SABINO CANYON UAV

By

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In Partial Fulfillment of the Bachelors degree
With Honors in

Aerospace Engineering

THE UNIVERSITY OF ARIZONA

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Abstract:

The purpose of this project is to design a small aircraft to be flown autonomously down a canyon 3-4 miles one way and back to a base station. The configuration of the aircraft is a flying wing rather than a conventional aircraft design and will have a short takeoff system and land with a belly skid. The aircraft will provide a video feed to a base station to assist rangers in search and rescue operations. The aircraft will fly on its own with given GPS waypoints from a user.

THE UNIVERSITY OF ARIZONA

Final Report

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Team Member Responsibilities

Stephen Pineda

Initial conceptual design of aircraft
Investigated methods of manufacturing
Material testing for strength and weight
Manufacturing of composite aircraft skin and molds
Assisted in flight testing and troubleshooting

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James Steinke

Aerodynamic analysis of all designs
Development of base station
Autopilot and component integration
Manufacturing of composite aircraft and molds
Flight testing and troubleshooting
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Cassie Palo

Investigation of FAA requirements
Manufacturing of molds
Assisted in flight testing and troubleshooting
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Robert Eby

R/C pilot for flight testing
Conceptual Design
Flight testing and troubleshooting
Manufacturing test platforms and molds

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Eric Wilder

Preparation of aerodynamic balance for eventual use in wind tunnel tests
Assisted in flight testing and troubleshooting (including autopilot)
Manufacturing test platforms and molds
Aerodynamic analysis of first design

Aerodynamic Analysis p. 20

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Clinton Hales

Design and manufacturing of mechanical launch system
Assisted in flight testing and troubleshooting
Solidworks design of platform and models for wind tunnel testing

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NOMENCLATURE

A.C.	Aerodynamic Center
C_D	Drag Coefficient
C_L	Lift Coefficient
C_L/C_D	Ratio of Lift Coefficient to Drag Coefficient
C_M	Moment Coefficient
CG	Center of Gravity
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
GPS	Global Positioning System
GUI	Graphical User Interface
IMU	Inertial Measurement Unit
L/D	Lift to Drag Ratio
MAC	Mean Aerodynamic Center
R/C	Remote Control
Re	Reynolds Number
UAV	Unmanned Aerial Vehicle
α (alpha)	Angle of Attack

Abstract

The purpose of this project is to design a small aircraft to be flown autonomously down a canyon 3-4 miles one way and back to a base station. The configuration of the aircraft is a flying wing rather than a conventional aircraft design and will have a short takeoff system and land with a belly skid. The aircraft will provide a video feed to a base station to assist rangers in search and rescue operations. The aircraft will fly on its own with given GPS waypoints from a user.

Project Description

The primary motivation in developing this UAV system is to have a platform with the ability to assist ground teams for search and rescue missions. With a camera system onboard, park rangers and rescue teams can send the UAV to search out the precise location of a lost or injured hiker, reducing the overall time needed to find the hiker. With a short take-off launching system, the UAV will be portable and not require a runway.

Background

Due to the numerous ways of approaching the task of designing and building a small, autonomous aircraft, three existing UAVs were analyzed prior to considering an initial design for our UAV platform. All three UAVs analyzed were designed for and have been used by military troops in the field, so they are known to be capable and can complete their given tasks. The three UAVs analyzed were the Lockheed Martin Desert Hawk, the EMT Aladin, and the AeroVironment RQ-11 Raven because their mission capabilities are similar to what our project required.

All three UAVs land with a belly landing, use electric motors, and have an endurance of one hour or longer. Similarly, our project utilizes belly landings, and electric motor, but does not require such a long endurance. Two of the three UAVs utilize pusher props, and all three have a conventional aircraft design and are hand or bungee launched.

With the initial design of the UAV, a pusher propeller configuration was chosen so that a forward positioned camera would not experience any interference. Also, instead of utilizing a conventional aircraft design, a flying wing configuration was chosen. This ultimately allows for simpler construction and less molds required in the final design. For the flying wing, a base design was chosen that was similar to that of a known flying wing glider.

Project Goals

Goals were generated in order to ensure that the plane would be able to complete the desired mission: an autonomous flight down a canyon and back providing video feedback. The goals are as follows along with their justifications:

1. **30 Minutes of Flight Time**
   The aircraft shall have at least 30 minutes of flight time, including loitering. This time will allow a standard mission to be flown, 10 minutes up the canyon, 10 minute loiter, 10 minutes return. To meet this goal we need to ensure that we have enough battery power on the plane to safely fly for 30 minutes.

2. **Operational Radius of 4 miles**
   The aircraft shall be able to fly over eight miles on a single charge of the battery system. That allows for at least four miles of flight one way. This is the distance the plane would fly from the beginning of the canyon to the to end, loiter, and return to the launch site. Included in this operational radius, our components will have to be able to communicate when the plane is at least four miles away from the base station, constant communication between the base station and autopilot is necessary for safety.

3. **Autonomous**
   The aircraft shall be piloted by an onboard autopilot. This will allow for a pilot with limited experience to operate the plane. The user would only have to input the GPS points desired for the plane to fly over.

4. **Short Field Takeoff/Landing**
   The aircraft shall be capable of short field landings and takeoffs. Due to the lack of a large runway in the Sabino Canyon area, the plane must be capable to taking off and landing in minimal area.

5. **Operable by a Novice**
   This goal includes several parameters that will make the airplane easy to use for a single person with not much experience. The aircraft shall have a wingspan of less than six feet so it can be transported in a vehicle easily. The airframe shall compose less than 40% of the weight of the entire system to allow for a light plane that can be easily moved by a single person. The launch of the aircraft needs to be operable by a single person and the autopilot system must be user-friendly and easy to understand with limited training or experience so beginners can use it with ease.

Component Layout

In order to ensure that the range of the vehicle would be sufficient, we selected high quality components even though they were slightly more expensive. The summary of the components is shown in the following table.

Component Type	Part	Cost
Autopilot	3DR Pixhawk	$199.99
Video Transmitter	ImmersionRC 5.8 Ghz	$70
Radio Control	Spektrum Satellite	$40
Camera	CCD Killer Camera	$50
GPS	3DR uBlox GPS	$90
Airspeed Sensor	MPXV7002DP	$30
Batteries	GenAce 4 cell 2700 MAh	$30
Telemetry	RFD900	$200
Servos	Hitech HS-7955TG	$120
Motor	Hyperion GS-3014	$50
Speed Controller	Hobbywing 40 A Platinum Pro	$50

Table 1: Selected Components

As the table shows, the major components have been selected. The power system selected depended on weight available on the airframe and how much power is be needed for at least 30-minutes of flight time. For the video transmitter, the options available were a 1.3 Ghz system and a 5.8 Ghz system. The 1.3 Ghz system has better range but lower video quality. The 5.8 Ghz system on the other hand offers better video quality but reduced range. The 5.8 Ghz was selected for beginning test due to the availability of components and low use of that frequency. For longer ranges, a 1.3 Ghz system will be utilized instead.

In order to reduce the amount of interference between the various antennas, not only were different frequencies chosen, but it was decided to maximize the physical distance between them. For this reason, the telemetry (900 Mhz) will be one wing while the GPS (1400 MHz) will be on the end of the other wing. The video transmitter is mounted on one side of the center while the radio receiver is on other side of the center. With additional low and high pass filtering, it will then be possible for all the frequencies to coexist without interference.

The autopilot and batteries are mounted towards the center, with autopilot being in the exact center of the plane. The battery position can be adjusted to make sure the center of gravity of the plane is correct, but should be towards the nose of the plane. The airspeed sensor is pushed out of the leading edge of the plane, just off of center.

The motor was chosen for it's high efficiency at cruise velocities. Judging by flight testing of various foam models (both the wicked wing and the foam core MH-60), less than 10 amps of current is required to maintain flight. At this current, the Hyperion GS3014 has a efficiency of 80% due to it low IO current. This gives a flight time of about The static thrust of the motor is over 5 lbs on a 4 cell pack, giving a thrust to weight ratio of about 1. Increasing the cells from 3 to 4 will provide the extra thrust needed to cruise the plane without drawing additional current. With two battery packs (5400 MAh total), a expected flight time of 30 minutes was calculated. However, one issue seen in flight is that motor takes a while to spool up, making it difficult to hand launch.

Airframe Design

The airframe consists of three main parts, the lower wing half, the upper wing half and support structure. The upper wing half and ribs will have mounting points for all of the components while the lower wing will have a central cutout for accessing components and batteries. A cover will then be installed on the lower wing in order to promote a smooth airflow and protect the exposed central components. The support structure will consist of two carbon rods running parallel to the leading edge, two spars near the trailing edge, and a rib near the center and end of each wing to join the support structure together.

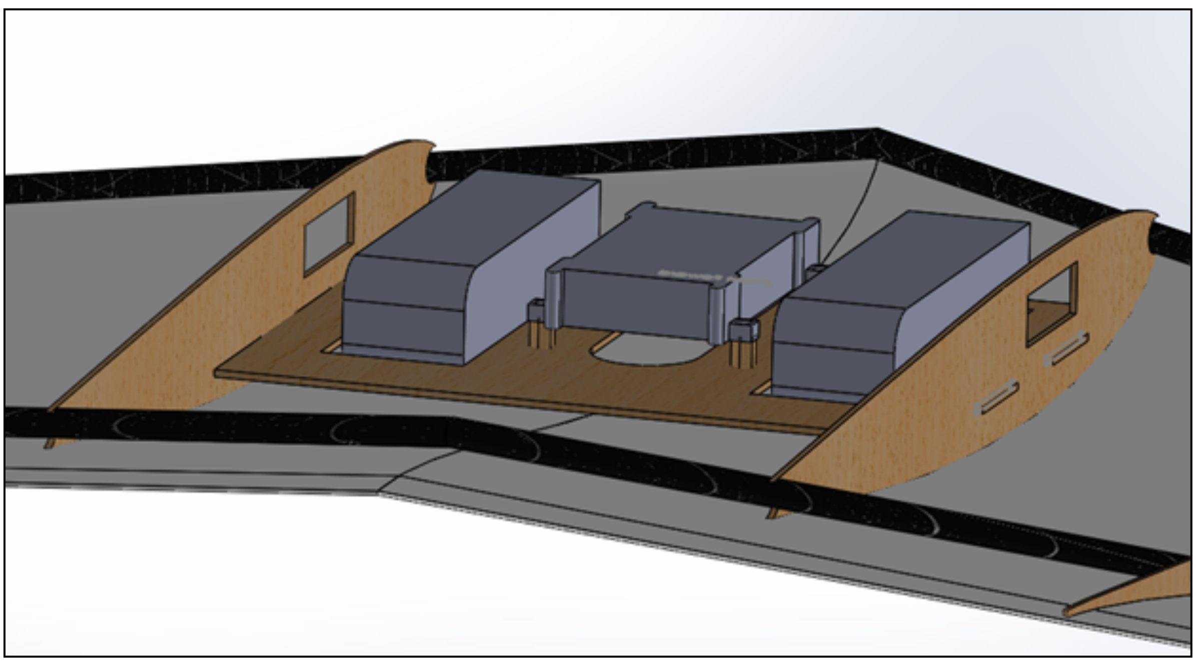

Figure 1: SolidWorks Model of 1st Generation Airframe

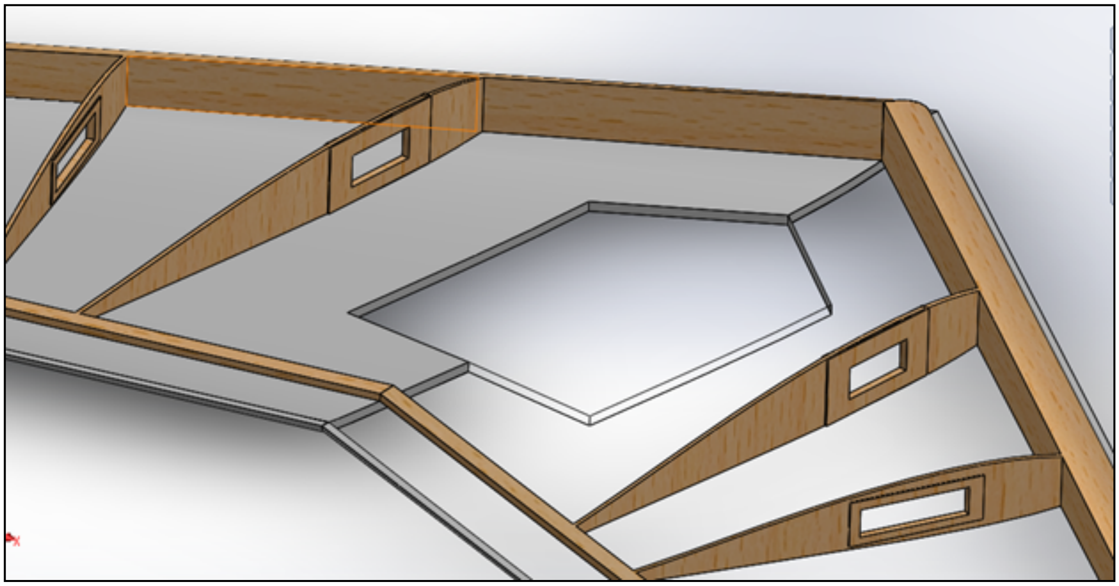

Figure 2: Solidworks Model of 2nd Generation Airframe

In the first generation airframe, the spars were made of carbon fiber, the control surfaces were solid, and the ribs were closer to each other. There were no reinforcements of the holes in the ribs, and as a result, the ribs failed and the carbon fiber rods cracked during a hard crash.

Figure 3: 1st Generation - Broken Spar and Rib

With the failure of the structure in the first generation, a FEA model was done to see where the highest stresses would occur. As shown in Figure 4 below, the maximum von Mises stress occurs along the leading edge, explaining why the carbon fiber rod broke. This stress then propagated through the structure to the first rib, breaking it as well.

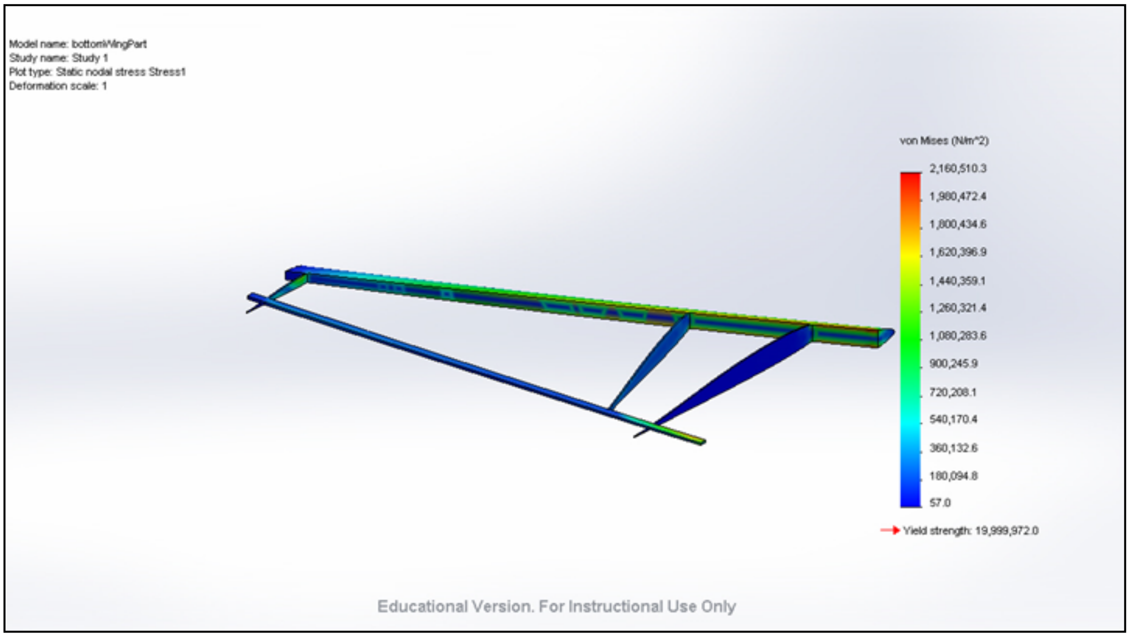

Figure 4: FEA Stress Analysis of Wing Supports

In the second generation airframe, the leading edge was made from balsa wood, and the control surfaces are built up over a hollow balsa structure. The leading edge was changed from carbon fiber to balsa wood because it is lighter, less expensive, and the stress observed from a hard crash would break the leading edge regardless of material (as seen by the FEA plot and previously snapped carbon fiber spar). The trailing edge is reinforced with a carbon spar along the length of the control surface. The ribs are also reinforced with 1/32 balsa to prevent splitting. Finally, mounting points were added for detachable landing gear.

Figure 5: 2nd Generation - Reinforced Rib and Trailing Edge

Manufacturing

The construction of the composite airframe required 2 molds. These molds were constructed from dense foam that had the airfoil shape plane geometry hot wire cut into it. The inner surface of the molds (where the airfoil shape is) was smoothed with spackle and sandpaper and then coated with a layer of fiberglass to provide a hard, smooth final surface. The construction of the airframe utilized a wet lay-up of composite materials, which were vacuum bagged and joined together once each half had been cured. Each half of the skin is constructed from an outer layer of 4 ounce fiberglass, an Aeromat core, and then an inner layer of 4 ounce fiberglass. During the layup process, micro-ballooned epoxy was placed at the leading edge to thicken it and provide more contact area when joining the two halves. Additionally, a carbon fiber rod was placed in the leading edge to provide strength and resistance to bending. The ribs were constructed out of aircraft plywood so that it remains strong but light, and the trailing edge spar is another carbon fiber rod. The elevons for the design are made from balsa wood and connected to the airframe with small hinges.

The use of composite materials such as fiberglass provides many advantages to other construction methods. First, with solid foam core construction, slots for all of the components must be cut into the structure, fixing them in one place. Using composite materials, the airframe can be strong but hollow, allowing for the components to be placed anywhere in the wing. One caveat to this is that multiple cutouts are required to access all of the components. In the current design there is only one central cutout; this makes it difficult to access components outside of the central compartment (additional panels are needed to access the rest of the components).

Secondly, utilizing composites can reduce the empty airframe weight. A known solid foam glider equal in size has a mass of 958 grams (including servos). Assuming ideal construction and minimal epoxy use in the composite lay-up process, the skin is estimated to potentially have a mass of 656 grams. Before components were added to the composite plane, it had a mass of 850 grams. The final airframe constructed has a mass of 1.2 kg, including all of the components, but not including the batteries and motor. With the power system, the final mass was about 2 kg. Finally, composite materials are proven to be very stiff and can provide better abrasion resistance for belly landings on rough surfaces compared to foam airframes.

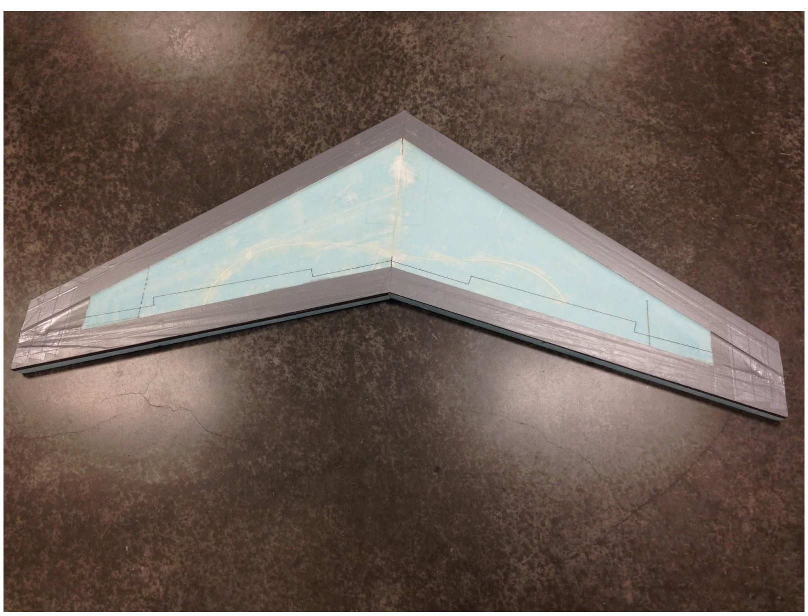

Figure 6: Foam Mold with a Layer of Fiberglass

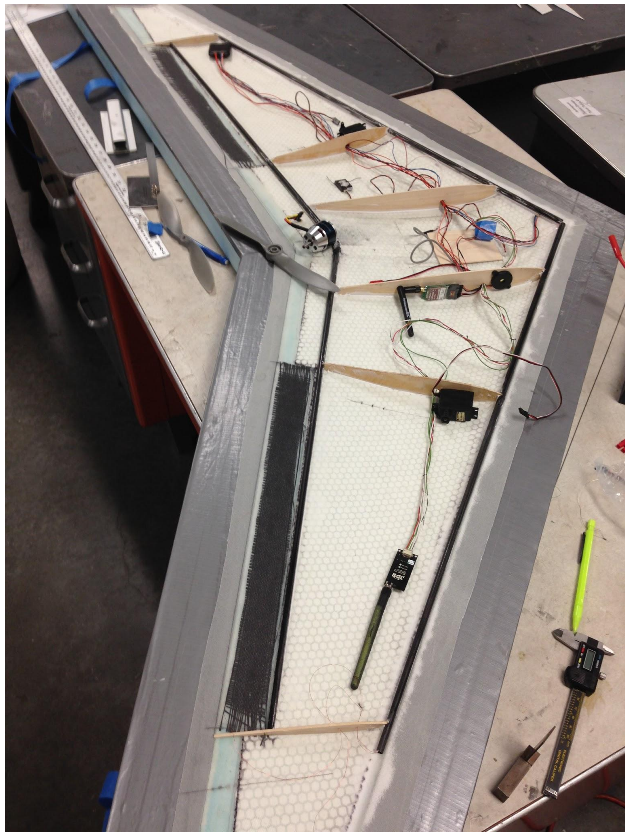

Figure 7: Composite Top Half with Inner Support Structure and Some Components

Base Station

The base station consists of two antennas, a 900 mhz to receive telemetry and a 5.8 Ghz to receive a video feed from a camera mounted in the front of the plane. The data streams are read using a laptop. The video feed can also be routed to a secondary monitor. This base station range is a fraction of our design goal with a max practical range of a half mile. The base station will be upgraded to a system capable of transmission over 40 kilometers which will meet the design range goal. Two major upgrades will be from a 100 mW telemetry transceiver to a 1 W system and moving from 5.8 Ghz video to 1.3 Ghz video. The current base station is valuable for initial flight tests where the vehicle is only capable of being piloted in visual range. In order to boost the range, direction antennas are used on the base station. However, due to their ineffectiveness with increasing angle, it is necessary for the ground station to track the plane. The ground station can pan and tilt the antennas to point directly at the aircraft using 2 geared brushed motors along with IMU feedback.

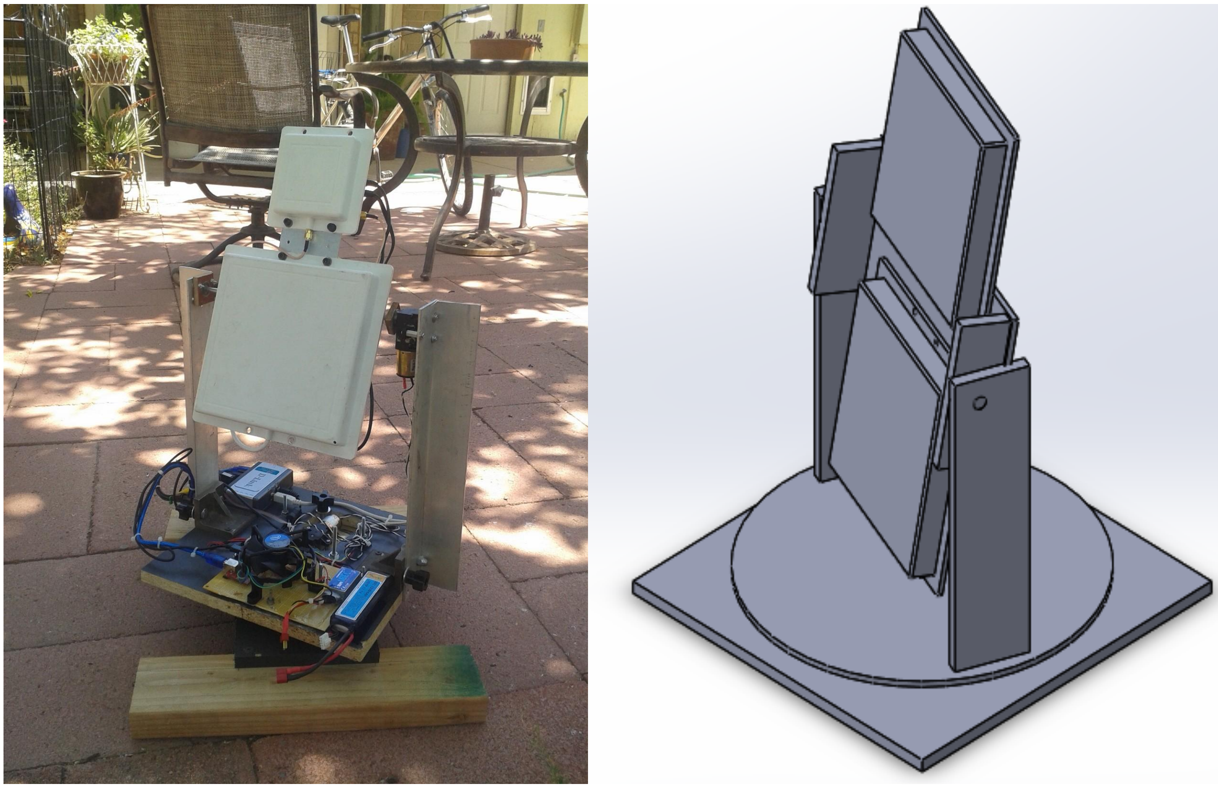

Figure 8: Base Station Setup and SolidWorks Design

Launch Platform

1. Initial Design

Due to constraints on the intended operating location of the plane a launch device had to be designed that was capable of accelerating the plane into a glide in a short distance (6 to 8 feet). After the plane is clear of the launch system the pilot then would power up and smoothly transition from a glide to powered flight. The initial launch platform design used rubber-latex exercise bands that are stretched and held in place with a quick release mechanism to provide the force to accelerate the vehicle. When the release is triggered the bands contract over a 6 foot distance rapidly accelerating the vehicle to glide speed. To minimize the length of the launch platform the latex bands are located on the underside of the framework and a rope transfers the force over a pulley at the end of the launcher down the top railing where the rope attaches to the vehicles launch hook and the quick release. By using multiple bands that could be added or removed the launcher could be calibrated close to the vehicles ideal launch exit velocity. During field testing, the launch platform provided successive consistent launches demonstrating that the platform can perform in environments that require very short take off distances.

Figure 9: Preliminary Launch Platform

Improvements to the launch platform were made following flight tests that demonstrated the launch technique to be a proven concept. Previously to set the launcher it took two people to pull the rope attached to the bands and hook it into the quick release. To improve the usability of the launch system a mechanism was designed that allows one person to easily set the launcher by way of a winch or similar mechanism. The ability to trip the quick release remotely will also be added using servos that can be tied into the autonomous programming allowing for an entirely autonomous launch sequence to be performed. Lastly the construction and build quality of the launcher will also be improved to reduce weight making it more portable. The aesthetics of the launch platform will be improved upon to make the system look like a professional product.

Vehicle mass (kg)	Distance accelerated(ft)	Required velocity (mph)	Acceleration (ft/s^2)	Acceleration time (s)	Force required (lbf)
1.265	6	35	217	0.24	18.77

Table 2: Required Launch Force

2. Final Design

The final design of the launch system uses a linear motion actuator that is modified to launch the aircraft. This design offers many advantages over the previous design: the stroke length of the actuator is 10 ft allowing for lower acceleration putting less stress on the aircraft, the LM actuator is rigid and at 80 lbs the weight helps to keep the launcher stable during launch, sensors on the rail can give acceleration and velocity of launch providing more consistent launches.

Initially the actuator was going to be driven by a servo motor, however to make the launch system more portable and less complex the actuator was modified so that elastic surgical tubing could be used to accelerate the bearing block with the plane attached. This also reduced the cost of the launch platform considerably.

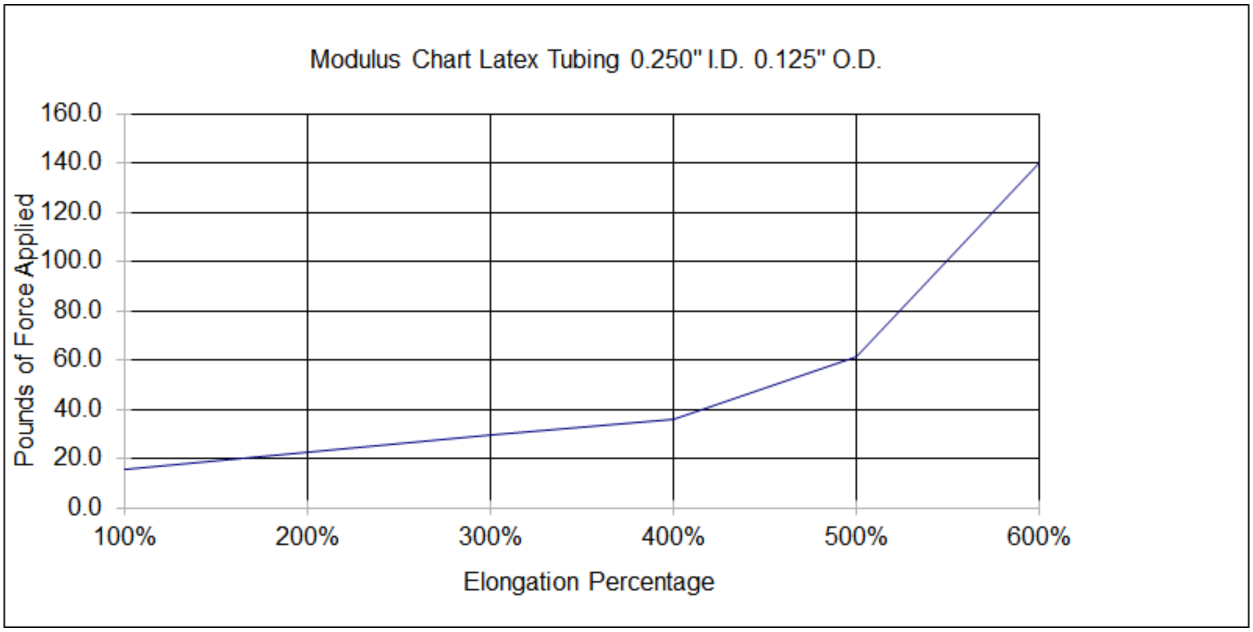

Figure 10: Latex Tubing Properties

Using the figure above the number and length of the latex tubes powering the launcher was set to 6 tubes each 20 in long. This configuration provides enough force to accelerate the plane to takeoff speed while still allowing for minor adjustment by way of the distance the bearing block is cocked back.

In conclusion the launch system is essential to the successful operation of the aircraft due to traditional launch methods such as a high start or hand launch giving poor results compared to the launch system. In its current state the launch system does not meet certain key criteria originally envisioned for the system. In regards to ease of use and reliability the launcher is difficult to use because the bearing block has to be manually pushed back by two people to the cocked position and then attached to the quick release. On the last day of testing when cocking the bearing block back the attachment method of the latex tubing to the belt attached to the bearing block failed rendering the launcher inoperable. To fix these issues of reliability and ease of use, the latex band method to provide the force to accelerate the bearing block should be scrapped and the launch system redesigned with a servo motor drive and accompanying portable power source along with motor control electronics. Lastly the method by which the plane attaches to the launcher needs to be refined and modified so that the propeller can be spun up while the plane is still on the launcher. Currently the propeller can only be powered after the plane has cleared the launcher otherwise the propeller would impact with the launcher upon release. This design change is important to provide for a smoother takeoff that relies less on the pilots ability to hit throttle at the right time.

Figure 11: Final Launch Platform Design

Flight Testing

Throughout the design process, several test platforms were built and used for testing. The majority of the initial hardware integration and troubleshooting was done on a platform known to fly well: the Hobby King Wicked Wing. Testing was then conducted on the platforms designed.

Platform I: Hobby King Wicked Wing

1. **Assembly of aircraft with all R/C components needed for flight**

   The first step was assembly of the airframe, the Hobbyking Wicked Wing was used as it is a similar aircraft to the final design. After the airframe was assembled all electronics needed for radio control flight were installed. Two servos were installed in the pre-molded pockets of the wing, a battery well was cut out to fit a 2200mah lipo battery, a brushless motor and speed control were mounted on the plane, and finally a 2.4Ghz receiver was connected to all components and installed on the plane. The plane was then balanced to have the CG at 20% MAC.

2. **R/C flight test**

   - Hand launch
     After the aircraft was assembled the first set of testing began. To make sure that the plane was assembled properly and all components were working correctly the plane

was hand launched. During this testing it was found that the plane was working as intended, but the hand launches posed a problem. Hand launching the plane was not difficult but it was inconsistent and required that one hand was holding the transmitter while the other is throwing the plane. Which would prevent problems if a novice user were attempting to launch the plane.

- Bungee launch

  In an attempt to find a better method of launching the plane a bungee launcher was used. This method was found to solve many of the problems with hand launching the plane but had the disadvantage of requiring a long distance for the bungee to extend during to launch.

- Launcher platform

  Next a launching platform was built that used the same hook and release system as the bungee system but was able to launch the plane in a significantly smaller area.

3. **Autopilot pass-through testing**

   Once the aircraft was proven to fly properly on a consistent basis the autopilot was installed on the plane but was only used as a pass-through at this time.

4. **Telemetry and GPS testing**

   With the autopilot on the plane the telemetry and GPS systems were tested to make sure that the autopilot was sending information to the base station through the duration of the flight. During initial testing it was found that there was a large amount of electrical interference and the components needed to be moved to opposite sides of the wing to minimize interference between components.

5. **Initial autopilot testing - manual launch and landing**

   After resolving issues with the telemetry, testing of the autopilot began by starting with manual takeoff and landing while performing short autonomous flights.

6. **Short autonomous loiter flights**

   The first tests of the autopilot were loiter patterns where the aircraft would circle around a fixed GPS point maintaining a constant altitude.

7. **Way point determined flights**

   After achieving consistent loiter pattern multiple waypoints were pre-set for the aircraft to fly.

8. **Integration of video system**

   To install the video system a small section of the leading edge was cut out and the camera was installed in its place. The leading edge was then covered over with clear tape to restore its shape and help protect the camera.

Platform II: Eppler airfoil

The first design used an Eppler 334 airfoil, and a foam core with fiberglass skin. This design was launched by hand and with the mechanical launcher. Flight testing of the Eppler airfoil showed that the configuration required large deflections were required to maintain level flight. During testing it was also found that the aircraft became unstable at low speeds.

Platform III: MH-60 foam core

To solve the issues with the Eppler airfoil configuration the airfoil was changed to the MH-60. Through testing of the foam MH-60 it was found that the relationship to CG placement and motor position was extremely sensitive to small changes. After testing the MH-60 airfoil construction of the composite versions was started.

Platform IV: Composite V1

The first version of the composite construction required use of the launcher. Takeoff from the launcher was unsuccessful as the aircraft would consistently pitch down on launch. The difficulties on launch were most likely due to the orientation of the motor and CG location on the aircraft.

Due to the method of construction the airfoil may have been distorted. this may have also caused the difficulties during testing. This may be seen when looking at the maximum thickness of the airfoil of this platform. While the design calls for a maximum thickness of 1.7 inches, this platform has a maximum thickness of 2.1 inches while the foam platform tested (Platform III) had a maximum thickness of 1.75 inches.

Platform V: Composite V2

After issues with the takeoff on the final construction were encountered, tricycle landing gear were installed. Through further testing the difficulties on take off were determined to be due to placement of the motor. Further testing is required to find an adequate solution.

Aerodynamic Analysis

A flying wing configuration was decided upon for the design. Flying wings offer aerodynamic efficiency in addition to being relatively easy to manufacture. The components used fit easily inside the cross section of the wing.

Based on experience with the first test platforms, a wingspan of 4.5 feet was selected. This provided a large planform area while remaining small enough to be reasonably portable. A leading edge sweep of 32 degrees and a taper ratio of 3:1 were used. The model was designed in Solidworks and then imported into XLFR5 for analysis. In order to select an appropriate airfoil and know what conditions to run the analysis at, a rough estimate of the Reynolds number was calculated.

Kinematic Viscosity (2500 ft)	$1.5515 * 10^{-5}$ m^2/s
Velocity	30-35 mph (13.411-15.646 m/s)
Mean Aerodynamic Chord	1.1 ft (0.335 m)
Reynold's Number	290000-340000

Table 3: Reynold's Number Calculation

For this estimated range of Reynolds numbers as well as the flying wing configuration, the Eppler 334 airfoil was first chosen. However, after flight testing, it was determined that this airfoil was unstable and difficult to fly.

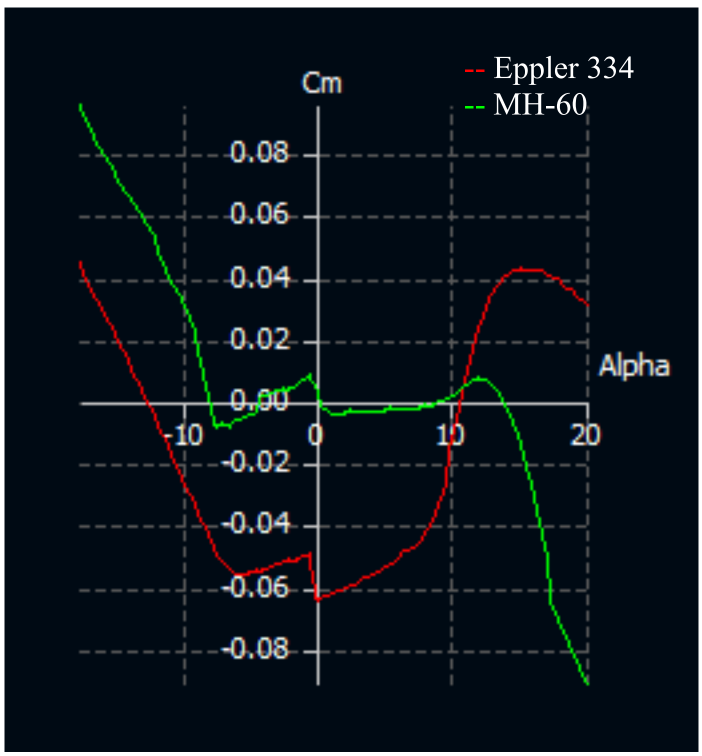

Figure 12: C_M vs Alpha Curve for MH-60 and Eppler 334

Although the Eppler appears to have higher performance than the MH-60, there are several factors that make it not ideal for our application. One is the highly negative slope moment coefficient curve coupled with the sweep (which further decreases the moment coefficient slope), major control inputs are required to prevent the plane from pitching down. However, the main issue is the way that it stalls, as the moment coefficient goes from negative to positive very quickly, resulting in the plane pitching upwards, making the stall essentially unrecoverable. This was confirmed during flight tests.

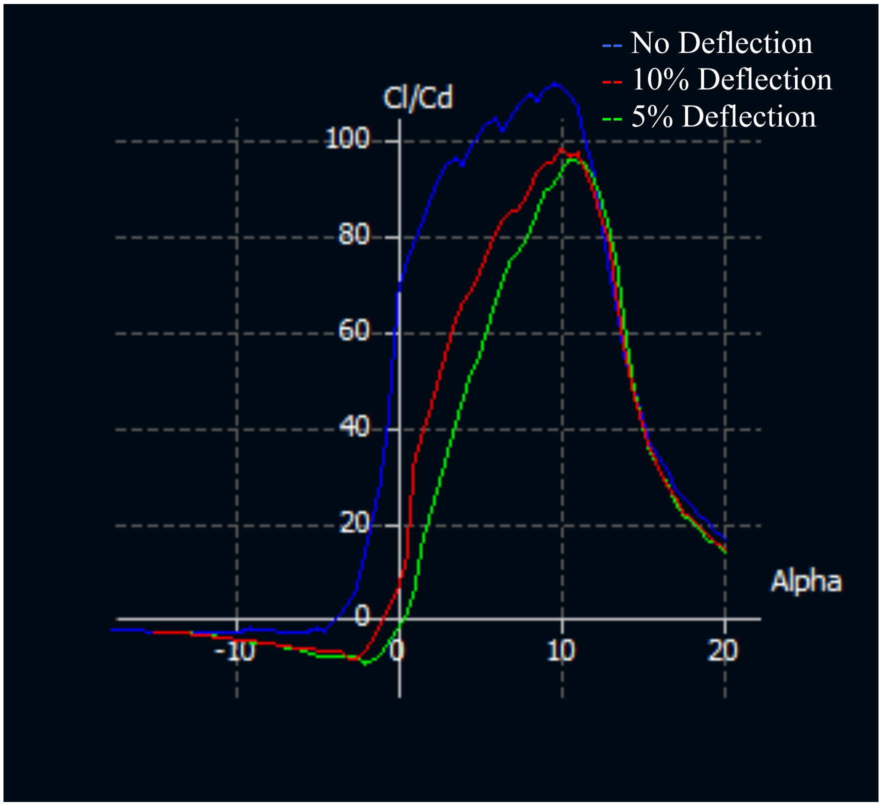

Figure 13: Cl/Cd vs Alpha for MH-60 Airfoil Configuration

Figure 13 highlights the problem with requiring controls deflections to offset the pitching down moment. A five to ten percent deflection results in a decrease in C_L/C_D by 20 at highest peak. However, the decrease is much more significant at lower alpha. (40 or more). This would have a significant impact on the efficiency of this airfoil for our application.

The MH-60 was suggested as an alternative as to avoid the large moment curve and poor stall characteristics while maintaining good performance. While the Eppler 334 is a higher performing airfoil than the MH-60, its stall characteristics and moment curve make it unsuitable for our project.

For a flying wing, wing twist is recommended, however adding twist greatly complicates construction of the design.

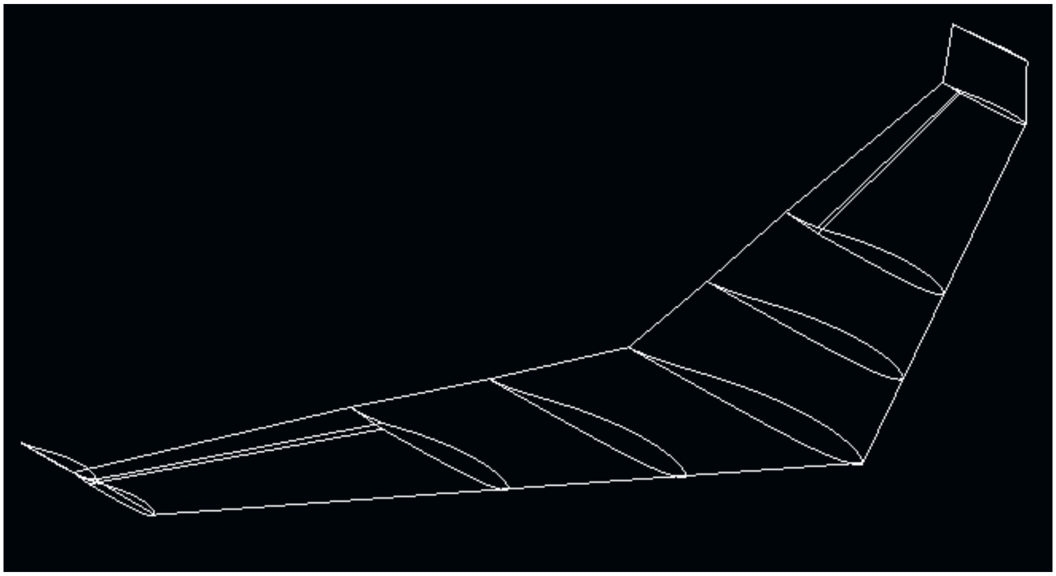

Figure 14: Rib Spacing in Final Configuration

Utilizing XFLR5, a theoretical analysis of the design with the MH-60 airfoil was conducted to get an initial estimate of its performance. The analysis was performed taking viscous effects into account; for the analysis, the plane mass was set to 2 kg to account for the airframe mass and the mass of all the electronics onboard. XFLR5 is not able to predict the performance of the airfoil near the critical angle of attack; wind tunnel testing will be required to predict stall behavior. The results of the analysis are shown below.

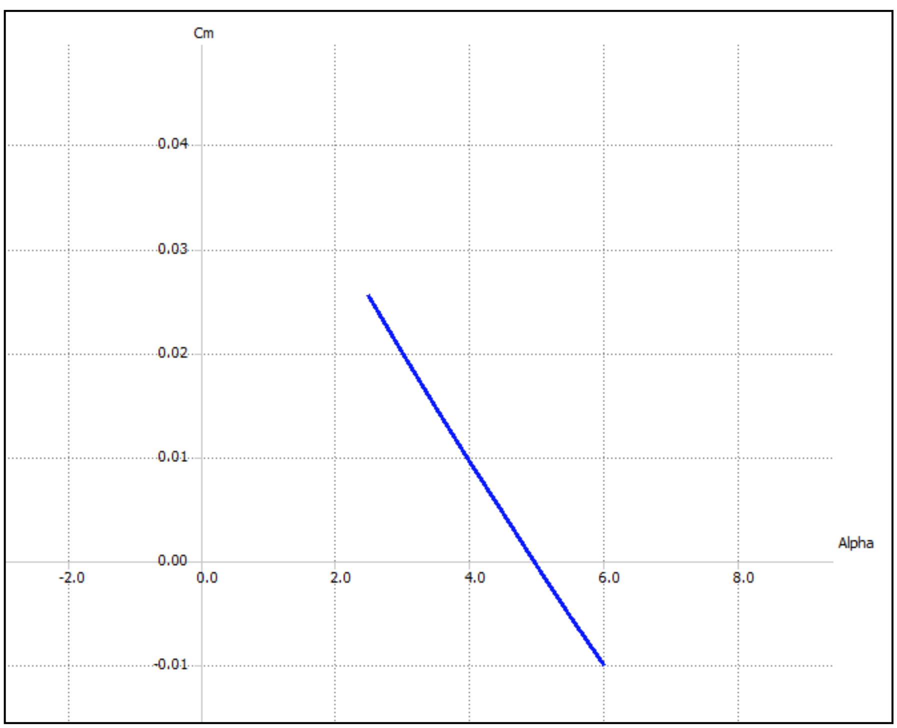

Figure 15: Cm vs Alpha for MH-60 Configuration

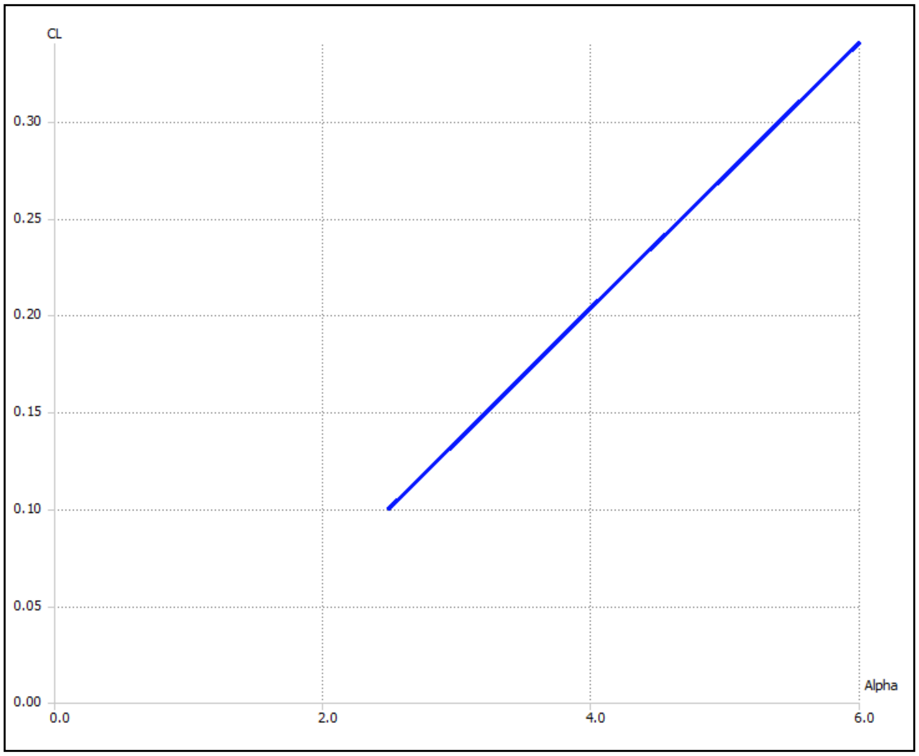

Figure 16: Cl vs Alpha for MH-60 Configuration

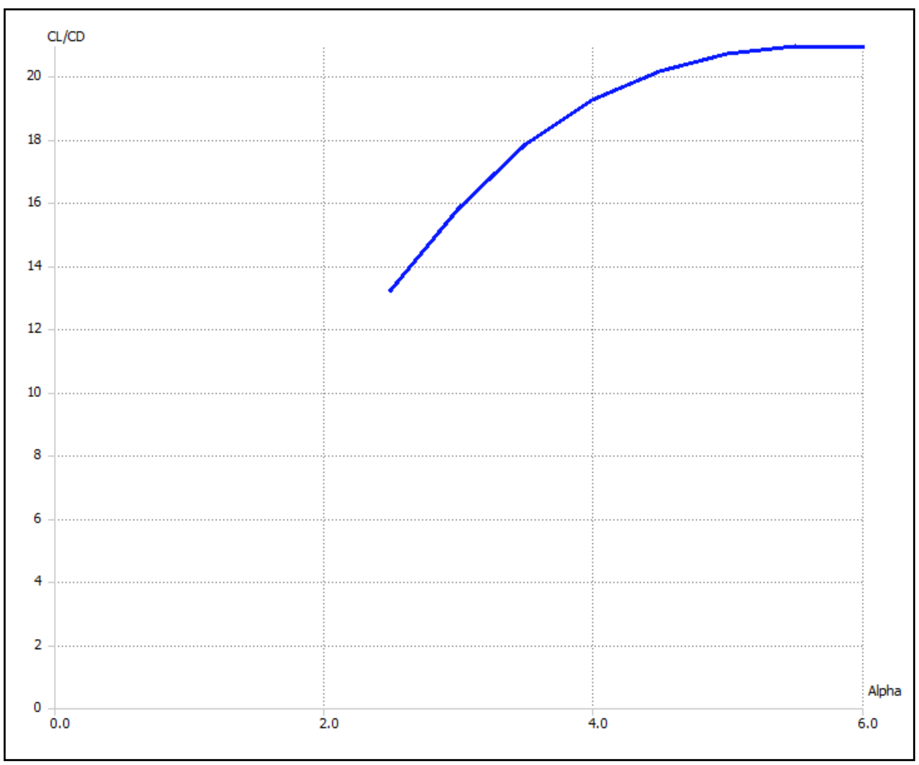

Figure 17: C_L/C_D vs Alpha for MH-60 Configuration

As can be seen above, the moment coefficient slope of the MH-60 is much more favorable for our application than the Eppler 334. In addition, the C_L/C_D of this airfoil is comparable to that of the Eppler if the control deflections required by the Eppler are taken into account.

With these results, a stability analysis was conducted in XLFR5 to determine the optimal flying condition of the design. These results are shown below in Table 4.

Wing loading	4.926 kg/m^2
Cruise angle of attack	5 degrees
Cruise Cl/Cd	22
Cruise velocity	17.1 m/s
Elevon deflection	5 degrees upward deflection
C.G. location	25 cm from leading edge
A.C. location	~ 30 cm from leading edge
Static margin	12 %

Table 4: Stability Results from Aerodynamic Analysis in XFLR5

Wind Tunnel Testing

In order to verify the performance of the theoretical model of the design, wind tunnel testing will be performed on a scale model of our final design. A half-span, ⅓ scale model has been designed in Solidworks for this purpose. The model was designed so that the 3D printer would construct the model with the span going vertical in order to avoid the visible stepping which occurs in the vertical direction on a 3D printer. The model is constructed in two parts, the half-span and winglets. This will allow the testing of various winglets in order to determine an optimal winglet design.

Wind tunnel testing would be useful to determine if the problems experienced with the composite airframe are due to the aerodynamic design or due to a problem with the manufacturing process. The airspeed required by the composite airframes means that it is likely that they will sustain damage in a crash. Wind tunnel testing would allow us to test the stability of the airframe without potentially destroying an airframe. Future work could also include using similar manufacturing methods like those of the composite airframes to create a scale model for wind tunnel testing in order to determine if manufacturing flaws are causing the stability issues experienced during flight tests.

Conclusions

The intended goals of the project were to create an autonomous aircraft capable of 30 minutes of flight time, operational radius of 4 miles, short field takeoff and landing capabilities, and most importantly operable by a novice. The chosen airframe was a Zagi design due to ease of manufacturing and its use in similar applications. After some trial and error the chosen airfoil for the platform was an MH-60, and other properties of the airframe were chosen based on applicational needs of implementing the airframe into use at Sabino Canyon. These include a small wingspan, light platform that is easily transportable, and a strong airframe to ensure no permanent damage will be taken upon belly landings.

From the flight testing that has been done it is shown that the chosen batteries will be able to withstand the 30 minutes of flight time needed for the intended mission, this 30 minutes of flight time and the chosen cruise speed for the airframe show that the intended operational radius of 4 miles is also obtainable. The linear bearing rail launch system that was designed allows for short-field takeoffs that are safe, and can be tuned with the autopilot so it can be operated by a novice. The chosen autopilot was a 3DR Pixhawk which has a user friendly GUI that takes GPS waypoints as inputs from a user. The waypoints can be changed mid flight as to ensure proper search of a canyon if people are spotted as part of a search and rescue.

Overall, the project was a success. The intended goals have been met although there is still need for future work on the project.

Future Work

More testing needs to be done with the composite aircraft in order to determine what is causing the stability issues seen during flight testing. The proposed wind tunnel testing may also be used to aid in the analysis of stability issues. Once these issues have been resolved, it would be desirable to build another composite airframe as significant weight has been added to both existing airframes to repair damage caused by crashes during flight testing. In addition, future work would include autonomous take-offs, autonomous landing, and integrating the base station with the launcher. Once all of the stability and flight issues are corrected, the final platform needs to be approved by the FAA for fully autonomous flight and for endurance testing out of line-of-sight. After final approval by the FAA, the last step for future work would be successfully implementing the airframe, base station, and launch system at Sabino Canyon along with training search and rescue rangers on its operation in order to make it easier for the rangers to find lost or stranded hikers in the area.

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