Team Manitoba Project Description

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Abstract

The Team Manitoba Aerial Vehicle Group entry for the 2009 AUVSI Student UAS competition is a continuation of the platform we have been developing over the past four years. We have remained with a similar airframe throughout, making modifications as needed while maintaining the integrity and robustness of the aircraft in order to ensure the safety of our payload. Through careful review and consideration of all competition rules and objectives, we have decided upon a system that is capable of performing the necessary tasks while remaining within a set budget. Because of our familiarity with Micropilot's 2028g autopilot, we continue to rely upon, and consider it an integral component of our system. Our main airframe advancements have been made to the imaging system, incorporating a new image acquisition system to which autonomous target detection software is applied. A second imaging station has been improved upon from previous competitions and is capable of determining target location through the use of edge detection, perspective correction, and predictive telemetry interpolation. It is our belief that the changes made to this year's UAS will allow us to complete the mission objectives as outlined in the 2009 Regulations Document.

Fig 1: University of Manitoba Unmanned Aerial Vehicle Group 2009 Entry Photo

1 Introduction

Over the past few years, interest in Unmanned Aerial Systems has continued to grow, influencing technological advancement in the areas of robotics, avionics, and surveillance equipment. Today, UAS are used in both military and civilian applications for the purpose of gathering information and limiting human exposure to potentially lethal situations. As the conditions and requirements placed upon each system is unique, it is important to take this information into consideration when planning out the design and construction of a UAS. For our 2009 AUVSI Student UAS Competition Entry, the Team Manitoba Unmanned Aerial Vehicle Group made sure to outline all the functional requirements of the system as dictated by the competition rules and objectives. These requirements were then referred to in the creation and implementation of the aircraft and all major system components.

1.1 Functional Requirements

In order to satisfy the functional requirements of the UAS, the competition rules were analyzed in order to ensure all of the mission objectives were addressed. These requirements were divided into two sub groups; those pertaining to vehicle control and those of the imaging system. For vehicle control, it was established that the aircraft must be capable of demonstrating four objectives including:

- Autonomous take off
- Ability to change flight parameters while in flight
- Ability to navigate through a series of GPS waypoints
- Autonomous landing

The functional requirements for the imaging system were also considered, and it was concluded that in order to succeed with the mission objectives, we must be able to:

- Capture imagery of a high enough resolution to identify targets
- Translate image coordinates to GPS coordinates in order to establish target positions within the search area

2 Airframe

For the past four years, we have been utilizing a Sig Kadet Senior airframe, enlarged 5%, to carry our mission payload. Our decision to continue with this aircraft stems from the fact that it has proven to be an extremely stable flying airframe with the capacity to carry the required components of our system. The time we have spent working with this aircraft has allowed us to come up with adjustments to the air vehicle that will better enable us to complete the outlined mission objectives. We now have two completed airframes that are capable of running independently of each other. Although we are not currently testing with the secondary vehicle, it is available to be used as a back up system in the event of primary aircraft failure.

2.1 Modifications

The greatest modification to this year’s competition entry is in the conversion from an OS 70 cu in four stroke engine to an E-flite Power 60 out-runner electric motor. The decision to convert to electric was made soon after returning from last year’s competition. After reviewing the footage taken from our cameras, it was discovered that motion blur was being introduced into the imagery through high frequency vibration caused by the four stroke engine. In order to reduce this blur, an electric motor was chosen to replace the existing engine. Subsequent tests have proven successful in that much of the motion blur we were experiencing has been eliminated.

The switch to electric has also proven beneficial in other regards when it comes to airframe performance. In previous years, we found we were spending a lot of time tuning the engine in order to make sure it performed adequately. For example, if the throttle idle setting was not correct, the engine would often stop during flight which prompted a need for our safety pilot to perform an immediate landing. The conversion has allowed us to better allocate our testing time to focus on the payload systems.

Changing to electric has also eliminated our dependence on fuel. Due to the strict regulations governing air travel, we have not been able to bring fuel with us to the competition. As a result, we have been reliant on the availability of our fuel type within the vicinity of Webster Field. On more than one occasion, we have had to buy fuel from other teams in order to fly due to local hobby stores not having what we were looking for. Thanks to the transition to an electric motor, our system no longer has this dependency.

Although the change to an electrically driven system has proven beneficial, it introduced several issues that needed to be addressed.

One issue that arose was an increase in weight due to the extra batteries now required for propulsion. The additional batteries weigh more than the fuel we carried previously. The three batteries used to power the aircraft weigh approximately 1 pound each and, unlike fuel driven aircraft, the weight does not dissipate with flight time.

In order to compensate for this increase in weight, we sought to reduce the airframe weight in other places. The main reduction in airframe weight was accomplished by reducing the size of our main landing gear by 25%. The previous landing gear design was quite robust and exceeded the requirements of our electric airframe.

The second aspect of the airframe that we sought to improve was the aerodynamics. Due to the limited flight time that the batteries are capable of providing, we endeavored to improve the airframe aerodynamics in order to increase the amount of time we can remain in the air. Two major sources of drag were identified: the firewall and the main landing gear wheels. To reduce the drag, we built a cowl to cover the firewall of the aircraft and wheel pants to cover the wheels of the main landing gear. In testing, these changes have increased our run time by 20% bringing the amount of time we can remain in flight to over 30 minutes. Testing and previous experience leads us to believe that this run time should be adequate to achieve all mission objectives while maintaining a safety margin.

Another issue arising from the use of an electric motor relates to the size of the batteries and the ease with which they can be accessed from outside the aircraft. In our previous design of the fuselage, we had included a side door so that we would be able to access the Lithium Polymer batteries we were using without having to remove the wing from the aircraft. With the conversion to electric and the introduction of three, much larger A123 batteries as our main power source, this side door has proven to be an insufficient access point. As a result, we have fully integrated the batteries into our system. Our electrical systems have been designed so as to accommodate charging of the batteries while they remain inside the fuselage.

The last modification made to the airframe was introduced during the construction of a new wing. In order to better accomplish the competition objective of performing an autonomous landing, the wings were altered to reduce the dihedral to a half inch. In testing with the previous wing, it was found that when subjected to cross winds on landing, the dihedral tended to catch the wind causing the plane to roll over onto its side. Although we have not had an opportunity to test an autonomous landing to date, it is believed that the removal of much of the dihedral will help to stabilize the aircraft during approach of the runway.

2.2 Layout

The layout of the electronics inside the airframe is critical to prevent interference between devices and to properly balance the aircraft. In particular, maximizing the distance between the antennas on the aircraft and ensuring the center of mass is between 25% and 33% of the chord of the wing are prime goals when designing the layout. The GPS antenna was mounted inside the tail near the vertical stabilizer while the ultrasonic sensor was placed on the bottom of the left wing and the radio modem antenna was mounted vertically inside the tail. The vertical orientation of the radio modem antenna was chosen in order to maximize signal strength regardless of aircraft orientation. The autopilot board was placed at the approximate center of mass of the airframe to ensure that the aircraft motion and acceleration it measured were as accurate as possible. The camera was installed below the autopilot in the belly of the aircraft to avoid obstruction of the camera's field of view by the landing gear and to aid in achieving proper balance of the airframe. The camera is solidly mounted to the frame by a CNC machined plastic bracket with slotted holes to allow for precise placement inside the bay. This adjustment feature is mainly used to achieve proper balance. The video transmitter is mounted near the center of the airframe to maximize its distance from not only the other transmitter/receivers, but also to minimize interference caused by the high current motor leads.

Flight testing raised concerns that long servo leads could receive radio control (RC) interference, therefore all servo leads were kept as short as possible by placing the servos in close proximity to the autopilot and RC receiver. Servos inside the payload bay were located at the corners to maximize the available space inside the bay and to keep them out of the way while working inside the airframe. There were two requirements for the mounting method selected for our electronics. It was important to provide a solid attachment to the airframe while allowing for easy removal for development and testing. In addition, some components are particularly sensitive to vibration. Larger devices like the autopilot were first attached to a flat sheet of balsa wood with screws through their corner mounting holes. Velcro was applied to this sheet on the outer edges as well as to equivalent rails inside the fuselage. Smaller components had Velcro applied directly to their outer cases. This satisfied the requirements for easy access and semi-solid attachment. To prevent vibration from affecting the autopilot's operation, we added a layer of foam between the balsa sheet and autopilot board. This acted to isolate the autopilot from vibration while still providing secure attachment to the airframe.

The batteries were mounted as close to the front of the airframe as possible to make the center of mass of the plane fall between 25% and 33% of the chord of the wing. They are held solidly in place through the use of Styrofoam snugly fit to the inside of the nose of the plane. Styrofoam was added to prevent movement of the batteries within the fuselage as Velcro alone was shown inadequate in keeping the three larger main battery packs securely in place.

The placement of the batteries towards the front of the aircraft, also allowed for the shortest possible wire length of the high-current cables from the batteries to the electronic speed controller (ESC). The ESC was mounted with Velcro to the "ceiling" of the cockpit. It is vital to ensure that these high-current wires remain as far away as possible from the rest of the electronics inside the airframe to minimize the noise created in nearby components. Similarly, we mounted the power regulation/distribution block next to the ESC on the "ceiling" of the cockpit. Its shielded case not only stops interference from entering (as open ports can act as antennae) but also from escaping and affecting nearby components.

2.3 Range, Performance and Mission Capabilities

From data collected during test flights, the endurance of the air vehicle is about 30 minutes. RC operation is possible to a range of about 1.5 km.

3 Autopilot

3.1 Requirements

The team identified a number of requirements for the autopilot system from the published competition rules and past team experience. The requirements for flight control can be separated into those which are mandatory and those which are optional. The mandatory requirements are:

- Flight must be stable and controlled.
- The safety pilot must have a manual override capability during all phases of the flight.
- Error conditions must be handled in a safe manner.
- Flight telemetry data must be accessible to the imaging software at the ground station.
- Flight status display must include airspeed, altitude, attitude, aircraft position, and any supplied boundaries.

The optional requirements are:

- The autopilot should support autonomous takeoff and landing.
- In-flight retasking should be possible.

To meet these requirements, the team selected the Micropilot MP2128g autopilot and its ground control station software called Horizon. The team will have nearly five years of experience with Micropilot autopilots at the time of the competition which provides us with strong institutional knowledge and well-developed flight processes.

3.2 Hardware Description

The autopilot communicates with the ground control station software via a 9600 baud RS-232 radio modem which operates on 2.4 GHz. It includes pressure sensors for airspeed and altitude measurement, accelerometers and gyroscopes for aircraft attitude measurement, a GPS antenna and processor for position information, and an ultrasonic altimeter for improved altitude resolution below 15 feet during autonomous landings. Telemetry packets are sent by the autopilot to the ground control station at a rate of 5 Hz. Aircraft attitude information is included in every telemetry packet, while less important information (such as position) may only be updated at a rate of 1 Hz.

The autopilot receives input from the RC receiver for the safety pilot inputs. These inputs can be placed in command by a switch on the safety pilot's RC transmitter. When the autopilot is in command, servo movements are generated by the autopilot and output through a demultiplexing breakout board.

3.3 System Operation

PID Control
A hierarchy of proportional-integral-derivative (PID) control loops controls the flight of the aircraft. They translate the operator's navigational instructions expressed in a mission script file into flight manoeuvres which are then further processed to generate servo outputs to manipulate the control surfaces of the aircraft.

Mission Execution
Mission planning is accomplished through the use of an autopilot scripting language. The language includes commands for autonomous flight phases (such as takeoff or landing), navigational instructions, control of flight parameters (such as altitude or airspeed), and direct manipulation of servo positions.
While some ingenuity may be required to construct a flight plan for a particular mission, the autopilot is capable of meeting all of the identified mandatory and optional requirements.

Telemetry Interface
The imaging software must have access to the autopilot telemetry data in order to associate imagery with a position on the ground. The simplest solution is to use a splitter in the RS-232 cable which sends telemetry from the radio modem to the ground control station. An additional connector was attached with only the receiving (RX) pin connected to the radio modem. This provides a duplicate of all telemetry data from the autopilot without any additional software requirements on either computer.

Development Priorities
From past competition experience, a few areas were identified as development priorities for the autopilot system.

- PID gain tuning

  Although the autopilot currently flies the plane in an acceptable manner, some less-than-ideal characteristics were identified. Better tuning of the PID gains results in more stable flight which is beneficial to the imaging subsystem.

- Imaging interface

  At the previous competition, the telemetry data was not provided to the imaging station and no position data regarding targets could be generated. We have since implemented the connection between the two systems.

- Error handler operation

  At the previous competition, a misunderstanding of the resolution criteria of the error handlers combined with the intermittent appearance of applicable error conditions resulted in a flight that had to be manually flown for a large portion of the mission. By more fully understanding the operation of the error handlers in the autopilot, we can make changes which provide an equivalent level of safety with the addition that momentary errors will not adversely impact the mission.

4 Electrical Systems

4.1 Electric Propulsion

Many factors needed to be considered when selecting an electric motor, ESC, and battery combination for our airframe. In order to help us select an appropriate system for our needs, we consulted the local modeling community. They offered us their experience with different systems and they directed us to MotoCalc, an application for modeling aircraft and electric propulsion systems.

Using MotoCalc and the physical properties of our airframe, we were able to determine several key properties of our airframe including coefficients of lift and drag for our wing,

wing loading, and stall speed.

Coefficient of lift at level flight = 0.52
Coefficient of lift at the optimal lift to drag ratio = 0.69
Coefficient of lift at maximum angle of attack = 1.2
Airframe drag coefficient = 0.062

Once we had determined these parameters, we were able to model the performance of our airframe with different motor, gearbox, ESC, and battery combinations. Our selection criteria included local availability, proven track-record, cost, performance, and efficiency. Considering these criteria, we selected an E-Flite Power 60 motor and an E-Flite 60A ESC. Although higher efficiencies could have been achieved by utilizing a reduction drive gearbox and larger propeller, local modelers advised us against using a gearbox for the relatively small increase in efficiency.

Once the motor and ESC were selected, we were able to determine what the optimal cruising speed of our airframe was and, subsequently, what the power draw of the motor and ESC would be during climb and level cruise.

Stall speed = 31mph
Optimal cruising speed = 35mph @ 271 Watts, ESC/Motor efficiency = 77.8%
Maximum speed = 44mph @ 460 Watts, ESC/Motor efficiency = 79.8%

Utilizing this power requirement information and the mission profiles from past competitions, we were able to determine how much energy we required for a typical mission. As an average, MotoCalc predicted that we would require 250 mAh per minute of flight time. Based upon a typical mission flight time of 20 minutes, allowing for a margin of additional flight time, and allowing for a margin of battery degradation over time, we determined that a battery capacity of approximately 7000 mAh at 18V would be required.

4.2 Batteries

In our conversion to an electrically propelled system, one of the most important decisions we had to make was with regard to the type of battery we were going to use to run the motor and other electronic systems. In talking with experienced airplane modelers, a relatively new battery type was suggested to the team. These batteries, manufactured by A123 Systems, are a lithium cell with the chemical composition lithium iron phosphate ($LiFePO_4$). Unlike other lithium-based batteries such as lithium cobalt oxide ($LiCoO_2$) and lithium manganese oxide ($LiMn_2O_4$), the new $LiFePO_4$ technology demonstrates some unique capabilities that have proven beneficial for us with regard to the project.

One of the benefits is the ability of these batteries to be charged quickly. In order to get the most out of our short flight season, we needed something that would allow us to get in a large number of flights during our practice runs. Because the A123s are capable of being charged in as little as 15 minutes, these batteries have proven ideal for our needs. This 15 minute charging time was considered acceptable as it provided us a window in which to analyze the flight and imaging data from the autopilot and camera.

Another major consideration with regard to battery selection was in the area of safety. Many lithium batteries are highly volatile and can become unstable when subjected to conditions such as over-heating, over-charging and high currents. The bonding between the iron and phosphate in the cathode of the A123s is much stronger than the chemical bonding in the cathode of other lithium batteries. This makes the cells inherently more stable and resistant to the abuses associated with repeated flight and charge cycling of the batteries.

Historically, modelers have considered it wise to remove batteries from the aircraft before charging. Because the design of our aircraft makes it difficult to remove the batteries and due to the A123's established stability, we designed the power regulation board for onboard charging as discussed in the next section. A123 batteries are available in two sizes, 2300 mAh and 1100 mAh. For the main battery, we selected three 6S1P (6 series, 1 parallel) battery packs which provided a total capacity of 6900 mAh (within 1.5% of our projected requirements).For the back-up battery, we selected 1100 mAh cells in 3S1P configuration. This provided us with a small, lightweight battery for emergency use.

4.3 Power Regulation

Due to the change to electric propulsion, the team decided to design a new power regulation board to supply all of the onboard electronics. The board uses Texas Instruments PTN78060W switching regulators to provide the appropriate voltages to a number of busses as shown in Table 1.

Table 1.

Voltage (volts)	Number of Output Connectors	Devices Supplied
6	2	Servos and spare
9.3	1	Video camera
10	3	Autopilot, radio modem, spare
12	2	Video transmitter, spare

Each output circuit includes an LED to indicate that it is receiving adequate power. The board also provides an unregulated connection from the main 22 V input batteries directly to the electronic speed controller.

The power regulation board is supplied through a number of connectors. It includes inputs for up to four 22 V main batteries, one 9 V backup battery, and a port which allows connection to an external charger.

To ensure that the aircraft would be able to land safely in the event that the main batteries were depleted in flight, the autopilot, radio modem, and servos were deemed essential. The 6 V and 10 V busses are, therefore, protected by a backup 9 V battery to provide them with enough power to allow the safety pilot to perform an emergency landing.

5 Imaging

Previously Faced Challenges

In the 2008 AUVSI UAS student competition, several problems with the imaging station were identified by the team, including:

- Color accuracy of the camera
- Low frame rate while processing images
- Blurred images due to vibration of the camera

5.1 Camera

To improve the quality of the captured imagery, a new 3CCD Panasonic SD9 Camcorder was selected for this year's competition. Camcorder quality has improved considerably over the past few years. The SD9 comes equipped with image stabilization capability called Advanced Optical Image Stabilizer (OIS) which makes use of gyro-sensors to detect shakes, shifts the lens, and adjusts its optical axis to compensate for shaking.

The Panasonic SD9 is a 3CCD camera system which offers more accurate color reproduction compared to 1CCD camera systems. In a 3CCD camera system, each individual CCD processes red, green and blue color channels respectively. A 1CCD setup interpolates the channels to achieve the same result. As such, higher color accuracy can be obtained with a 3CCD camera system.

The SD9, being relatively inexpensive and feature-packed (image stabilization, 3CCD system, built-in digital signal processing for tuning contrast, etc.) was a good choice for our imaging system.

5.2 Autonomous target detection

From past experience in the competition, it was shown that when flying at an altitude of around 400ft, a target will appear for approximately two seconds on the live video feed. This puts a heavy stress on the operator and does not provide ample time to properly scan through the frames to search for targets. Thus, an autonomous target recognition software is developed is used to improve the reliability of the operator while ensuring high video frame rates. This software picks up and highlights any potential target on the video feed to help the operator identify targets more rapidly. Therefore, the operator's job changes from scanning each frame looking for targets, to scanning the potential targets and picking the true positives from the set of potential target candidates.

Image processing can be computationally expensive especially on a live video feed. To ensure a smooth video display, Canny edge detection is used with a highly optimized variant of a floodfill algorithm. Using this approach, the frame rate performance increased from last year's 2 frames per second to approximately 25 frames per second.

To further ensure a smooth video display, the captured image frames are not saved directly to the hard disk as I/O of large images will slow down the computer. The captured frames are initially saved to memory, and the software provides a way for the operator to save them after the target passes.

Fig 2: Screenshot Depicting Autonomous Target Recognition Capabilities.
Target found and bounded by a cyan rectangle

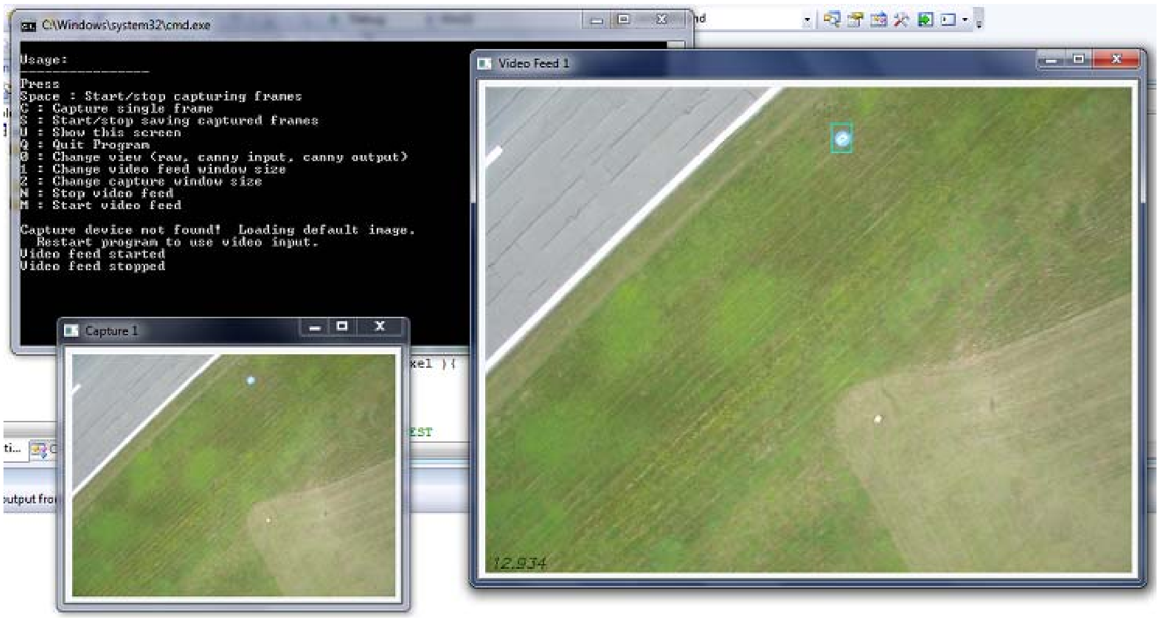
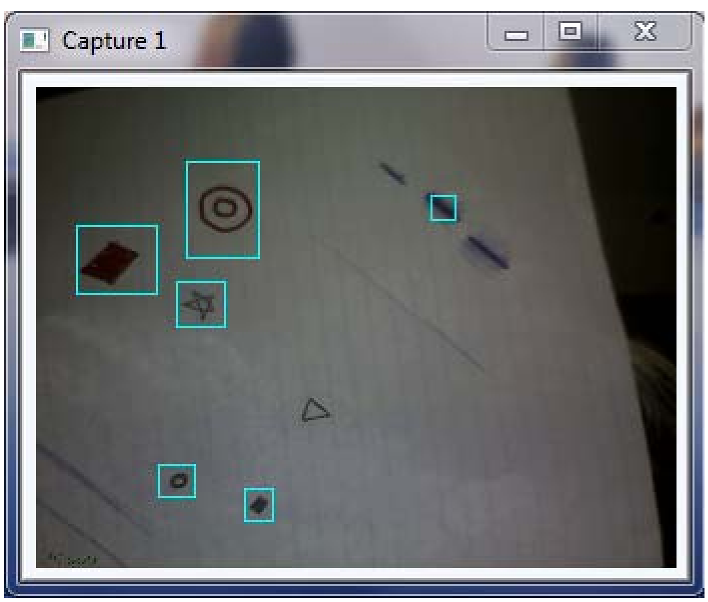


Fig 3: Various shapes



5.3 Secondary imaging station

To effectively identify the target's position and characteristics, a second imaging station is used to perform post-processing. This station will receive the images captured by the primary imaging station, and perform the following tasks:

- Use telemetry data from the autopilot to remove perspective distortion.
- Camera calibration to remove lens distortion.
- Time-stamp matching and telemetry interpolation to provide accurate telemetry data for each image.
- Color calibration to compensate for signal loss during transmission from the UAV to the ground station.

To provide GPS coordinates that are as accurate as possible, the secondary imaging station's operator efficiently handles vision tasks that are not worth automating. For each image, the operator ensures the pixel coordinates for the center of the target are accurate. The operator can eliminate false positives by selecting the true target and can easily override the automated target detection when required. Images with no targets are discarded, while images with targets are grouped by which target is visible. It is initially assumed that each sequence of captured frames shows a different target, so grouping rarely requires any manual work. To further improve the speed of the secondary station's operator, the primary imaging station captures frames at a relatively low frequency (currently 5 Hz).

For each image, appropriate telemetry data is automatically assigned and GPS coordinates for the target are computed. For each target, all the computed GPS coordinates are plotted on a map and one central/average GPS location for the target is pinpointed. The final coordinates are then displayed and written down by the secondary imaging operator. If necessary, the plane can make an additional pass over the target to improve the location estimate.

6 Safety

While operating the UAS, special precautions must be taken to ensure the safety of the aircraft, payload, and the students and spectators at the airfield. In order to avoid damage to the UAS and injury to others, a series of tests are performed at the start of each flying day, to make sure all of the system components are running optimally.

These pre-flight tests are deigned to ensure the integrity of the airframe, the proper operation of the autopilot and its sensors, and acceptable range of the UAS radios including the safety pilot's R/C transmitter. Examples of the tests performed include pitch, roll, and yaw responses of the airframe control surfaces, airspeed and ultrasonic transducer checks, and vibration checks of the electronics. A full list of the tests conducted is included in the Preflight Safety Checklist in Appendix A.

All battery voltages are checked before takeoff and monitored continually throughout the flight in order to ensure that we do not operate the UAS with low batteries. Because our UAS relies so heavily on batteries for both propulsion and control, we regularly conduct charge-discharge cycling of the batteries in order to both ensure that their capacity is adequate and to obtain accurate voltage discharge curves for use in estimation of remaining battery capacity.

Along with our safety checklist, several flight safety routines were programmed into the autopilot including the loss of signal events as required by competition standards. Additionally our system allows the safety pilot to activate the flight termination routine at any time from his R/C transmitter.

7 Conclusion

In order to complete the mission objectives outlined in the 2009 Competition Regulations Guide, the University of Manitoba UAV Group followed a requirement driven approach to determining the design of this year's entry. Particular detail was paid to the areas of the airframe, autopilot, ground station, imaging station, as well as, to the safety of the UAS and its crew, in order to optimize our chances of completing all of the assigned competition tasks.

References

1) Paul Furgale, Sancho McCann, Jim Majewski, Andrew Bugera, Kory Zelickson, and Jon Kurtas. Team Manitoba 2006 AUVSI Student Competition Project Description. In Association for Unmanned Vehicle Systems International (AUVSI): 4th Annual Student Unmanned Aerial Vehicle Competition, Lexington Park, MD, June 2006.

2) Andrew Bugera, Timothy Herd, Ashley Keep, Shun Jie Lau, Mo Ran Wang. Team Manitoba 2008 AUVSI Student Competition Project Description. In Association for Unmanned Aerial Vehicle Systems International (AUVSI): 7th Annual Student Unmanned Aerial Vehicle Competition, Lexington Park, MD, June 2008.

Appendix A

Fig 4: Modified 2006 Pre-Flight Safety Checklist

Date and time:								
Pre - Flight								
Pitch Response:								
Roll Response:								
Yaw Response:								
Main Battery Voltage:								
Back-up Battery Voltage:								
Airspeed Transducer:								
GPS Lock:								
Flight Plan Simulated:								
Radio Modem Link:								
AGL:								
Radio Control								
Range:								
Control Deflection:								
Transmitter Voltage: (9.5V - 12V)								
Engine								
Full Throttle:								
Transition from min. to full throttle:								
Vibration Test:								
Invert Plane Test:								
Runway Tests								
Vibration Test:								
Airspeed:								
CIC/PIC Switch:								
Ground Station Final Checks								
Battery Voltages:								
No Error Messages:								