Final Report

Team Six: Autonomous Unmanned Aerial Vehicle

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Abstract

The main objective of this project is to design, build and program an Autonomous Aerial Vehicle capable of performing specific tasks. The aircraft will be designed and programed according to the 2014 Undergraduate Students Unmanned Aerial Systems Competition and will be evaluated on the quality of the performed tasks as well as the consistency of its technical design and report.

Acknowledgement

This project would not have been possible without the help and support of numerous groups and individuals. Team Six, along with all of the other participants of the Student Unmanned Aerial System (SUAS) competition, owe our thanks to the Seafarer Chapter of the Association for Unmanned Vehicle Systems International (AUVSI) for hosting the competition. We would like to express our deep gratitude to Dr. Shih, for his generous funding and patient guidance throughout the year. Team Six would also like to thank Dr. Amin and Dr. Frank not only for providing us with constant advice and assistance and helpful feedback, but also for keeping us focused and on track with the schedule. Our thanks extend to Dr. Alvi, Dr. Yu, and many other FAMU-FSU College of Engineering faculty members that have provided us with technical knowledge.

We give special thanks to Robin Driscall for his expertise and the several mornings he spent preparing us to pilot the aircraft.

Furthermore, we would like to thank Mr. Cloos and the other office staff for helping us with the procurement and numerous other administrative procedures. Finally we would like to thank the local HobbyTown and its employees for sharing their knowledge in radio controlled airplanes.

Project Overview

Unmanned Aerial Vehicles (UAVs) are pilotless aircrafts, controlled either by onboard computers or through the use of a remote control on the ground. They have become widely used in a variety of civilian, industrial, and military applications. One of the more public (and perhaps controversial) uses of the drone technology is to provide aerial reconnaissance for military commanders and ground troops in forward deployed locations. On the other end of the spectrum, this technology can be used by local law enforcement for search and rescue operations.

These drones, programmed with complex imagery systems, can be extremely effective in scanning oceans for stranded vessels, national parks for lost hikers, or neighborhoods for abducted children (think AMBER alert). Why stop there? It is hard to argue against a swarm of autonomous helicopters bombarding a wildfire with flame retardant, routing to designated refill zones, and repeating until the fire is neutralized. Many of these applications would typically put an onboard pilot in danger, making the UAV even more appealing. These difficult and pivotal missions have led to a rising demand for more advanced autonomous aerial technology.

Most of these applications require substantial research, testing, and development of complex autonomous systems. Luckily, much of the ground work is already done. There are autopilot systems that require only slightly more work than planning a trip using Google Maps. Computer vision systems that can recognize faces have been researched for decades. This project will work to combine these advanced autonomous systems with fundamental mechanics of flight, while incorporating cooperation between the FAMU/FSU College of Engineering and UNIFEI in Brazil, in order to produce a competition-ready UAV.

The Unmanned Aerial Vehicle (UAV) was first introduced in the 1960's by the United States Air Force to perform aerial missions without risking the pilot's life. The UAVs provide a number of additional advantages:

- Greater maneuverability and stealth capabilities due to its small size;
- Greater design flexibility as pilot's physiological constraints are removed ;
- Greater endurance: physical durability and increased flight time.

The increase of non-military use of UAVs in the recent years has brought more significance to the development. UAV's non-military applications include remote sensing and surveillance, domestic policing, exploration and scientific research, search and rescue, and transportation to name a few. With the growing popularity and growing number of functions, design projects such as this will contribute to the development of a great engineering field.

Project Objectives

The goal of this senior design project is to design and build an autonomous search and rescue remote control plane. The team is no longer planning to attend the annual Student Unmanned Aerial Systems (SUAS) competition in June 2014. Instead, it will compete in "Designing for the Future", a competition sponsored by ASME that showcases the capstone projects of undergraduate students and requires a technical slideshow presentation of 30 slides.

The slideshow will consist of the completion of goals and objectives based on the SUAS competition. This includes primary tasks such as requiring the plane to autonomously fly along a set of waypoints while searching the ground for targets using onboard cameras. Targets are correctly identified by determining the following criteria:

- GPS coordinates (longitude/latitude)
- Background color
- Orientation (NE, W, etc.)

- Alphanumeric character on the target
- Color of the alphanumeric character
- Shape of the target

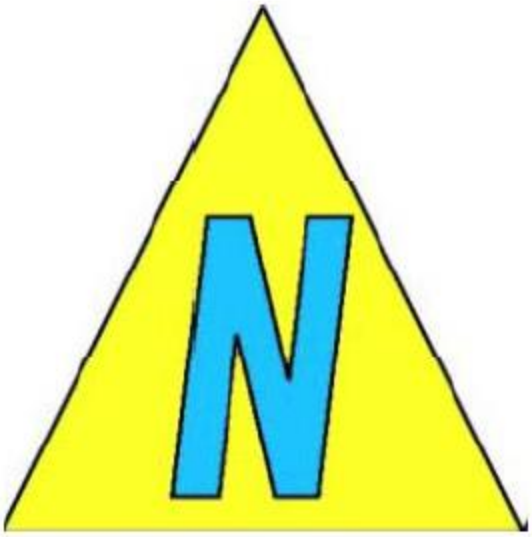

Figure 1- Example Target

The SUAS Competition has many secondary tasks which award bonus points. Due to time constraints, the team was not able to accomplish all of them. The following tables show the secondary tasks which the team completed.

Automatic Detection, Localization, and Classification – **Find and describe the target's characteristics automatically using imagery analysis**		
Parameter	**Threshold**	**Objective**
Automatic localization of each target	N/A	Identify target position with 100ft
Automatic classification of each target	N/A	Identify at least three of five target characteristics
False alarm rate	N/A	Demonstrate less than 50% false alarm rate

Airborne Actionable Intelligence - **Provide complete and accurate target characteristics while airborne**

Parameter	**Threshold**	**Objective**
Actionable Intelligence	N/A	Identify target location within 50ft and all 5 target characteristics while airborne

Emergent Target – **Given coordinates of a last known location, find and describe an emergent target in the form of a human engaged in an activity of interest**

Parameter	**Threshold**	**Objective**
In-flight re-tasking	N/A	Add last known position of the emergent target as a waypoint
Autonomous Search	Searching for emergent target	Autonomously search for the emergent target
Target Identification	Provide an image of the emergent target	Provide an image of the emergent target, location within 50ft, and an adequate description of the target'

Off-Axis Target – **Provide target characteristics of an off-axis target within the search area**

Parameter	**Threshold**	**Objective**
Imagery	N/A	Provide an image of the off-axis target
Classification	Identify any two target characteristics	Identify all five target characteristics
Tracking	N/A	Automatic tracking of the off-axis target

Air Drop – **Drop a simulated emergency rescue canister within a target location while airborne**		
Parameter	**Threshold**	**Objective**
Release	Manual release within the target area from a specified direction, no greater than 200ft away from the target, airspeed above 25 knots, and altitude between 300-400ft	Autonomous release within the target area from a specified direction, no greater than 200ft away from the target, airspeed above 25 knots, and altitude between 300-400ft
Accuracy	Less than 100ft from the bulls-eye	Less than 50ft from the bulls-eye

In addition to the tasks required for the competition, this project required the acquisition of materials and products to better enhance parts of the previous teams project. These enhancements include the purchase of a higher quality video camera as well as a new RC airplane. Furthermore, the image processing software was upgraded to a matrix based image processor that has many tools readily available to assist with target detection.

One final objective the team selected was to create an Operations Manual for future teams to utilize and maintain. This manual will explain this term's current objectives and the instructions the team pursued to achieve those goals. Future teams should take the information that is provided and focus on modifying and improving the current goals to satisfy future objectives. In addition to the instructions, the manual will include contact and bulletin information for the SUAS Competition to ensure all important dates and deadlines are known.

Constraints

Several constraints are involved in developing a system capable of functioning as required by 2014 Undergraduate Students Unmanned Aerial Systems Competition. In order to present the constraints, the following list is given with brief description about the topics stated by the Seafarer Chapter (AUVSI; International).

Preflight Constraints

- Gross Weight Limit - The aircraft may not exceed fifty five (55) pounds in weight.
- Radios - The use of 2.4 GHz radio is required for all competing aircraft.

Inflight Constraints

- Takeoff - Takeoff shall take place within one of two designated Takeoff/Landing areas, depending on wind direction during competition.
- Waypoint Navigation - Air vehicles must autonomously navigate to selected waypoints, and will be restricted to assigned airspace and avoid no-fly zones.
- Waypoints - GPS coordinates (ddd.mm.ssss) and altitudes will be announced the day prior to the flight competition.
- Enroute Search – Air vehicles will be required to fly specific altitudes while identifying several targets along the predefined entry route.
- Targets - Targets will be constructed of plywood of a given size, basic geometric shape, and color. Each target will be a different shape and a unique color.
- Area Search - Once transitioning into the predefined search area via the entry/exit route, the air vehicle shall autonomously search for specific targets of interest.
- Landing - Landing shall be performed completely within the designated takeoff/landing area.
- Total Mission Time - Total mission time is the time from declaration of mission start (from the judges) until the vehicle has safely landed, transmitters are shut off, and target data sheet (or spread sheet) is handed to the judges.
- Real Time Actionable Intelligence - Extra credit will be given for providing complete and accurate information (actionable intelligence) during flight within the search area: once that information is provided, it cannot be modified later.

Miscellaneous Constraints

- Budget: At the beginning of spring semester, a budget of $1500 was available to develop the entire project (Team Six has spent around $1325; see budget section for more information regarding funds).
- Time Management: As the project involves routinely testing, all the test flights need to be scheduled and planned ahead in order to save time and avoid unexpected situations.
- Pilot: Having a skilled and experienced pilot is crucial to test the implemented systems and consequently to the development of this project.
- Energy Supply: The competition plane has being designed to be capable of performing a flight time around 30 minutes. However, the flight time may vary depending on flight characteristics. As all the systems installed on the plane are powered by batteries (including motor), therefore two packs of batteries were bought to give the amount of energy necessary for each system to perform a 30 minutes flight.

Design and Analysis

Given that unmanned aerial vehicles have become common not only in industrial and military applications, but as projects for hobbyists around the world, much research and product development has been done on the topic. To succeed in this competition, Team Six must become familiar with these developments and choose the most effective options to incorporate or modify into the design of a competing vehicle. Considering both the requirements of flight and the previously stated competition objectives, three imperative mechanical components of this project are the vehicle body, motor, and camera mounting system. The requirements and specifications of these aspects will first be discussed, followed by evaluation of available options.

The three major electrical components include the autopilot system, communications system, and the camera system. After initial testing of the previous team's hardware, Team Six found that not only are the major components in working order, but they are relatively new with suitable specifications excluding the burnt video transmitter. Therefore a decision has been made to inherit most of the electrical components. This will not only help with the budget but will also allow for some of the designs from last year to be reused if applicable.

Vehicle Body

Function Analysis:

The first aspect to consider was, of course, the vehicle. Since the goal of this project was to have a working autonomous aircraft ready to compete by the spring of 2014, since the competition did not require the construction of a novel vehicle, it would have been an inefficient use of time and funds to do so. Instead, Team Six focused on modifying an existing vehicle to operate autonomously. The primary specifications for this vehicle involve:

- Ability to support approximately fifty five (55) pounds in weight, including the weight of the vehicle's body
- Availability of space inside body of vehicle to house chosen camera system and egg-drop system
- Structural integrity to allow for modifications to body
- Flight stability to facilitate coding for autonomous flight, takeoff, and landing

Taking these requirements into consideration, the clear choice for a vehicle body was an airplane with a large aspect ratio to increase stability and support added loads. After consultation with a local hobbyist, the Senior Telemaster airplane was chosen for modification. Specifications for this model include:

- Wingspan: 73in
- Body Length: 53½ in
- Wing Area: 838 in^2
- Flying Weight: 6 lb
- Available Controls: Ailerons, Elevator, Rudder, Flaps, Throttle

Figure 2 - Senior Telemaster Airplane

Design Concepts:

Team Six had the option of refurbishing and modifying an inherited Senior Telemaster, or purchasing a newer model (Figure 2) to modify from its original condition. The option of purchasing a new model was chosen.

The inherited Senior Telemaster was in working condition, but removing or altering the modifications made by the previous design group would have required extensive repairs to the structure, and could have resulted in structural weakness. Additionally, upon the first test flight with the inherited plane, it was clear that the unreliability of a nitro-powered plane was an unnecessary complication. This realization was supported by local hobbyists who recommended a DC motor over a nitro engine (Motor Selection further discussed in a later section).

Purchasing a new airplane allowed for the selection of a model with wing flaps, which will be pivotal in the implementation of autonomous takeoff and landing due to increased lift (Figure 3), and therefore lower stall speed. In this application, the use of flaps will theoretically reduce a stall speed of 19.8 mi/h to 16.1 mi/h. This nearly 20% decrease in landing speed will dramatically reduce the risk involved in autonomous landing, since even an imperfect touchdown will occur with less momentum.

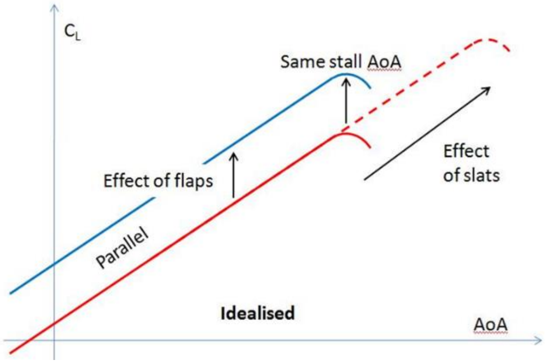

Figure 3 - Effect of Flaps on Coefficient of Lift

Another major benefit of purchasing a second plane is that Team Six has the ability to use the inherited plane to test new equipment and code, as well as learn how to fly. This removes the high risk involved with testing new modifications on the airplane intended for competition.

Just as the local hobbyists supported the thought of moving away from nitro-powered planes, purchasing an electric plane would increase the number experienced individuals available to provide assistance for steps like pre-flight ops checking, general maintenance tips, and (most importantly) an experienced pilot during testing. It is worth noting that no other nitro planes were seen at the airfield during any testing session and the pilots present were more than willing to answer any questions.

The final decision to work solely with only one plane as opposed to using both a training plane and more protected competition plane resulted from the realization that the onsite pre and post flight ops checks were far too time consuming to perform twice in the same test session. It became clear that it was far more productive to focus all attention on one plane than double our work in an attempt to minimize damage to the competition plane. Furthermore, using the electric plane, combined with working with an experienced pilot, significantly reduced the risks involved in a field test.

Table 1- Modification of Inherited Senior Telemaster Airplane

Positive Aspects	**Negative Aspects**
• Zero initial cost • Available immediately	• Repairs must be made to body • No wing flaps for added control during autonomous takeoff/landing • If electric motor is chosen, it would need to be purchased separately • No chance to practice flight or test coding and equipment – high risk

Motor

Function Analysis:

In order for the UAV to fly, it must have a motor meeting certain baseline requirements. Requirements of the motor include:

- Ability to support weight of airplane
- Ability to run for a maximum of 40 minutes

The Senior Telemaster airplane can fly with either an electric or nitro-powered motor. The nitro-powered option is inherited from a previous design team, and has the following specifications:

- Model: Magnum XL .91RFS
- Stroke: 24.8mm
- RPM: 2,000-11,000
- Weight: 1.4 lb
- Propeller Size: 14x6

The electric motor option has the following specifications:

- Model: .46 Brushless Outrunner
- RPM/Voltage: 600 RPM/V
- Battery Range: 4-6 Lithium Polymer
- Weight: 0.474 lb

Design Concepts:

Since there is a precedent set by the previous design team, implementing the nitro-power motor is relatively simple. This is an inherited motor, so using it comes at zero monetary cost. However, as the previous design team experienced, the vibrations caused by a nitro-power motor can cause high levels of distortion in the images captured by the onboard camera. Since target detection and area scanning are a major component in the competition, this is highly undesirable.

The final decision to reject the nitro-power motor was made during the first test flight of the inherited Senior Telemaster. Just minutes into the flight, the nitro-power motor stalled and was unable to recover. Team Six was able to steer the airplane into a relatively controlled landing, suffering only minor damages, but this is clearly not an attractive option for competition. Barring similar failure of the electric motor, the electric motor will be utilized in the final design.

Implementing an electric motor will eliminate most of the camera vibrations experienced by previous design groups, however, the batteries needed to power the electric motor are bulky and heavy. If the weight or required space of additional batteries becomes too great, the maximum flight time of the AUV will be reduced. Using two 5Ah, 22.2V Lithium-Polymer (LiPo) batteries in parallel to power the motor, the team estimates a flight time of 30-40 minutes.[1] Actual flight times are currently not available due to shipping problems with the distributor, however in the event of insufficient flight times, the team is prepared to join one or two more LiPo batteries in parallel. Per manufacturer's specification, each battery weighs about 840g (1.852lb) so

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[1] Estimations calculated using http://ecalc.ch/motorcalc.htm

diminishing returns is certainly a factor. As a last effort, the team is prepared to land mid-mission to replace expended batteries.[2]

These aspects are compared in the tables below.

Table 2 - Nitro-Powered Magnum XL .91RFS

Positive Aspects	Negative Aspects
• Zero initial cost • Ease of implementation • Fuel easily fits into airplane body	• Produces high levels of vibration – very undesirable for captured image quality • Relatively high weight: 1.4 lbs • **Motor failure minutes into test flight**

Table 3 - Electric .46 Brushless Outrunner

Positive Aspects	Negative Aspects
• Minimal Vibrations – highly desirable for captured image quality • Relatively low weight: 0.474 lb	• Will have to be purchased if new Senior Telemaster (already equipped with electric motor) is not purchased • Batteries will add considerable weight • Flight time may be diminished if additional batteries become too heavy or require too much space

Camera Mounting System

Function Analysis:

Many objectives in the AUVSI competition require the aircraft to be equipped with a camera capable of scanning the area both beneath and adjacent to the flight path for specified targets. With this consideration, the camera mounting system should:

- Provide clearance in front of the camera lens for effective image capture
- Allow for various angles of scanning outside flight path
- Minimize disruption of air flow over vehicle

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[2] Per competition requirements, teams are able to land their aircraft during the mission for any reason without penalty. This is a last resort as it will drastically cut into mission time and increase the probability of other problems occurring.

- Resist tendency to vibrate during flight

Design Concepts:

The typical approach used to control the angle of a mounted camera is a gimbal system (Figure 4), or a system that allows the rotation of an object about a single axis. This allows for the camera to self-stabilize during flight and rotate to view targets outside the flight path. However, the gimbal system is very sensitive to vibrations caused by the motor, its complexity leads to heightened risk of failure, and it is expensive. Additionally, the gimbal system mounted outside the body of the airplane will disrupt the flow of air over the body.

Figure 4 - Gimbal System

A new approach considered by Team Six involves using a solid-mounted camera inside the body of the airplane, with the lens of the camera extending out of the body through a fitted hole. While this would eliminate many of the complexities and risks of the gimbal system, concerns were raised regarding whether or not the airplane would have to remain completely level to acquire useful images under the flight path, or if the entire airplane must also autonomously rotate to view images outside the flight path.

To address these concerns, the solid mount approach was tested using the inherited Senior Telemaster and a Go Pro camera (Figure 5 and Figure 6). After reviewing the footage from the flight, the wide angle and high resolution of the Go Pro camera proved to be effective in eliminating the need for the airplane to rotate or remain level to capture usable images (Figure 7).

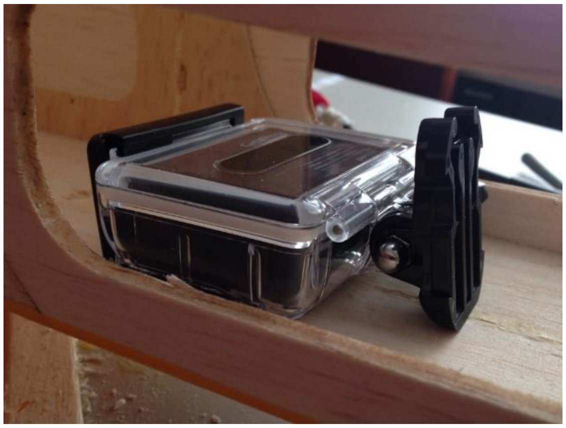

Figure 6 - Interior View of Solid Mount Camera

Figure 5 - Exterior View of Solid Mount Camera

Figure 7 - Test Flight Image

Clearly the image in Figure 7 has very little distortion. The solid mount approach will therefore be used in the final design unless it is determined later that the gimbal system is absolutely necessary.

The positive and negative aspects of these options are listed below.

Table 4 - Gimbal System

Positive Aspects	**Negative Aspects**
• Ability to self-stabilize • Rotation to scan area not directly under flight path • No barriers between camera lens and desired view	• Sensitive to vibration • Added complexity • High cost • Potential risk of failure • Disrupts airflow over body

Table 5 - "Glass Door" approach

Positive Aspects	Negative Aspects
- Mechanically simple - Inexpensive - No disruption of airflow - More resilient to vibration	- Airplane must remain level to avoid distorted images in flight path - Airplane must rotate to view objects outside flight path - Glass could potentially reflect light or become cloudy

Autopilot and Communication Systems

Functional Analysis:

A functional autonomous flight can be easily achieved with the Ardupilot Mega 2.5 (APM) autopilot system (Figure 8). While it does not provide fine controls for high precision flight out of the box, it is a powerful system capable of being configured and customized for achieving the necessary stability and precision for succeeding in the competition. The main autopilot module along with most of the peripherals such as the GPS module and sensors used in last year's project have been tested to be fully functional and sound in hardware integrity. Some of APM 2.5's features include:

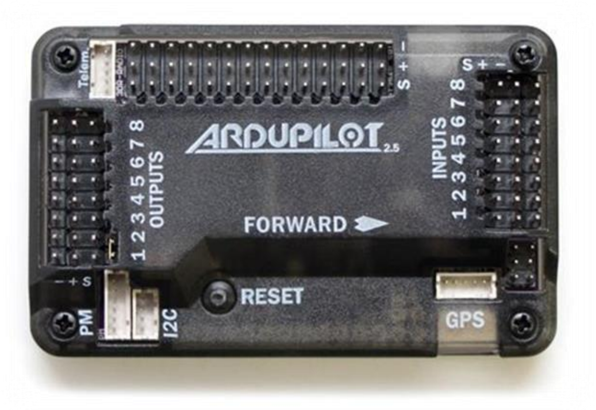

Figure 8 - Ardupilot Mega 2.5

- 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer, 2-way wireless telemetry
- Support for external GPS module and various sensors
- Support for full "hardware-in-the-loop" testing with a flight simulator
- Support for autonomous takeoff and landing
- Waypoint-based navigation

The APM comes fully supported by the Mission Planner flight planning tool suite. Mission Planner is open source, and is pivotal in planning complex missions. It supports the ability to create custom actions in-flight with the inclusion of an onboard Python interpreter. Not only does it include support for simple 3D navigation waypoints, but it also supports mission planning, real time in-flight parameter tuning, on-board video display, voice synthesis, and full data logging with

Figure 9 - Futaba T6J remote control

replay capabilities. The autopilot module is fully customizable through Mission Planner allowing for the simple programming of flight modes. Example flight modes supported by the APM include full-auto and full-manual control, a stabilize mode which maintains level flight and constant heading without operator input, and a guided mode which allows the user[3] to direct the aircraft (real time, in-flight) to points on a map in Mission Planner using a simple point/click interface. There are about a dozen different flight modes supported by the APM, however only a handful will be utilized for the purposes of the competition.

In order for the APM to be fully function, it requires the support of a long-range remote control receiver and transmitter pair. The communications system, including the Futaba T6J remote control inherited from last year's project, is fully functional and meets all of the competition's communications and safety requirements (see appendix of competition rules). The 6-channel controller operates at 2.4GHz; with a 6.8ms response time and a variable pulse-width modulated channel (knob below the "T6J" label in Figure 9), the controller is capable of selecting up to six different flight modes on the APM system.

Design Concept:

The current design implements the functionality described in the function analysis. The controller is programmed to allow the operator to switch the current mode of flight with minimal effort. Currently, when the channel 6 knob is oriented to the 4'oclock position, the APM will engage manual control. That is, the autopilot system will not assist the operator in any way. At 12'oclock, the APM will engage the stabilize mode, and lastly, the APM engages full autopilot at the 8'oclock position. As long as there is a valid mission loaded, the APM unit will direct the aircraft to the first waypoint in the mission.

Using channel five, a bipolar switch positioned near the top-left of the controller, the operator can manually control the bay doors of the aircraft in support of the air drop requirements. To help ensure mission success, future designs will implement the air drop functionality using a

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[3] The "user" is not the operator of the aircraft while it is in flight. Guided mode requires a second user which interfaces with Mission Planner while the operator spots the aircraft.

custom python script described in the functional analysis of Mission Planner. The script can be coded to have the APM open the bay doors of the aircraft at a specific coordinate/altitude.

Since the previous year's team destroyed the video transmitter, new equipment had to be purchased to support the basic mission requirements. Team Six determined that using a new transmitter (same model, new device) would not transmit the video feed with sufficient quality to perform any imagery analysis. In fact, it would not even come close. The old system boasted a meagre 200mW transmitter which would not be capable of transporting the resolution output from the GoPro at distances of a few kilometers. In order to fully support high-resolution long-range transport and still fall within FCC/competition requirements, the team opted for the Foxtech 2.4G 32Ch 600mW video transmitter.

Camera System

Functional Analysis:

The competition requirements do not list many technical specifications for the imaging system. Therefore the inherited KT&C KPC-E700NUB camera is sufficient for achieving the minimum goals. However, as the imaging system was the weak point of last year's project, (camera system from last year suffered greatly from vibration) Team Six decided to purchase and implement a higher quality camera to greatly improve various aspects of the project. A GoPro HERO3+ Silver Edition was purchased. Listed below is the full comparison of the two cameras in specifications, positive and negatives aspects related to the project, and sample images:

KT&C KPC-E700NUB:

- Color NTSC spec (analog, standard definition)
- Effective pixels: 976(H) x 494(V)
- Shutter speed: 1/60 – 1/100,000S
- SNR: over 50db

GoProHERO3+ Silver:

- Fully digital, HD capable
- Built-in WiFi and included GoPro app for remote control
- Video: 1080p at 60fps, 960p at 60fps, 720p at 120fps
- Photo: 10MP and 10fps burst

Table 6 - KT&C camera

Positive Aspects	Negative Aspects
• Zero initial cost • Meets competition specs	• Hardware susceptible to vibration • Analog data susceptible to high noise • Low resolution • More complex and more difficult image processing

Table 7 - GoPro HERO3+ Silver Edition Camera

Positive Aspects	Negative Aspects
• Overall high spec • Digital, HD resolution • Built-in WiFi • More resilient to vibration • Less complex and less difficult image processing	• Cost • Required a new mounting system design different than last year's

Image comparison[4]

Figure 10 - Image from KT&C camera (left) and GoPro (right)

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[4] The blue doors in the center are of ideal target size(6ft x 8ft) and ideal distance away(100ft)

Design Concept:

The imaging system from last year's project suffered greatly from mechanical vibration and electrical noise in the analog data. However, with the new mechanical design choice of the electric motor, vibration is not a constraint on this year's imaging system. In the initial tests, the GoPro's digital system with a built-in data communications capability has provided a much greater quality image over an analog system, as digital signals are less susceptible to noise. However upon further testing, a full HD digital video transmission system capable of the necessary range was determined to be out of the team's project scope and budget. Nevertheless Team Six is confident the quality of the GoPro with the analog transmitter/receiver system is far superior to the quality of the KT&C camera-gimbal system from last year.

The video stream from the receiver is fed to the image processing ground station via the StarTech SVID2USB2 video capture cable. The ground station then processes still frames from the video at an intermittent rate rather than wasting the computing power in processing the complete video stream.

As mentioned earlier, a mounting system different from last year's will be implemented. In addition to the GoPro's wide angle and high resolution, its flat front surface made it ideal for solid-mounting in the bottom of the fuselage. Due to the vibration-dampening mounting system along with the high spec camera, the new system reduces errors in the image processing and makes the implementation of auto target detection easier as well.

Evaluation of Designs

Because not all positive and negative aspects are equally important to the project goals, it is useful to rate different qualities of each option on a weighted scale to determine the optimum choices. Below is a decision matrix showing the different options discussed above, rated with respect to competition priority, cost, difficulty of implementation, required time for completion, and risk. Rows highlighted in the same color are in competition with each other, and the option with the highest point value was chosen.

Also shown in this decision matrix are optional secondary objectives of the competition. Since it would not be feasible to attempt every secondary objective, only objectives scoring thirty or more points will be initially attempted. If time and resources allow, additional secondary objectives will be attempted in order of point values.

Table 8 - Decision Matrix

Objective	**Competition Priorities**	**Cost**	**Difficulty**	**Required Time**	**Risk**	**Totals**
Autonomous Flight	10	10	8	9	5	**42**
Buy New Plane	6	4	9	9	10	**38**
Modify Old Plane	4	8	6	6	4	**28**
Nitro-Powered Motor	4	10	4	7	3	**28**
Electric Motor	8	5	6	7	7	**33**
Retractable Landing Gear	2	6	6	5	6	**25**
Glass Camera Door	3	9	8	9	9	**38**
Retractable Camera Door/Gimbal System	9	5	5	3	6	**28**
Infrared Camera	7	0	5	7	0	**19**
Modular Design	3	7	4	4	5	**23**
Autonomous Takeoff/Landing	7	9	5	6	3	**30**
Autopilot System Training	2	7	3	3	8	**23**
Autonomous Target Recognition	7	9	3	3	8	**30**
Air Drop System	7	6	6	7	8	**34**

Secondary Objectives

Implementation of the electric motor and the glass camera door will take place as soon as possible, since although the potential benefits are high, both involve considerable risk of being ineffective for completing the objectives.

Air Drop System

Function Analysis:

This task will simulate a major objective of autonomous aerial vehicles: the ability to drop an object on an identified target, such as flame retardant on a forest fire or supplies to a disaster area. For the purposes of this competition, the air drop has the following goals:

- Create a mechanism (autonomous or remote controlled) to drop plastic egg filled with flour (Figure 10)
- Drop egg when a target is recognized
- Time drop for egg to land within target boundary

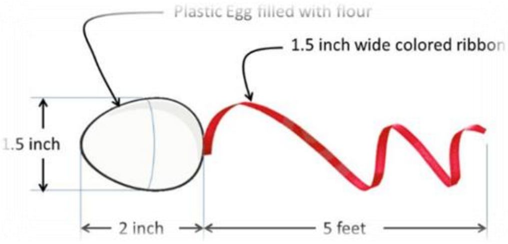

Figure 11 - Plastic Egg for Air Drop

Design Concepts:

The primary concern for the air drop mechanism is to avoid disruption of the air flow over the airplane body before and during the drop. For this reason, the mechanism will be located inside the body of the airplane. A design involving a horizontally retractable door was briefly considered, but after conversation with an experienced remote control airplane pilot, it was abandoned in favor of a hinged door approach.

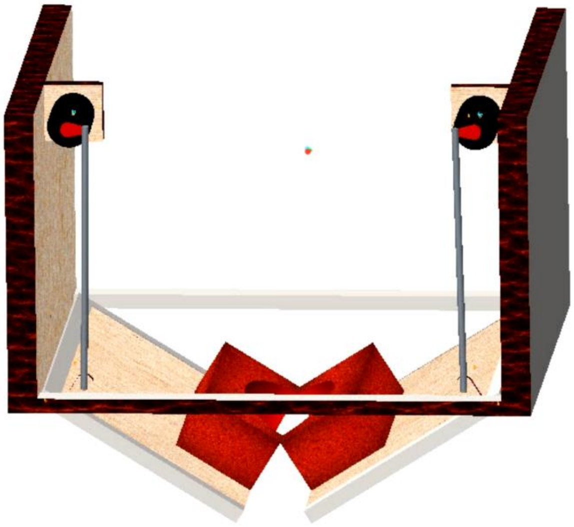

Figure 12 - Model of Air Drop System Design

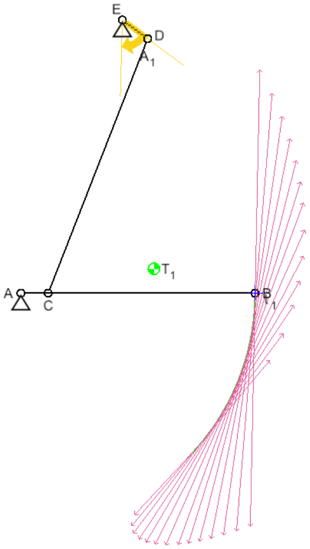

Figure 13 - Fourbar Simulation

In the hinged design (Figure 12), two doors will be used to eliminate additional horizontal velocity components from the egg rolling down the inside of a single door. With this design, the only starting velocity component to be considered for drop accuracy will be that of the airplane. The doors will open out toward the sides of the airplane, causing the least possible induced pressure drag. Servo motors will be attached near the hinges of the doors, creating a simple four-bar mechanism to open the doors to a gap of 6.5 cm, and then shut the doors. Using Autodesk® ForceEffect™ simulation (Figure 13) and calculation tools, the minimum time required for full opening of the trap door is 0.14 seconds, with an additional 0.14 seconds to close the doors. This is taken at top servo motor operating speed, or 79.2 rpm. At less than two tenths of a second, the opening time is effectively negligible for consideration in the air drop timing.

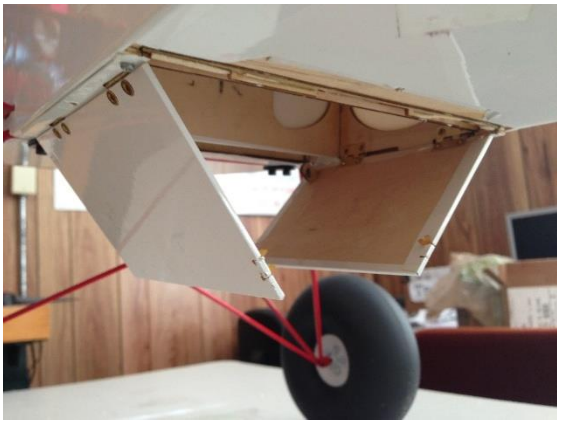

Figure 14 - Implemented Air Drop System

A foam pad with a cavity matching the shape of the plastic egg will be cut into two parts and attached to the two doors, cushioning the egg during flight, but allowing the egg to fall when the doors are opened. This design has been successfully implemented, as shown in Figure 14 - Implemented Air Drop System.

With the physical system functional and successfully tested, the next step was to provide targeting analysis to ensure the package hits its target. A Simulink analysis was created to determine offset coordinates of an airdrop based on initial conditions. The code accepts current wind conditions (provided by the user) combined with the current velocity of the plane to analyze the forces acting on an object dropped from the current elevation. The equations (shown below) were formed using the LaGrange Equation.

$$ma_x = \frac{1}{2}\left(v_{w_x} - v_x\right)^2 C_{d_x} A_x \rho$$

$$ma_y = \frac{1}{2}\left(v_{w_y} - v_y\right)^2 C_{d_y} A_y \rho$$

$$ma_z = \frac{1}{2}\left(v_{w_z} - v_z\right)^2 C_{d_z} A_z \rho - mg$$

where v_w is the wind speed, and C_d is the drag coefficient.

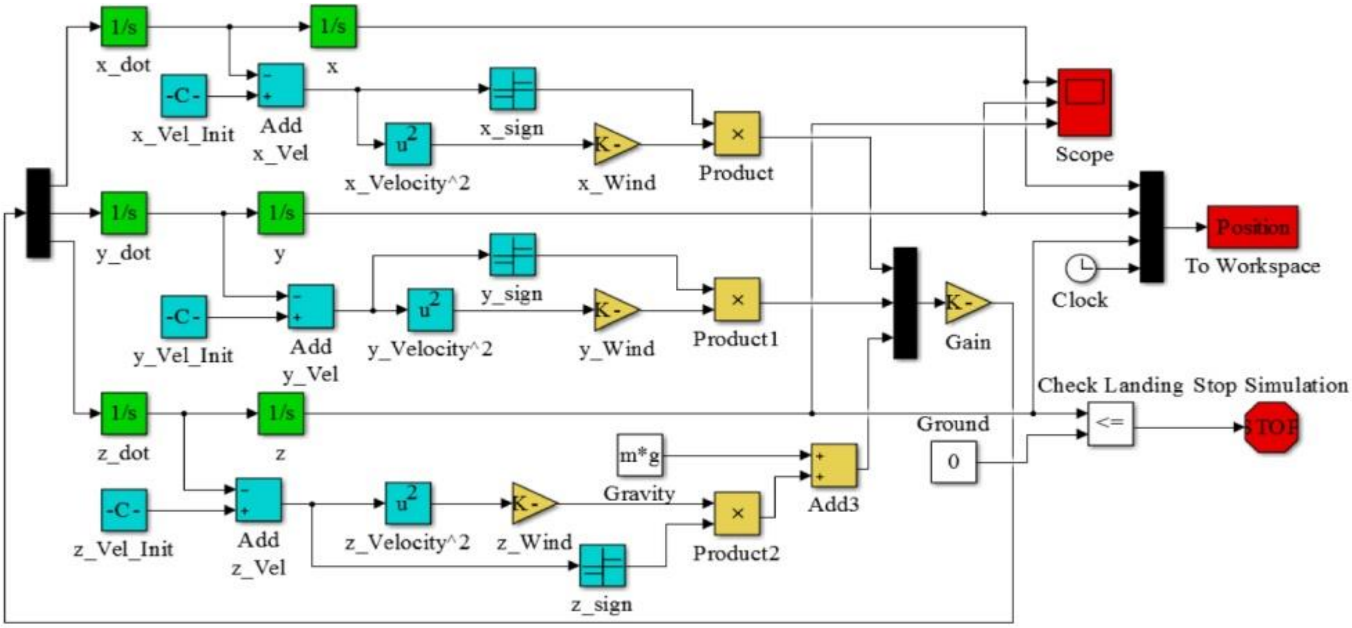

Figure 15 - Simulink Airdrop Analysis

The analysis (Figure 15 - Simulink Airdrop Analysis) has gone through many simulated tests and is ready to be tested in a physical experiment. Although the data from the simulations appears to demonstrate a successful analysis, there has been no real data for comparison. Additionally, some assumptions were necessary, including constant wind velocity throughout the freefall, and some simplifications on the dimensions and aerodynamic properties of the projectile. These assumptions may be refined as more physical data is collected.

Assessment of Risks and Reliability

Flying vehicles have certain inherent risks associated with them. When a flying vehicle is then turned into an autonomous flying vehicle those risks become even larger. While the risks cannot be eliminated, certain precautions can be implemented to reduce the risks as much as possible, which was one of Team Six's goals during this project. The risks of this project stem from errors that can be broken down into three categories: Human errors, vehicle malfunctions, and software malfunctions.

Looking first at human errors, while this project eventually involves flying an R/C airplane autonomously, before that can be accomplished many manual flights must be completed in order to prepare the plane for autonomous flight. These manual flights are when the largest risk of human error plays into the equation. When flying an R/C plane, the pilot must maintain absolute focus on the airplane at all times; even a few seconds lapse of focus could cause the plane to go out of sight and come crashing down. In addition to remaining focused, the R/C pilot must have advanced piloting skills because when the plane is coming towards the pilot, certain controls are reversed and the pilot must have the natural instinct to give the plane the correct inputs to avoid crashing. In order to minimize the human error associated with these flight tasks, Team Six brought in an expert R/C pilot, Robin Driscall, to fly the plane during preparation for autonomous flight, which allowed for relatively low risk autonomous flight. In addition to just flying the plane, the risk of human error is also present when preparing the plane for flight. Before every flight, the battery charges must be checked for adequate charge, the center of gravity of the plane must be set in the correct location, and the R/C controls must be set to the correct directions. These risks are easy to minimize as long as those in charge of preparing the plane are diligent in their pre-flight checks and do not cut any corners in set up.

Next, looking at the vehicle malfunctions, the risk of a servo motor failing in flight, or the risk of the motor turning off mid-flight always exists. In order to reduce these risks, pre-flight checks should be run on the ground before the flight to ensure the servos and motor responds correctly and reliably. In addition, the choices of which equipment can be made so that the most reliable products are used on the plane. For example, in the R/C field, electric motors are known to be more reliable than gas motors, and the test plane that was inherited from last year’s project used a nitro/gas motor. During a practice flight the gas motor stalled, resulting in a crash, which solidified the decision to use an electric motor for this year’s plane due to its reliability and ease of use.

The final group of risks in this project comes from software malfunctions. When flying an airplane autonomously, the flight completely depends on the software taking in inputs correctly and then responding appropriately with outputs to the mechanical components flying the plane. The first tests of the software were through simulators on the ground, and although the ground simulations demonstrated correct functioning of the autopilot software and telemetry, there is no way to guarantee that the actual flight would respond the same way. For this reason, when testing the autopilot software in the air for the first time, in order to reduce risk, the plane was flown manually to an altitude greater than what normal flight would require, (about 100 meters above ground) and then the autopilot was switched on, which would allow for a switch back to manual mode in the event of disaster. As it turned out, disaster struck during the first test. When engaged for the first time the plane took a nose dive directly for the ground (more below), but because the risk was reduced by flying so high, the team was able to switch back into manual mode and save the airplane about 20 feet about ground, and certain destruction of the plane.

Prerequisites

All teams must submit a video as proof that the team has successfully achieved flight at least once. Although, the demonstration does not have to follow the competition requirements (autonomy, searching, etc.), the video must show the plane can "attain flight, sustain flight, and terminate flight in a safe manner." Failure to submit a proof-of-flight video will revoke a team's right to participate in the flight-mission demonstration. In addition to the video submission, the team must also submit a journal paper outlining the intended mission plan. The paper must illustrate how the team will safely complete the mission as well as provide test data verifying that the team can perform the tasks as explained. Failure to submit a journal paper will result in the team's disqualification from the competition.

On Site

One of the three sections of the competition is an oral presentation. This will act as a Flight Readiness Review, where the team will explain to the judges how they plan to safely accomplish the mission. This is the team's final opportunity to "demonstrate to the judges that the team is ready to compete safely, with low risk, in the flight-mission demonstration phase of the competition." A safety check will follow the Flight Readiness Review where the judges will inspect the aircraft, ground station, and other equipment to ensure that the team is ready to perform safely with minimal risk. The judges will physically check the structural integrity of the plane (internal and external) to ensure all components are properly secured. They will also perform a ground check of the system's failsafe and termination procedure. The flight termination procedure is in place to assure immediate return of the plane to the ground in the event of a loss of communication.

The base execution involves two phases, although other methods may be applied to ensure safe recovery of the aircraft. Phase one requires a return-home algorithm that will execute in the event of a loss of communication for over thirty seconds. Phase two requires the immediate termination of the flight if the communications loss lasts for more than three minutes. If no design considerations are made for recovery, the termination could result in damage to the UAS. The flight termination should be manually executable by the team's safety pilot.

Image Processing

One of the projects main objectives is the processing and analysis of images in a real time environment. The team last year used a C++ based application for their approach. This year, the team decided to replace the C++ based software with a MATLAB program. MATLAB has several “toolboxes” that the students have access to via the College of Engineering. The toolboxes that were used for this portion of the project are the Image Processing Toolbox, The Image Acquisition Toolbox and the Neural Network Toolbox. Other software platforms were considered, such as OpenCV. OpenCV is an open-sourced image processing based platform with a very helpful and informative support community. The drawback to using this software was the amount of time needed to compare and “learn” the specific shapes and alphanumeric digits that are required for this project.

For the Optical Character (Alphanumeric) Recognition portion of the software, a comparative approach was taken. The software, using the Image Processing Toolbox, will analyze the picture and search for patterns similar to those that are loaded into the program’s library. When an item is recognized, the program will display the digit, along with any other digits it detects, in a text document on the user’s screen (Figure 16Figure 16 – Demonstration of). The user can then save the document or annotate the digit that is displayed in an appropriate location.

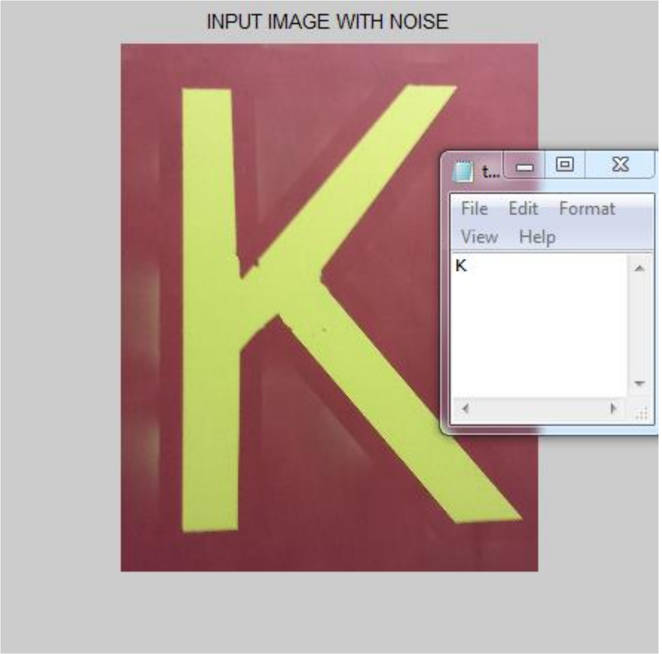

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Figure 16 – Demonstration of correct target recognition

The shape recognition software took a slightly different approach. It still used the Image Processing Toolbox, however, this program runs the image through several filters before beginning the analysis process. The program first processes the image through a grey scale filter. Next, it converts the image to a pure binary image consisting of only black and white colors. The final step the program takes before analyzing the image requires the inversion of the black and white colors. Once all those steps are completed, then the programs searches the image for white shapes on a black background. If a shape is detected, the program will produce the original image with the addition of a circle, square or the letter “x”. These symbols denote a confirmed shape; either a circle, square or rectangle, respectively (Figure 17).

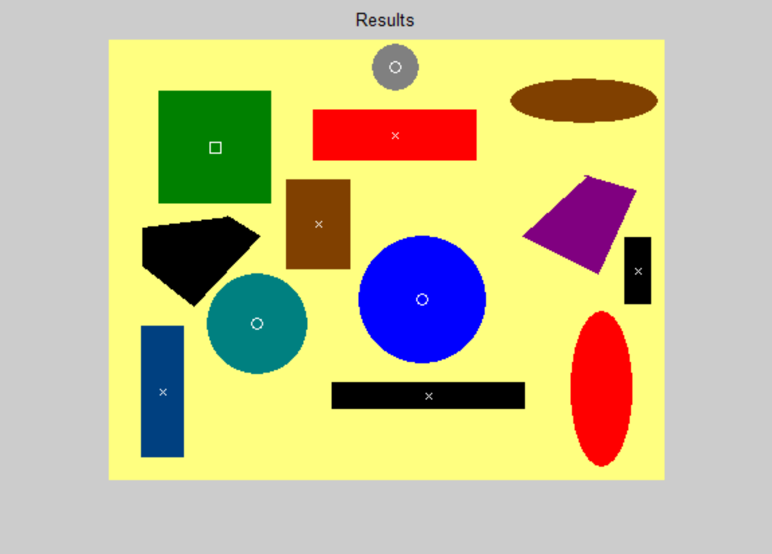


Figure 17 - Currently recognizable shapes

Future improvements of this software will need to include the incorporation of scaling and rotational biases of the images produced to the software. Several options include (but are not limited to) a neural network and the rotation of images. A neural network could be designed and implemented to “learn” the different shapes and digits that are required for this project. The rotation of images would require a powerful processor. Once the image has been processed, the program would need to rotate the image several degrees and process the image again. These step would repeat itself until the image has been spun 360 degrees.

Another feature to incorporate in the future would be cross communication between the image processing software and auto-pilot software. This would enable the image processor to send a signal to the auto-pilot software when a confirmed target is found. The auto-pilot software would then annotate the location at which the target was found.

Test and Analysis

The initial testing of the competition airplane was completed on March 1, 2014. During pre-flight preparations, the airplane and component assembly was evaluated by an experienced RC Pilot. At this time, the center of gravity was adjusted for optimum flight by relocating the batteries to be situated in the body directly under the wings. Components were fitted with hook and loop mounting fabric to ensure that movement within the airplane body would not occur during flight. One of the two servo motors controlling the air drop system was found to be critically malfunctioning, so the air drop test was re-scheduled to occur after a new servo motor could be purchased.

Before takeoff, the throws of the airplane (or the angles that the servo motor-controlled ailerons, flaps, elevators, and rudder make with the airplane body) were set to neutral values. In order to achieve accurate readings of mid-flight yaw, pitch, and roll, the plane was manually held in a perfectly horizontal position (confirmed by a level) while the APM accelerometer was calibrated to this position. Waypoints for the autopilot control were set at various locations surrounding the airfield, and the autopilot cruising altitude was set at $100m$. The high elevation allowed for sufficient time to regain control of the aircraft if the autopilot fails.

After completing all pre-flight requirements, the airplane was flown under manual control to a cruising altitude of $30m$. At this point, the autopilot system was engaged. Instantaneously, the throttle was cut down to less than 50% of average flying level, which did not produce enough thrust to keep the airplane airborne. The airplane rapidly pitched forward, but potential disaster was averted by switching back to manual mode before the airplane reached the ground. The log data from the flight can be seen in Figure 18.

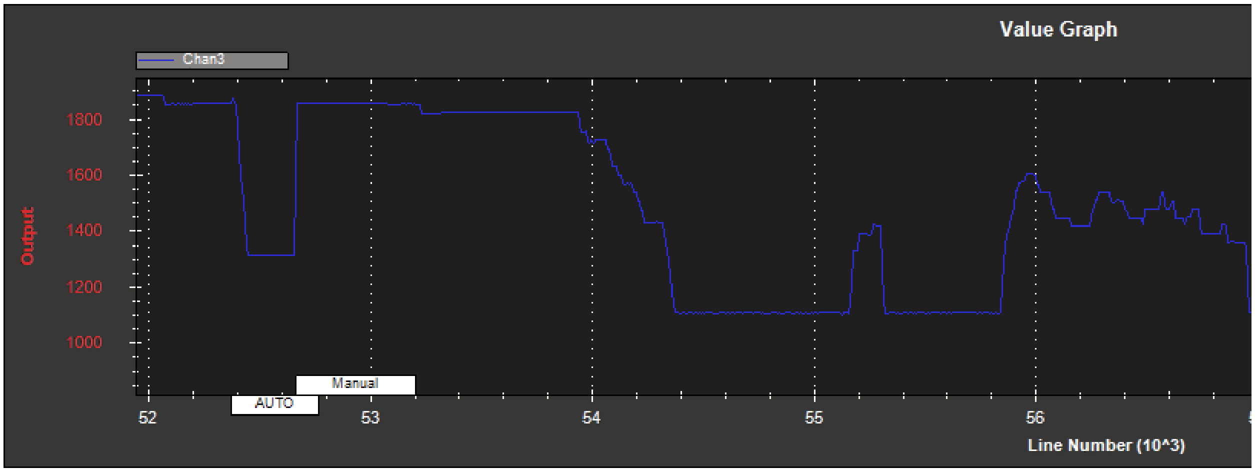


Figure 18 - ArduPilot Output Readings as a Function of Time

The ordinate reflects the pulse-width modulated (PWM) signal controlling the throttle power. A higher PWM value indicates more power to the motor. Just before autopilot was engaged, the APM shows that the [manually controlled] throttle was just below full power. Just after the autopilot engages, the throttle power cuts to around 50%. Post-flight inspection shows a single point of failure. The autopilot was misconfigured due to a communication link error. The parameter which controls the throttle at a cruise was not properly written to the APM module. This parameter ensures minimum required throttle to sustain altitude. Because of the communication link error, the parameter was not updated to the correct value, resulting in the plane *appearing* to lose all power. This flight was pivotal in that the lessons learned contributed to the outstanding results of the preceding test flight.

The final Autonomous Aerial Vehicle design was tested on April 4, 2014. After replacing the servo motor, the air drop, autopilot, and image capturing systems were all viable for testing. The same pre-flight calibrations were executed as in the previous flight, with the exception of the neutral pitch angle recorded by the ArduPilot. Setting a true neutral would require more advanced tools than those available, so since catastrophic flight failure is a result of pitching the nose of the airplane toward the ground, the "neutral" angle was purposefully set to err on the side of slightly elevating the plane.

Again, the airplane was brought to a cruising height of $100m$ by an experienced RC pilot. The air drop system was successfully tested, although a low cloud ceiling prevented the application of package targeting. After this test, stabilization mode of the autopilot system was activated. Recall that this mode maintains level flight at a constant heading without operator input. After this was successfully executed, the autopilot system was engaged. The aircraft successfully navigated to the set waypoints, after which it followed a command to circle the airfield. The last waypoint was terminated early due to the fact that the aircraft was circling directly overhead and posed a safety threat. The path of this flight can be seen in Figure 19, where the blue lines represent the manually controlled flight, and the waypoint navigation is shown by the green and yellow markers.

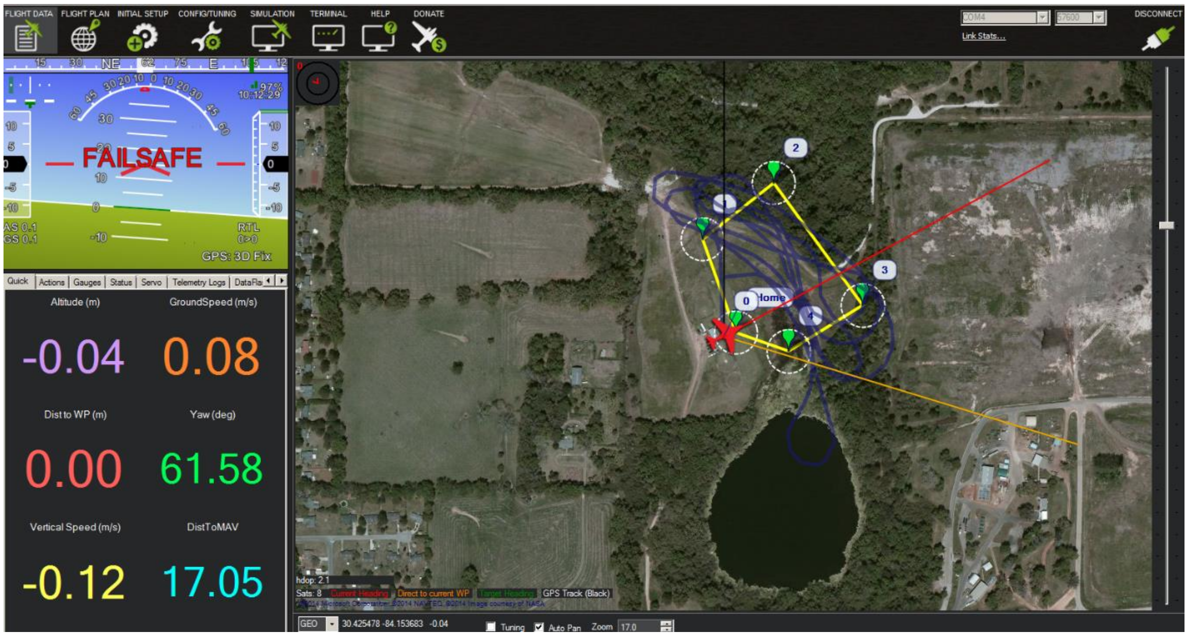


Figure 19 - Successful Autopilot Mission

Following this success, the control system was returned to manual flight, and the airplane was brought in for landing by the pilot.

It should be noted that all markers in the flight simulation indicate that a successful autonomous takeoff would be possible at this point in development, however due to insufficient runway clearance at the airfield and generally bad weather conditions (low visibility, low cloud ceiling), the team ruled in the direction of safety and called off the test. In the case of weather related problems mid-flight, the pilot has ample time to regain control of the aircraft and ensure a safe landing, however during the takeoff phase, the aircraft is necessarily very close to the ground and the window to regain control (in the case of a strong gust of wind, for example) is small to nonexistent. This would have been a considerable risk, and the safety of the aircraft took priority.

Design for Manufacturing

Since this project was not intended for mass production, and consisted primarily of modifications to an existing aircraft with little to no fabrication of new parts, the topics discussed in this section will cover difficulties involved in these modifications and suggestions for potential manufacturing.

The primary physical modifications of the aircraft involved implementation of an air drop system, creation of a camera mounting hatch, and fitting of electrical components into the body of the aircraft. These tasks proved to be difficult given that the interior of the aircraft was not designed for this purpose, and in multiple situations support beams of the body blocked the area designated for new components. In these situations, portions of the existing support structure had to be removed with a dremel tool. New supports were hand-cut from balsa wood and glued into the body of the aircraft. Figure 20 shows a cavity in the plane body cut for implementation of the camera mounting hatch, and Figure 21 shows the completed camera mounting hatch as well as the open air drop system.

Figure 20 - Open Camera Mounting Hatch with Excavated Aircraft Cavity

Figure 21 - Closed Camera Mounting Hatch and Open Air Drop System

If this design was to be implemented into a manufactured product, these structures should be incorporated into the original body design for the airplane. As the figures above show, while hand-cutting balsa wood is the most cost-effective method for small scale or one-off production, gaps between the hatch and the aircraft body are inevitable within the tolerances of hand cutting. Additionally, parts such as the latch and hinges were purchased from retail stores and repurposed for this application. While the drag from non-aerodynamic hinges is slight enough to lack a significant effect on the system as a whole in this application, if this project was to be manufactured, latches and hinges could be incorporated directly into the hatch/body material and joined with pins. This would provide both an aerodynamic surface of the body as well as a more polished appearance.

Although fabrication of the aircraft body was outside the scope of this project, it should be noted that this type of airplane is generally assembled by hand. In the case of hobbyists, this is desirable and recreational. However, if this design was to be manufactured, hand crafting each aircraft would be extremely expensive, as well as subject to variations between individual models. Taking this into consideration, an alternative should be found that would make replicating this project on a large scale more feasible. The most logical method would be to create a 3D model of the entire aircraft and use injection molding of a high strength-to-weight ratio plastic to create identical shells of the airplane body's structural elements. This would also allow for the inclusion of shelving, giving more distinct placement of electronic components and pathways for the attached wires. In the current model, working around existing structural elements and inability to deconstruct the aircraft body resulted in wiring where order was somewhat difficult to maintain, such as the arrangement shown in Figure 22.

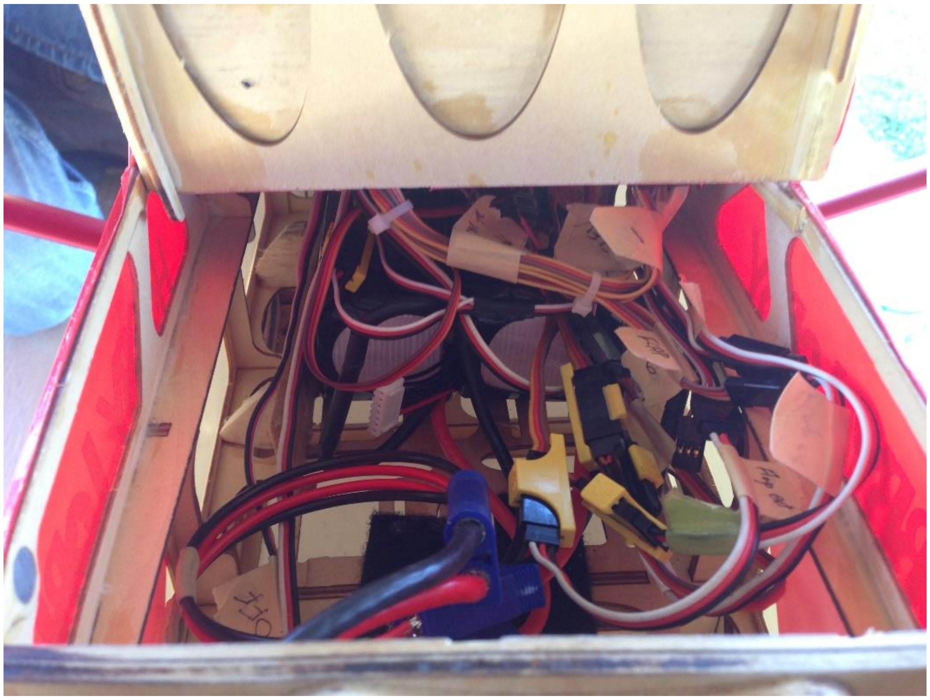


Figure 22 - Wiring of Electronic Components

This method would not only increase the economic viability of manufacturing the design, since the fabrication could be done by machine and not by hand, but it would also dramatically increase the reliability of the finished product. When made by hand, the structural integrity of the aircraft is subject to variations in wood thickness, glue application, and overall skill of the craftsman. This would inherently vary between models. If the structural elements were made to be identical to the 3D model, this variation and potential source of failure is dramatically reduced.

Procurement

This project was given an initial budget of $1500. Over the course of the past year of project time, Team Six spent $1410. The $1410 was spent on the following: $160 for the RC test plane, $580 for the new competition Senior Telemaster Plus, $250 for two 6s batteries that will be used to power the new electric motor, and $230 for the GoPro HERO3+ Silver Edition which will be used for the image analysis, $30 for the supplies necessary for the air drop system, $75 for the live video feed transmitter, $10 for a replacement servo motor for the airdrop mechanism, $60 for wood and paint to run our competition simulation, and $15 for hinges and screws for the camera door. This means that Team Six was left with $90 remaining in the budget at the end of the year. In our initial budget the plan was to have two team members certified to fly the plane, however, it was decided that instead of having inexperienced pilots flying the RC plane, we would make use of the skills of expert RC pilot Robin Driscall, who flew our plane for our test flights. This decision was made because flying the RC planes is of greater difficulty that initially planned, and Team Six did not want to risk crashing the competition plane. The final budget chart can be seen below.

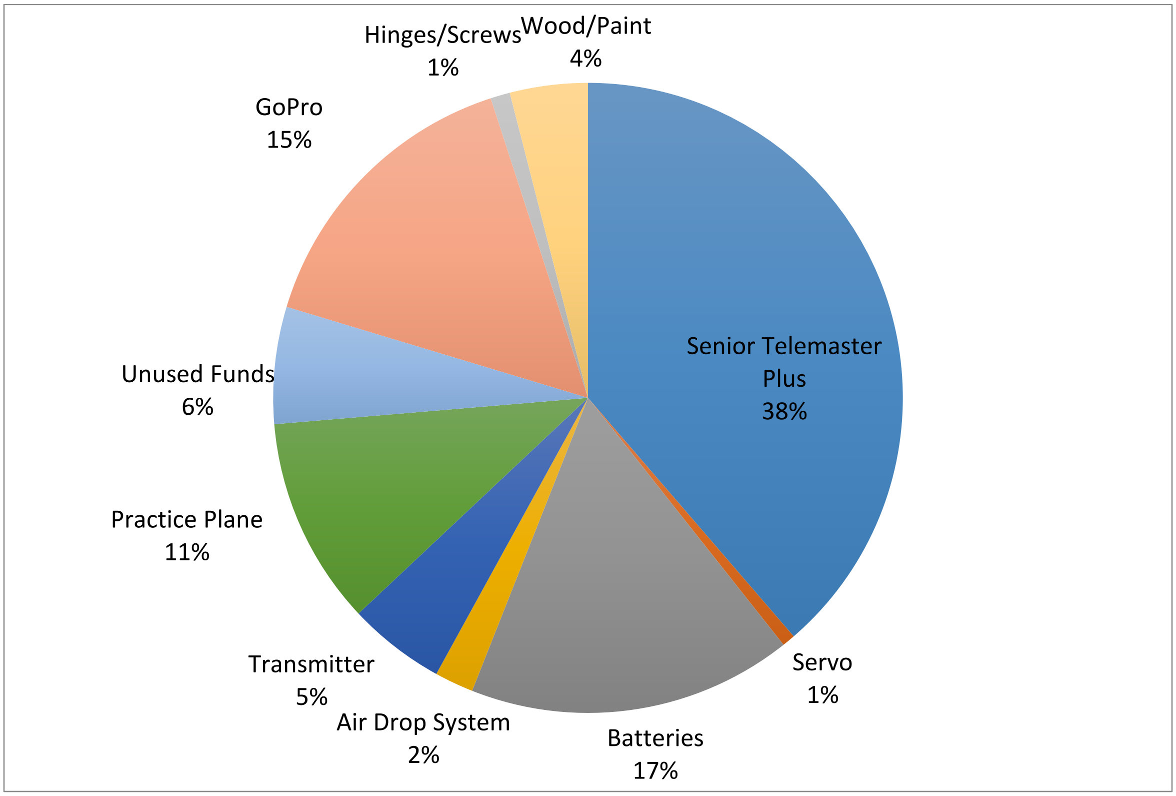


Figure 23 - Budget Visual

Environmental/Safety/Ethical Issues

The AUVSI competition that this plane is being built for is set up to simulate a raging fire in the mountains of Idaho that fire fighters are in the process of fighting. The UAS in this project is used by the firefighters in order to survey the area and determine where the firefighting resources would be most efficiently used (in addition to possibly dropping supplies to someone in need). Because of this, the small environmental impact of the RC plane is negligible, especially compared to the environmental impact of what it replaces. This RC plane will be doing the job of a much larger, regular plane or helicopter. The larger helicopter/plane would run on regular/jet fuel and can burn anywhere between 10 gph and 65 gph (depending on flight conditions, size of aircraft, etc.), whereas the small RC plane discharges two batteries in roughly 45 minutes, which is significantly better for the environment. In addition, the full size aircraft burns through fuel in the flight from the airport to the survey zone and back, which could be a very long distance depending on the location of the fire. The UAS that is being designed in this project will be transported to the fire site in a ground vehicle, which does not burn obscene amounts of fuel in the process.

When looking at safety issues, RC planes do present some safety issues during typical operation. RC planes are normally used for recreational flight, and when in recreational flight there is always the issue of something going wrong with the plane and it crashing. Obviously because it is an RC plane, if it crashes the concern doesn't come from a pilot getting hurt, but instead from the actual plane acting as projectile and crashing into someone. This is normally an issue, but when put into perspective, a real plane/helicopter flying over a fire has a greater risk of crashing than normal because of the extreme heat and smoke conditions, and when a real flying vehicle crashes the chances of severe injury or death are of serious concern for the pilots. In addition, a crashing plane or helicopter becomes a much larger projectile than a small RC plane. Therefore, the environmental and safety issues of this project are really not issues at all, but instead are actually positive aspects of the project.

The ethics of this project are fairly straightforward. As long as the plane is being flown safely and under control at all times, there are no ethical questions about using an RC plane to rescue victims of a wild fire, whether it be controlled by a remote pilot or be fully autonomous. Therefore, this project is ethical, and it would be a hard argument to prove otherwise. However, whenever one talks about autonomously controlled flying vehicles, the question of use in warfare applications arises. With the recent advances in technology, unmanned aerial vehicles are now being used in great numbers in oversees combat. This obviously brings up huge ethics questions because part of the consequences of taking human lives are being removed from the equation. Now, instead of actually watching a missile kill someone in person, the action is being done over a computer screen, similar to what it is like to play a video game. Several military leaders state that as long as the human is still the one pressing the button to release the missiles and take the human lives, then the ethics are the same whether that person is flying in the plane on location or is behind a computer on the opposite side of the globe. In addition, the drones used in warfare have a better ability to locate and strike targets accurately and at the least destructive time because they can standby in the air longer than conventional jets. As it currently stands, the jury is still out with regards to the ethics of fully autonomous fighter jets, and something needs to be decided soon because technology is advancing at such a rapid pace that it is leaving the ethics discussion behind.

Communications

Strong communication was pivotal in this project not only between Team Six and the team's advisor, but between individual members of the team. This project was unique in that for the first semester of work, one team member was working from Universidade Federal De Itajuba (UNIFEI) in Brasil. In order to successfully work together, steps were taken to virtually unite the team across the continents. Weekly video conferences were held between the team members to facilitate general discussion, updates on progress, and delegation of tasks. An internet forum was also established as an open line of communication and a means to share files between group members.

Bi-weekly meetings were held with staff and advisors. Team Six discussed recent developments in the project and solicited design guidance. Feedback from recent reports and presentations was discussed, and plans for future work were monitored to insure that the team remained on course.

Additionally, Team Six sought flight related assistance from local experts, including hobbyist Robin Driscall. Given that flight poses a high level of risk and that no members of Team Six had previous flight experience, communication with an expert proved to be an invaluable tool.

Conclusion

The competition rules stated several primary and secondary objectives that needed to be accomplished. The majority of the decisions were made with the following aspects in consideration: the priority of the objectives, time, and available budget. Early on, the decision was made to purchase a new plane (Senior Telemaster Plus) equipped with flaps and an electric motor. This allowed for better control in takeoff and landing, and a better image quality due to reduced motor vibration. Another aspect that was taken into consideration when choosing the new plane was the camera implementation. A GoPro camera was purchased because it had a better image quality and a wider view angle than the previous camera. A fixed camera mount was also chosen over the gimbal system used in last year's project. The camera was tested in flight, and the quality of the resulting images exceeded mission requirements.

The ArduPilot Mega 2.5, supported by Mission Planner, allowed for Team Six to achieve successful autonomous navigation through a designated flight path. Utilizing video from the successful test flight, the MATLAB image processing toolbox was used to identify and annotate the required target characteristics. The built-in functionality and available online support led to rapid development and implementation of the image processing application.

As a secondary objective, Team Six implemented an air drop system into the aircraft frame to simulate the deployment of equipment to isolated locations. The air drop is manually operational, and models have been developed to predict the trajectory of the payload.

Through careful consideration of design options, Team Six remained under the allotted budget of $1,500.

With the achievement of the competition's baseline objective, autonomous navigation, the future team is in a prime position to focus on refining secondary objectives. The developed image processing application will provide a sound foundation for the subsequent team to implement more comprehensive target recognition capabilities. With improvements in target recognition, the projectile models are ready for implementation to allow for autonomous payload deployment.

Recommendations for Future Work

With the end of the year in sight, the time has come to pass the project on to the next group of seniors. Team Six has a few recommendations for the future.

First, the team believes that the balance of mechanical engineers to electrical engineers should be modified so that next year's project has a higher ratio of electrical/computer engineers to mechanical engineers. This year, Team Six was able to build up and equip the aircraft's mechanical components to fly autonomously for over 20 minutes, take and transmit high definition video, and drop an egg-sized projectile. This constitutes a majority of the mechanical aspects of the project. The image processing application, autonomous payload delivery, and autonomous takeoff/landing are objectives which require extensive work in order to be competition ready. All of these require expertise in programming, which is why Team Six recommends additional members from the ECE department. Furthermore, the team also recommends that one or more members be an experienced RC pilot. Even seemingly simple tasks like preparing the aircraft for flight (throw, trim, and center of gravity adjustments) can be difficult to those who are inexperienced with flying RC aircraft.

With the success of the project during the 2013-2014 academic year, Team Six is confident that the FAMU/FSU College of Engineering team will demonstrate a strong showing at the competition in summer 2015.

Appendix I – Calculations

Lift:

Density at STP

$$\rho := 1.23 \frac{kg}{m^3}$$

Coefficient of lift at 0 angle of attack

$$Cl_0 := .42$$

Estimated weight of the UAV

$$W := 13lbf = 57.827N$$

Wing Area

$$S := 1330in^2 = 0.858m^2$$

Minimum Velocity to avoid stall in level flight

$$V_{stall} := \sqrt{\frac{(2 \cdot W)}{(\rho \cdot S \cdot Cl_0)}} = 16.153 \frac{m}{s}$$

$$\boxed{V_{stall} = 36.132 \cdot \frac{mile}{hr}}$$

Flying at 10 degree angle of attack

$$Cl_{10} := 1.4$$

$$V_{s5} := \sqrt{\frac{(2 \cdot W)}{(\rho \cdot S \cdot Cl_{10})}} = 8.847 \frac{m}{s}$$

$$\boxed{V_{s5} = 19.791 \cdot \frac{mile}{hr}}$$

Takeoff and Landing with Flaps down, angle of attack of 10 deg, estimated

$$Cl_{10f} := 2.10$$

$$V_{s10f} := \sqrt{\frac{(2 \cdot W)}{(\rho \cdot S \cdot Cl_{10f})}} = 7.224 \frac{m}{s}$$

$$\boxed{V_{s10f} = 16.159 \cdot \frac{mile}{hr}}$$

Total lift of plane flying at 35 miles per hour and 5 deg angle of attack, no flaps

$$V_{30} := 35 \frac{mile}{hr} = 15.646 \frac{m}{s} \qquad Cl_5 := 1.0$$

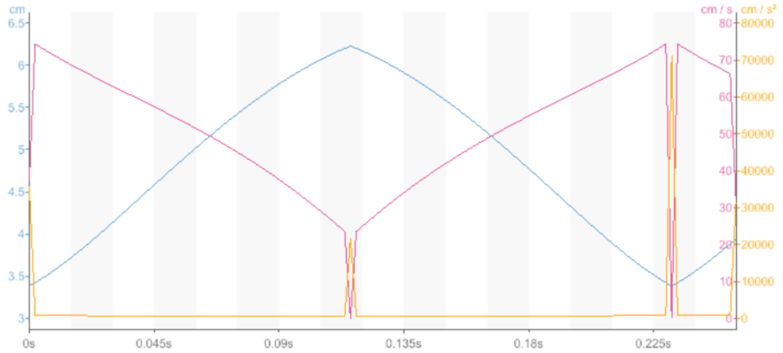
$$L := \left(\frac{1}{2}\right) \cdot \rho \cdot V_{30}^{\,2} \cdot S \cdot Cl_5 = 129.188N$$

$$\boxed{L = 29.043 \cdot lbf}$$

Air Drop Mechanism:

Tracepoint B

Graph of Displacement, Velocity, and Acceleration



Time *(s)*	**Horizontal Displacement** (cm)	**Vertical Displacement** (cm)	**Total Displacement** (cm)	**Velocity** (cm/s)	**Acceleration** (cm/s^2)
0	3.2893	-0.79502	3.38328	37.41674	35561.89
0	3.28676	-0.9525	3.42392	74.3331	866.7344
0	3.28422	-1.10744	3.46456	73.35012	842.5663
0	3.27406	-1.25984	3.51028	72.39508	819.9806
0	3.2639	-1.41224	3.556	71.47052	798.8198
0	3.2512	-1.55956	3.6068	70.56628	778.9494
0	3.23342	-1.70688	3.6576	69.6849	760.2499
0	3.21564	-1.85166	3.71094	68.8213	742.6198
0	3.19532	-1.9939	3.76428	67.97294	725.9752
0	3.16992	-2.1336	3.8227	67.13982	710.2399
0	3.14452	-2.27076	3.87858	66.3194	695.3453
0	3.11658	-2.40792	3.93954	65.50914	681.2356
0	3.0861	-2.54254	3.99796	64.7065	667.8651
0	3.05308	-2.67208	4.05892	63.90894	655.193
0	3.02006	-2.80162	4.11988	63.119	643.1839
0	2.9845	-2.92862	4.18084	62.3316	631.8098
0	2.9464	-3.05308	4.24434	61.54928	621.0503
0	2.9083	-3.17754	4.3053	60.76442	610.8827
0	2.86766	-3.29692	4.3688	59.9821	601.2967
0	2.82448	-3.41376	4.4323	59.19724	592.2848
0	2.7813	-3.5306	4.49326	58.41238	583.8393
0	2.73558	-3.6449	4.55676	57.6199	575.9577
0	2.68986	-3.75666	4.62026	56.82488	568.6425
0	2.64414	-3.86588	4.68122	56.02478	561.9013
0.1	2.59588	-3.97256	4.74472	55.21706	555.7342
0.1	2.54508	-4.0767	4.80568	54.40172	550.1564
0.1	2.49682	-4.1783	4.86664	53.57622	545.178
0.1	2.44602	-4.27736	4.9276	52.7431	540.8092
0.1	2.39522	-4.37642	4.98856	51.89728	537.0652
0.1	2.34442	-4.4704	5.04698	51.0413	533.9588
0.1	2.29108	-4.56438	5.1054	50.17008	531.5052
0.1	2.23774	-4.65328	5.16382	49.2887	529.7221
0.1	2.18694	-4.74218	5.22224	48.38954	528.6172
0.1	2.1336	-4.82854	5.27812	47.47768	528.2057
0.1	2.08026	-4.91236	5.334	46.54804	528.4953
0.1	2.02692	-4.99364	5.38988	45.60062	529.496
0.1	1.97358	-5.07238	5.44322	44.63796	531.2131
0.1	1.92278	-5.14858	5.49656	43.65498	533.6464
0.1	1.86944	-5.22224	5.54736	42.65422	536.7909
0.1	1.81864	-5.2959	5.59816	41.6306	540.6466
0.1	1.7653	-5.36448	5.64642	40.5892	545.1983
0.1	1.7145	-5.43052	5.69722	39.52494	550.4332
0.1	1.6637	-5.49656	5.74294	38.43782	556.326

0.1	1.61544	-5.56006	5.78866	37.33038	562.8589
0.1	1.56718	-5.61848	5.83438	36.19754	569.9989
0.1	1.51892	-5.6769	5.87756	35.04184	577.7103
0.1	1.4732	-5.73278	5.9182	33.86328	585.9551
0.1	1.42748	-5.78612	5.95884	32.65932	594.6902
0.1	1.38176	-5.83692	5.99694	31.42996	603.8672
0.1	1.33858	-5.88518	6.03504	30.17774	613.4329
0.1	1.29794	-5.9309	6.0706	28.89758	623.3338
0.1	1.2573	-5.97408	6.10616	27.59456	633.509
0.1	1.2192	-6.01472	6.13918	26.26614	643.8976
0.1	1.1811	-6.05536	6.16966	24.91232	654.431
0.1	1.14554	-6.09092	6.1976	23.5331	665.0431
0.1	1.11252	-6.12648	6.22554	0	21704.34
0.1	1.14554	-6.09092	6.1976	23.5331	665.0431
0.1	1.1811	-6.05536	6.16966	24.91232	654.431
0.1	1.2192	-6.01472	6.13918	26.26614	643.8976
0.1	1.2573	-5.97408	6.10616	27.59456	633.509
0.1	1.29794	-5.9309	6.0706	28.89758	623.3338
0.1	1.33858	-5.88518	6.03504	30.17774	613.4329
0.1	1.38176	-5.83692	5.99694	31.42996	603.8672
0.1	1.42748	-5.78612	5.95884	32.65932	594.6902
0.1	1.4732	-5.73278	5.9182	33.86328	585.9551
0.1	1.51892	-5.6769	5.87756	35.04184	577.7103
0.1	1.56718	-5.61848	5.83438	36.19754	569.9989
0.1	1.61544	-5.56006	5.78866	37.33038	562.8589
0.1	1.6637	-5.49656	5.74294	38.43782	556.326
0.1	1.7145	-5.43052	5.69722	39.52494	550.4332
0.1	1.7653	-5.36448	5.64642	40.5892	545.1983
0.1	1.81864	-5.2959	5.59816	41.6306	540.6466
0.2	1.86944	-5.22224	5.54736	42.65422	536.7909
0.2	1.92278	-5.14858	5.49656	43.65498	533.6464
0.2	1.97358	-5.07238	5.44322	44.63796	531.2131
0.2	2.02692	-4.99364	5.38988	45.60062	529.496
0.2	2.08026	-4.91236	5.334	46.54804	528.4953
0.2	2.1336	-4.82854	5.27812	47.47768	528.2057
0.2	2.18694	-4.74218	5.22224	48.38954	528.6172
0.2	2.23774	-4.65328	5.16382	49.2887	529.7221
0.2	2.29108	-4.56438	5.1054	50.17008	531.5052
0.2	2.34442	-4.4704	5.04698	51.0413	533.9588
0.2	2.39522	-4.37642	4.98856	51.89728	537.0652
0.2	2.44602	-4.27736	4.9276	52.7431	540.8092
0.2	2.49682	-4.1783	4.86664	53.57622	545.178
0.2	2.54508	-4.0767	4.80568	54.40172	550.1564
0.2	2.59588	-3.97256	4.74472	55.21706	555.7342
0.2	2.64414	-3.86588	4.68122	56.02478	561.9013
0.2	2.68986	-3.75666	4.62026	56.82488	568.6425

0.2	2.73558	-3.6449	4.55676	57.6199	575.9577
0.2	2.7813	-3.5306	4.49326	58.41238	583.8393
0.2	2.82448	-3.41376	4.4323	59.19724	592.2848
0.2	2.86766	-3.29692	4.3688	59.9821	601.2967
0.2	2.9083	-3.17754	4.3053	60.76442	610.8827
0.2	2.9464	-3.05308	4.24434	61.54928	621.0503
0.2	2.9845	-2.92862	4.18084	62.3316	631.8098
0.2	3.02006	-2.80162	4.11988	63.119	643.1839
0.2	3.05308	-2.67208	4.05892	63.90894	655.193
0.2	3.0861	-2.54254	3.99796	64.7065	667.8651
0.2	3.11658	-2.40792	3.93954	65.50914	681.2356
0.2	3.14452	-2.27076	3.87858	66.3194	695.3453
0.2	3.16992	-2.1336	3.8227	67.13982	710.2399
0.2	3.19532	-1.9939	3.76428	67.97294	725.9752
0.2	3.21564	-1.85166	3.71094	68.8213	742.6198
0.2	3.23342	-1.70688	3.6576	69.6849	760.2499
0.2	3.2512	-1.55956	3.6068	70.56628	778.9494
0.2	3.2639	-1.41224	3.556	71.47052	798.8198
0.2	3.27406	-1.25984	3.51028	72.39508	819.9806
0.2	3.28422	-1.10744	3.46456	73.35012	842.5663
0.2	3.28676	-0.9525	3.42392	74.3331	866.7344
0.2	3.2893	-0.79502	3.38328	0	71123.78

Appendix II – Manufacturer’s Specifications

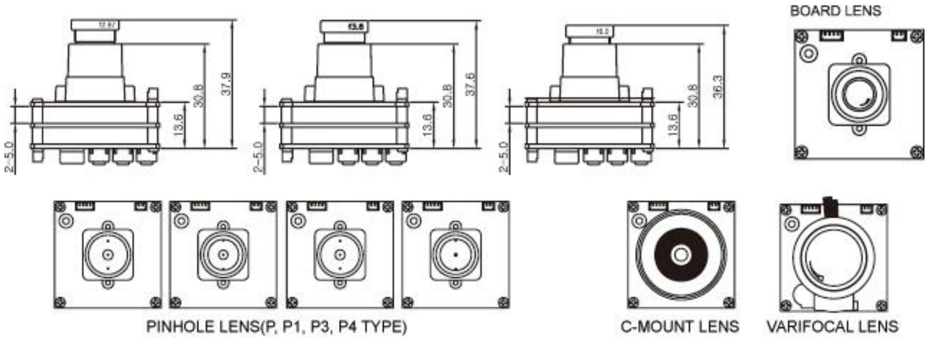
Model Plane:

Senior Telemaster Plus

Weight	Wingspan	Length	WingArea
9 lb	94 in	64 in	1330 sq-in

Camera:

KT&C KPC-E700NUB



Power	Operating Temperature F (C)	Total Pixels	Scanning System
DC 12V - 70mA(Max 110mA)	14 - 110 (-10 - 50)	1020 x 508	2:1 Interlace

Motor:

Magnum XL .91CI 4-Stroke

Displacement	Weight - w/o(w)	Prop Shaft Dia.	Practical RPM
0.91 ci (14.95 cc)	21.7 oz (22.4 oz)	5/15 - 24	2k - 11k

Servos:

Futaba S3004

Power	Torque	Speed	Weight
4.8V	44 oz-in (3.2 kg-cm)	.23 sec/60°	1.3 oz(37 g)
6.0V	57 oz-in (4.1 kg-cm)	.19 sec/60°	

Futaba FP-S148(Precision)

Power	Torque	Speed	Weight
4.8V	33 oz-in (2.4 kg-cm)	.28 sec/60°	1.6 oz (44 g)
6.0V	42 oz-in (3.0 kg-cm)	.22 sec/60°	

Radio Control:

Futaba 6J 2.4 GHz

Type	Power	Freamerate	Requires
2-stick; 6 Channel; FHSS/S-FHSS	4.8 - 7.4 V(170 mA)	6.8 ms	AA x 4 + Reciever

Battery Packs:

Tenergy Li-PO 11.1V

Voltage (Capacity)	Weight	Cont. Discharge	Dimensions
11.1 V (2200mAh)	185 g	25C/55ª	110x35x25mm

Tenergy Ni-Mh 4.8V

Voltage (Capacity)	Weight	Type	Dimensions
4.8 V (2000mAh)	108 g	Flat	58x15x52 mm