Entry for the 3rd Annual AUVSI Student UAV Competition

Massachusetts Institute of Technology
Unmanned Aerial Vehicle Team

Jonathan Downey, Derrick Tan

June 16, 2005

Abstract

This year, the MIT Unmanned Aerial Vehicle Team will be competing in the Student UAV Competition for the first time. Each year, this competition challenges students to build an autonomous aircraft that is capable of completing a realistic mission. While our UAV is very simple and only uses off-the-shelf parts, it will be a valuable asset to all future developments by our team. This paper describes our aircraft and some of the design decisions made during its development.

Table of Contents

Introduction

This year, the Association for Unmanned Vehicle Systems International (AUVSI) will be hosting the third annual Student UAV Competition. This competition seeks to engage students with the difficult task of building and testing an autonomous aircraft. By doing so, AUVSI hopes to foster ties between these undergraduate engineers and the organizations developing UAV technologies. Each year, the competition requires a team's UAV to complete a realistic mission. This year's mission requires a radio controllable aircraft to navigate a specified course and use onboard sensors to asses a series of man-made objects on the ground.

Starting a Team

The MIT UAV team is made up of five undergraduate engineering students from three disciplines at MIT. Jonathan Downey, an electrical engineering and computer science (EECS) junior, founded the team in January after being a member of the MIT Remotely Operated Vehicle (ROV) team for two years. Jonathan imagined that working on an autonomous system, especially an aerial one, would provide many new challenges and an opportunity to gain practical and hands-on engineering experience. Jonathan was in charge of the aircraft's electronics and avionics. He also found sponsors and funding for the development of our vehicle.

Derrick Tan, a mechanical engineering junior, was in charge of the airframe and video system. With a background in aeronautics, he was able to find an almost-ready-to-fly aircraft and modify it heavily to increase flight stability, accommodate sensors, and carry more weight. He is also the team's pilot with years of R/C experience.

Eric Adjorlolo, a mechanical engineering sophomore, worked on the ground station hardware and software. He is also developing a path-planning algorithm for future aircraft control.

Mathew Doherty, an EECS junior, is responsible for large parts of our next-generation avionics system, the webpage and helping with sponsorship.

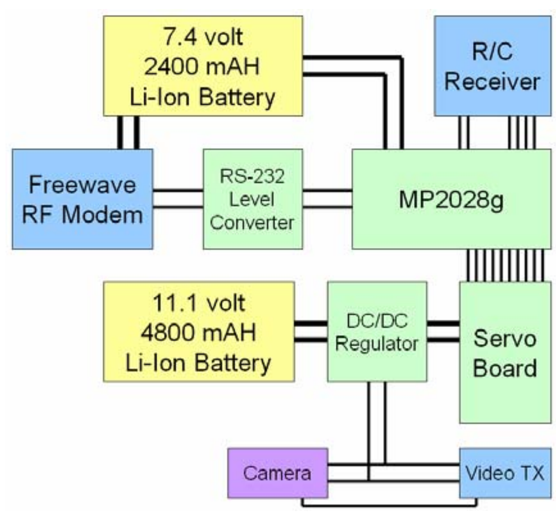
Jon Gibbs is our only Aeronautics and Astronautics student and is currently president of the MIT chapter of AIAA. He works on flight controls for our next-generation avionics system.

Team Goals

After starting late in the year with a handful of people and no resources, a large amount of our efforts have been aimed at developing a team, securing funding, and finding a place to work. With the long-term in mind, our team goal for this year has been to develop an easily modifiable and reconfigurable aircraft that can be used for both this year's competition and competitions in the future. In support of a long-term aircraft, we have been developing two avionics systems. One avionics system is made from off-the-shelf parts based on the MP2028g autopilot. This system will get the job done, but will not have all of the capabilities and precision of our next-generation system. The next-generation system is a largely custom avionics suite based on modular components.

Design Details

The purpose of this year's design is to give us a launch point for full-scale development next year. With this in mind, development of a sturdy and reconfigurable aircraft was the highest priority to us. We also desired to gain familiarity with the radio equipment, batteries, video equipment and other electronics that we will be using in the future. As a result, our aircraft is very simple and demonstrates only basic autonomous capabilities.



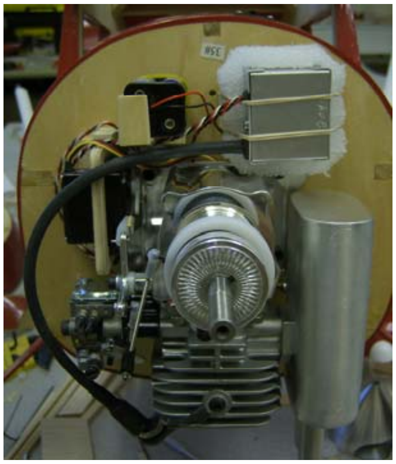
Aircraft

In choosing the airframe for the MIT UAV, many requirements had to be met. The aircraft would need to be a stable platform that could fly slow enough to take accurate image data and fast enough to cover distance at a decent rate. It would also need to have good flight duration, range, and lifting capabilities that would allow a useful payload to be accommodated. The ability for short takeoffs and landings for short fields was also a priority.

With these requirements, the Kangke Monocoupe was selected as the best aircraft for the intended application. It is a ¼ scale model of a 1930s aircraft called the Monocoupe 90A.

The model aircraft has a 98 inch wingspan with a wide chord giving it the capability for lifting large loads. With so much wing area, the wing loading is low allowing for low speed landings. It also offers an interior with enough volume for a sizeable payload. With such a large aircraft, there would be no problems in carrying all the present and future avionics and camera equipment. A high winged aircraft, the Monocoupe is also inherently stable.

Modifications were made to increase the usable space within the airplane. The original design called for servos, engine ignition, and battery to be located within the main cabin but this severely reduced useful space. Instead, the servos that controlled the elevator and rudder were relocated to the farthest point back in the airplane as possible. This not only opened up space but also had the added plus of reducing the amount of play in the control surfaces. The original design also called for the ignition battery, ignition, and engine servo to be located behind the firewall in the main cabin but this also took up useful space. Again, modifications were made and all these components were relocated out of the main cabin and into spaces surrounding the engine. Relocation opened up significant amounts of space.

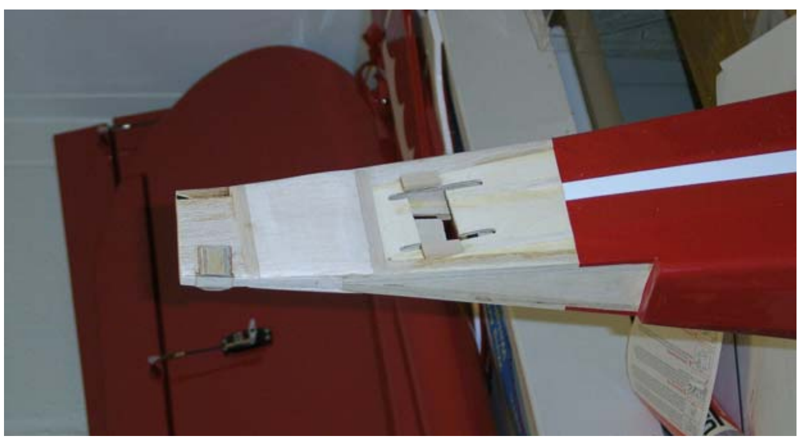


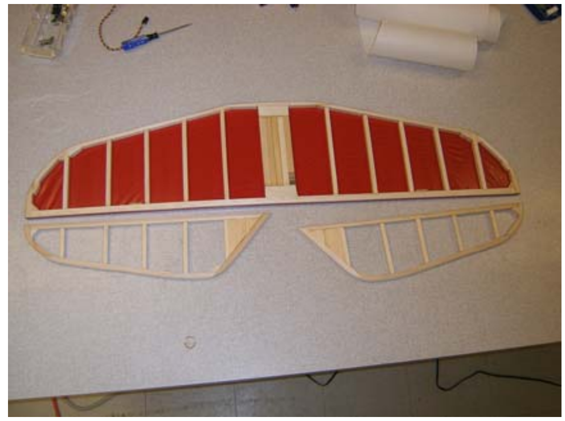
The first power plant used on the Monocoupe was a 25.4cc Zenoah gasoline engine. It had sufficient power but needed to work harder than desired to pull the plane up to altitude. The plane, loaded with all the avionics, required more power.

Thus a second, larger engine replaced the Zenoah to deliver this power. A 39.4cc Brison engine was installed that not only weighed approximately the same as the smaller engine but output significantly more power. This engine allowed the plane to climb vertically and hover on engine thrust alone. With this setup, the plane flew with authority.

During flight tests for structural integrity, the Monocoupe's airframe was put through various aerobatic maneuvers and a problem not related to the airframe's strength was brought to attention. A minute after inverted flight, the engine would sputter and die. The immediate culprit was thought to be the fuel system as a new mounting technique had been used to save space. The system was composed of three gas tanks in series. Two 32 ounce tanks served as the main tanks and were mounted vertically to save space while a small horizontal header tank was placed between these tanks and the engine. The header tank was used because it was thought that it would prevent the possibility of air bubbles entering the fuel line. It turned out that the tank only delayed the bubbles from reaching the engine and didn't eliminate the problem. Thus the header tank was scrapped and the two main tanks were remounted horizontally. This took up useful space but solved the problem and completely eliminated any engine failures.

Oftentimes, aircraft are designed for responsiveness to control input, but this comes at a cost of less stability. The Monocoupe was designed in this way so that initial flights unveiled a tendency for pitching oscillations. For the purpose of reconnaissance however, flight that is predictable and as stable as possible is desired. Thus it was determined that modifications to the original airframe design had to be made. The body of the aircraft was lengthened by four inches and the stabilizer and rudder were enlarged by 50 percent to dampen any oscillations that existed. Once flight tests commenced, all prior stability issues disappeared.



Testing revealed another weakness of the aircraft design. The airframe had been designed to fly at a lower weight but the current configuration held three times the fuel as well as electronic and video equipment. With all of this added weight, the landing gear bent on hard landings. Thus the gear was modified to accommodate the extra load. Struts with spring suspension were added to soften landing stresses and hold the weight of the plane.

Redundant controls were built into the aircraft just in case anything failed during flight. With two ailerons and two flaps, control would be maintained even if one failed. The elevator was split into two parts, each powered by a servo to ensure the elevator would also be functional if any servo died. Using redundant controls, the airplane was ensured to land safely in the event of a single mechanical failure.

Overall, the aircraft design was completely successful as it achieved all goals set for it. The final airplane is very stable as inputting no control to the airplane results in straight and level flight. The gasoline engine gives the Monocoupe a cruising speed of

75 mph allowing crisp video while also allowing the UAV to cover significant distances in a timely manner. The powerful engine allows the plane to takeoff within 10 feet while flaps allow a slow landing speed and landing distance of 40 feet. The large fuel capacity gives the airplane a flying duration of 2 hours and range of 150 miles.

Autopilot

We are using the MP2028g provided in the Micropilot sponsorship package. This autopilot is reasonably small and is capable of achieving the minimal autonomy that we are looking for at this point.

Power

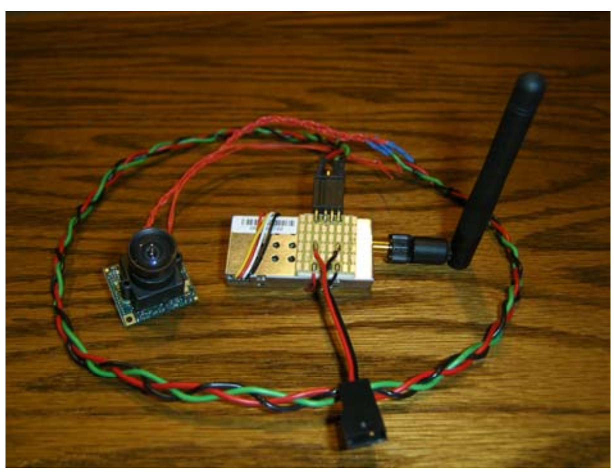
Two custom battery packs supply power to all of the aircraft's electrical systems. The first battery is a 7.4 volt lithium-ion pack that directly powers both the MP2028g and the RF modem. The second battery is a much larger 11.1 volt pack that is capable of supplying nearly five amp-hours of current. This battery powers a DC/DC converter that supplies five volts to all of the servos, the camera and the video transmitter. These batteries should be able to supply the aircraft with power for about two hours.

Video

Real time, wireless video was chosen as the imaging system of choice for several reasons. It allows a target's GPS coordinates to be determined when the aircraft flies directly over it and allows verification that the aircraft is operating normally when the airplane is out of visual range. Real time means that the location of the target is exactly the location of the plane when the target is directly below. And because the GPS coordinates of the airplane are always known, the target location can also be determined.

The wireless video camera is mounted to the airplane's wing via a soft foam mount to help reduce vibrations and provide the best picture quality possible. A servo tilts the camera up and down to allow a forward as well as straight down view. While traveling to the destination where targets are expected to be, the camera aims forward to give the ground station team members the progress of the aircraft as it moves towards the target. Once the destination has been reached, the camera is manually pointed downward to track the ground and determine the GPS coordinates of the targets.

A 470 line color CCD camera was chosen to give a high resolution video feed of ground targets. It gives good accuracy and enough resolution to identify targets. A 71 degree field of view lens is installed on the camera to give good situational awareness in the images taken. All images and video are relayed to the ground via a 2.4 GHz, 600mW transmitter located within the airplane's main cabin.



At the ground station a receiver is used to collect the radio data to be analyzed by team members. Tests with common video receivers had produced video that showed static and snow due to multipath issues. To clean up the video, a new receiver called a Diversity Receiver was used. The Diversity Receiver consists of two receivers receiving the transmitted video signal while a separate circuit compares the two signals and selects the best one to output. Thus the video feed output by the Diversity Receiver results in almost unbroken video. The analog output of the receiver is input into a television tuner which then outputs a digital signal via USB 2.0. This is then recorded directly to a hard drive within a laptop to allow the video to be rewound and analyzed to verify GPS coordinates of targets. To enhance the range of the video receiver, the common dipole antennas were replaced with 14dbi patch antennas. This roughly quadrupled the range when the antennas were pointed at the aircraft.

Communications

The aircraft is able to communicate with the ground station using a set of long-range 900 MHz frequency-hopping spread-spectrum data modems made by Freewave technologies. These modems can transmit data at a rate of up to 115.2 kbps and have a range of up to 60 miles line-of-sight. With embedded electronics, they are able to establish secure communications, reject noise, and retransmit lost data.

Ground Station

The team's ground station consists of two laptop computers. One laptop computer runs the HORIZON software and communicates with the MP2028g over the data modem. The other laptop connects to the TV tuner and records video from the plane. This video, along with time and GPS data from the autopilot, is then used by an operator to locate the targets visually.

Budget

The following is a short summary of our budget that went towards this year's competition entry.

Category	**Price**
Airframe	$1,720
Communications	$2,040
Navigation	$10,500
Ground Systems	$1,655
Machine Vision / Cameras	$265
Travel	$3,110
General Expenses	$1,745
Total Budget	**$21,035**

Conclusion

This past semester turned out to be very different than any of us expected. We all expected challenging technical problems, but we ended up having to spend a majority of our time dealing with other issues such as sponsorship, procurement, and regulations. In particular, finding a flying field was extremely difficult because of the size of our gas aircraft. We were forced to drive a long way to a flying field which made flight testing very difficult. Snow also caused many problems when it covered the flying field until late April. As a result of these problems and other deterrents, we were not able to flight test our aircraft nearly as often as we would have liked to.

Despite problems such as these, we feel that our small team has made progress in a lot of areas this past semester. While we may only be able to demonstrate very limited autonomy, our aircraft is rock-solid, reliable and will be a valuable asset to us in the future. We look forward to this competition as a stepping-stone to continued development.

Acknowledgements

We would like to extend a special thank you to all of the sponsors and individuals that have made this opportunity possible for us. First of all, thank you to the MIT Edgerton Center for funding our team, providing us with guidance, and managing our finances. Thank you, Sandi Lipnoski, for always being patient with us while managing our account. Also, thank you to the MIT Laboratory for Information and Decision Systems and our advisor, Professor Eric Feron.

We would also like to thank our platinum sponsors: L-3 Communications and NovAtel. L-3 Communications is our largest financial supporter and provided funding for the majority of our development. NovAtel has been extremely generous by providing us with exceptional GPS equipment at a highly discounted price.

Thank you, Altium, for your industry-leading Protel PCB software. It was used in the design of much of our next-generation electronics. Thank you, Microsoft, for all of the software that you generously donated to our team for our ground control station. Thank you, Micropilot, for the sponsorship package including the MP2028g. Thank you, Freewave, for the abundance of reliable RF equipment. Thank you, Phytec, for the single-board computer that is also a part of our next-generation system.

We would also like to thank A.M.E. Manufacturing, EHK Adjorlolo & Associates, and Geneva Aerospace for their generous sponsorship of our team.