plane while the other starts the engine.

- Prior to each flight, the transmitter and receiver range check is performed according to the manufacturer's suggested procedure.
- All flights are conducted using a skilled pilot covered by AMA insurance.
- No spectators or operators are allowed to stand in front or to the side of a rotating propeller. All team members must remain behind the airplane while the engine is in motion.
- All autonomous fine-tuning flights are conducted at a minimum altitude of 500 ft. This altitude is to provide enough time to safely transition from autonomous to manual flight in case of an emergency. Also, in the event of an engine failure, the conservative altitude provides the pilot with a better chance of safely landing the aircraft.

## 6.2 Hardware Handling

- The tips of the propeller are painted white so that its boundary is visible at all times while in rotation.
- All battery charging ports and switches are placed either under or on the side of the fuselage opposite to the engine's exhaust port in order to prevent possible short-circuiting due to fuel or oil ingestion.
- The Lithium-Polymer battery charging port is marked in order to distinguish it from the other battery ports. This is done in order to prevent improper charging which could result in fire or a possible explosion.
- The fuel is stored in a fireproof cabinet and never left unattended under the direct heat of the sun.
- All batteries onboard the aircraft are checked for proper charge prior to each takeoff in order to prevent loss of control or communication during flight due to insufficient battery charge.

- A redundant voltage monitoring LED indicator switch is installed on the battery supply of the MicroPilot board.
- All onboard wires are shielded with copper tape and all onboard electronics are isolated by metal sheets to decrease radio frequency emissions that could potentially lead to interference with other electronics.
- All software files and programs pertinent to the autonomous project including the operating system of the ground station are backed up and saved. This gives the ability to retrieve the information in case of loss or damage of the original one.

## 6.3 Safety Subsystems

### 6.3.1 *Battery Backer*

The Battery Backer is a commercial product that increases the safety level of the entire system by providing continuous monitoring and active control of the servo battery power. In case of a battery voltage drop of below 6V, the backer immediately switches to the backup battery source (i.e. the MP battery). Specifically, if one of the batteries stops emitting the expected correct voltage reading, the Horizon software will yield a displayed warning signal indicating the power drop. This power drop warning will alert the operator to start the recovery procedure for a safe landing.

### 6.3.2 *Glitch Buster*

The "Glitch buster" is an amplified, opto-coupled, 8 channel servo power isolator. It is used to reduce the possible glitches in the servos caused by long power cables.

### 6.3.3 *Safety Switch*

The safety switch is a custom-built device created by Reactive Technologies<sup>10</sup> and the collaboration of NCSU<sup>11</sup>. The device acts as a servo signal input selector. The switch works both manually and automatically. It will allow the pilot in command to bypass the autopilot in case of power loss or other failures.

However, in case of loss of the RC transmitter signal, the switch will automatically turn the control to the RC receiver and by that initiate a spiral-to-the ground preprogrammed fail-safe maneuver (in compliance with the AUVSI competition rules)

## SYSTEMS INTEGRATION

Although the aircraft was purchased in an “Almost Ready to Fly” condition, it was not designed for the avionics and communications equipment that were subsequently placed on board. Several modifications to the structure and arrangement of existing components were required to accommodate the new components.

For a detailed electronics flowchart you can refer to Appendix II. In addition to the airframe modifications mentioned in the “aircraft modification” section, the following changes were made while integrating all the autonomous components.

### **1 Autonomous System:**

The autonomous MP system was enclosed in a small  $\frac{1}{16}$  inch plywood box. The enclosure was mounted via a quick-release mechanism on two foam mounts in order to reduce possible vibrations and placed at the CG.

The AGL signal generating unit was enclosed in a  $\frac{1}{16}$  inch plywood box over aluminum sheeting and then placed right behind the CG. The AGL piezoelectric transducer was placed on a  $\frac{1}{4}$  inch balsa mounting box on the outer portion of the underside of the right wing. The Pitot tube was also placed on the outer tip of the right wing.

The GPS antenna wire was shortened and placed over a copper plate on top of the windscreen. Six switches and charging ports were installed on the airframe in order to operate the appropriate electronics.

### **2 Hard-Wired Communications:**

One USB port was installed on the port side of the fuselage to download the mission pictures to the ground station.

An RS-232 data port was installed on the fuselage connecting to the communication port of the autonomous system.

### **3 Software:**

During the course of the project, MicroPilot Company updated the operating system of the MP2028<sup>g</sup> fourteen times leading to continuous learning curves. The most difficult part was learning the operational peculiarities of HORIZON and HyperTerminal. These included differences between specified manual instructions and actual operating instructions, as well as a proprietary programming code for tasking.

## TESTING

### **1 Components**

Testing of the aircraft continuously evolves as new features are brought online. The aircraft’s main control surfaces and sensors were tested in parts: on the bench, and during piloted, semi-autonomous, and autonomous flight. The bench testing ensures that each control is actuated properly, and has a proper range of deflection to accomplish the task in flight.

Appendix IV provides a sampling of errors encountered during systems testing, their possible causes, and solutions. These and many other issues had to be addressed prior to attaining radio controlled and fully autonomous flight. Though some problems stood out more than others, all had to be approached with equal care and methodology so that the next problem could be remedied.

### **2 Autonomy**

Autonomy was first achieved about a year ago on April 8, 2005. After our successful

participation at the 2005 AUVSI student competition we sought to further improve autonomy from takeoff to aerial navigation to landing. Even though the airframe was reasonably toned, we decided to further fine-tune each feedback loop to an even higher degree of accuracy so that if desired we could consistently achieve autonomous landings at every unmanned flight. An example of an un-tuned and then of a tuned Level Flight PID feedback loop can be seen at Appendix III.

Gradually, the project progressed to more sophisticated command programming and tasking. Later, additional systems were incorporated such as the photogrammetric system. As of this submission, more than 120 autonomous flights have been achieved including 30 autonomous takeoffs and 15 autonomous landings.

## CONCLUSION

Many considerations must go into the design of an autonomous aerial vehicle program, from aerodynamics and structures to electronics and communications. This paper has briefly introduced the University of Texas at Arlington's Autonomous Vehicle Lab's UAV. You were familiarized to the process by which the air vehicle was selected, the suite of electronics chosen to be integrated, the tuning of the autonomous system and the modifications that took place on the airframe in preparation for the AUVSI 2006 Student UAV Competition. A brief rationale for each subsystem's choice as well as the method of implementation to the UAV was discussed.

Safety was paramount to this project. The participating students had to become familiar and fully aware to the associated risks of dealing with flammables, internal combustion engines and propellers. Safety compliance was addressed with checklists and constant reinforcement of situation awareness.

Within the consideration of the context of this document, it is clear that the UTA UAV is capable of achieving the performance goals of the 4<sup>th</sup> AUVSI Student UAV Competition.

## ACKNOWLEDGEMENTS

Special appreciation goes to our main sponsor, Bell Helicopter Textron, for their generous financial sponsorship. We also thank the MicroPilot Company for their generous contributions and discounts used on the project. Also to Reflex XTR for donating a computer R/C flight simulator to use for pilot training. Additional thanks goes to Multiplex giving the team a wonderful deal on their radios and other electronics. Special thanks go to Jay Francis from Reactive Technologies for developing and donating two of his bypass boards to the AVL.

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## APPENDICES

### Appendix I: Airframe Characteristics

#### Aircraft Parameters

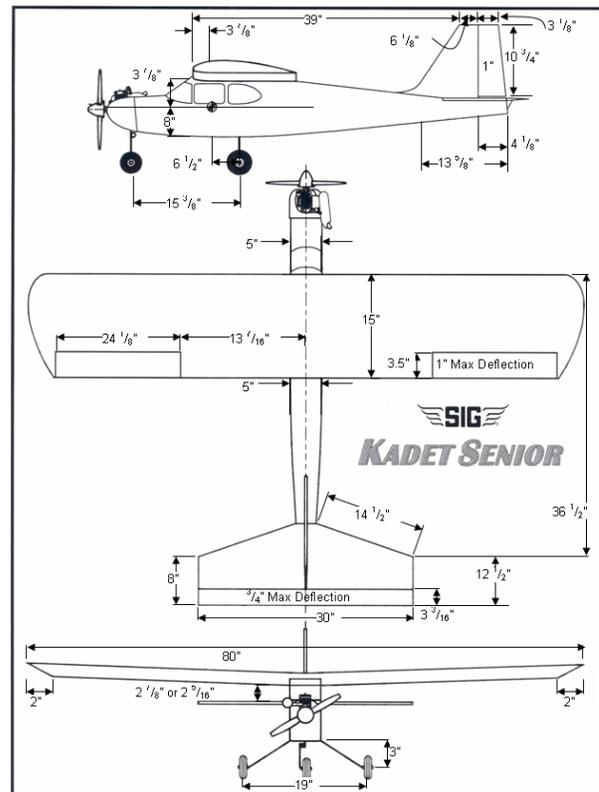
SPECIFICATION		UNITS
Aspect Ratio	5.07	
Wing Area	7.92	ft <sup>2</sup>
Wing Span	6.33	ft
W/S	0.66	lb/ft <sup>2</sup>
Fuselage Length	5.33	ft
Fuselage Width	0.42	ft
Weight Take-Off	12	lbs
Weight Landing	11.5	lbs

#### Engine Specifications

O.S. Model	61 FX (OSMG0561)
Displacement (cu in)	0.607
Bore (in)	0.945
Stroke (in)	0.866
RPM	2,000-17,000
Output (HP@rpm)	1.90 @ 16,000
Weight (oz)	19.4
Recommended Props	11x8-10, 12x7-11, 12.5x6-7

#### Flight Characteristics of UTA UAV

Cruise Speed (mph)	40
Max Speed (mph)	70
Cruise Altitude (ft)	250
Max TO Weight (lbs)	14
Empty Weight (lbs)	10.5
Range (mi)	20
TO Distance (ft)	60
Landing Distance (ft)	60
Wing Loading (lbs/ft <sup>2</sup> )	1.768



## Appendix II: Hardware Characteristics

### Combined Radio Communications Equipment Specifications

Model	Multiplex Evo 9 	Multiplex Synthesized Receiver 	MaxStream XTend Radio Modem 	Black Widow 2.4Ghz 1000mW Transmitter 	Black Widow 2.4Ghz 1000mW Receiver 
Type	Transmitter	Dual Conversion Receiver	Transmitter and Receiver	Video Transmitter	Video Receiver
Channels	9	9	7	8	8
Frequency	72 MHz	72 MHz	900 MHz	2.4 GHz	2.4 GHz
Range	1.5 mi	1.5 mi	Up to 20 mi.	-	-
Operating Voltage	DC 8.2V	DC 4/6V	DC 8.7V	DC 12V	DC 12V
Connectivity Hardware	PC Interface Cable	Servo Control Wires	RS-232 PC Serial Interface Board	RCA F-type Wire Connectors	RCA F-type Wire Connectors

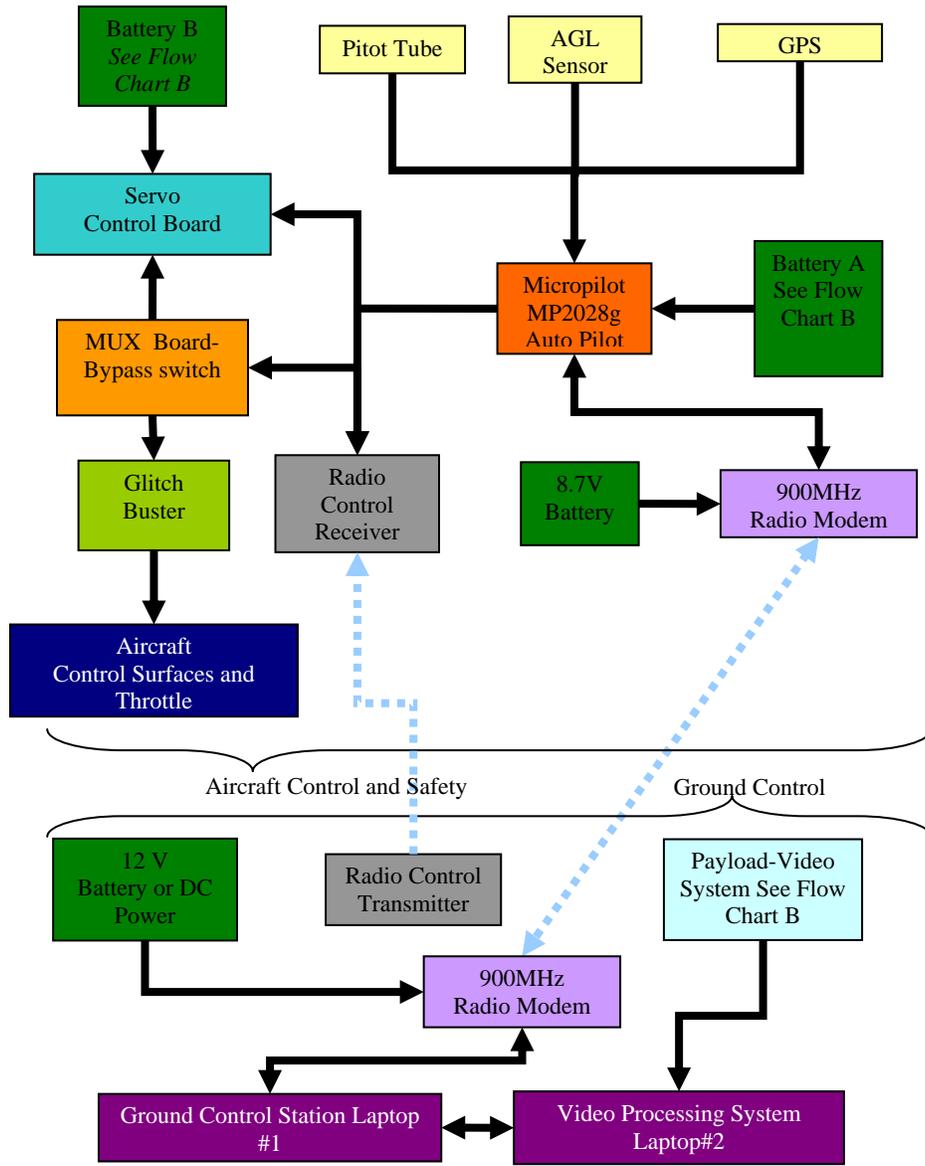
### Camera

Model	Black Widow KX141 
Signal format	NTSC
Resolution	768 x 494 pixels
Operating Voltage	12V, 130mA
Lens	5mm – 50mm varifocal lens
Battery:	11.1 V LiPo

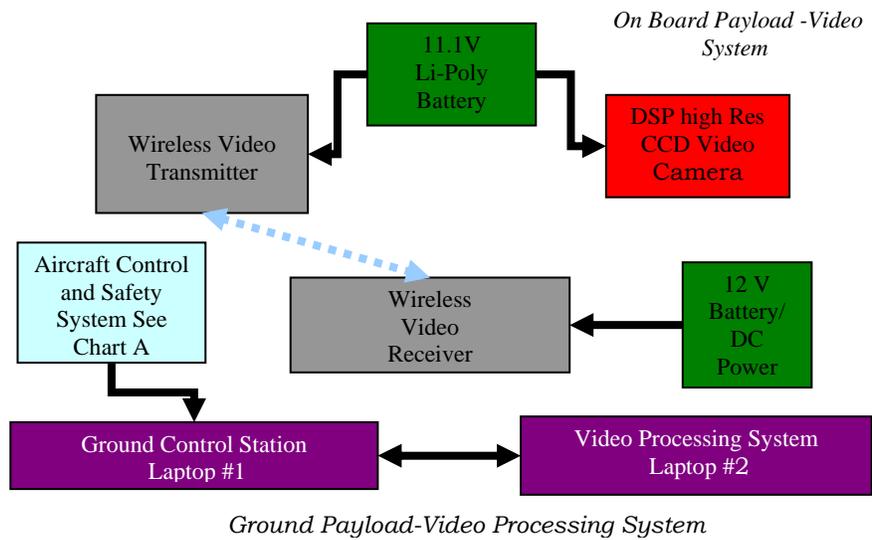
### GPS Antenna

Model	San Jose Navigation Inc. Model: MK-4 
Type	Mini GPS Receiver
Frequency	1575.42 MHz
Size	1.34 x 1 x 0.4 inches
Gain	+5 dB

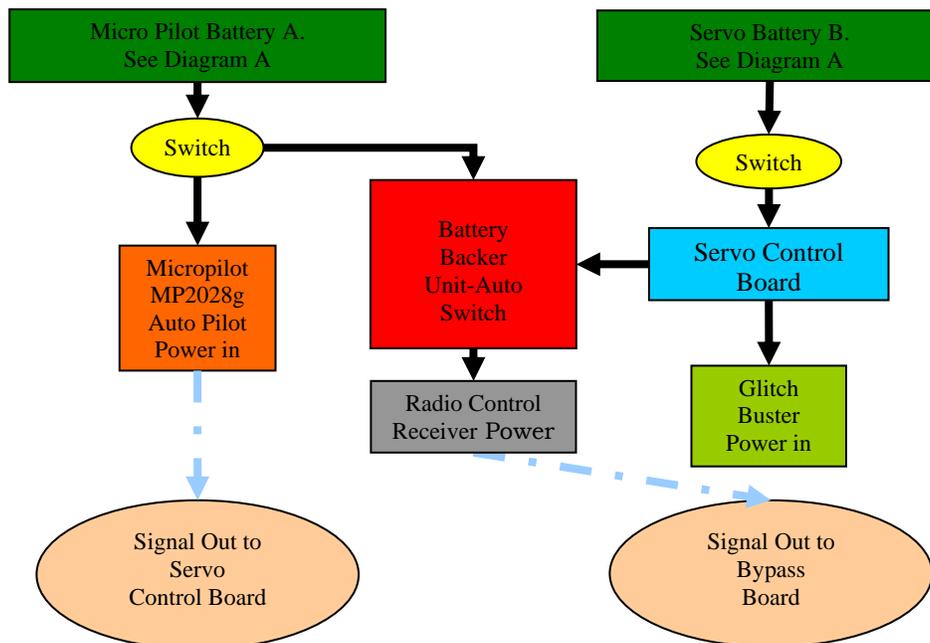
### Appendix III: Avionics and PID Tune-up



**Flow Chart A: Aircraft Control & Safety, and Ground Control System**



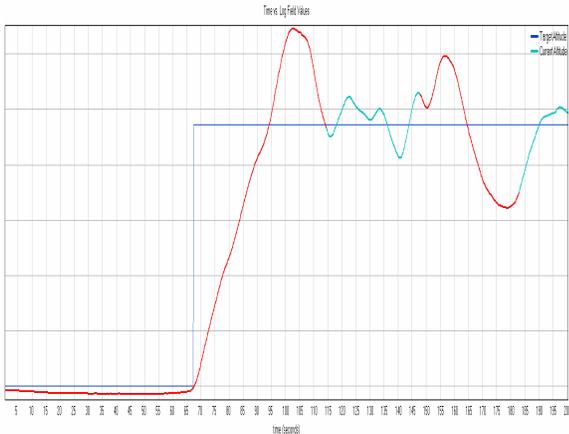
**Flow Chart B:** *Onboard Payload system and Ground payload processing system.*



**Flow Chart C:** *Battery safety system backing system*

## LEVEL FLIGHT PID FEEDBACK LOOP EXAMPLE

The following comparison exemplifies a Level Flight feedback loop (altitude hold) of a tuned and un-tuned setup.



**Time sec**

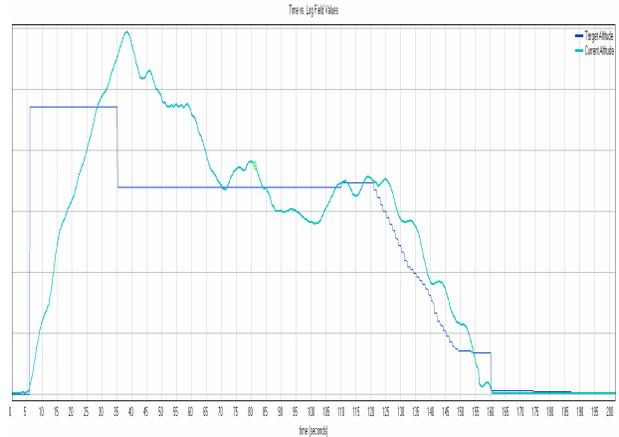
**Figure A.** The above represents an un-tuned setup for the outer PID loop “Elevator from Pitch” and inner PID loop “Pitch from altitude”

Target altitude 500 ft:

On a 6 mph wind oscillation between 342 to 684 ft

As you can see in the above graph the actual altitude (unsteady line) considerably deviates from the target altitude (straight line). Once the level flight inner and outer loops were properly tuned the current altitude versus the target altitude deviation dramatically decreased.

The following figure exemplifies a tuned inner (pitch from altitude) and outer (elevator from pitch) loop that yield a steady and consistent level flight and altitude hold.



**Figure B.** The above represents a tuned setup for the outer PID loop “Elevator from Pitch” and inner PID loop “Pitch from altitude”

Target altitude 180 ft:

On a 20 mph wind oscillation between 201 to 153

Clearly the aircraft while under stronger winds was able to hold a better altitude than the first case. Accordingly all other loops were carefully examined and tuned appropriately.

## Appendix IV: Troubleshooting

### Sample Troubleshooting Chart

Problem	Possible Cause(s)	Solution
Positive pitching moment	Negative thrust angle	Change the thrust angle to 0 deg
Radio frequency interference	<p>GPS signal is causing an interference</p> <p>Radio waves emitted from wires are causing interference.</p> <p>Radio frequencies from the modem are causing interference.</p>	<p>Locate the GPS receiver away from the MicroPilot in a position in which its wires do not cross the MicroPilot or servos.</p> <p>Shield wires with copper tape with gap in the shielding and connect all the negatives to a common ground.</p> <p>The same as GPS signal interference. Separate main power source cables away from signal cables</p>
Malfunctioning MicroPilot.	<p>Radio frequency interference.</p> <p>Vibration from the engine is causing an interference</p>	<p>Cover micro pilot with 1mm thick copper box to isolate MicroPilot from frequencies and follow above solutions.</p> <p>Mount the engine on vibration reduction mounds. Replace the engine to a less vibrating one.</p>
Malfunctioning Radio Transmitter.	Transmitter is out of tune.	Send to the manufacturer for oscilloscope tuning.
Airplane making shallow bank turns.	The PID term "roll from heading" for is lower than required.	Increase PID term in order to get required bank angle.