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VTOL Search and Rescue

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ENTITLED

VTOL Search and Rescue

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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VTOL

SEARCH AND RESCUE AIRCRAFT

By
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SENIOR DESIGN PROJECT REPORT

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Abstract:

This project focuses on the design of a hybrid vertical takeoff and landing (VTOL) aircraft that, by using separate propulsion systems, transitions from a quadcopter into horizontal flight. It was designed for use in search and rescue (SAR) missions in national parks due to their high costs, long search times, and the volume of these missions. The aircraft can be easily deployed in less than a couple minutes reducing search time, costs only $2000 saving SAR teams money, and allows for camera integration for hiker location. The aircraft used a pre-built airframe with added modifications, and a specifically designed avionic system to have vertical and horizontal flight capabilities. The propulsion system was tested individually in the vertical and horizontal flight modes. The quadcopter system ran in an altitude hold mode for approximately 8 minutes while the forward flight system ran for over triple that, approximately 25 minutes. This proved our VTOL aircraft's main objective of increased fixed-wing flight efficiency. The modified airframe structure was proved not to fail under vibrational and static loading using FEA. The total weight of the aircraft is 1.9 kg, meaning we need approximately 18.6 N to fly. By performing CFD analysis on the aircraft, at a speed of 15 m/s, it was found that 28.5 N of lift were produced, allowing for successful horizontal flight.

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1 Introduction

1.1 Background Information

According to research, the activity that most often leads to Search and Rescue (SAR) missions is not a dangerous or extreme sport as some may think. The activity leading to the most missions per year is hiking. The chart in Figure 1.1 shows the number of Search and Rescue missions associated with various different outdoor activities in the state of Oregon[2]. It is clear from this data that hiking is responsible for a large number and percentage of these search and rescue missions and this is not just an anomaly in Oregon. In fact, when looking at National Park Services (NPS) data, it was found that approximately 25% of cases where people required rescue were on hikes at elevations between 5,000 feet and 15,000 feet[1].

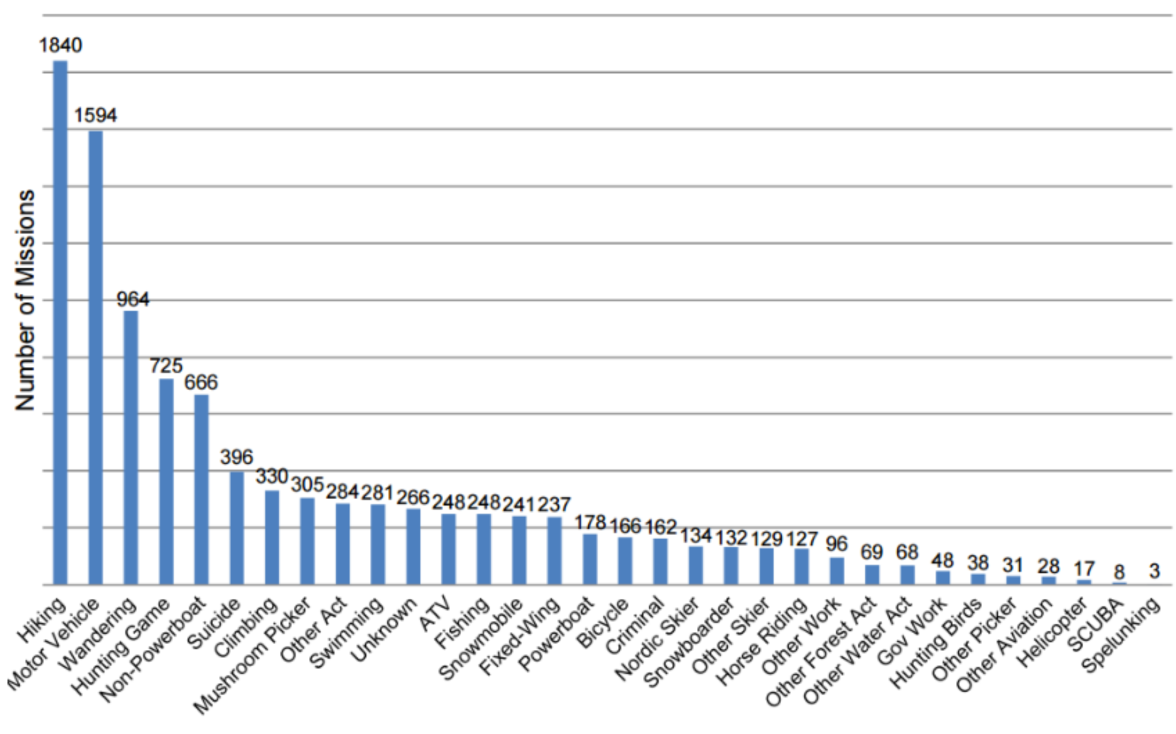

Figure 1.1: Number of different SAR missions conducted in Oregon from 1997-2014[2]

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[1] Moss, Laura. "When Hikers Need Help, Who Foots the Rescue Bill?" *MNN - Mother Nature Network*. N.p., 23 Oct. 2015. Web. 07 Dec. 2016.

[2] Public Domain: *Office of Emergency Management*. Berlin: Walter De Gruyter, 2014. *Search and Rescue: Annual Report for 2014*. Oregon Military Department. Web.

Many people in different parts of the world enjoy hiking. Some appreciate close contact with nature and others enjoy the competition of challenging hikes. These scenarios are only a portion of the numerous reasons people partake in this hobby. However, with the fun of almost every outdoor hobby, comes implied risks. This is again shown above as a large number of search and rescue mission result from a hiking incident. And, with the population of hikers continuing to grow (an estimated 44 million worldwide in spring 2016[3]) so do these associated dangers. Figure 1.2 below shows the continued increase in hikers in the United States.

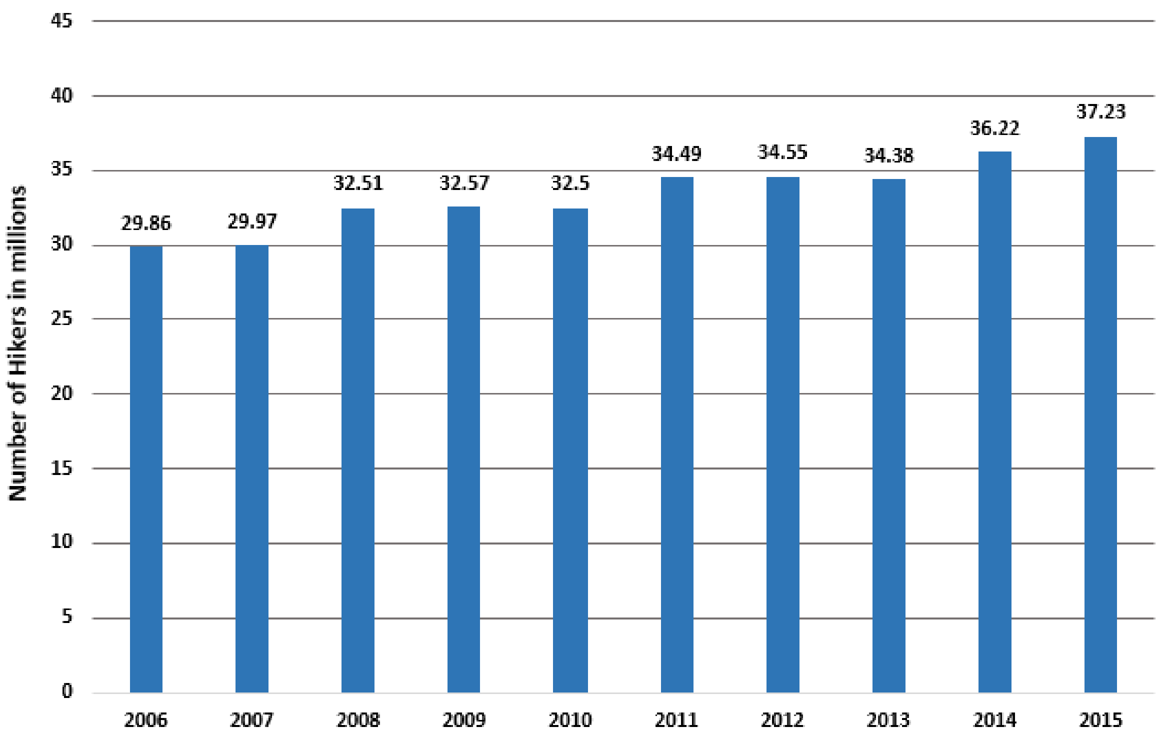

Figure 1.2: Number of hikers per year in the United States in millions[3]

Most hikers in the U.S. are not experienced hikers. This fact, coupled with the increasing number of hikers and the frequency that people hike in new and unfamiliar terrain, will continue to increase the number of hiking related incidents.

Without proper preparation, experience, and equipment, many of these hikers lose their way or are injured on the journey. In situations like these, and in others as well, hikers are in

[3] Public Domain: Nielsen Scarborough. "Number of Hikers and Backpackers in the U.S. 2016 | Statistic." *Statista*. President, BCG Senior Vice, n.d. Web. 07 Dec. 2016.

need of immediate help. As a result, the park's respective search-and-rescue (SAR) teams conduct increased SAR missions, more than 2,600 such searches were documented by National Parks Services in 2014 alone[4]. They invest extensive amounts of time and money in these missions, which can last anywhere from several days to several weeks and beyond. These lost hikers are in urgent need of help and if they are not found quickly enough, the result will almost always be fatal. On top of this, the missions themselves are often dangerous to the SAR team. By sending people out into the field to carry out these searches, many lives are put at risk. Current methods for search and rescue missions are outlined more in detail in Section 2.5, Benchmarking Results.

Unmanned vehicle design is a rapidly growing field of study as it offers solutions that do not involve human risk. In particular, Unmanned Aerial Systems (UAS) are being developed as part of search and rescue efforts. However, not many practical solutions have been developed as there are still many drawbacks to using a UAS. Most designs are complex, require a government license, and demand the skills of a seasoned pilot. In other words, they are expensive and impractical except in the most urgent situations. On the other hand, more inexpensive commercialized drones do not meet many of the requirements needed for SAR applications. This is because commercial drones usually have a short flight time, limited functionality, and low payload capacity.

Our team designed and built a hybrid quadcopter aircraft that couples both the ease of vertical take off and landing with the benefits of aerodynamic lift in fixed-wing flight. This will greatly reduce battery demand and consequently increase the aircraft's speed, its range of search, and the duration of its search, without sacrificing convenience or versatility

1.2 Review of Field/Literature

Design and manufacturing of this aircraft has required review of fields such as aerodynamics, and the utilization of different electrical components. In order to design the

[4] "Survival Statistics: Survival Of The Common Sense Challenged." *Survival Statistics: Survival Of The Common Sense Challenged*. N.p., n.d. Web. 07 Dec. 2016.

aircraft, the book *Designing Unmanned Aircraft Systems*[5] was read. This book discusses the entire design process of UASs. It covers topics such as mass distribution, aerodynamics, and communication systems. All of the information gained from this book has been applied in the design, construction, and analysis of our unmanned aircraft.

The need for a UAS aircraft for SAR missions was confirmed after reading Laura Moss's article[1]. In this article she writes how 4 million dollars are spent every year by the government in search and rescue missions. This source confirmed that the team was addressing a valid issue and helped outline low cost as an important objective for our aircraft.

Statistics from De Gruyter's [2] and Scarborough's [3] publications were also of great help as they provide an accurate number of hikers that were searched for and rescued in the U.S. in 2014[2] as well as providing the total number of backpackers in the U.S.[3]. These sources once again confirmed the need of an unmanned aerial vehicle with search and rescue capabilities.

1.3 Problem Statement

Extensive amounts of time, resources, and money go into search and rescue missions every year. A large portion of these missions are for hikers who have lost their way. The current methods for carrying out these searches are inefficient and expensive as mentioned above and they also put the rescue team themselves at risk. Although use of unmanned aerial systems is quickly developing, most SAR aircraft are designed simply as quadcopters with frame designs that have aerodynamic efficiency tailored for 4 motor flight. These products waste battery life and are not ideal for longer endurance flight applications.

Our team has chosen to design a low cost unmanned remote control Vertical Takeoff and Landing (VTOL) aircraft with efficient and long endurance flight so that it may practically and successfully be used in search and rescue missions, while also reducing the exposure of the SAR team members.

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[5] Gundlach, Jay. Designing Unmanned Aircraft Systems: A Comprehensive Approach. Reston, VA: American Institute of Aeronautics and Astronautics, 2012. Print.

1.4 Project Objectives

The team chose to design a low cost unmanned remote controlled aircraft that is efficient and capable of carrying out up to 2 hours long flights so that it may be successfully implemented into search and rescue missions. Moreover, this aircraft will reduce the exposure of SAR staff to various dangers of manned SAR missions. Such a vehicle is needed in National Parks in order for the SAR team to locate lost hikers as efficiently and safely as possible.

The VTOL aircraft will reduce the number of motors used for propulsion from 4 to 1 as it converts from vertical takeoff and landing to fixed-wing flight. This was our main objective. This will greatly reduce battery drainage and subsequently increase the aircraft's speed, its range of operation, and therefore increase the time of search.

The goal was for the aircraft to utilize detection devices such as cameras, sound recognition systems and GPS to locate the lost hiker. The use of a thermal camera helps locate the hiker by detecting the heat produced by their body. The HD camera allows for a clear recognition of the lost hiker from above, and the sound recognition device lets the pilot evaluate the hiker's conditions through communication. The GPS is also a very important component since it will allow the location of the aircraft to be known at any time during the search. The cameras and sound device would transmit live feedback to the pilot located at basecamp.

Even though attachments such as cameras and sound recognition are needed to perform successful search and rescue missions, our team was not able to complete the full assembly. The aircraft's payload does allow for these attachments, however, they have not yet been integrated into the system. What was completed, however, includes the integration of all the necessary system apparatus. Our final product is able to takeoff and land vertically as well as transition to horizontal flight. The GPS is also attached on our final product in order to locate the aircraft. Future development of the aircraft will be carried out by one of the following year's senior engineering teams.

2 Systems Level Overview

2.1 Customer needs

Before we began the design of the VTOL aircraft, we had to find out the specific needs of our customers and people in the field. These needs were used in outlining the initial requirements of the system and in the selection process for the conceptual design. Because the mission of the aircraft is to find lost hikers, the customers of our project were search and rescue personnel of National Parks Services. A few of our resources included; Levi Yardley of the Yosemite Helicopter Search and Rescue (YOSAR) and park paramedic team, Greg Lawler who is the Secretary of the Interior of National Park Services, and Andrew Hower, deputy chief of National Park Search and Rescue. From these resources, the importance of the following requirements were decided upon.

The first requirement concerned the flight time of the aircraft as well as the range of the receiver and transmitter. Most of the customers emphasized that hikers most commonly get lost in the deeper parts of the trails. This means that, in order to reach them from trail heads, the aircraft would need to have a long enough flight time about 1-2 hours, and be controllable from long distances about 10-15 miles. This customer feedback confirmed that a VTOL aircraft would be beneficial since the current quad rotor drones are unable to meet these requirements. In addition to flight time and distance, an important aspect is the detection of the missing hikers. This can be done through components such as cameras and GPS. The user needs to be able to see the lost hiker as the aircraft flies by, so having high quality, live video feedback is crucial. Also for this same reason, it is very important to know the exact location of the aircraft as it searches.

The aircraft's ability to go into hover mode will improve the stillness and quality of video, but the video will need to stream from up to 10 miles away while flying. The customers emphasized the importance of the HD camera in particular and that sound transmission and thermal imaging were bonuses but are of lower importance. Also we found that the price of the aircraft is was less important that we originally thought because millions of dollars are spent on search and rescue teams each year. Since having this aircraft would help lower the overall costs and time on missions the price of the vehicle would not be as much of an issue.

Different National Parks have different terrains, but many of them have large changes in altitude. That being said the aircraft will need to be able to fly over these higher parts of the park. This ensures that the user can navigate over some hills or cliffs that may be in the way of the lost hiker. A final requirement from the customers was to have a stable aircraft, as weather conditions especially wind may be a factor for sustained flight in National Parks. This means that the aircraft design must be durable, and be able to handle different types of conditions.

2.2 System Requirements

The main system requirements are outlined in Table 2.1 below. These important specifications were decided on using customer feedback above as well as research on our specified mission.

Table 2.1: Initial Design Specifications

Main Design Specifications	Goals	Decision Process
Flight time	1-2 hours	Maximum speed of 30 miles per hour (~15 m/s).
Max Altitude	1000 ft. from sea level	National parks have difficult terrain with mountains and canyons.
Receiver Range	10-15 miles from base	Most incidents occur about 10-15 miles away from the trailhead.
Live HD video Feedback	5-10 miles	SAR team must be able to see and locate the hikers.
Flight Transition	Automated switch	Quickly enables the aircraft to transition from vertical hovering to horizontal fixed wing flight

2.3 System Level Sketch and User Scenario

The following illustration in Figure 2.1 depicts the conceptual design of the aircraft with the primary components labelled.

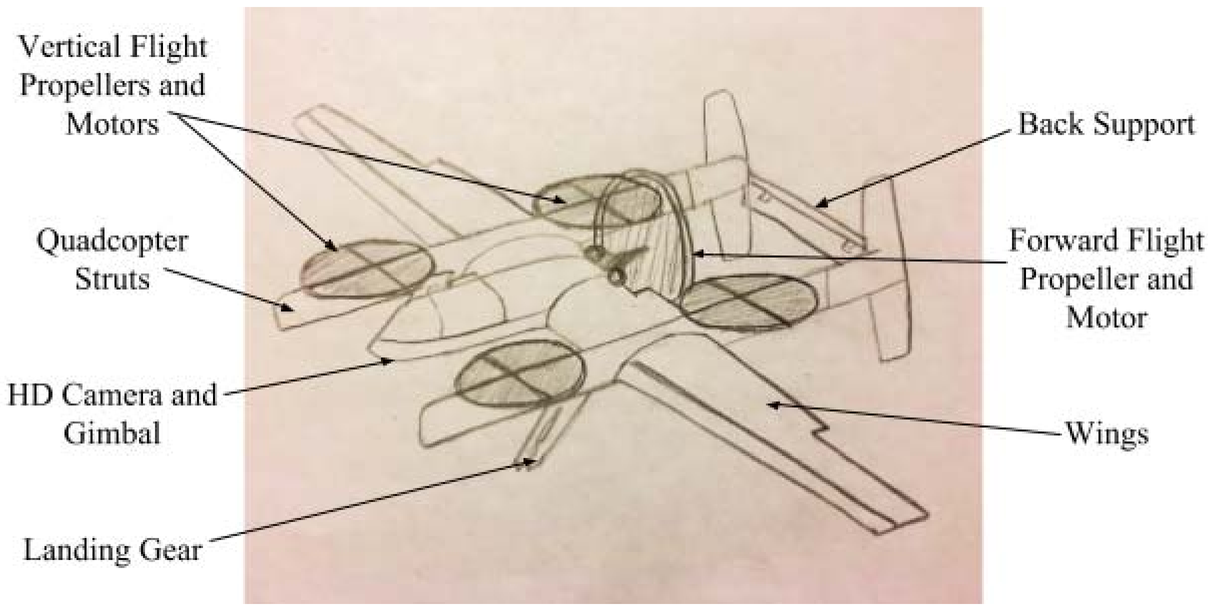

Figure 2.1: Initial labeled sketch of overall design

The goal of this design is to allow for easy assembly of the aircraft for the search and rescue team or other user. The search and rescue team has two main uses for the aircraft. If they receive a call that there is a lost hiker, they can quickly fly the aircraft over the area where they believe the hiker is lost. Then, it will hover around searching for the hiker using video, thermal, and audio feedback. Once the hiker is found, they can dispatch their team to that exact location. An additional use is for the team to send out the aircraft each afternoon and do a quick survey of the trails. Many times lost hikers have no means of contact, so searching each afternoon can reduce the time that the hikers are lost, which improves the rescue rates. The batteries are rechargeable so every night the batteries may be charged and be ready for the following day.

2.4 Functional Analysis

The hybrid search and rescue aircraft performs vertical takeoff and landing as well as horizontal fixed wing flight to carry out search and rescue missions. Horizontal flight capability helps the aircraft to save power and achieve longer flight time, since vertical landing, takeoff, and hover mode drains the batteries. This design benefits from an HD camera as a visual aid to spot hikers and control the aircraft. It also includes a thermal imaging system that helps locate possible hikers who are unconscious or those who may be difficult to detect due to lack of light the composition of the surrounding terrain. Also, this design contains a communication system that helps find hikers using sound detection. Once the hiker is located, the user may communicate with them to assess their status and needs.

2.5 Benchmarking Results and Goals

As mentioned briefly in the background, current methods carried out by SAR teams in search of lost hikers have many drawbacks.

Figure 2.2: Pictures depicting the current search methods[6]

Table 2.2: Current Methods for hiker Search and Rescue

Search Method	Terrain	Power Source	Risk	Efficiency	Cost
Helicopter	Air	Gas	Medium	High	High
Off Road Vehicles	Land	Gas	Medium	Medium	Medium
Manned Searches	Land	Gas	High	Low	Medium

[6] Public Domain: "Shutterstock Official Logo." *Search-and-rescue Stock Images, Royalty-Free Images & Vectors | Shutterstock*. N.p., n.d. Web. 02 June 2017.

All of the current search and rescue techniques are helpful for finding lost hikers, however, there are some major drawbacks. Helicopters cost around $1,600 per hour to operate[7]. This high price costs the search and rescue teams a lot of money. Helicopters use cameras and thermal cameras to do their searches while someone is piloting it. An unmanned aircraft may have an HD camera, thermal camera, and a user to fly it using a remote control. However, the cost to purchase an unmanned aircraft may be around the same price that is spent on flying a helicopter for one hour.

Off road vehicles are good for open terrain, but they are very limited at many national parks. An unmanned aircraft has the ability to fly over any rough terrain that a vehicle may not be able to get over or around. In addition, an unmanned aircraft can search a much larger area in a shorter amount of time than an off road vehicle can.

Manned searches are important in search and rescue because they will be able to help the lost person right when they find him/her. However, manned searches are very slow and meticulous. An unmanned aircraft can be utilized to search the area much more quickly, and then, once the lost person is found, the search and rescue teams will be able to go straight to their location. This will cut down on a lot of search time.

There are currently no unmanned aircraft regularly being used in SAR missions, but other products on the market that could fulfill this mission to a certain extent are listed in Table 2.3 below. A first thought was to use quadcopter drones. These vehicles are simple to use and are low cost. In addition, many successful designs are heavily commercialized, making them easy to purchase.

[7] "Who Pays for Search and Rescue Operations?" *HowStuffWorks*. N.p., 17 Mar. 2010. Web. 07 Dec. 2016.

Table 2.3: Drone Competitors of VTOL Aircraft

Manufacturer	DJI	YUNEEC	GO PRO
Name	Phantom 4 Quadcopter	Typhoon H Hexacopter	Karma Drone
Price	$999.00	$1499.99	$799.99
Number of Propellers	4	6	4
Flight Time	25-30 minutes	25 minutes	20 minutes
Max Speed	50+ mph	43.5 mph	40-45 mph
GPS	x	x	x
Thermal Camera			
HD Camera	x	x	x
Sound Transmitting			
All Electric	x	x	x

All of these designs are based on a simple quad rotor setup. This setup is simple and effective, however, there is one major flaw in its design. When flying, the drone is constantly using the power of all four motors in order to lift its weight and sustain flight. This results in a high rate of current discharge from the battery to the motors, thus quickly draining the battery. This leads to the low flight times of no more than 30 minutes. In order to perform successful search and rescue missions, a longer flight time must be achieved. This can be accomplished through a change in the aircraft's design. Our team decided to design and build a hybrid quadcopter to help achieve our goals. Keeping a quadcopter base for vertical takeoff and landing purposes, this new aircraft would be able to transition to forward flight. This design would include wings and a more traditional airframe in order to use aerodynamic lift to sustain its flight, conserving battery power and increasing flight time.

For this VTOL aircraft there were many possible design options for switching from hover mode to flight mode. Several of these designs are successfully implemented into a few aircrafts that are shown in Table 2.4 below.

Table 2.4: Commercialized VTOL Designs

Manufacturer	Ares RC	Birds Eye View	XCraft
Name	V-Hawk X4 RTF	FireFLY 6 DIY 25	XPlusOne: Platinum
Price	$249.99	$1,999.00	$1499.99
Number of Propellers	4	3	4
Flight Time	20 minutes	25 minutes	20 minutes
Max Speed	30+ mph	65 mph	60+ mph
GPS		x	x
Thermal Camera			
HD Camera		x	x
Sound Transmitting			
All Electric	x	x	x
Autonomy		x	x

These current solutions show possible VTOL design, but because of their size and small batteries, their flight times have not improved from the drone designs above. These designs were examined, and although they successfully made the VTOL to aircraft switch, there were a few problems with them.

The Ares had rotating propellers at the end of the wings to transition from vertical takeoff to horizontal flight. A major problem with this design is that all four motors would still be in use during horizontal flight. This means that the power consumption of this design was only a slight improvement from the quad copter drones.

The Birds Eye View aircraft implemented three vertical motors that rotated into horizontal flight. A major problem with this design was stability. In order to accurately find lost hikers, our aircraft needs to be stable so the live video feeds will be clear.

The XCraft aircraft uses four motors to vertically take off, and then it transitions into horizontal flight by simply turning its frame. The transition for this aircraft is simple, but this type of frame would not work well for the mission. The XCraft has no place to put any of the cameras or any of the other additional attachments needed to locate the hiker.

Although none of these hybrid aircrafts served as a baseline model for our search and rescue aircraft, they gave good insight as to pros and cons of different designs. Finally, after some more research, Latitude Engineering's HQ-40 was found. This aircraft had most of the necessary design features that are required for search and rescue missions, and it is pictured below in Figure 2.3.

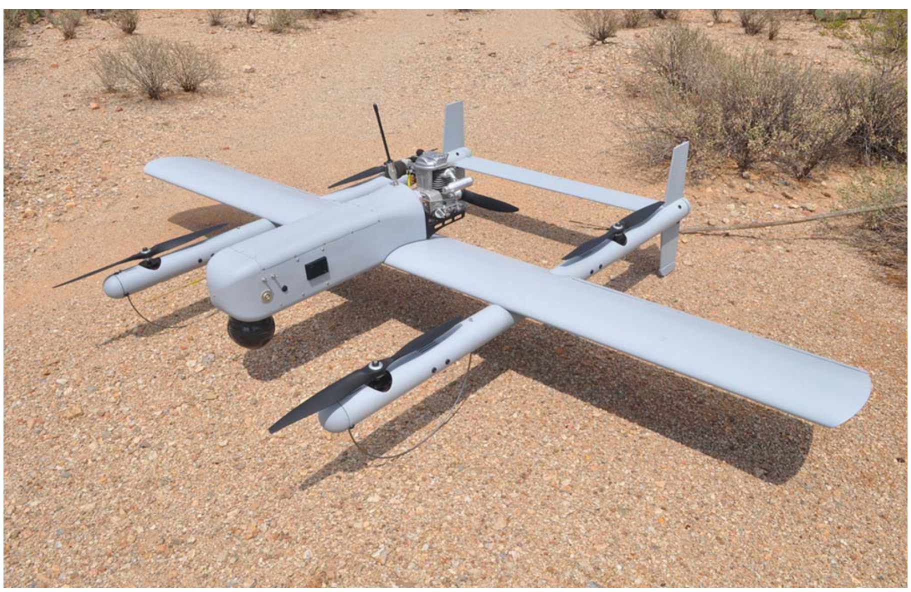

Figure 2.3: HQ-40 VTOL Aircraft[8]

[8] Permission to Reproduce: https://latitudeengineering.com/

Table 2.5: Specifications of the HQ-40 model.

Manufacturer	Model	Flight Time	Max Speed	Weight	Cost
Latitude Engineering	HQ-40	4-5 hours	50+ mph	40 lbs	$25,000

This vertical takeoff and landing design has a clear advantage over the rest of the products on the market due to it's ability to conserve battery. The aircraft uses four motors for hover mode, but once it switches to horizontal flight, only one motor is used. The aircraft uses aerodynamic lift and the battery conservation can be seen in the flight time of 4-5 hours. It is able to carry a load such as a camera and reach high speeds. However, the problems with this design involve the size, cost and it uses a gas motor to power horizontal flight. Besides those flaws listed, this aircraft was the main design that helped improve and develop our search and rescue aircraft design.

2.6 Design Overview and Selection Process

Our team aimed to design a hybrid, quadcopter aircraft that would couple both the ease of vertical take off and landing, with the benefits of aerodynamic lift in winged flight. This would greatly reduce battery demand, and subsequently increase aircraft speed, its range of search, and time of its search. We had a baseline of what type of design we wanted to make based upon the existing products.

Our design sought to incorporate a HD-FPV and thermal camera, as well as sound recognition features. It's long distance capabilities and hybrid functionalities of transforming from a drone into a plane midflight will make it an ideal aircraft for finding lost hikers in any terrain. The hiker recognition attachments were selected in order to most easily help the search and rescue user locate the missing person. However, these were ideal goals, so for the project we focused on making an aircraft with the hybrid capabilities.

2.6.1 Key System Level Issues

The attachments that we were looking to add to our aircraft could in fact be attached to some other commercial drones and be used for SAR missions, however the existing designs have their drawbacks, which are shown in the comparison to competition in Tables 2.2, 2.3 and 2.4. VTOL has a huge advantage over regular drone technology as it can incorporate the same functionality as a drone during hover mode, but has improved efficiency in horizontal flight. The VTOL design is more successful for SAR missions mainly because of its horizontal fixed wing flight, allowing it to conserve energy and easily increase its overall flight time. Flight time, or endurance, was the key overall issue for our design. The selection process of these initial specifications are outlined in more detail in the subsections below.

With an all electric propulsion system, the flight time directly correlates to the capacity and size of the power source, or battery. Increasing battery power may not increase flight time because of battery weight. These two variables were optimized in order to achieve the maximum flight time for the design by using an efficient, lightweight battery. This longer flight time would be needed in order to perform long duration searches or long range missions. These tradeoffs are talked about more in depth in the sections of the individual subsystems.

2.6.2 Layout of System Level Design

The design was broken up into a few main categories to ease the design process. First, we started with the fuselage and wings. For these we decided between purchasing an existing aircraft and modifying it, or customizing our own airframe. We needed to make sure the airframe could provide enough lift to hold the attachments and avionics, and be light enough to fly efficiently.

Once we had the general layout of what to use for the airframe, we looked at the avionics of the aircraft. For these we needed to make sure there could be a transition between vertical and horizontal flight based on the airframe design and how the avionics were set up. Additionally, the motors, batteries, electronic speed controllers, and propellers all needed to be sized correctly for the amount of voltage and current needed, as well as the amount of thrust the motors would provide.

Finally, the integration design needed to be configured. Modifications to the airframe and the avionics were designed to allow for ease of vertical takeoff and landing and transferring to horizontal fixed-wing flight. All components needed to be assembled together so the aircraft would be sturdy durable, and aerodynamic. The final system level block diagram that we used may be seen in the Integration section in Figure 4.1.

2.7 Project Management Overview

2.7.1 Team Roles and Responsibilities

The aircraft was split into separate subsystems, and the team worked collaboratively to develop each of those subsystems.

Table 2.6: Team Member Roles

Team Members	Roles
Nicholas K.	● Team Lead ● CAD Modelling ● Avionics ● Airframe
Francesca	● Interviewing customers for performance specifications ● Hand Calculations ● Weight Distribution ● Airframe
Nicholas G.	● CAD Modelling ● Computational Fluid Dynamic (CFD) Analysis ● Airframe ● Avionics
Joshua	● CAD Modelling ● Avionics Leader
Kiavash	● Sizing Calculations ● Finite Element Analysis (FEA) ● Avionics

Many of the roles of the team members complemented each other. CAD models were developed by Nicholas K., Joshua and Nicholas G. These models were developed after Kia and

Francesca calculated initial sizing and optimization of the aircraft. From these CAD models, Nicholas G., and Kia used CFD and FEA analysis to compute lift, drag, pressure and stress distributions, vibrational nodes, etc. to verify the performance of the aircraft. The airframe was modified and constructed based on the performance analysis, and then the avionics was implemented into the airframe. All of the avionics were shifted around in order to keep the center of gravity at the correct location. All of the team members jobs were integrated, and came together to create the final product that was tested. As the entire team was composed of mechanical engineers, jobs such as the avionics portion were more difficult because of its unfamiliarity. However, with the help of everyone in the group we were able to overcome many challenges.

2.7.2 Project Challenges, Constraints, and How They are Dealt with

The main project challenge was programming the transition between vertical and horizontal flight. Currently, we are still calibrating the individual test modes but the modes do work. As explained earlier, this senior design team only had mechanical engineers in it so this was a difficult challenge. In order to solve this, a lot of time was put into learning how the avionics needed to be set up. Once all of the avionic components were wired and the software was downloaded, there was a lot of testing to be done in order to complete individual flight modes, and finally the transition. The individual test modes had to go through many safety constraints as described in Section 5.1.1 Flight Testing. In addition, calibrating each motor took much longer than expected.

The second main project challenge was designing an all electrical aircraft to have enough lift to take off vertically, as well as fly horizontally. We first attacked this problem by reading the book *Unmanned Air Systems: UAV Design, Development, and Deployment*, taking aerospace classes, and learning about other aircraft designs. These helped us decide on an airframe, wings, and sized our avionics to help keep added weight minimal, while increasing lift.

The final challenge was time. Due to the large number of goals we sought to accomplish, this project could take teams years to finalize. However, we were only a team of 5 mechanical engineers who were still full-time college students. We had less than a year to finish our senior design, so we prioritized different aspects of our project. The most important part was to theoretically show that our aircraft would work, and it would be able to maneuver as we planned. Next, we wanted to build a prototype that had all of the airframe and avionics integrated together. Once everything was integrated, we wanted to have the aircraft perform vertical takeoff, horizontal flight, and finally, the transition during flight. If at the end we had time, we planned to attach the hiker recognition features and test them. This was the overall objective of our project, however we understood that time would be a huge limiting factor. Because of time, we were only able to complete the individual test modes. However, the aircraft was build in order to host the attachments and completing the transition is within reach.

2.7.3 Budget

The main issue when budgeting was that all of the components were going to be bought for one time use. Our aircraft was designed to be purchased by search and rescue teams all over the United States and possibly the world, so in an ideal situation the components would be bought in bulk. This would lower the cost of each individual aircraft. In addition, the cameras of the aircraft would be the most expensive parts. This is another reason the cameras were set to be the final component of the aircraft. The loads of the cameras were calculated into the design of the aircraft so we could first, and more importantly, make an aircraft that was capable of the flight before it was able to implement searching tools.

Our project received $2,500 of funding so everything was carefully considered when budgeting. The following table is an initial budget overview. The final expenses can be seen in Appendix B: Current Budget.

Table 2.7: Proposed Expenses

EXPENSES				
	Item	Quantity	Unit $	Total Cost
Airframe	Body	1	$300.00	$300.00
	Blades	5	$15.00	$75.00
Main Electrical System	Ardupilot	1	$120.00	$120.00
	Receiver/Transmitter	1	$100.00	$100.00
	Li Po Batteries	2	$50.00	$100.00
	Controller	1	$60	$60.00
Propulsion System	Motors	5	$25.00	$125.00
	Electronic Speed Controller	5	$25.00	$125.00
	Propellers	5	$20.00	$100.00
Attachments	Thermal Camera	1	$500.00	$500.00
	HD FPV Camera	1	$300.00	$300.00
	Sound Recognition	1	$100.00	$100.00
Miscellaneous	Licensing	2	$150.00	$300.00
	Budget Total			**$2,305.00**

2.7.4 Timeline

The timeline of our project changed many times throughout the quarter. We would set weekly and quarterly goals, but many times we would either finish a task earlier or later than expected. The following table is a brief timeline overview of the basic project goals that were set up and accomplished throughout the quarters. The Gantt chart that was used is shown in Appendix D.

Table 2.8: Quarterly deadlines to achieve general goals

Deadlines	General Goals
Fall Quarter	● Set goals ● Develop general mockup ● Compile general hardware listing ● Consumer Design Report
Winter Break	● Develop CAD models/drawings ● Order parts
Winter Quarter	● Perform CFD analysis ● Perform FEA ● Develop prototype
Spring Break	● Order new parts ● Finalize build
Spring Quarter	● Integrate final airframe and avionics ● Test and calibrate individual flight modes ● Final presentation ● Finalize thesis

2.7.5 Design process

Before we came up with the design, we had formed our group based on the interests of the members. We all wanted to design an aircraft that could improve quality of life or help people. Many ideas were brainstormed based upon the purpose of the vehicle. After researching aircrafts and drones on the market, we found that there are only a few drone companies looking to help in searching for lost hikers. Those drone companies were creating autonomous quadcopters that followed trails while searching for hikers. In order to separate ourselves from the other companies, our mentor, Dr. Ayoubi, and the team decided to make a VTOL aircraft that could have a much longer range and flight time than the other drones. Additionally, we planned to have the aircraft be remote control and all electric

Once we had our goal, coming up with the design and components was much easier. Having an HD camera, GPS, thermal camera, and sound transmission were important features that would greatly improve the user's ability to find the lost hikers. More importantly, the design of the aircraft must be capable of horizontal and vertical flight modes. It had to be stable during hover mode and have good horizontal aerodynamics. The initial design was based on Latitude Engineering’s HQ-40.

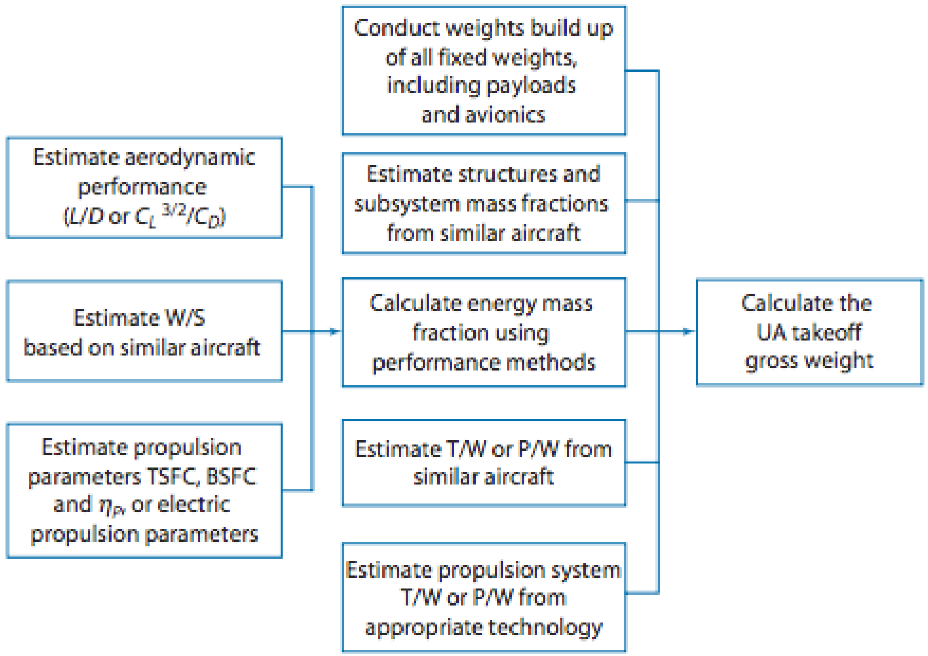

Figure 2.4: Initial UAS design flowchart

The flowchart above depicts the initial steps taken early on in our conceptual design in order to size, and figure out what kind of aircraft we could be capable of producing. However, as the senior design project continued, we created a full design flow chart that documented and labeled each step we took in order to reach our final product. This chart was used iteratively in our design process and may be seen in Appendix F.

2.7.6 Risks and Mitigations

Manufacturing, assembly, testing, and disposing of the aircraft had many associated risks. The approved safety review may be see in Appendix E. During the manufacturing process, the Santa Clara University machine shop was used. These machines, along with the material used, had risks. All of the safety guidelines while using the machine shop were followed specifically. Safety glasses were worn at all times. All of the machines had specific guidelines that were followed and the shop was not used unless a team member was properly certified. All material were handled with care in case of any sharp or hot pieces.

The assembly of the aircraft involved wiring many electrical components. These needed to be carefully assembled because of the current that runs through them, and soldering has many risks involved such as serious burn. In addition, assembling the airframe and other parts was handled with care in order to not break the components or be hurt from sharp parts.

The testing of the aircraft was done following local and FAA regulations. The exact procedure on how we planned to go through all of the testing phases is described in Section 5.1.1. The aircraft had many risks involved with the voltage and current being sent through the avionics, and the speed of the propellers. All testing was done behind a safe screen and we had a safety shut off next to us at all times. Once a test had been done, the aircraft was examined thoroughly to see if any damage had occurred to any of the parts. Any slightly damaged parts were either removed or fixed before performing the next test.

The disposal of the aircraft would need to follow specific procedure and laws. However, due to the interest of a future design project, all of our components were handed over to Santa Clara University. All components were disconnected and safely stored.

2.7.7 Team management

In order to have the most effective team and make sure everyone was on track, we held weekly meetings on Sunday. This allowed for one on one communication and to make sure everybody knew their job for the upcoming week. In addition, weekly meetings with Dr. Ayoubi were set up on Wednesdays to go over chapters from the book, *Unmanned Air Systems: UAV Design, Development, and Deployment,* and then later were held one every two weeks to update Dr. Ayoubi on our progress. These meetings kept Dr. Ayoubi up to date on our progress and he was able to assign specific tasks for us. Dr. Ayoubi also taught us any important concepts that we needed to know in order to head in the right direction.

In addition to the team meetings, we split up into two smaller teams to work on the electrical components and the aircraft frame. These were assigned by each person's area of interest and was seen in Table 2.6. Everything we did was also overseen by Nicholas Keyes, who we appointed the team manager. If any arguments or clarification issues came up, Nicholas had the final say and decision. This helped the team run more smoothly because we are able to quickly get past any obstacles or disagreements that arose.

3 Subsystems Overview

3.1 Airframe

The figure below shows our initial CAD model made in SolidWorks of the conceptual VTOL airframe design. This design was modeled after our datum aircraft, Latitude engineering's HQ-40, which provided easy quadcopter integration as well as flight stability. However, this design proved to be a challenge to design and construct. Therefore, because of the time constraints on the project and its other important aspects we decided to modify an existing airframe. This simplified the airframe design and manufacturing time, allowing us to finish the avionics system and meet our goals of transition between vertical and horizontal flight modes.

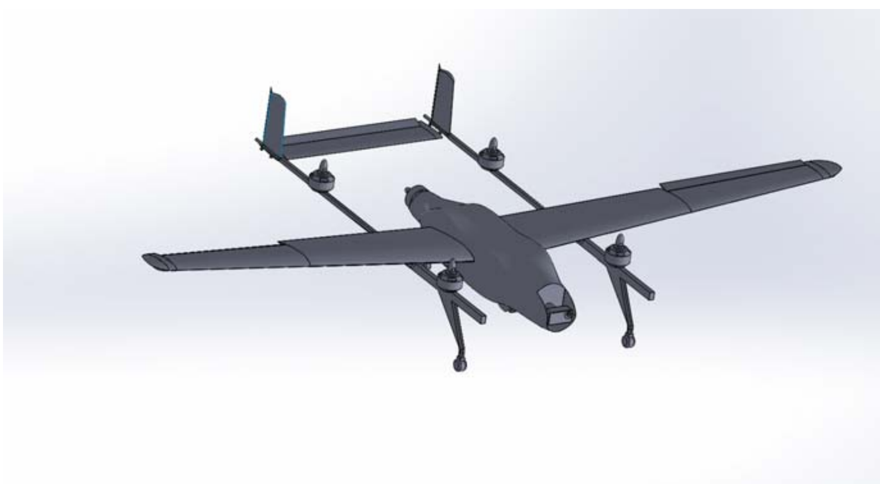

Figure 3.1: Initial CAD model of the Airframe

The purchased components were taken from the Horizon Hobby Radian 2.0 Glider Airframe. This plane is shown in Figure 3.2 below.

Figure 3.2: Horizon Hobby Radian 2.0 Airframe[9]

As stated, our design utilizes a purchased airframe modified in order to support vertical flight. The CAD model of our final airframe design is SolidWorks shown below in Figure 3.3. This design consists of the purchased fuselage, wings, and carbon fiber tubing to mount the four motors on.

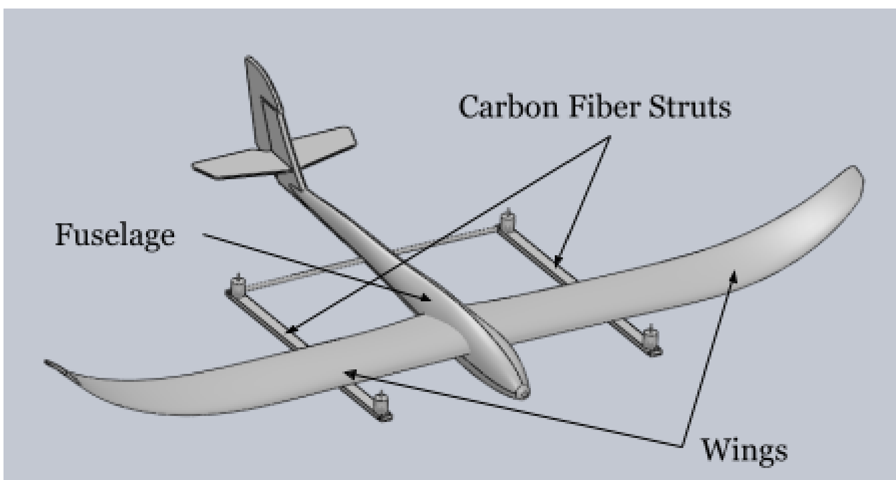

Figure 3.3: Final CAD model of the Airframe

The design of this airframe was assembled using store bought as well as some manufactured parts. The electronic hardware and flight control system were integrated into the fuselage. These parts will be mentioned in more depth in the system integration section.

[9]Permission to Reproduce: https://www.horizonhobby.com/radian-bnf-basic-efl4750

3.1.1 Quadcopter Chassis

The basis of this vertical flight mode is the quadcopter frame as this will be the chassis onto which the four vertical motors are attached. The main body of the aircraft is then modified to allow for its VTOL capabilities by connecting this chassis to the airframe. The configuration chosen for this subsystem's design is an H-frame. This is visible in the CAD model of the aircraft above in Figure 3.3. This frame has a quadcopter motor at each tip of the "H" and supports the middle of the wings and fuselage of the aircraft. Below are some of the considered materials for this construction.

Table 3.1: Materials and their characteristics

Material	Construction	Rigidity	Durability	Weight	Cost
Wood	Easy	Medium	Medium	Light	Low
Aluminum	Medium	High	High	Medium	Medium
Carbon Fiber	Hard	High	High	Light	High
ABS/PLA	Easy	Medium	Medium	Medium	Medium

In order to have a rigid as well as durable design, this chassis must be made of a strong material. At the same time, however, it must still be as light as possible since the weight of the airframe is a key factor in its performance. Initial ideas on the material for this component were wood, aluminum, and carbon fiber. Each of these have their clear advantages and disadvantages when it comes to the main areas of concern listed above.

As mentioned in the overview of the Airframe in section 3.1. our group decided to modify store bought components in some cases instead of building the entire frame from scratch. To this end, integration was definitely a key consideration. However, in making a final decision on the struts for the H-frame, weight and strength proved to be the more important factors. This led us to settle on the use of carbon fiber tubing. Since integration was still a concern, we decided on rectangular tubing to ease both the wing to strut interface and the strut to motor connection. Below is a picture showing the carbon fiber wrapped tubes used in our quadcopter frame design.

Figure 3.4: Isometric view of the 0.375" x 1" cross-section of the carbon fiber tubing [10]

3.1.2 Wings

As is true for many subsystems, the wings cannot be designed on their own as an individual piece. First the weight of the aircraft must be decided on. This is not only the airframe, but also includes all of the aircraft's systems: the controls systems, electronic hardware, propulsion systems, and the necessary payload. For the sake of the progress of the project, this weight was conservatively estimated using our design goals as about 15lbs. More detailed calculations on the mass of the overall system are shown in Appendix G. Using this weight, the necessary motors can be found to provide the required takeoff power. This is talked about more in section 3.2, Propulsion systems. These values will determine the required lift of the wings as well as the maximum thrust that can be produced. Once this values are found, then they may be used to design the wing.

What we are trying to achieve in the design of this airframe is similar to that of any plane. The aircraft will cruise for a long time at a set speed and use the minimum amount of power. To

[10]Produced without Permission: https://www.rockwestcomposites.com/shaped-tubing/rectangular-tubing/standard-modulus-carbon/25501

best do this, we want an airfoil that produces the least coefficient of drag for the required coefficient of lift.

Lift Coefficient

The lift coefficient of any given airfoil is determined as

$$C_L = \frac{2L}{\rho V^2 A}, \tag{1}$$

where L is lift force required (*N*), ρ is the density of air (*kg/m*^{3}), V is the aircraft's velocity (*m/s*), and A is the lift area or area of the wings (*m*^{2}). The lift force needed is equal to the overall weight of the aircraft, 1.9 kg. The velocity will be approximately 15m/s and the density of air at these lower altitudes can be considered a constant. In this case we took the wing area into account when choosing the purchased wings in Figure 3.5, in order to maximize the lift of our aircraft .

Reynold's Numbers

Early investigations into the theory of fluid dynamics predicted a certain number of constants to which similar disturbances, like an airfoil produce similar effects. For our smaller and slower aircraft, the only "number" which really needs to be considered is the "Reynold's Number". This number is defined as

$$Reynold's\ Number = \frac{Vl}{\nu}, \tag{2}$$

where V is the relative speed (*m/sec*), l is the characteristic length (*m*), and v is the kinematic viscosity of the air (*sec/m*^{2}).

The speed is the free stream velocity or, in other words simply the speed at which the aircraft is moving through the air.The characteristic length for this small aircraft is the chord length of the airfoil. For smaller aircraft and remote control models like this design, the Reynold's number ranges between 10,000 to 400,000.

Using the lift coefficient at the estimated Reynold's number range, different airfoils can be analyzed to determine a good design and angle of attack. We used the NACA 2412 airfoils to simulate our purchased wings and came out with a lift of 34.28 N for both wings. We compared these hand calculations to the CFD analysis to more accurately calculate the lift and drag of our wing and airframe in section 5.2.

Again the main requirement of the airframe, and overall system for that matter, is flight efficiency. With this in mind we looked for a wing that would provide ample lift. Also we needed this lift to allow for the extra weight we added for the quadcopter integration. The wings we purchase from the Horizon Hobby Radian 2.0 airframe are pictured below in Figure 3.5.

Figure 3.5: Purchased Wings[11]

These were glider wings which gave us a very high lift to drag ratio. The tapered profile helped reduce the frictional drag caused by the airflow over the profile and the curved wing tips helped reduce the drag caused by wingtip vortices.

The wings for this aircraft are made from a material called Z-Foam, which is a type of Expanded Polypropylene foam. This material have its advantages in weight, manufacturability, and durability. However, it lacks the strength and rigidity needed to support and sustain stable flight. In order to assemble the aircraft and add the necessary support to the wings, spars were placed inside the airfoil up to about halfway down the length of the wing. These spars were also used to support the carbon fiber struts and to integrate them into the airframe. Since the strength of the wings, as well as weight, were the key components in successful, flight carbon fiber tubing was used for the spars.

[11] Permission to Reproduce: https://www.horizonhobby.com/wing-with-spar%3A-radian-bnf-basic-p-efl4702

3.1.3 Fuselage

The fuselage of the aircraft was purchased from Horizon Hobby as seen in Figure 3.6 and the fifth motor frontal pulling motor was attached to the nose and used for horizontal flight this is shown in the CAD model in Figure 3.3. This structure also was used to hold the majority of the power and avionics system include the battery and microcontroller. The batter was housed in the front of the fuselage using the canopy shown below.

Figure 3.6: Purchased Fuselage[12]

3.1.4 Tail

The tail of the aircraft again was purchased from Horizon Hobby to match and fit our purchased fuselage. It is picture below in Figure 3.7.

[12] Permission to Reproduce:
https://www.horizonhobby.com/bare-fuselage-without-canopy%3A-radian-bnf-basic-p-efl4701

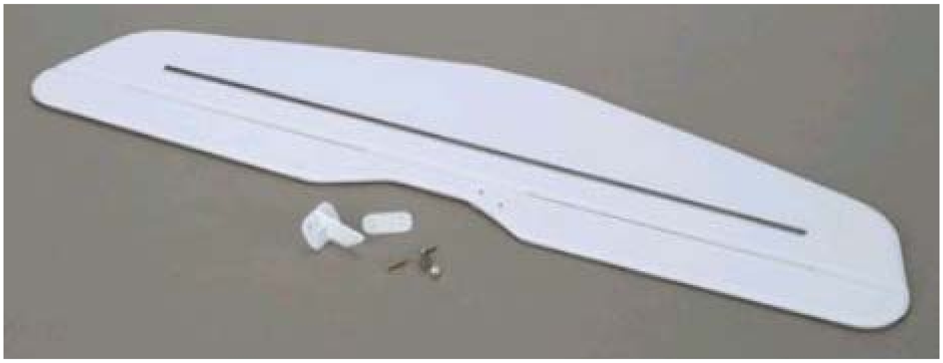

Figure 3.7: Purchased Tail[13]

3.1.5 Challenges and Tradeoffs

A tradeoff in the design of the airframe of the aircraft in its size, wingspan, etc. Obviously a large wingspan will give more lift however is also adds weight and cost. This makes it harder to transport, and also harder to deploy. One of the main focuses of this project is to allow for easy use and deployment of the aircraft as time is of the essence in missions like these. This will define our size requirements as we see what will give the most efficient flight but is still easily deployable.

3.2 Propulsion

3.2.1 Overview

The aircraft will consist of two propulsion systems, one for vertical flight and another for horizontal flight. Although they are using the same means of fuel through Lithium Polymer batteries, the amount of current and power required will be different for each. The four vertically oriented motors with use the power necessary to take off and hover, whereas the horizontally oriented motor will use minimal battery power relying mostly on the aircraft's aerodynamic lift for sustained flight.

3.2.2 Quadcopter Propulsion

The quadcopter mode is essentially the use of four motors to propel the aircraft upwards. The types of propellers used, the amount of current that the motors draw, their max RPM, and the aerodynamic efficiency of the aircraft with respect to vertical flight were all factors in optimizing the performance of this mode. We decide to use 960kv brushless motors and 10 inch by 4.7 pitch

[13]Permission to Reproduce: https://www.horizonhobby.com/horizontal-tail%3A-radian-pro-pkz4725

propellers. This was because of test data that we found documenting that at max power this motor propeller combination could lift over 800 grams. This was slightly less than half of our total system's weight of 1.9 kg. This meant that at about half throttle with four of these motors and propellers our aircraft would begin to takeoff.

	Tested with Angel 20A ESC				
Prop	Volts (V)	Amps (A)	Watts (W)	Thrust (g)	Efficiency (g/W)
9x4.7	7	4.4	30.8	360	11.69
	8.5	5.7	48.45	510	10.53
	10	7.3	73	610	8.36
	11	8.3	91.3	720	7.89
10x4.7	7	7.5	52.5	540	10.29
	8.5	9.6	81.6	660	8.09
	10	11.2	112	760	6.79
	11	12.4	136.4	820	6.01

Figure 3.8: Sizing the motor and propeller[14]

3.2.3 Winged Plane Propulsion

This mode only requires the use of one motor, but the entire weight of the aircraft will determine the thrust force required to generate the necessary amount of lift. This system drew power from the same LiPo battery as the quadcopter system. The aerodynamic analysis of this aircraft determined we needed a velocity of about 10-15 m/s to fly and perform maneuvers. We again chose a 960kv motor with a 9.75 inch by 7.5 pitch propellers. We decided this because this motor propeller combination was proven to provide the thrust needed to achieve 15 m/s for the unmodified Radian 2.0 airframe.

3.2.4 Challenges and Tradeoffs

Because the quadcopter mode requires the use of four motors, there can be a max current of 120 mA being drawn from the LiPo at any one time. On top of this while the aircraft transitions from vertical to horizontal flight all 5 motors may be active resulting in a possible 150 mA max current load This required more expensive batteries and electrical components such as the power

[14] Public Domain: http://rchobbydeal.com/image/cache/data/products/5082-3-500x500.jpg

module to be specified for these high current loads. The challenge was that these components like the more powerful battery increased the aircraft's overall weight.

The challenge with both of the modes is designing an aircraft that can suit the aerodynamic effects that both motor setups create when either mode is turned on. Most aircrafts are not designed to optimize vertical and horizontal flight, leading the team to test unconventional designs that will try to optimize flight efficiency in several different directions.

For example, if the weight of the battery for quadcopter mode heavily affects performance but we find that our system is in horizontal/plane mode 80% of the time, then the efficiency of the battery for drone mode can be minimized. Such performance considerations must be balanced before coming to a conclusion on final battery and motor selection.

3.3 Control System

3.3.1 Flight Transition

The flight transition is achieved in the custom, prebuilt software that is uploaded into the flight controller. This is done by uploading custom parameter lists provided by mission planner. The parameter list is a set of flight characteristics that can be modified and tuned and uploaded via a USB connection. The source code within Ardupilot has configurable values that change the response of the aircraft based on inputs from the environment and inputs from the radio controller. Certain switches on the radio controller send a constant stream of pulse width modulation values within different frequencies. The following figure depicts a range of PWM values.

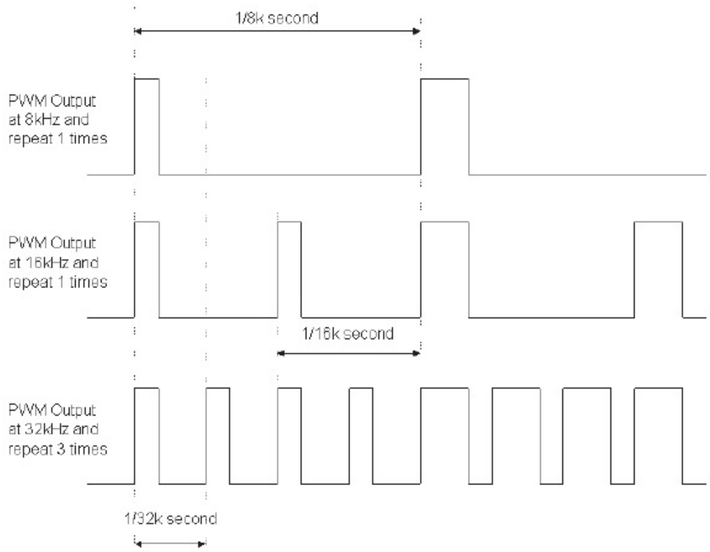

Figure 3.9: PWM values of different frequencies[15]

The frequency that the flight controller receives dictates the flight mode that it is in. The user can set custom flight modes to correspond to different PWM frequencies by adjusting and turning a knob on the radio controller. The following feature on the mission planner application was the method through which setting these flight modes was achieved:

[15] Public Domain: https://coherentmusings.files.wordpress.com/2012/10/playback2.jpg?w=1400

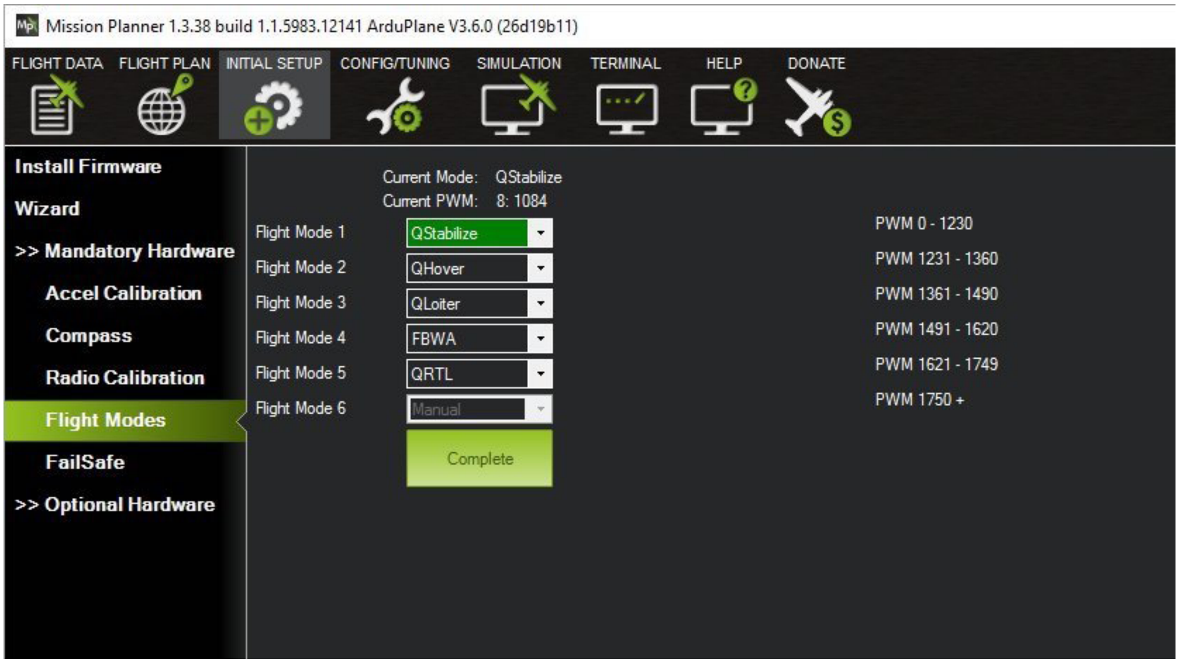

Figure 3.10: Mission planner flight mode setup

On the list of parameters, there is an option to set Q_ENABLE to 1, allowing the user to select flight modes corresponding to the quadcopter setup of the plane. This is observed in the preceding figure, where flight modes starting with Q imply which propulsion system is being used. Flight modes without the Q indicate plane mode.

3.3.2 Challenges and Tradeoffs

An issue in the control system of the aircraft is switching between flight modes. As shown above in the system sketch in section 2.3 we will be using separate propulsion systems to control the different flight orientations. The four vertical propellers are used in order to achieve a steady take off landing and hover flight when needed while the front pulling horizontal propeller is used for the long endurance fixed wing flight. Based on the mission planner software, the aircraft needs to be at a specific flight speed before it can transition from quadcopter to plane mode, provided that its flight starts off in quadcopter mode. The following parameters within the provided parameter list are what dictate the transitional behavior of the aircraft:

- ARSPD_FBW_MIN: The minimum airspeed of the aircraft before the transition between fixed wing and quadrotor flight can be achieved. The aircraft shouldn't simply switch between different modes as this erratic behavior will result in a crash.
- Q_TRANSITION_MS: The amount of milliseconds before the quadrotors are cut off from the power supply. When transitioning, the plane motors need to throttle to the appropriate speed before completely taking over - the quadrotors assist in aircraft lift before the complete transition.
- Q_ASSIST_ANGLE: The minimum error in the angle of the aircraft that allows for the transition. The aircraft must be within a certain range of attitudes before allowing for the transition to take place. Unpredictable aircraft attitudes will result in a crash.

3.4 Communications

Communicating between the ground station and the aircraft requires the use of telemetry kits and two-way wiFi modules. XBee is a popular telemetry brand that manufactures radio modules typically used to provide serial communication between two microcontrollers. In the case of using sensors, XBee would have been the appropriate choice for maintaining long distance communication with data collection on the aircraft and reception on the computer. A long distance telemetry kit replaces the standard telemetry kit that comes with the Ardupilot/Pixhawk flight controller kit. This subsystem will be connected to both the ground station (computer) and aircraft.

Figure 3.11: Radio telemetry to pixhawk input pins[16]

The telemetry modules mounted on the pixhawk and the respective ground station laptop allow wireless communication between the aircraft and mission planner software. The mission planner application provides the user with feedback regarding altitude, orientation and location.

3.4.1 Radio Control (controller/receiver)

Long distance radio control would have consisted of the following system:

- A UHF system at 433 MHz manufactured by DragonLink FPV will allow for long distance control of the gimble when attached to the port of the custom Taranis Radio Controller.
- A 12 channel micro receiver would be attached to the pixhawk, allowing for long distance control using 12 knobs and switches on the radio controller.
- The Taranis Radio Controller is a fully customizable controller with 16 channel availability, implying more than enough control for an aircraft loaded with different subsystems.

The following figure consists of the attachments to the pixhawk system described earlier:

[16] Public Domain: http://ardupilot.org/copter/_images/Telemetry_3DR_Radio_Pixhawk.jpg

Figure 3.12: Dragonlink setup for long distance communication between the taranis radio controller (shown on the right) and flight controller[17]

The dragonlink augment on the taranis would have allowed for flight distances of at least 20 miles and control of up to 12 channels. Subsequently, this would have allowed for more effective search and rescue missions.

3.4.2 GPS

The Mission Planner application, when connected to the aircraft's flight controller, automatically pinpoints its GPS locations on its respective graphical user interface. The GPS unit is its own electrical component that is connected to the flight controller. The output pins for the GPS consist of RX, TX, ground, and VCC. They directly transmit and coordinates to the ground station computer which interprets the airplane's location on a map.

3.4.3 Live Video

Live video feed is fed directly from the FPV HD camera into the goggles that come with its respective kit. Our current design's main purpose was to prove the A long distance audio-video transmitter and receiver kit will be used. Obtaining live video feed involves connecting an LCD screen or goggles to the receiver kit and the HD FPV camera to the transmitter kit.

- The fpv camera would require an available 5 - 15v power supply.

[17] Public Domain: http://www.getfpv.com/frsky-taranis-x9d-plus-2-4ghz-accst-radio-mode-2.html

- The transmitter sends signals from the camera through an antenna to the ground station. The antenna would have been a circular polarized antenna as this does not require the pilot to be directly in line of sight of the aircraft.

3.4.4 Challenges and Tradeoffs

Lastly, in the communications subsystem the focus is on detection methods because in the end even with sustained flight this system would not be successful unless it can properly relay information back to search and rescue team members. As discussed, after interviewing sources and doing research, the HD live video feedback was found to be the most successful or most wanted in the market. Because of the long endurance and long range flights needed for these missions, the communication with the live video must also be long range. Ideally if the aircraft has to fly 10 miles out in order to search an area, then the HD video should be able to be seen at some specified ground station from this 10 miles distance. The issue with this right now is the quality of the video sent back as well as the time lag. These issue can be fixed by repeating the signal to some closer by vehicle (like a helicopter) but this is not very convenient. This range is the option that needs to be extended in order to have a successful design and may be a limiting factor in the vehicle range.

3.5 Payload/Detection Methods

The payload for the system includes the detection instruments that are installed on the aircraft consisting of an HD camera, a thermal camera, and an audio recognition device.

3.5.1 HD camera

The HD camera is essentially a lightweight camera such as a GoPro that is installed safely and securely onto the aircraft. Due to time constraints, the actual integration of this subsystem within the aircraft was not met. However, a theoretical list of the setup would have been as follows:

- Tarot TL2D01 T2-2D 2-Axis Brushless Gimbal PTZ For Gopro Hero 4/3+/3 TL2D01 FPV Gimbal

- Gopro Hero 4

The wiring diagram for the Tarot's IC is as follows:

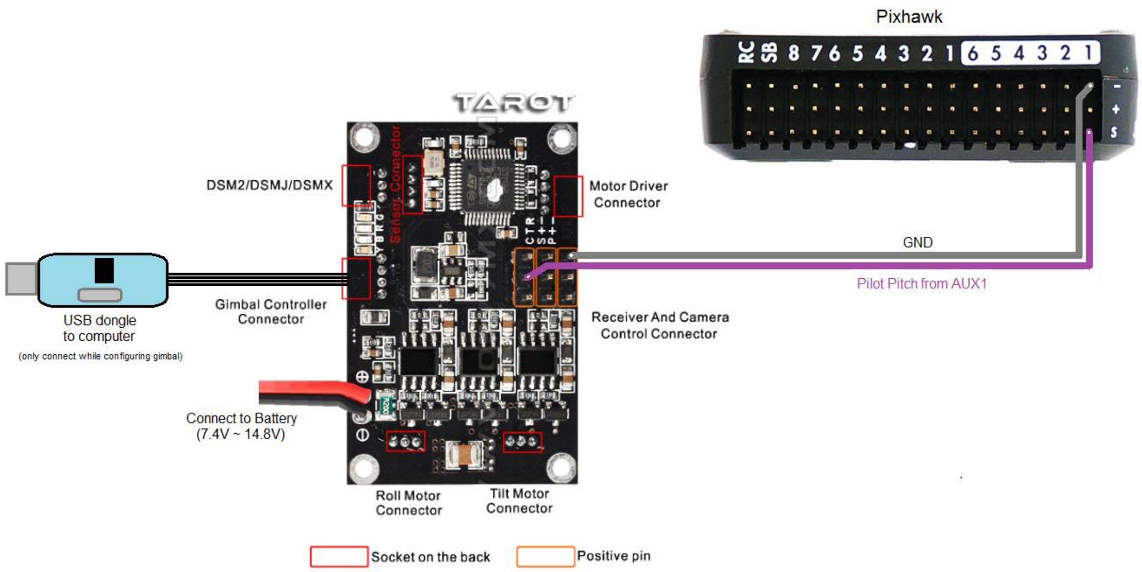

Figure 3.13: Gimbal IC connections to the pixhawk output pins[18]

A single knob on the Taranis radio controller would have been able to change the angle or rotation of the onboard camera. The camera attached to the gimbal has 2 degrees of freedom, allowing the pilot to effectively see the plane's landscape.

3.5.2 Thermal Camera

Thermal imaging on the aircraft behaves as its own separate subsystem. Given the high cost of industrial-grade thermal cameras, a cheaper alternative such as LEPTON's longwave infrared camera module must be used. The thermal module would communicate to a computer via bluetooth. The following figure depicts such a system.

[18] Public Domain: http://ardupilot.org/copter/_images/Gimbal_Pixhawk_Tarot.jpg

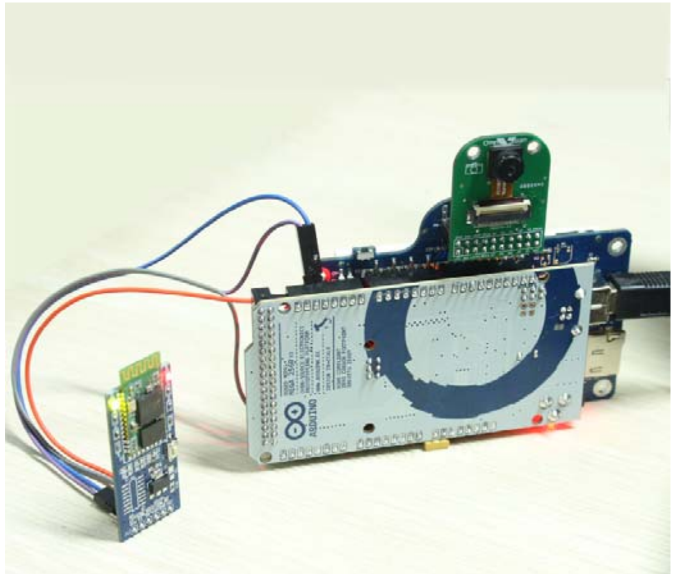

Figure 3.14: Circuit setup of a camera and bluetooth module connected to an Arduino Mega microcontroller[19]

Once the setup is configured on the aircraft, the max range must also be determined. Thermal imaging range is dependent on several factors:

- Strength or intensity of the infrared light emitted by a human body
- Camera sensitivity
- Resolution of the camera
- Optical characteristics of the camera

A ubiquitous method was developed by the U.S. military called the Johnson criteria, which provides a means for determining the max perceptible distance of a camera for a certain object based on pixel resolution. For an object to be perceived it must occupy 4 pixels per meter of physical space that it occupies. For an object to be discernable as a human body versus that of a car or animal, it must occupy at least 16 pixels per meter of occupied physical space. In actual application, the method for determining the max sensing distance of a camera is as follows:

[19] Public Domain: http://www.arducam.com/wp-content/uploads/2013/02/ArduCAM_RevB_3.jpg

$$PPM\ (pixels\ per\ meter)\ =\ \frac{minimum\ target\ height\ displayed\ (pixels)}{target\ height\ (m) * 100\%} \tag{3}$$

$$Pixel\ IFOV\ \ (mrad)\ =\ \frac{detector\ pixel\ pitch\ (\mu m)}{optics\ effective\ focal\ length\ (mm)} \tag{4}$$

$$Range\ (m)\ =\ \frac{1000\ (radians/mrad)}{PPM(pixels/m) * pixel\ IFOV\ \ (mrad)} \tag{5}$$

The following specifications were determined by the datasheet for the LEPTON Camera module, which consists of the same hardware for the Micro UAV camera module that would theoretically have been placed on the aircraft:

- target display height = 2 pixels
- average human target height = 2 meters
- pixel pitch = 17 micrometers

3.5.3 Audio Recognition

The audio recognition system is essentially a walkie-talkie and it connects the aircraft to the base with its receiving end located at the ground station. The biggest challenge in the design of this subsystem is the noise produced by the propellers. In order to reduce and ideally cancel the noise the team will take advantage of electrical and mechanical solutions to tackle this problem. Gopro FPV setups also incorporate audio feedback, implying the lack of a need for a separate dedicated circuit setup.

3.5.4 Visual - Blinking Light

The blinking light feature is a system of LEDs that are electrically wired to blink periodically. The following is the list of electronic components:

- 555 Timer IC: this integrated circuit provides time delays that can be programmed with another external IC.
- Resistor 1: 1 kOhm
- Resistor 2: 10 kOhm
- 10 microFarad capacitor

- 0.01 microFarad capacitor
- Resistor 3: 1 kOhm
- Resistor 9: 1 kOhm

Resistors 3 and 9 are multiplied depending on the amount of LED's the aircraft needs to provide the appropriate amount of luminosity at the appropriate distance for a hiker to recognize the aircraft. The time delay between blinks would be optimized based on the average flight speed of the aircraft and the distance between perceptible blinks.

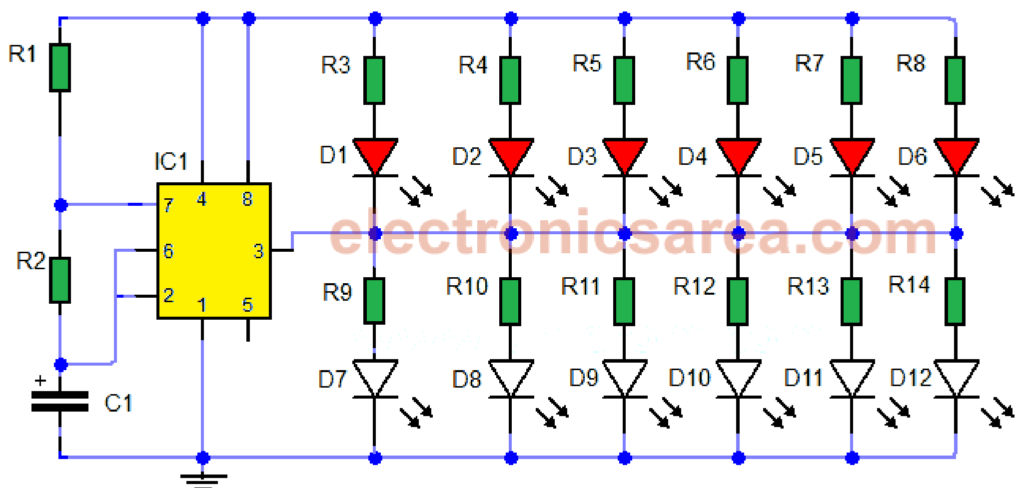

Figure 3.15: Circuit diagram for blinking LED's connected to a 555 Timer IC[20]

This subsystem does not need to be connected to the pixhawk as it is its own external circuit. It may be used with the onboard Lithium Polymer battery provided a step-down voltage converter is used. An Arduino Mega with its own built in timer could also be used in place of the single 555 IC timer. This allows for dual integration of the camera and bluetooth module described in 3.5.2.

3.5.5 Challenges and Tradeoffs

The reliability of the data collected by thermal imaging is contingent on the quality of the thermal camera used. Due to lower quality of the thermal camera, the data gathered through

[20] Produced without Permission: http://electronicsarea.com/wp-content/uploads/flashing-led-bike-lights-circuit.gif

thermal imaging may be unreliable unless the camera has a field of view with minimal number of objects blocking its sight. Voice recognition is particularly challenging due to surrounding noise as well as noise created by the aircraft's propulsion system. In order to be able to detect useful and valuable sound the aircraft needs to be still and in hover mode. Filtering the noise is a design challenge that faces the team when developing the audio recognition device. The blinking lights need to be strong enough for lost hikers to spot in any condition, no matter if it is through many trees or even during daytime. The LEDs also need to be selected in such a way that most individuals can recognize it as a search-and-rescue vehicle.

4 Integration

4.1 Overview

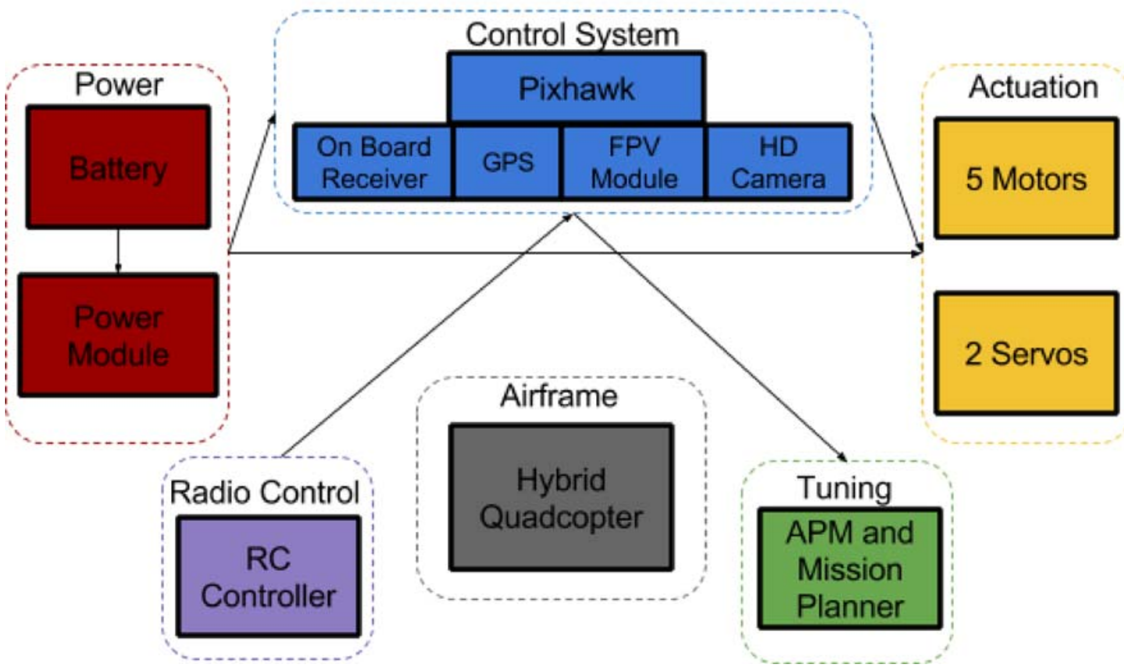

Figure 4.1: System component block diagram

The above figure is a component block diagram of the entire VTOL aircraft system. The battery power is directly connected to the power module which safety sends the correct amount of current to the pixhawk flight controller in order power but not harm in. The remaining current is then split and spread to the five motors. The pixhawk is using to control all seven of the actuators through the radio signal it receives from the Radio Controller through the receiver. These power and control components are then integrated on-board to the airframe.

Figure 4.2: Picture of Final Prototype for Testing

The figure above is a picture of our finished prototype. As seen in this image the four vertical takeoff motors are attached to the carbon fiber tubes. This is done with a bolt and nut. This bolt goes through the base of the motor through the carbon fiber tubing and a machined ABS plastic block we made to allow for a more secure attached while not compromising the tubes strength. This ABS part is shown in a SolidWorks drawing in Appendix I. The carbon fiber tubes were then attached to the wings by integrating them to the carbon fiber spar that support the wings. This was done using an aluminum strip of sheet metal that hooked around the spar on the inside of the wing while being securely fastened to the quadcopter struts. Lastly the entirety of the control and power systems with housed inside the foam fuselage of the airframe.

4.2 Main Challenges and Issues

As stated above in the initial system requirements section () the main defining factor of the design is flight time. This specification determines weight of the design meaning that it also determines the aircraft's size, payload, battery, and propulsion. The goal for the project design as far as weight is approximately 2 kg. This weight must then be allocated to the different subsystems of the design. These include airframe, electronic and control systems, propulsion and battery, and communication telemetry. Therefore, it is the main problem faced for the integration of these separate subsystems.

First, the propulsion systems and battery are reliant on the wanted flight time. If a flight time of 1 hour is needed for the mission then this must be used to calculate the needed power and size or capacity of the battery. This involves calculating the amount of thrust need to provide the needed lift for aircraft's weight and then calculating the time the battery could supply the power needed to sustain the needed thrust.

Once a propulsion system is found to successfully provide this flight time then its weight is analyzed in relation with the other subsystems in order to determine the size and weight of the remaining parts. The bulk of this remaining weight is in the airframe obviously and because of this it's design is the one that may be manipulated most in order to obtain the correct weight. However, this airframe design is also arguably the most important for successful flight so the total weight may be increased if need be. The electronic and control system (microcontroller, electronic hardware, etc.) are a very small and are almost negligible in weight as far as the overall design.

Lastly is the communication telemetry and detection apparatus. The detection apparatus we will use is a Tarot gimbal and GoPro HD camera and the remaining telemetry is a simple FPV module add on to the pixhawk. This will add approximately 0.35 kg to the system which will hurt the function of our aircraft flight and may result in upgrading our motor and propeller combination for vertical flight however according to our CFD analysis we have the lift to support this payload.

5 Testing and Analysis

5.1 Goals and Procedures

5.1.1 Flight Testing

The testing of the motors and propellers will go through different stages. During each of the testing and operation stages, the users must be in a safe area, away from the rotating parts.

They must have proper eyewear. After each test and operation, the aircraft must be checked for any damage, or loosening that they may have experienced during the trials. If any damage or loosening is noted, safely remove or tighten the part while all power is off.

1. In order to safely test the motors and propellers, the first test will be to see if they rotate correctly. Next, they will be correctly assembled to the aircraft. The aircraft will then be strapped down, and the motors will be run to see if the shafts rotate properly, and in the correct directions.

2. Once the motors have passed these initial tests, the propellers with be added. The aircraft will be strapped down on a gimbal to test the stability of the vehicle. This will not test the hovering capability, it will only test whether the aircraft will stay level when faced with mild disturbances.

3. Then, once this test is passed, the aircraft will have to pass a tethered test. With the aircraft in a safe, and legal location, it will be tethered from a ceiling. The aircraft may then be tested to see if hovering mode works while it is in a small, enclosed area.

4. Once the aircraft passes hovering mode, it may be tested with no controlled degrees of freedom. For this test, the aircraft must follow all of the FAA, and local regulations on flying unmanned aircrafts. In addition, only an operator with a certified unmanned aircraft licence may fly it. The aircraft will be tested for flight time, distance, velocity, and stability. These will all be done in an outside area that has been approved by the FAA.

The flight testing is currently in progress, and the vertical flight mode is being calibrated. Both the vertical and horizontal motors rotate correctly using the controller, however stability is still being worked out. The battery life then was tested both in horizontal flight and hover mode. In each case the aircraft was strapped down and the motors were run at a speed that would have produced ample lift. These tests found that the hover mode lasted roughly 8 minutes while horizontal flight lasted three times that amount, 25 minutes. This proved that having a VTOL aircraft is much more efficient in terms of saving battery life.

5.1.2 Weight Distribution

In order to perform the weight distribution calculations, all the weights acting on the aircraft were laid out and placed at the desired distance as shown in Figure 5.1 below. Most of the components attached to the airframe were fixed in location. For example the Pixhawk could only be placed at one location due to the airframe geometry and the receiver could only be placed at the very back of the airframe since it has to be as far as possible from the Pixhawk in order to avoid any interference.

The center of gravity of the airframe had to be kept at a fixed location which is 6.3 cm behind the front edge of the wing. The electronic speed controllers (ESCs) were the only components not being fixed in location. In fact, there was some freedom to move them along the carbon fiber struts. Therefore all the distances of the components from the center of gravity were measured and the ESCs distances from the c.g. were kept as variables. The sum of the moments about the center of gravity was then calculated and the result allowed us to find the ideal location of the ESCs that would keep the airframe stable.

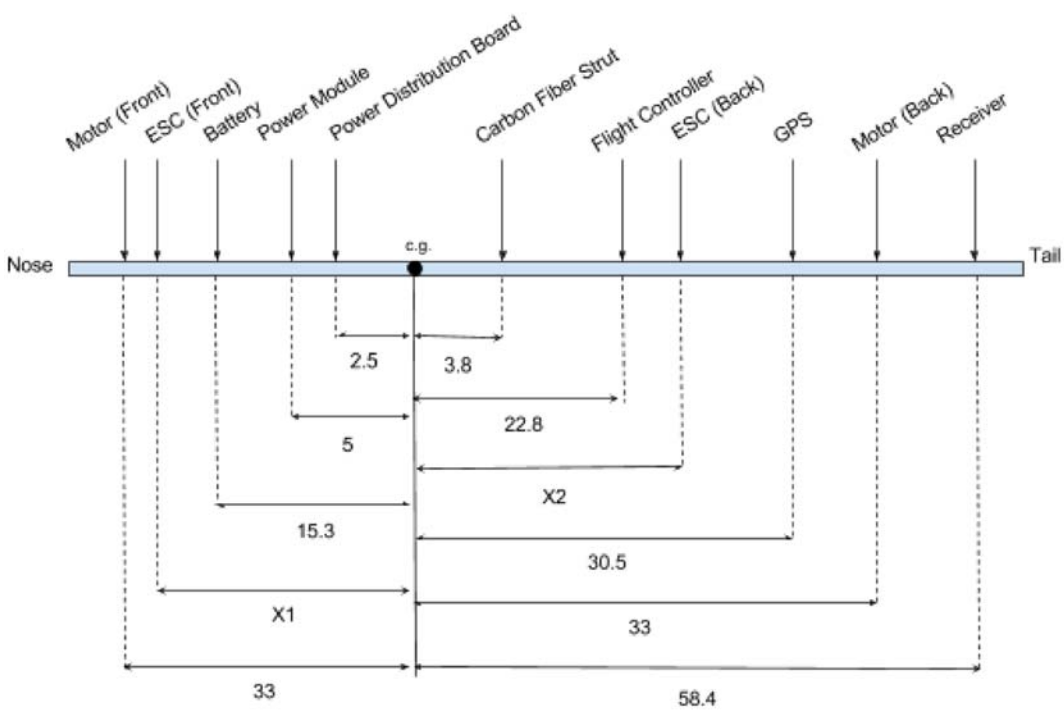

Figure 5.1: Distribution of weights on the aircraft. Measurements are in cm (drawing not to scale)

5.1.3 Computational Fluid Dynamic Analysis (CFD)

In order to confirm that the wing and fuselage chosen would be adequate for horizontal flight, CFD analysis was used. The program used was STAR-CCM+ as it was most familiar to us from the curriculum at Santa Clara University. CFD analysis was used in order to find lift, drag, velocity distribution, shear stress distribution and pressure distribution. The lift and drag helped determine the aircraft's flight performance, while the latter three were used when performing FEA analysis.

The first CFD analysis performed was on a single wing. Due to the complexity of meshing and the time the program took to run a simulation, a single wing and then a half model were used for analysis. Once the single wing testing was finalized, the half model was analyzed to confirm lift and drag results.

When importing the wing and plane models in STAR-CCM+, a rectangular box was placed around the model and then the box and model were subtracted from each other make a cavity of the wing and half model. The box may be seen in Appendix H. The front plane was where a velocity flow of air was simulated at 15 m/s toward the modeled wing or half model and its type was modeled as a velocity inlet. The rest of the planes were set as pressure outlets, and the model was kept as a wall type. The meshing used was a tetrahedral, surface remesher, and prism layer meshing surface. Physical properties of air at standard sea level were used in the simulations. The simulations for both models were run for 150 iterations in order to make sure the lift and drag values settled to a correct amount. The simulations were also ran multiple times to confirm the results found.

The main goal of the CFD analysis was to make sure the aircraft would have enough lift during horizontal flight. Many avionic components were added to the aircraft, which resulted in the aircraft weighing 1.9 kg. The CFD analysis needed to confirm that the airframe provided enough lift, and that the resultant pressure, when put through FEA analysis, did not cause any harmful vibrations or rupture any components.

5.1.4 Banking Angle and Radius of Curvature

The banking angle and the radius of curvature were calculated in order to analyze the performance of the aircraft. Given Figure 5.2 below, φ represents the banking angle (*degrees*) and R the radius of curvature (*m*).

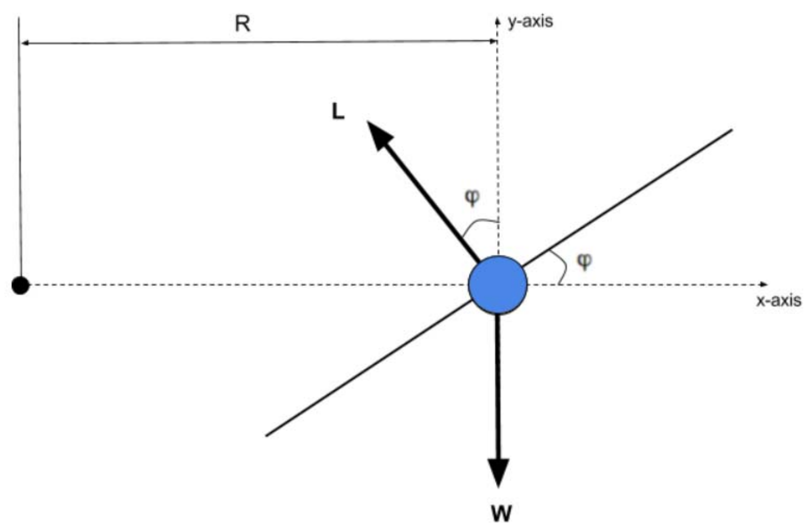

Figure 5.2: Banking angle and radius of curvature calculations

The hand calculations for Figure 5.2 show how the values of φ and R are found by summing the forces in the x and y direction using equations 6,7,8, and 9.

$$\Sigma F_y = 0 \rightarrow L\cos\varphi = W \quad (6)$$

$$\Sigma F_x = \frac{mV^2}{R} \rightarrow L\sin\varphi = \frac{mV^2}{R} \quad (7)$$

$$\text{Load factor: } n_{bank} = \frac{L}{W} = \frac{1}{\cos\varphi} = \sec\varphi \quad (8)$$

$$\tan\varphi = \frac{V^2}{R\,g} \Longrightarrow R = \frac{V^2}{\tan\varphi\, g} \quad (9)$$

The results from these calculations are shown in section 5.4 below after finalizing the weight of our aircraft and determining the lift from the CFD analysis.

5.1.5 Finite Element Analysis (FEA)

FEA analysis was used to examine the aircraft and its behavior using Modal Analysis for vibration behavior and also Static Analysis in order to determine the resulting stresses due to the loads. Both Modal and Static analysis was done by using ANSYS Mechanical software.

Since the CAD model of the aircraft was very detailed and included every minimal fillet, small areas and curvatures, meshing the model in order to analyze it became a challenge. In order to be able to mesh the model, the CAD models had to be simplified in a way that the model would keep its original structural characteristic while losing its finer details. In order to complete the simulation, the model was successfully simplified and meshed, and the electronic devices were put on the body using point mass option.

Static Analysis was used in order to analyze the structure's strength, resistance to the loads exerted on it, and to make sure that no yielding would occur within the material on the aircraft. Moreover the results helped determine if the connections between the wings and fuselage, and also the backfin and the rudder, will be able to withstand the consequent stresses due to the exerted loads.

The simplified model was also used to run vibrational analysis in order to determine the shape modes and their corresponding natural frequencies and deformations, in order to make sure that the design will keep its integrity.

5.2 Weight Distribution Results

In order to verify the theoretical results from the weight distribution calculations, the plane was hung by its center of gravity (6.3 cm behind the front edge of the wing) as shown in Figure 5.3 below. This allowed the team to confirm that the hand calculations agreed with the experimental procedure.

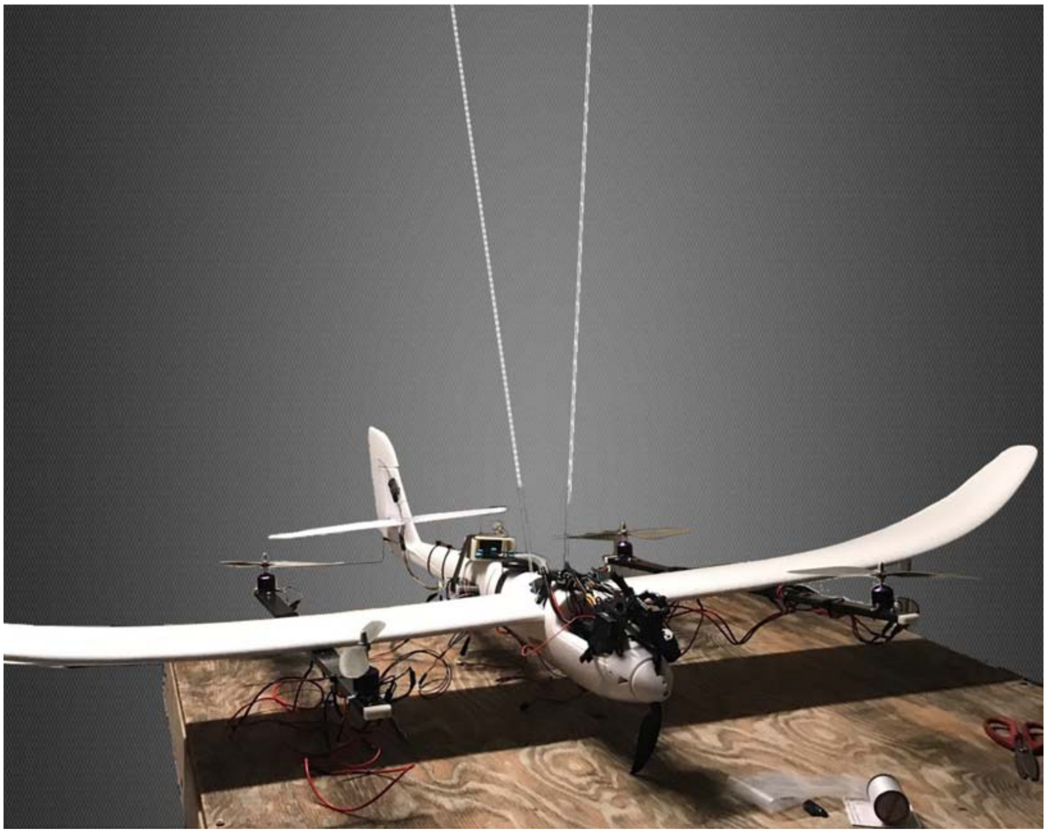

Figure 5.3: Experimental weight distribution test

5.3 Model Validation

To verify that the aircraft would have enough lift to fly, the lift and drag of the airfoil was calculated by hand. This allowed us to confirm that the aircraft would be able to fly given the lift and drag values shown below. In order to obtain those values, equations 10 to 15 were used.

$$Re = \frac{\rho V_{max} c}{\mu} = 159202 \tag{10}$$

From Appendix D in "Introduction to Flight" (by Anderson Jr.) airfoil data for NACA 2412:

$$c_l = 0.7 \qquad c_d = 0.007$$

$$C_D = c_d + \frac{c_l^2}{\pi\, e\, AR} \;\rightarrow \text{Assume elliptical wings } e = 1 \tag{11}$$

$$C_D = 0.008 + \frac{(0.9)^2}{\pi \times 11.252} = 0.02086 \tag{12}$$

Standard sea level conditions:

$\rho = 1.225\ \frac{Kg}{m^3} \qquad \mu = 1.789 \times 10^{-5} Pa \bullet s \qquad V_{max} = 15\ \frac{m}{s}$

$$q_\infty = \frac{1}{2} * \rho * V^2 = 137.812\ \frac{kg}{m\, s^2} \tag{13}$$

$$D = q_\infty\, S\, C_D = 1.02\, N \tag{14}$$

$$L = q_\infty\, S\, c_l = 34.28\, N \tag{15}$$

As seen in the calculated results above, the lift came out to be 34.28 N and the drag was 1.02 N. These results were for the NACA 2412 finite airfoil and CFD analysis was then performed to confirm these results. Based on the lift value of 34.28 N, and the aircraft weighing 1.9 kg, the results confirmed that the aircraft had enough lift to fly.

5.4 CFD Results

As stated earlier, in order to find the results using STAR-CCM+, the wing and model of the plane had to be put in a box, subtracted from each other, meshed, all physics and output values set up, and an air flow input to simulate flight was done to find the lift, drag, pressure, velocity, and shear stress distributions.

The following figure shows the shear stress, velocity, and pressure distributions of the single wing. These values were later used in FEA simulations.

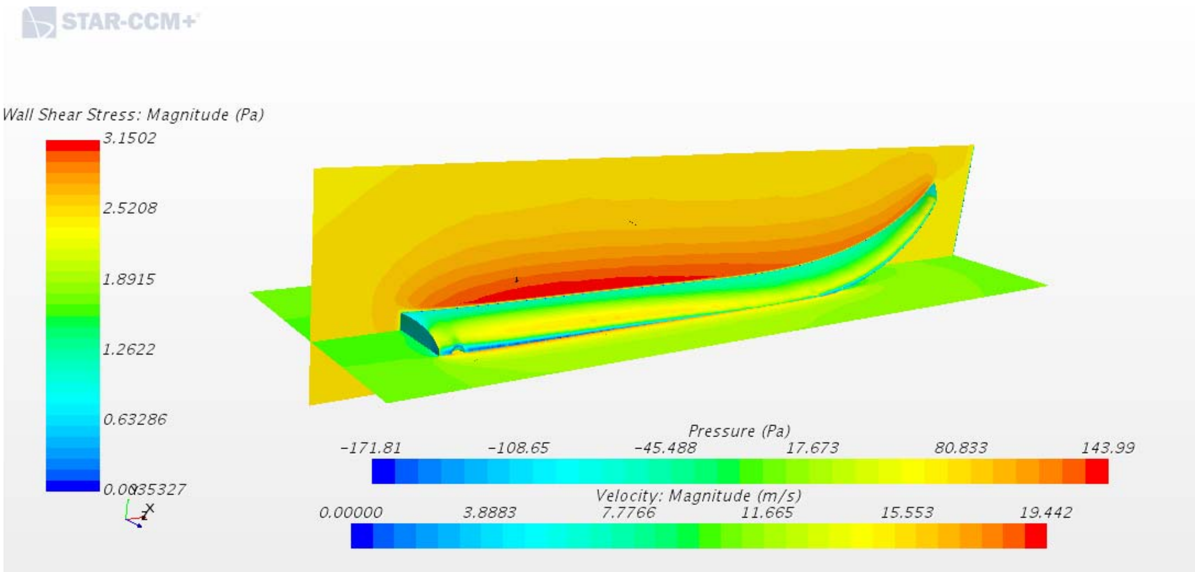

Figure 5.4: Shear stress, velocity and pressure distributions are shown on the wing after simulating flight using STAR-CCM+

From the CFD Simulation, the single wing had a lift of 12.772 N, and drag of 0.499 N. This was for a single wing, so for both wings the drag came out to be 1.0 N, and the lift was 25.544 N. This compared to the hand calculated results of 1.02 N of drag and 34.28 N of lift confirming the validity of hand and simulated results. Because the aircraft weighs 1.9 kg, these calculated results confirmed that the aircraft theoretically would have enough lift. The plot monitor from this simulation may be seen in Appendix H. The shear stress never exceeded 3.15 Pa, and the pressure never exceeded 144 Pa. This information was then used during FEA analysis to make sure the wing would not fail during flight.

To further examine the results, the half model was used in the CFD analysis. This can be seen in Appendix H. Once again, the pressure, shear stress and velocity distributions were found to be used in FEA simulations. The lift of the half model plane came out to be 14.25 N and 1.177 N of drag. These values confirmed that the aircraft will theoretically fly horizontally even with the added weight from avionics and modifications. All of these simulations were run at 15 m/s which was used based upon the theoretical fastest, cruising speed. In addition, the shear stress never exceeded 2.66 Pa and the maximum pressure was under 175 Pa. These values were later used during FEA analysis.

5.5 Banking Angle and Radius of Curvature Results

Once the value for the lift was obtained from the CFD analysis, it was possible to create graphs to show the behavior of the increasing lift versus the banking angle (Figure 5.5), as well as the banking angle versus the radius of turn (Figure 5.6).

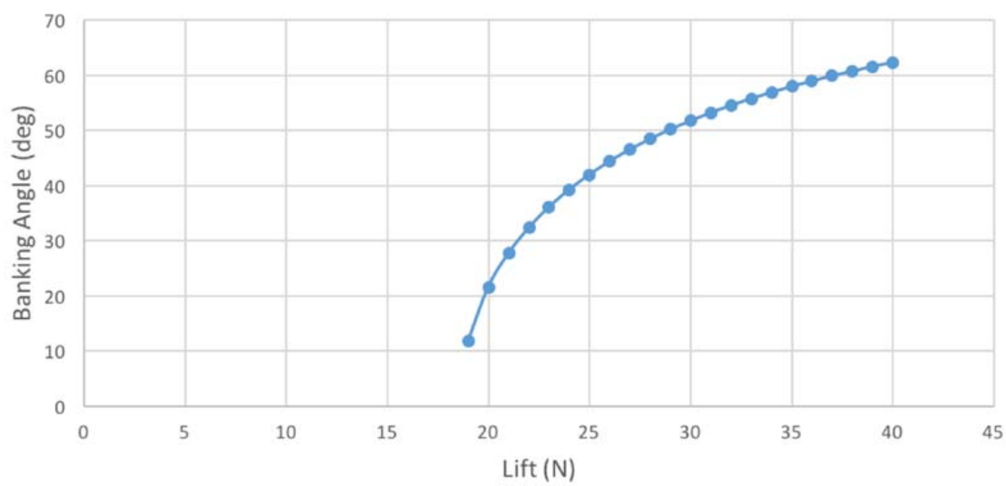

Figure 5.5: Lift vs Banking Angle

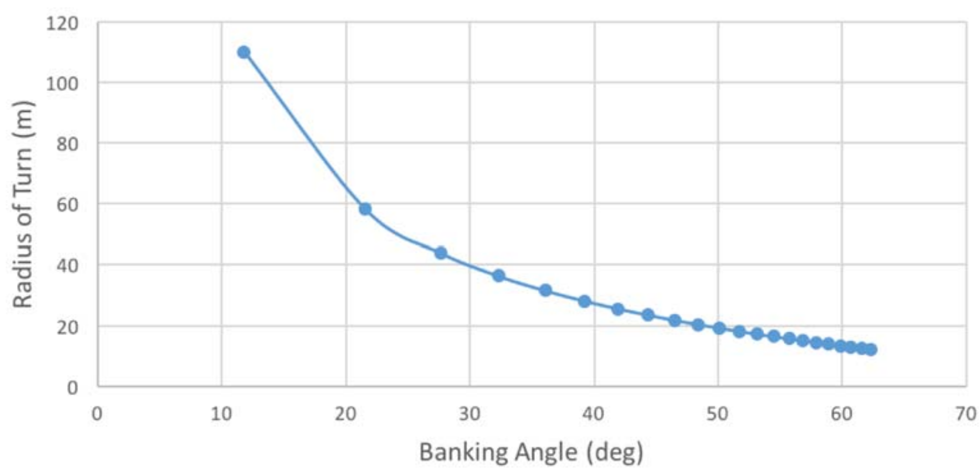

Figure 5.6: Banking Angle vs Radius of Turn

5.6 FEA Results

After Static Analysis was run in ANSYS Mechanical, it was determined that the stresses that arise due to the loads exerted on the aircraft are on the order of 500 kPa and the maximum deformation is 1.47 cm, which is way below the yield point of the material, therefore, they would not cause yielding within the material. Furthermore the results confirmed that the connections between the fuselage and the wings and also the backfin and the rudder would hold with no major problems. The results are shown in figures below.

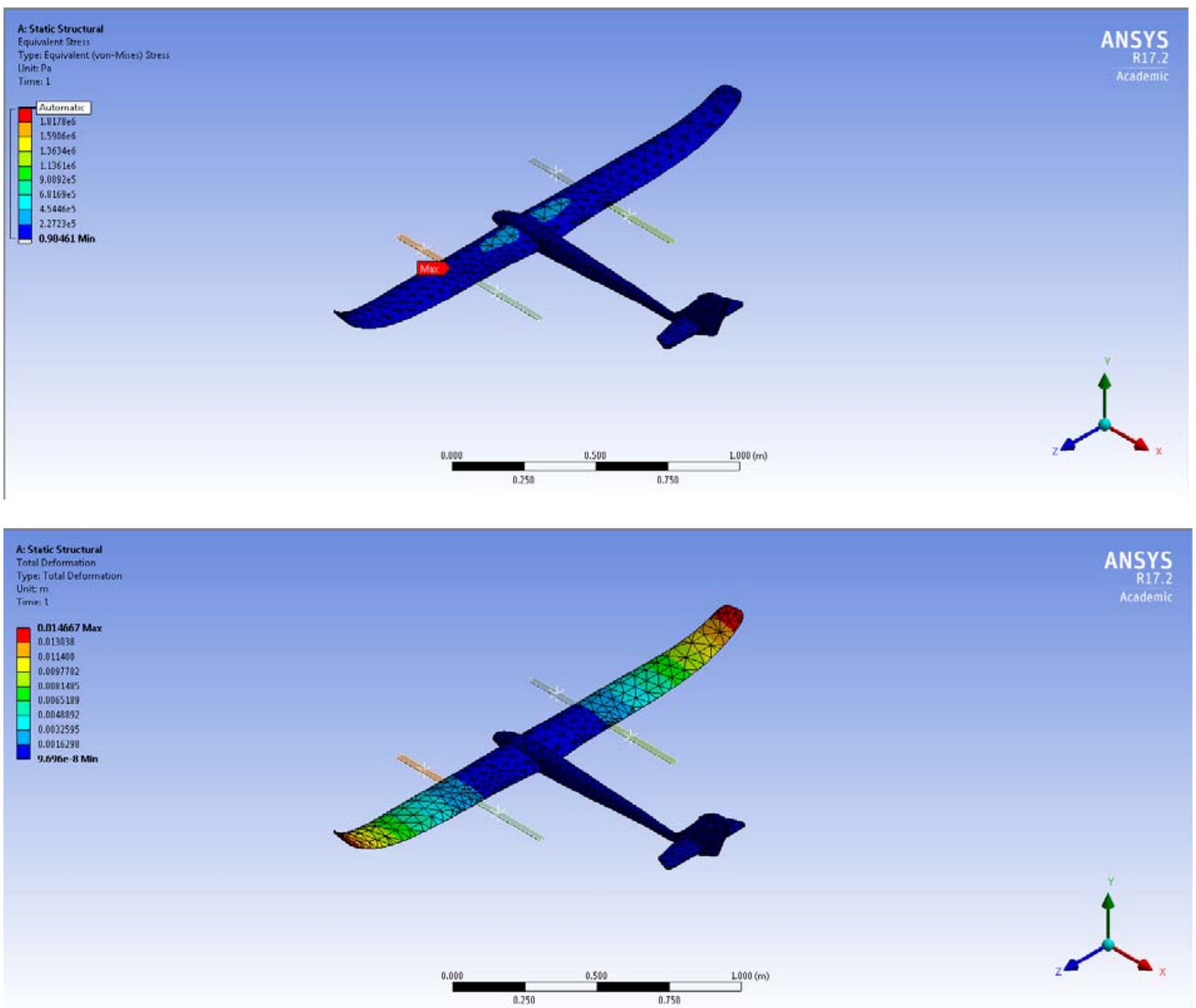

Figure 5.7: Static Analysis of CAD model.

Deformation Range: 0.01467 m (red) to 9.69e-8 m (blue)

The modal analysis helped determine the pertinent mode shapes of the aircraft and their corresponding natural frequencies and deformations. After the simplified model was setup in

ANSYS Mechanical, the results of the modal analysis showed that the main mode shapes, namely wing flap and wing twist, occur at natural frequencies of 16.7 and 167 Hz and the deformation caused by vibration is so minuscule that the values can be considered negligible. The figures below present the modal analysis results.

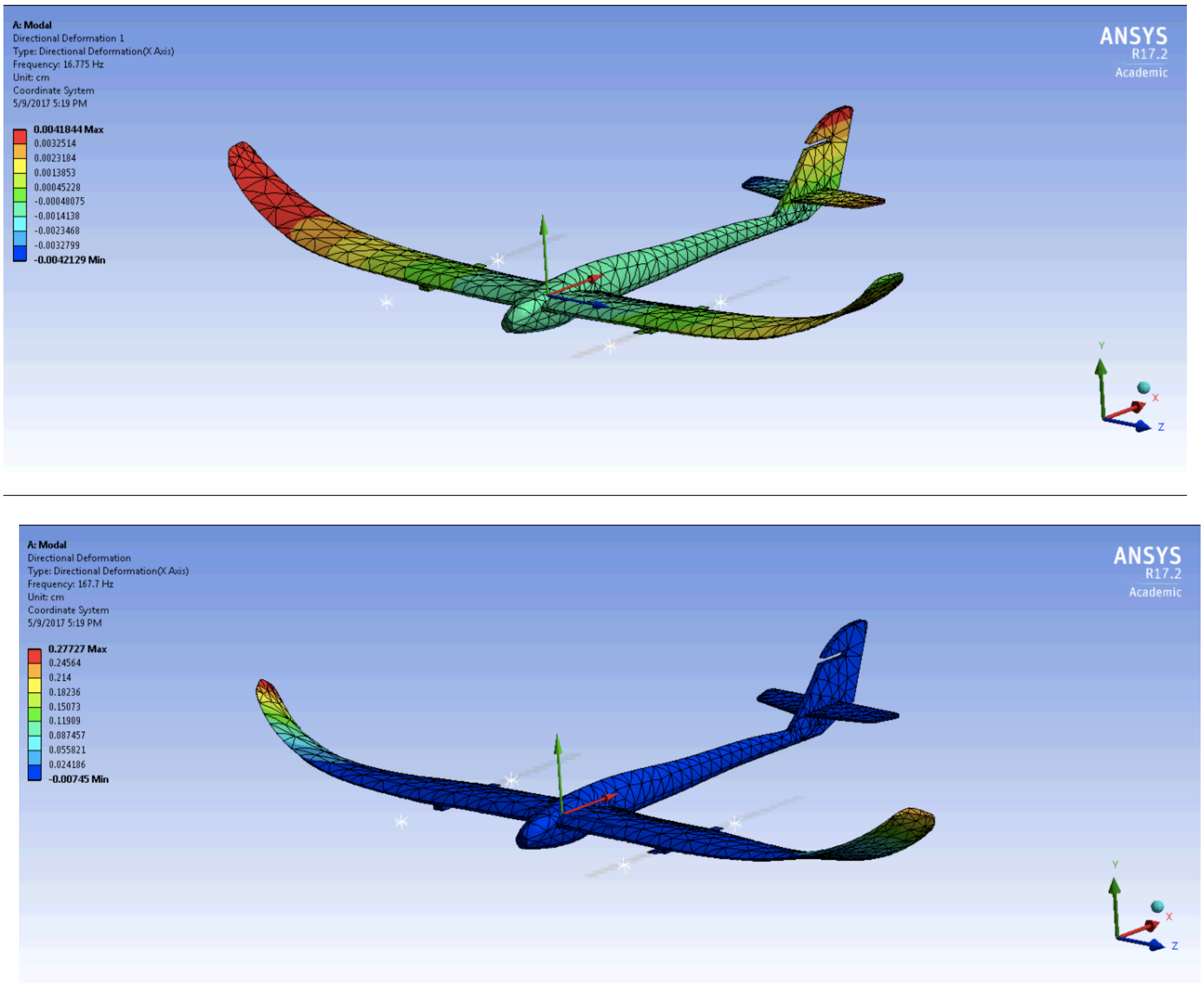

Figure 5.8: Modal analysis of CAD model.

Deformation Range: 0.277 cm (red) to -0.00745 cm (blue)

5.7 Testing Conclusion

In conclusion, all of our experimental and simulated results proved to confirm our objective. The mass distribution tests confirmed that we kept the center of gravity where it needed to be. This means that with all of the added avionic components and modifications to the fuselage, the aircraft should fly in the most efficient manner. The flight testing confirmed that horizontal flight was much more efficient than quadcopter mode. The CFD analysis proved that the aircraft does have enough lift to fly horizontally during cruising speeds even with the added weight. Finally, the FEA analysis showed the aircraft will not fail during high amounts of pressure, and during flight, the vibrations will not cause any serious deformations to the aircraft.

6 Cost Analysis

6.1 Overview

Unmanned aerial systems have a large range of prices. Some can be bought for as low as $50, while the more expensive ones can be over $100,000 or even millions of dollars. These prices depend on many factors, but size, flight time, and functionality are very important. The mission of the aircraft is what ultimately helps make decisions on pricing. This aircraft needed to have a long flight time, great stability, reliable searching features, and be operable by a single user. From these goals, the estimated cost of the aircraft was $2,000 which included all of the search functionality such as a thermal camera. This price is higher than many drones that can be bought commercially, but those drones will not have the same functionality as this hybrid aircraft. In addition, there are more expensive unmanned aircrafts with longer flight times, however, our VTOL design looks to offer comparable functionality for a much lower price.

Our hybrid search and rescue aircraft project received funding for a total amount of $2500. This amount is right around the initially proposed budget. Because of the small difference between our budget and our funding, the spending had to be carefully planned in order to not go over the given amount. Breaking parts, or poorly manufacturing parts could easily put the team behind budget.

6.2 Manufacturing and Assembling

A timeline of when parts would be bought was developed in order to make sure the most important features of the aircraft would be developed first. The quadcopter component of the airframe is the first subsystem that was bought and developed. The aluminum H-frame to house the electrical components was store bought or manufactured in the machine shop. The foam wings and other components of the airframe will be purchased as well in order to allow for easily interchangeable parts if they break or are damaged.

Once the airframe is developed, the propellers, motors, control board, controller, servos, and transmitters will be bought. These parts will have gone through cost analysis, and the motors and propellers will have gone through flight analysis to make sure they provide the necessary propulsion. These will be bought in terms of lowest price, but the parts must have passed regulations in order to use it during flight because of FAA regulations.

If the aircraft development and testing outcome is a product that can hover and horizontally fly, then the attachments will finally be ordered. The attachments will include an HD camera, thermal camera, sound transmission, GPS and a WiFi module. These components will only be ordered once the aircraft is able to properly fly because spending money on these components would be a waste if there is not an aircraft to attach them to. Additionally, the attachments listed are expensive so that money could be used to purchase new wings, or a new propeller in case of any damage that happens to the aircraft.

6.3 Use in the Market

The cost of the aircraft had to be reasonably priced for national park services and search and rescue teams. The number of search and rescue missions is climbing along with the number of hikers per year. Seen below is a graph depicting the number of missions conducted over a 17 year span in Oregon.

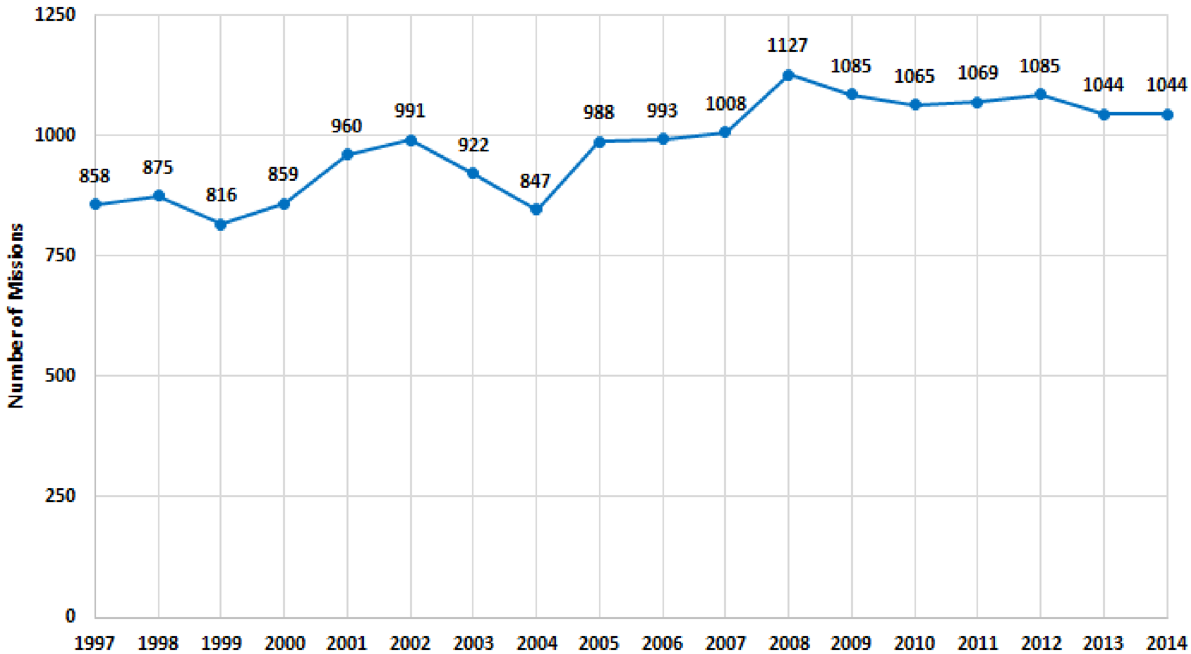

Figure 6.1: Graph shows missions conducted in the state of Oregon from 1997-2014 [21]

As seen in the graph, the number of the search and rescue mission has been slowly on the rise. With the high expenses of these teams, roughly 4 million per year in the U.S.[22], having a cheaper way to help conduct these missions can have a large impact. The one time cost of the aircraft will save money for the services, and it will help keep rescue member's lives out of risk.

7 Business Plan

7.1 Goals/Objectives

The goal of the company is to shift the popularity of using drones for Search-and-Rescue (SAR) missions to hybrid-type aircrafts. However, the market for the product is limited as such features are needed depending on the environment that the mission is conducted in. Although there are SAR teams that need technological help in optimizing their search missions, our product is a unique solution to locating lost individuals. The goal is to take advantage of existing solutions on the market by increasing their efficiency in order to achieve longer flight time. The

[21] Permission to Reproduce: *Office of Emergency Management*. Berlin: Walter De Gruyter, 2014. *Search and Rescue: Annual Report for 2014*. Oregon Military Department. Web.
[22] "National Parks Traveler." *National Parks*. N.p., n.d. Web. 07 Dec. 2016.

team must identify specific terrains where the product can perform at its best, collaborate with its respective park services team, and potentially work with local law enforcement agencies who conduct actual SAR missions.

7.2 Potential Markets

Since federal agencies are primarily responsible for SAR missions, our team must target those specific SAR organizations that are located near terrains that would make effective use of our product. Given its recent popularity, multirotors have yet to be widely used among park services nationwide. The most popular means of aerial support is seen in helicopters outfitted with supplies for hiker relief. By modifying the existing design, our product could potentially hold different payloads such as medicine, food, and water. In doing so, the new capabilities of our design will expand the product into more markets.

Amazon delivery services have recently explored the use of multirotor drones for delivering goods. However, they are using the power of at least four motors to lift a load rather than relying on the aerodynamic efficiency of a plane. This method is extremely inefficient as it wastes battery power and would require the delivery to be done in only distances for the aircraft to safely return. A hybrid aircraft would require less power to lift a payload, and it would have the ability to safely handle the payload when switched to loiter mode. The customer base for such a product would be far reaching given its capability for long distance flight. The team could potentially market the idea to delivery services such as UPS, Amazon, and Ebay. However, the allowance for such an idea is within the jurisdiction of the FAA.

Our team may also find popular support among companies that design such helicopters. We may potentially offer the service of integrating components to build a hybrid aircraft branded under SAR helicopter manufacturers that need augmented aerial support.

7.3 Sales/Marketing Strategies

Informing national park services about our product requires a dedicated sales-and-marketing team. Although the engineering team can perform such tasks with a relative degree of success, their resources are better spent in product development. National park services will be interviewed with regards to their park's terrain, yearly number of SAR missions, and the logistics by which such missions are carried out. By understanding the potential buyer's concerns, the team can also understand where the product can perform the best, and thus far many positive responses have been received from potential customers, given our products originality. Levi Yardley, the head of paramedics and the SAR team at Yosemite National Park, showed interest in our product and offered advice and counselling during its development stage. Human resources such as Levi are vital due to their critical role and experience in carrying out missions, providing medical aid to the distressed, and knowledge of the appropriate methods of identifying individuals.

To passively market the product, one strategy is to use printed materials. A detailed product brochure would be mailed to certain national parks in the United States. Once SAR organizations are informed and the product has received enough positive feedback, the team can further extend their markets by appealing to other international organizations. This will depend on sales volume within the U.S. park services. Moreover, further market penetration will expose the team to different types of competition as other emerging companies may be developing other products that can be used in SAR missions.

The main pitch to SAR market is the aircraft's efficient use of battery for a more efficient flight and longer flight time, and hopefully more successful missions. A global trend emerging among consumers is the use of multirotor drones for a myriad of different missions that are not limited to SAR. Although these types of aircrafts benefit from robust control systems, they are extremely inefficient in battery life consumption when carrying payloads. China has recently introduced civilian drones for mailing packages, creating a possible need for long distance drone deliveries. However, hybrid-type aircrafts are yet to be popularized regardless of their outstanding performance capabilities. Our product is scalable, and it can meet market demands taking advantage of its ability to adapt to different environments. The aircraft geometry is not limited to a slender-high speed plane. Different plane models can be outfitted with any number of multirotors. Additionally, by switching to different propulsion systems, the aircraft can account for several different loads and mission requirements. Our product has the potential for tapping into many different markets.

7.4 Manufacturing Plan

Successfully manufacturing and selling the product requires an understanding of the activity of the employees, the capacity of materials and production, and the allocation of the team's respective resources. In reality, one design was developed and has yet to be marketed to potential customers. The following manufacturing plans have assumed a positive trajectory of our team and product.

During the first year, 60 aircrafts will be built, since there are 59 National Parks in the US. At this point, the process should not be automated and a technician should be hired at an hourly rate based on the current supply & demand. In other words, there is no set schedule for the single employee. Materials needed to develop the aircraft will be ordered in multiples of 5 based on supply and demand as well. We want to stay ahead of orders so production of the aircrafts will not stop if no orders are in. For the first year, manufacturing will take place in a small warehouse or garage in order to save costs.

As demand grows, money will be put into purchasing better equipment to make production quicker. The improvement could be upgraded versions of the current equipment, or an automated type assembly depending how high the demand is. The warehouse may also need to be expanded. The aircraft's need to be stored in safe locations as they are produced, so the warehouse needs to be large enough to house all of our equipment and inventory.

There are many tradeoffs in manufacturing. As a business, we are going to need to adapt to demand and be able to accurately predict the future of the company. Investments on the size of the warehouse, quality of equipment, and production rate are the main areas of focus in terms of costs and adjusting based upon demand.

7.5 Service/Warranties

Our product will have a 6 months warranty that includes a free replacement of all airframe or electrical components. We will not cover any damage costs if the aircraft is damaged during flight due to poor piloting. The aircraft that need to be fixed will be sent back to our company and we will make the necessary repairs. If the problem is a faulty battery or motor, a new replacement will be mailed to the buyer. It is up to the consumer to make the necessary electrical repairs as most fixes are trivial and do not need to be conducted in-house. Any repairs that need to be made after the warranty is expired, or any damages to the aircraft that are the owners fault will not be covered by our company. The user of the aircraft must have their drone piloting license to prove their ability of flying unmanned aircraft in order to cover their warranty.

7.6 Financial Plan/Product Cost

There are a few fix costs that goes into the initial business. A place to build the product, equipment to manufacture and produce the aircrafts, and initial building of prototypes to ensure quality are the main components that comprise the costs. On top of these costs are the variable production costs. In the first year we plan to produce 60 units at a cost of roughly $2,000 per unit. This price may go down due to bulk orders, but is a reasonable starting point for all of the components going into the aircraft. All the costs mentioned combined will result in a total cost per unit of $2,458.33 as seen in Table 7.1.

Table 7.1: Costs during the first year.

Fixed Costs			Unit Cost	# of Units	Total Cost	Total Cost per Unit
Warehouse	Equipment	Prototypes				
$10,000	$10,000	$7,500	$2,000.00	60	$120,000	$2,458.33

Based upon the costs during the first year, we are looking to sell each aircraft for $3,000. The aircraft comes with a HD camera, thermal camera and sound recognition system so the price is competitive with the current drones on the market due to the high price of thermal cameras. From the estimated product cost, we will be spending $147,500 in the first year. In order to cover these costs, we will look for funding from investors or search and rescue foundations. In addition, we could take out loans and once the product starts selling, we can slowly pay it off. By selling 60 units in the first year at a cost of $3,000 per unit, it results in $180,000. The 50th unit sold will put the business in the positive for that given year. Hopefully as production goes up, we are able to drive production costs down by investing in more effective ways to produce the aircraft. Additionally, as discussed in the potential market section, if we are able to expand to the potential market for the aircraft then the number of units we are able to sell will drastically increase. This is when we will invest in better production methods. The first year will be important to break into the market and see the demand on these aircraft. Hopefully, National Parks will start buying more than one aircraft in order to increase the amount of area searched at a given time by flying multiple aircrafts at once. During each year we plan on keeping some of the money on the side in order to have for warranty coverage. Additionally, each member of the team will need to be paid. These costs will put the business in the negative if only 60 units are being sold each year. Once 150 units or more are sold each year, at $3,000 per unit, the business will break even on all costs.

8 Engineering Standards and Realistic Constraints

8.1 Environmental Consideration

There are a few main environmental factors that impacted the design of the aircraft. The first factor was the decision between gas or electric motors. Using gas motors hurt the environment more than electric. However, a gas motor was used in a similar design of an aircraft that was being examined. The gas powered motor provided a lot of propulsion, but environmental impact and gas cost was not justifiable. Electric energy may be harvested through natural way such as wind, solar, and biomass. In addition, electric motors would be able to efficiently power the aircraft based on the size, weight, and purpose of it.

When deciding on the parts and amount of material that would be used in the aircraft, the environmental impact was considered. Material will only be ordered when it is needed, and any excess will be recycled or properly disposed of. The aircraft frame will be efficiently built in order to minimize the amount of material used, while keeping the quality of flight high.

8.2 Manufacturability

Manufacturability is a large constraint when it comes to making a vertical takeoff and landing aircraft. The aircraft had to be designed to have it be easily manufactured and modeled.

The main parts of the aircraft will be CAD modeled and used for analysis. This makes the complexity of the parts an important consideration. Regardless of its need to outfit two different propulsion systems, the aircraft's design was simple where two struts were added to an already existing airframe. In addition, the material used for each of the parts is constrained by the manufacturability of the material. Foam and aluminum were decided on for the airframe because of the availability to custom manufacture parts needed. The rest of the components apart of the aircraft were also decided on based on the access to manufacture and complete the design.

8.3 Health & Safety

Health and safety factors come up during the manufacturing, testing, and completion of this project. During the manufacturing stages, the proper safety guidelines and restrictions outlined by the machine shop at Santa Clara University needs to be followed when working on the project. In addition, precautions will be made when working with all of the electrical components during assembly, as well as any other features of the aircraft such as the blades or epoxies.

During testing, there are health and safety risks to all of those who are in the area of the flying vehicle. There are FAA restrictions about flying at night and overhead of people, but no matter when or where the aircraft is flying, there are health and safety risks. The detailed steps for testing have been outlined in Section 5.1.

Once the project is completed, the components need to be carefully taken off and either stored or disposed of. Taking apart electrical components has risks, and finding a proper way to dispose or store parts is important to consider because of health and safety risks that can come up after time.

8.4 Economical Consideration

The vertical takeoff and landing aircraft was designed to improve search and rescue, but also to reduce costs. National park services spend upwards of $4 million a year on search and rescue missions[23]. These costs include paying for helicopters and people's time. The average cost

[23] "National Parks Traveler." *National Parks*. N.p., n.d. Web. 07 Dec. 2016.

to power a helicopter is $1600/hr[24]. In comparison, the vertical takeoff and landing aircraft that was designed will roughly cost $2500. This is a one-time fee and will be able to conduct searches every day. In addition, the aircraft was designed to be cost efficient. The airframe and materials used were planned to be inexpensive yet durable and capable of the mission. With limited funding, these decisions were made to stay within budget and had an impact on the design.

8.5 Ethical

The purpose of designing this aircraft was to have a positive impact on the world. The aircraft was designed to reduce the time it takes to locate lost hikers. Lowering this time greatly increases the chances of survival of the lost hiker. In addition, the aircraft puts less search and rescue teams at risk. Search and rescue teams will not have to spend as much time outside, scaling difficult terrain in order to find hikers. The aircraft allows for a quick and easy way to scan large areas of land to locate lost hikers, while being controlled from a safe area.

9 Conclusion

Hiking is a popular activity among people all around the world and the number of hikers is growing, approximately 45 million hikers in the U.S. in 2016. As the number of hikers increase, so does the amount of search and rescue missions. Each year, search-and-rescue teams are spending several millions of dollars of government funding to carry out those missions. Our unmanned aircraft not only brings this cost down but it will also reduce SAR team members' exposure to danger and increase the success rate of the missions by reducing the time. Hybrid aircrafts are yet to be used within this field, although they are developed by companies for applications in other areas. Our VTOL design team had set goals to develop an unmanned aircraft fit for the search and rescue application. We solved this by developing an aircraft designed for aerodynamic efficiency in horizontal fixed wing flight, increased battery life due to its hybrid functionality, and, subsequently, increased range and time of search.

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Appendix A: PDS

Table A.1: Updated PDS

Specifications	Datum: Latitude Engineering HQ 40	Goal	Possible Problems
Cost	Not on the market yet. Around $25,000.	$2,500 (prototype)	Must be cost efficient in terms of material, size, and the design.
Weight	40 lbs	3.5 lbs	Need to maximize battery weight with flight time
Extra Allowable Payload	5 lbs	0.5 lbs	Weight of thermal camera, HD camera, etc.
Max Flight Speed	23.15 m/s	15 m/s	Do not want this speed in order to analyze the video.
Hover Flight Time	15-20 minutes	10 minutes	May need to hover for longer period to better search certain areas.
Horizontal Flight Time	5 hours	30 minutes	May need to travel on the longer end of this flight time if the speed is lower.
Flight Control	Fully autonomous	RC control Automated transition between hover and flight mode	Will need a pilot to fly and control the aircraft.
Propulsion Systems	Electric vertical flight. Gas powered horizontal flight.	Electric battery power for both vertical and horizontal flight.	This may result in a tough time achieving wanted flight time.
Ideal Altitude	n/a (these are camera specs)	~25-75 meters	Does not give as larger of a field of vision as we want.
Field of Vision above height (HD Camera)	n/a (these are camera specs)	~120° (10,000m^2 - 62,500m^2)	Might need to fly longer if the altitude is this low.

Max Altitude (W/O Thermal)	10,000 ft	1,000 feet	Will it make it over most mountains.
Receiver Range (for RC)	Fully autonomous	10-15 miles	Receiving live video at this range.
Video Feedback	n/a (these are camera specs)	Live video for Couple mile range	The latency is an issue, but the technology is there.
Video Range (existing attachable hardware)	n/a (these are camera specs)		
Charging	Unknown spec on the aircraft	Easy battery charge (~1-2 hour for full charge)	May have longer charging time if larger batteries are needed.
Operation	More difficult to deploy and operate because of size and weight.	Easy operation and deployment for people without expertise	Need license for RC flight.
Weather Resistant	Water resistant, very stable and durable.	Water resistant, able to be stable during wind gusts up to 25 mph	The aircraft must be light/cost effective, but durable.

Appendix B: Budget

INCOME			
Category	Funds Received		
Grant	$2,500.00		
TOTAL	$2,500.00		
EXPENSES			
Category	Description	Spent	
Frame			
	Foam Airframe	$193.49	
	Back Up Wings/Fuselage	$115.99	
	Carbon Fiber Tubing	$148.33	
On-Board Avionics			
	Anti-Vibration Damping Plate	$7.49	
	Flight controller & Power Module	$66.80	
	Power Distribution Board	$5.81	
	Batteries	$101.72	
	Gimbal	$68.90	
	Rasberry Pi	$8.67	
	ESC's	$117.21	
	Terminal Board	$22.52	
	Voltage and Current Breakout	$29.95	
	Micro SD Card	$13.01	
Ground Control Avionics			
	Equipment Case	$73.99	
	LCD Screen	$38.93	
	Telemetry Cable	$19.99	
	LCD Driver Board	$29.68	
	Lipo Battery Pouch	$7.80	
	Battery Checker	$5.69	
	Turnigy Charger	$15.99	
	Battery Charger	$38.90	
	Transmitter Upgrade Cable	$8.99	
	Pixhawk Flight Controller	$10.25	
	Radio and Receiver	$257.74	
Propulsion System			
	Brushless Motors	$33.52	
	Propellers	$14.99	
	Propeller Adapters	$16.60	
Miscallaneous			
	Male and Female Bullet Banana Plug Connectors	$34.76	
	16-Gauge Wire	$7.01	
	Heat Shrink Wire Wrap	$10.19	
	Zip-Ties	$8.99	
	Electrical Tape	$7.27	
	12 Gauge Silicon Wire	$9.49	
	Male Adapter Extension	$7.34	
	Soldering Wire	$11.99	
	Shipping (not included in some purchases)	$84.21	
		Spent	Net Reserve
		$1,654.20	$845.80

Figure B.1: The list of expenses from the senior design project. The amount of money leftover is shown as "Net Reserve"

Appendix C: Concept Scoring

	TARGET or	DESIGN IDEAS															
CRITERIA	FACTOR	1 = Baseline		Wing		Body Frame		Back Propeller		Wing Propeller		Electronic Hardware		Control Systems		Detection Methods	
Time – Design	1	1		1		1		2		2		1		2		2	
Time – Build	1	1		3		1		3		3		1		1		2	
Time – Test	1	1		1		1		3		2		1		1		2	
Time Score	10		10		16.67		10.00		26.67		23.33		10.00		13.33		20.00
Cost – Prototype	1	$ 1.00		$ 3.00		$ 1.00		$ 4.00		$ 2.00		$ 1.00		$ 2.00		$ 1.00	
Cost – Production	1	$ 1.00		$ 3.00		$ 1.00		$ 4.00		$ 2.00		$ 1.00		$ 2.00		$ 1.00	
Cost Score	10		10		30.00		10.00		40.00		20.00		10.00		20.00		10.00
Aerodynamics	7	3	21	2	14	1	7	2	14	3	21	2	14	2	14	2	14
Reliability	6	3	18	4	24	4	24	2	12	2	12	4	24	4	24	4	24
Weight	1	3	3	3	3	3	3	4	4	4	4	2	2	3	3	3	3
Durability	3	3	9	4	12	4	12	4	12	4	12	3	9	4	12	3	9
Manifacturability	2	3	6	2	4	3	6	2	4	3	6	2	4	2	4	2	4
Maintainability	5	3	15	3	15	3	15	2	10	2	10	2	10	2	10	2	10
Aesthetics	0	3	0	4	0	2	0	4	0	3	0	2	0	1	0	3	0
Sustainability	4	3	12	3	12	3	12	2	8	2	8	3	12	2	8	2	8
	TOTAL		84.0		57.3		79.0		17.3		49.7		75.0		61.7		62.0
	RANK																
	% MAX		100.0%		68.3%		94.0%		20.6%		59.1%		89.3%		73.4%		73.8%

Figure C.1: Concept scoring spreadsheet

Appendix D: Gantt Chart

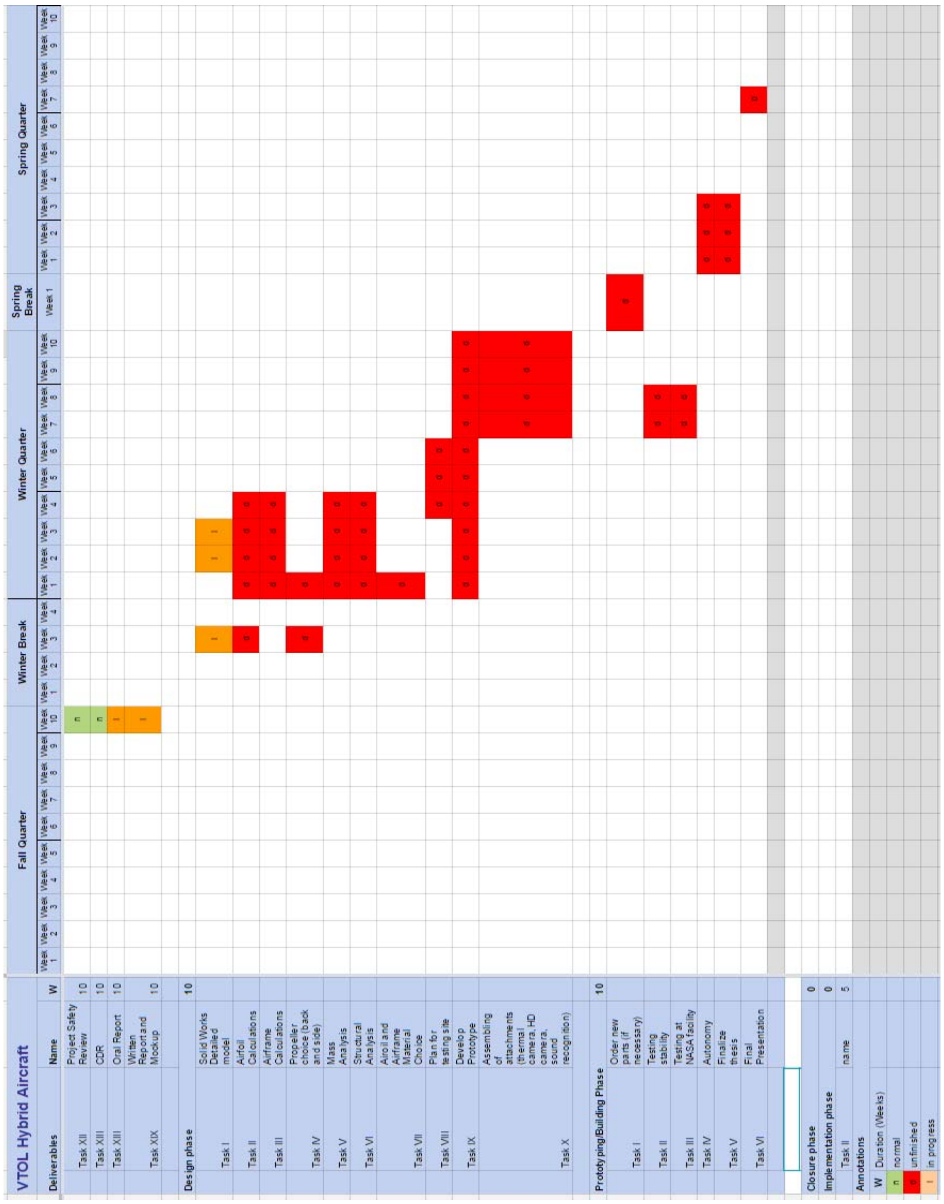


Figure D.1: The Gantt chart shows the goals aimed to achieve each quarter

Appendix E: Approved Safety Guideline

1. Rotating Mechanical Parts

   a. Manufacture

The rotating mechanical parts used in the VTOL aircraft are going to be the motor, shaft and propellers. Each of these items will be bought already built, therefore there will be no risk in terms of manufacturing these parts.

   b. Assembly

The assembly of the rotating motors and propellers does bring some safety hazards. When working with these parts the following guidelines need to be followed:

1. Never attach the propellers to the shaft of the motor while the motor is wired and able to rotate. The propeller should have no chance of rotating while it is being attached.
2. Only have one person assembling the propellers and motors at a time. They should be assembled in an open area where there is no interference.
3. The propellers need to be securely attached to the shaft so they are unable to come undone while in operation.
4. Before any assembly is done, the motors, shafts, and propellers need to be examined for any damage, cracks or anything that looks out of the ordinary. If the part has been damaged to any extent, do not use until it is cleared by an advisor or has been researched to confirm there are no associated risks.

   c. Test/Operation

The testing of the motors and propellers will go through different stages. During each of the testing and operation stages, the users must be in a safe area away from the rotating parts. They must have proper eyewear unless the parts are completely enclosed.

In order to safely test the motors and propellers, the first test will be to see if they rotate correctly. Once the rotating parts are correctly assembled, they will be attached to the aircraft. The aircraft will then be strapped down to a gimbal, and the motors will be run to see if the shafts rotate properly and in the correct directions.

Once the motors have passed the initial test of them working correctly on the aircraft, then the propellers with be added. Now the aircraft will strapped done on a gimbaled holder to test the stability of the vehicle. This will not test the hovering capability, it will only test whether the aircraft will stay level even when it faces mild disturbances.

1

Then once this test is passed the aircraft will have to pass a tethered test. With the aircraft in a safe, and legal location, it will be tethered from a ceiling. The aircraft may then be tested to see if hovering mode works while it is in a safe, enclosed area. Do not enter the enclosed area, unless all power to the aircraft is completely turned off, and the propellers have stopped turning.

Once the aircraft passes these initial tests, it may be tested with no controlled degrees of freedom. For this test, the aircraft must follow all of the FAA, and local regulations on flying unmanned aircrafts. In addition, the users must not go near the aircraft until the propellers stop rotating and the aircraft has completely shut down.

After each test and operation, thoroughly check the rotating parts for any damage, or loosening that they may have experienced during the trials. If any damage or loosening is noted, safely remove or tighten the part while all power is off.

d. Display

For the display of the rotating parts for the senior presentation, the motors and propellers will be connected but there will be no power to the aircraft. The battery will be taken out so there is no chance of it accidentally going off. Also, nobody should touch the aircraft, especially the propellers, under any circumstances. This will reduce any risk of damage to the aircraft, as well as keep the people looking at the aircraft safe because the blades may be quite sharp.

e. Storage

When storing the rotating mechanical parts, they may be left attached to the aircraft or taken off. In either case, they will be unattached from the power source. Safely unhooking the electrical wiring for these components will be discussed in part 5. The propellers will be removed from the shafts of the motors and safely put in a container where they will not deteriorate or be damaged. The aircraft with the motors will be stored in a safe area where it will not be tampered with. The motors, once stored, should not be reused unless completely checked and re-tested.

f. Disposal

Once the rotating parts for the aircraft are no longer needed, they need to be properly disposed. The propellers will be made of plastic or carbon fiber. Plastic propellers shall be properly disposed in the recycling unless there is metal on them, then they must be disposed in the waste. Carbon fiber propellers are more complicated.

If the carbon fiber is coated with hexavalent chromium primer then it is classified as hazardous waste. These may not be recycled or sent to a landfill. This type of part will need to be brought to a drop-off facility, and specifically characterized by the facility to properly dispose it. There are specific carbon fiber recycling facilities that carbon fiber without hazardous primers may go to when the propeller is broken or out of use.

The motors, once out of use must be properly disposed of at a recycling facility or donated. The small motors may be brought to recycling facilities for a small fee, and the company will properly dispose of the motor. Another option is to donate the motor to places such as Goodwill, or small appliance stores. Many people like to fix motors or would like to buy a cheaper, used motor. Depending on the condition of the motor, it will need to be properly brought to one of these places so that it does not provide a safety hazard to the environment.

If any of these parts are broken, or have been deteriorating, they will need to be handled with extreme care. Gloves may be needed when handling these parts to avoid any injuries. Additionally, once handled, avoid touching any part of your body and thoroughly wash your hands.

2. Compressed Cylinder Gases

Compressed cylinder gases will not be handled in manufacturing, testing, displaying, storing, or disposing processes at any point of the VTOL senior project.

3. Cryogenic Fluids

Cryogenic fluids will not be handled in manufacturing, testing, displaying, storing, or disposing processes at any point of the VTOL senior project.

4. High Temperature Fluids

High temperature fluids will not be handled in manufacturing, testing, displaying, storing, or disposing processes at any point of the VTOL senior project.

5. Electrical Parts and Assemblies

   a. Manufacture

The electrical components of the VTOL are the flight controller board, the controller, long distance transceiver, electrical speed controllers, servos, and the batteries. All of the electrical parts will be commercially bought meaning they are already built so there are no safety hazards involved in the manufacturing process.

   b. Assembly

In order to safely assemble the electrical components the following guidelines must be followed:

1. Before starting the assembly all electrical parts must be carefully examined to make sure that they are not damaged.

2. The assembly must be done in properly designated work areas. Working areas must be kept clean and free of static generating materials including styrofoam, vinyl, plastic, fabrics and other static generating materials. To help keep the assembly area clean there must be no eating or smoking in those areas.
3. Proper attire must be worn during assembly to avoid accidental damage to the assemblers. Eyes and hands must be protected by wearing safety glasses and gloves
4. The flight control board must be handled by its edges. Avoid touching the board and its components.
5. When assembling the components to the board, they must be properly insulated and disconnected from the batteries to avoid any chances of operator electrocution.
6. The assembly must not be powered during the assembly process to avoid any accidents, therefore the batteries must be the last components that are put in place.
7. Motors must not be powered at any time during assembly.

c. Test/Operation

All testing must be done in safe designated areas to avoid accidents to the operators. The testing area must be properly grounded, free of water, and of static generating materials. Safety gear, i.e. safety glasses and gloves, must be worn during testing. There must be no eating, drinking, or smoking in the test area before, during, and after testing to avoid damage to the electrical parts.

d. Display

The electronics are very sensitive parts and can be easily damaged, therefore during display they must be insulated and protected so nothing comes into contact with them. All electronic components are to remain dry and preferably out of touch to avoid accidental electrostatic discharge.

e. Storage

Electronic parts must be stored in shielded bags or boxes where they are kept dry and shielded from static electricity. Stacking of the electronics must be avoided to ensure that they will not be physically damaged.

f. Disposal

Many components of any electronic part are reusable. In order to safely dispose the electronic parts of the assembly, they must be taken to an electronic recycling center to be recycled/disposed of.

6. Harmful and Noxious Chemicals

The harmful and noxious chemicals used in the production of the VTOL aircraft will be any epoxy or hardeners used, and any 3D printed products. Both of these have harmful vapors and direct contact with skin may cause irritation and some risk.

a. Manufacture

The epoxy and hardeners will not be manufactured. However, they may be mixed. When handling the epoxy and hardeners, they are most toxic in their liquid states. Once they have dried, they are practically harmless. If mixing must be performed before applying then there a few guidelines to follow. They must be kept closed and secure until the mixing is ready to be performed. The mixing must be done in an open room with quality air flow. The directions to the epoxy or hardener must be read thoroughly, and if gloves or a mask are recommended, they must be worn. Eyewear must also be worn. Once mixed, securely close the lids back on for the epoxy or hardener.

When manufacturing parts in the 3D printer, make sure the 3D printer is properly set up, and it is in an open room with quality air flow. Not all 3D printing releases harmful or noxious chemicals, but some are when they release toxic fumes known as volatile organic carbon. These are not an extreme risk, and as long as the room has air flow it will not be a problem.

b. Assembly

When dealing with the epoxy or hardeners, they should be applied carefully. They may need to be applied under a ventilation hood depending on the chemical. In addition, they should only be applied by one person in an open room where there is no interference with their task.

The epoxy and hardeners should never directly come in contact with skin until it is completely dry. The person applying the epoxy or hardener should wear long pants and sleeves. If it comes in direct contact with skin then dermatitis or skin inflammation may occur. It is important to quickly and thoroughly wash away any epoxy or hardener that comes in contact with skin. Do not touch any other parts of the body, especially face or mouth, after applying it or if any comes in contact with skin.

Only one layer of epoxy or hardener may be done at a time. This reduces the amount of fumes released, and allows the room to ventilate all hazardous fumes. Once the first layer is completely dry, the next layer may be applied.

After carefully assembling a 3D printed part, the user must wash their hands before touching their face or eating food. This will ensure no chemicals enter their system that could be potentially harmful. Also, if the 3D printed part is sharp, it must be handled and assembled with care. Only one person is allowed to assemble at a time, and it should be done in an open room where there is no interference.

If pain, inflammation, or sickness from these chemicals continues for a period of time, or become severe, please immediately see a doctor.

c. Test/Operation

Most epoxy or hardener will not need to be tested because there should be reliable data on the chemical already. The load that the epoxy or hardener will be receiving must be calculated in order for the correct material to be picked. Also, the epoxy or hardener must be able to work with the material that it is going to be applied to. Therefore, the data about the epoxy or hardener will be known before it is used.

After using the aircraft during each trial runs, the epoxy and hardener should be examined for any possible points of failure. If any points are noted, discontinue testing and do not use the aircraft until more epoxy or hardener is used, or a different solution is performed.

The 3D printed parts should go through proper testing. The parts must be able to carry the amount of load it will receive when the aircraft is in use. This can be calculated or experimentally done. Once the 3D printed part passes strength tests and is assembled to the aircraft, it must be examined after each test or operation for any damage. If any damage is noted, the part must be removed and should be exchanged for an undamaged one.

d. Display

When the aircraft is displayed with epoxy, hardener, and 3D printed parts, they need to make sure they are all secure. The epoxy and hardener must be completely dry so no fumes or chemicals may affect people looking at or touching it. The 3D printed parts must be properly secured and assembled in the aircraft so they are not loose or come undone during transportation of the aircraft.

e. Storage

The epoxy and hardener shall be properly stored in the correct temperature environment with their lids completely closed. If any epoxy or hardener was mixed, it must be discarded correctly as described in the next section.

The 3D printed parts will be secured in the aircraft when sent into storage. The 3D printer, will be left exactly as it was before it was used.

f. Disposal

The disposal of epoxy and hardener must follow the RCRA regulations. The chemicals may fall under the hazardous or corrosive categories. If neither epoxy or hardener fall under these categories when mixed, once they are completely hardened, the chemicals may be easily disposed. However, is the material is hazardous or corrosive, there may be many steps to follow before disposal.

Before disposing of any epoxy or hardener, fully research the material on how to properly dispose of it. There are waste management places that will pick it up, or the material may be dropped off at one of the places. A good start is to call Lion Technology, and ask about the specific chemical before trying to dispose it on your own.

7. Other Potential Safety Hazards

A potential safety hazard comes from machining the frame and parts of the aircraft. The aircraft will have both aluminum and foam parts. When working with both of these materials in the machine shop, a few important safety factors need to be followed. All safety guidelines in accordance to the Santa Clara University machine shop need to be followed. These machines will only be open to those who have passed the safety course and tests for the shop.

While machining aluminum follows the regular guidelines of the machine shop, the foam requires slightly more attention. When machining and sanding the foam, particles from the foam will be in the air and may be inhaled. In order to prevent this, the person that is altering the foam will wear a particle mask. This will stop any harmful foam particles to be inhaled, and this is an added safety regulation on top of all the normal regulations that must be followed while in the Santa Clara machine shop.

a. Manufacture

When manufacturing the foam and aluminum, the Santa Clara University machine shop safety rules and regulations must be completely followed. In addition, a particle mask must be worn when working with the foam.

The manufacturing of any parts must be done with caution, and meticulously.

b. Assembly

While assembling the manufactured parts, they must be handled with care as to not damage the part or cause an injury. Some of the parts may be sharp so they need to be held on the dull edges. Large parts must be carried and assembled by more than one person.

Only assemble the parts in open rooms with no obstacles. Make sure anybody that is not helping assemble stays a safe distance away from the aircraft.

c. Test/Operation

When performing testing, or operating the parts, make sure there is a barrier between the aircraft and you. Additionally, follow the testing steps as described earlier so the aircraft does not attempt flight right away.

After each test, carefully examine the manufactured parts for any damage. If any damage is noted, make sure it will not have an affect on the flight or safety of the aircraft. If the damage increases the risk of the aircraft falling apart, or it affects the aircraft's ability to fly, the part must be fixed or replaced before the next test or operation.

d. Display

Before the aircraft is displayed, make sure all manufactured parts are secure and nothing could potentially be harmful. Any sharp edges must be noted, and others must be informed before they examine or touch the aircraft.

e. Storage

The assembled aircraft with the manufactured parts must be stored in a place that could not damage the environment, or affect others. The foam and aluminum parts may corrode after time, so properly storing the aircraft in a box that will not let these parts affect anything around them is important.

f. Disposal

Any aluminum that must be disposed, should be taken to an aluminum recycling plant. These places may be looked up locally, or The Aluminum Association may be contacted, and they can properly explain where to dispose of the aluminum.

The foam that will be manufactured may be recycled. There is drop-off recycling or mail-in recycling for the foam. The foam should not be sent to a landfill as it is a good product to recycle and reuse as different things.

8

Figure E.1: The approved safety guideline that was made prior to manufacturing

Appendix F: Design Flowchart

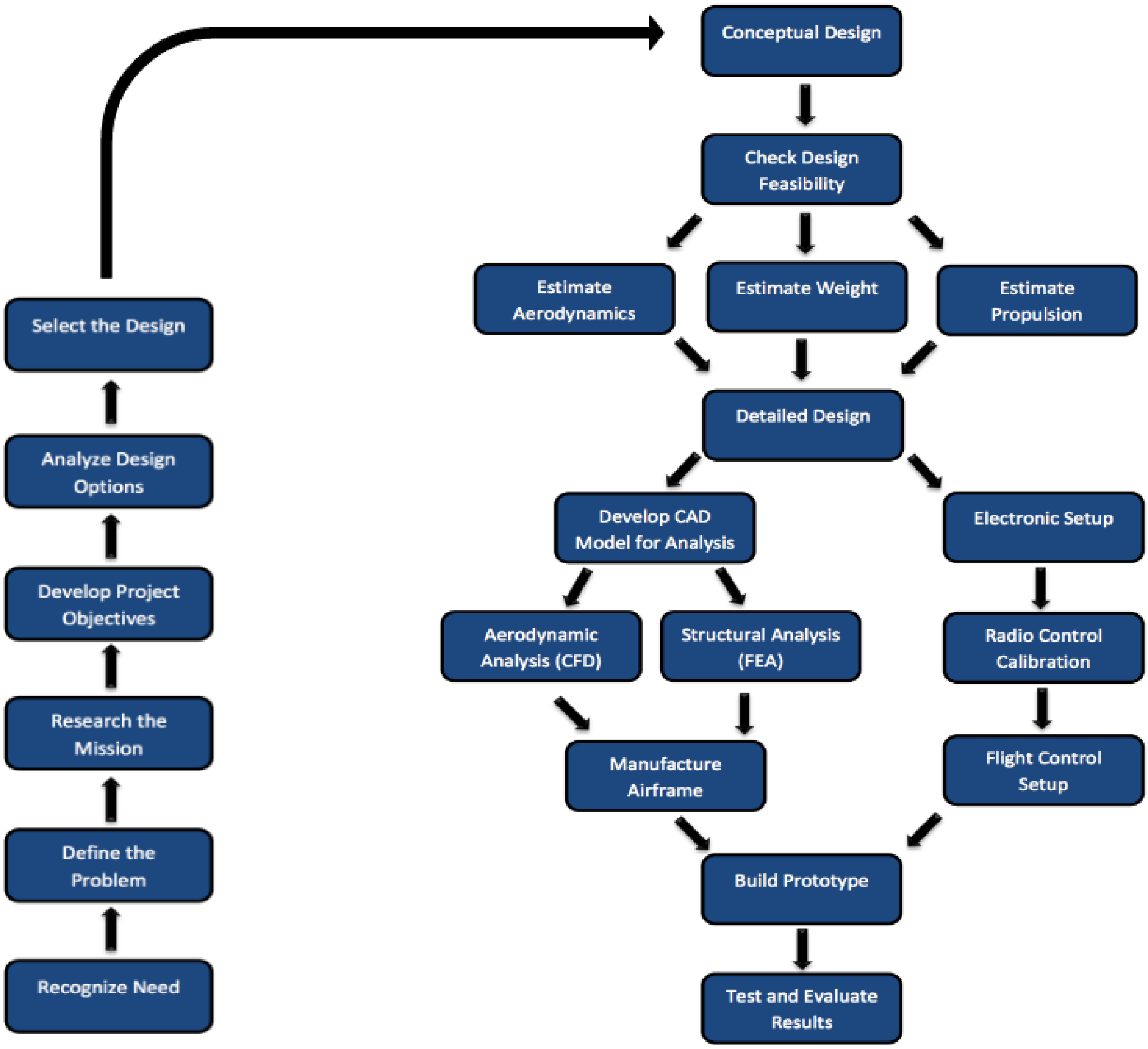


Figure F.1: The full design flow chart that was followed

Appendix G: Hand Calculations

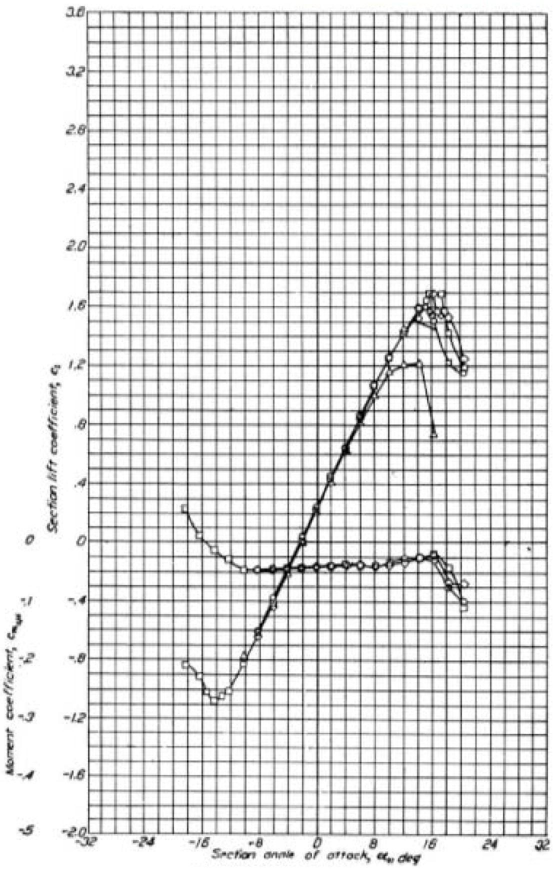


Figure G.1a: NACA 2412 angle of attack vs. lift coefficient

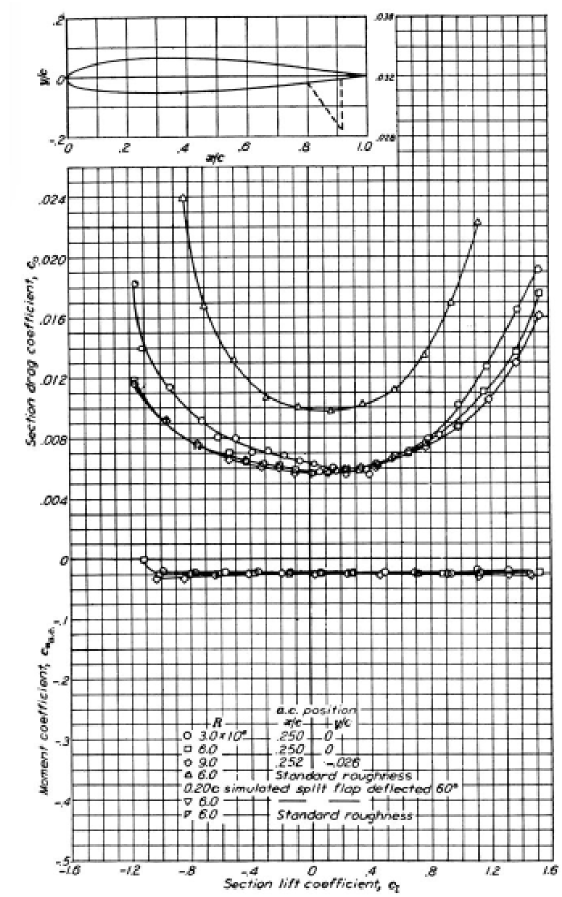


Figure G.1b: NACA 2412 section lift coefficient vs. section drag coefficient

Mass Distribution Calculations

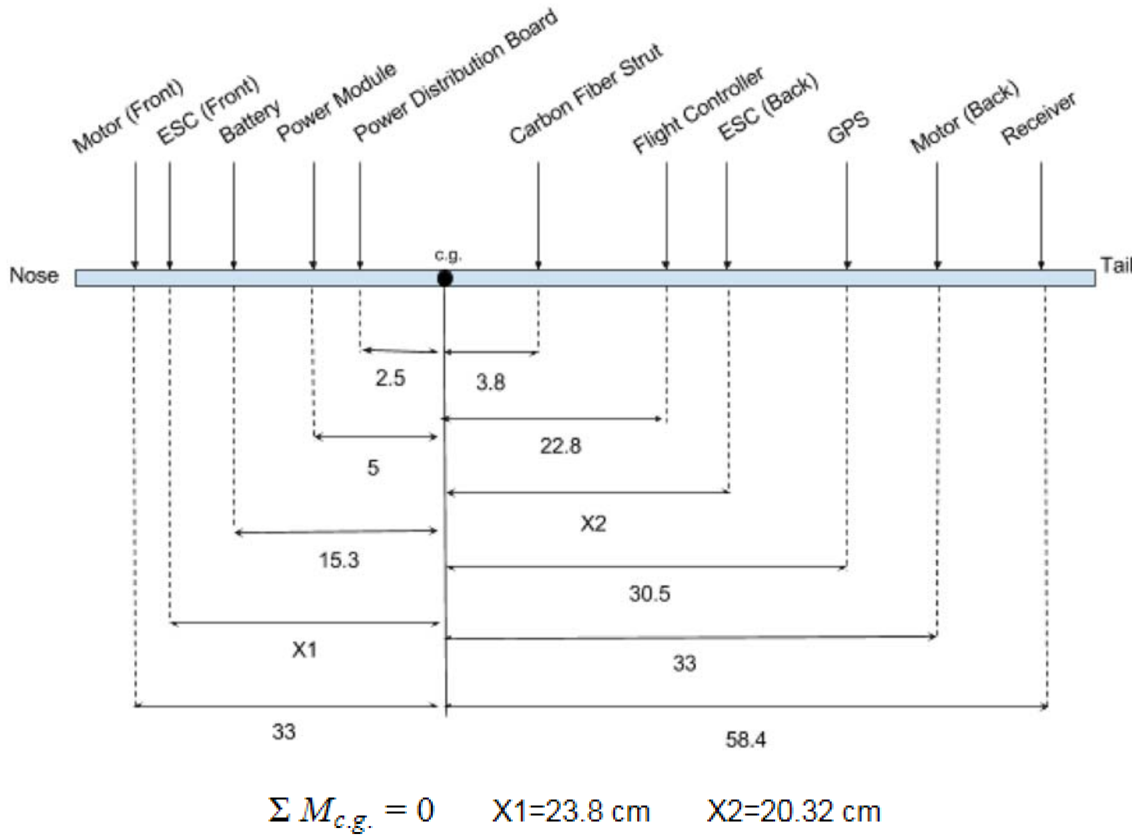


Figure G.2: Shows the placement of all of the components along the length of the fuselage

Table G.1: Measured weight of each component and the entire aircraft.

Part	Measured Weight (grams)	# Used	Total Weight (grams)
Flight controller	34	1	34.00
Motor	50	5	250.00
Power distribution board	54	1	54.00
GPS module	36	1	36.00
Battery	263	1	263.00
Power Module	26	1	26.00
Electronic Speed Controller (Red)	23	5	115.00
Gimbal	155	1	155.00
Receiver	6	1	6.00
Carbon Fiber	95.25	1	95.25
Battery (Not Used)	128	1	-128.00
Airframe	880	1	880.00
Total			1,896.25

Appendix H: CFD

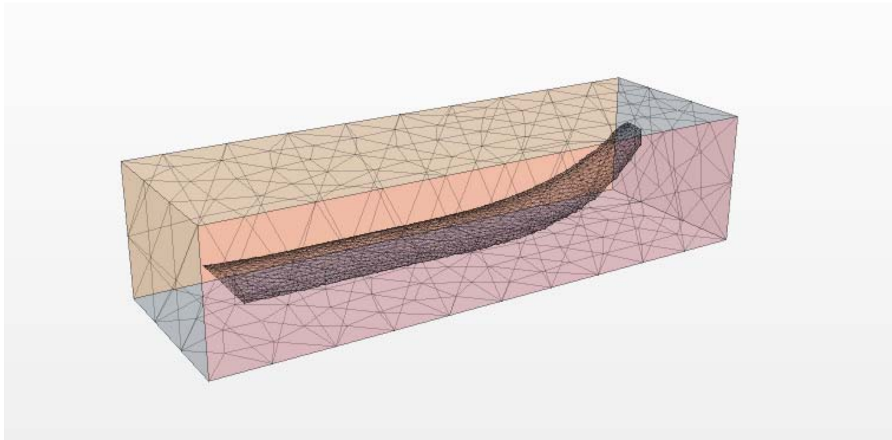
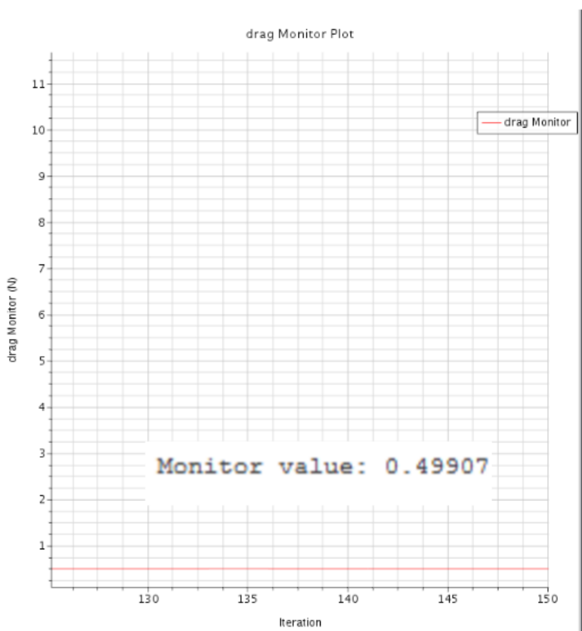


Figure H.1: The single wing is shown meshed in STAR-CCM+. The inlet flow goes in the front plane of the box



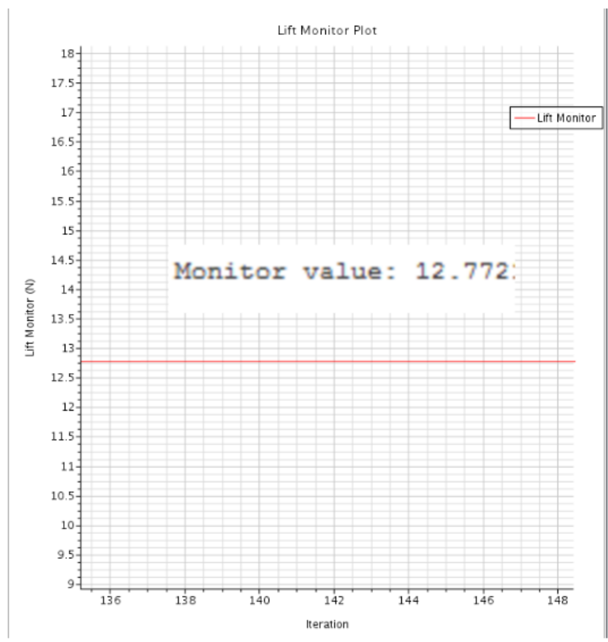


Figure H.2a: The drag results single wing **Figure H.2b: The lift results from single wing**

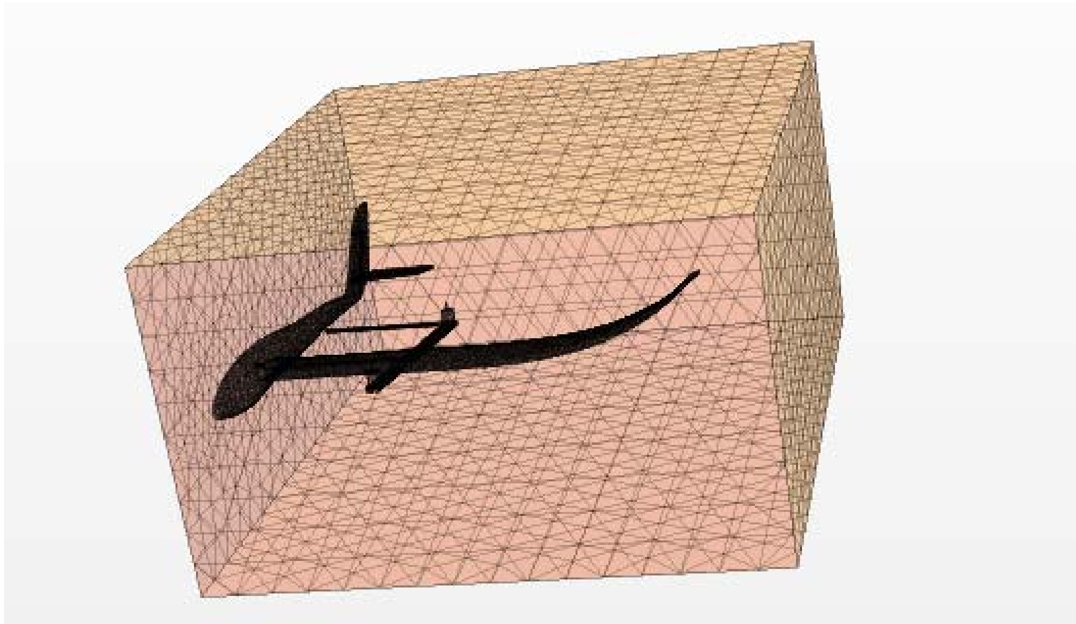


Figure H.3: The half plane model meshed in STAR-CCM+

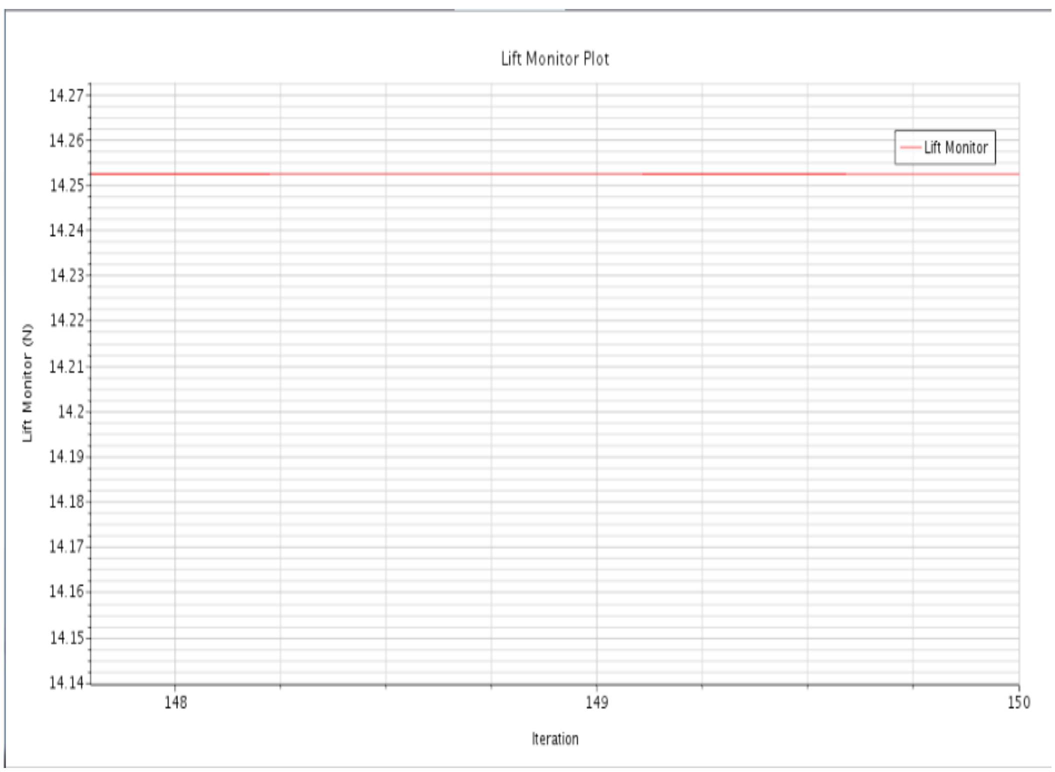


Figure H.4: The lift monitor from the half model simulation

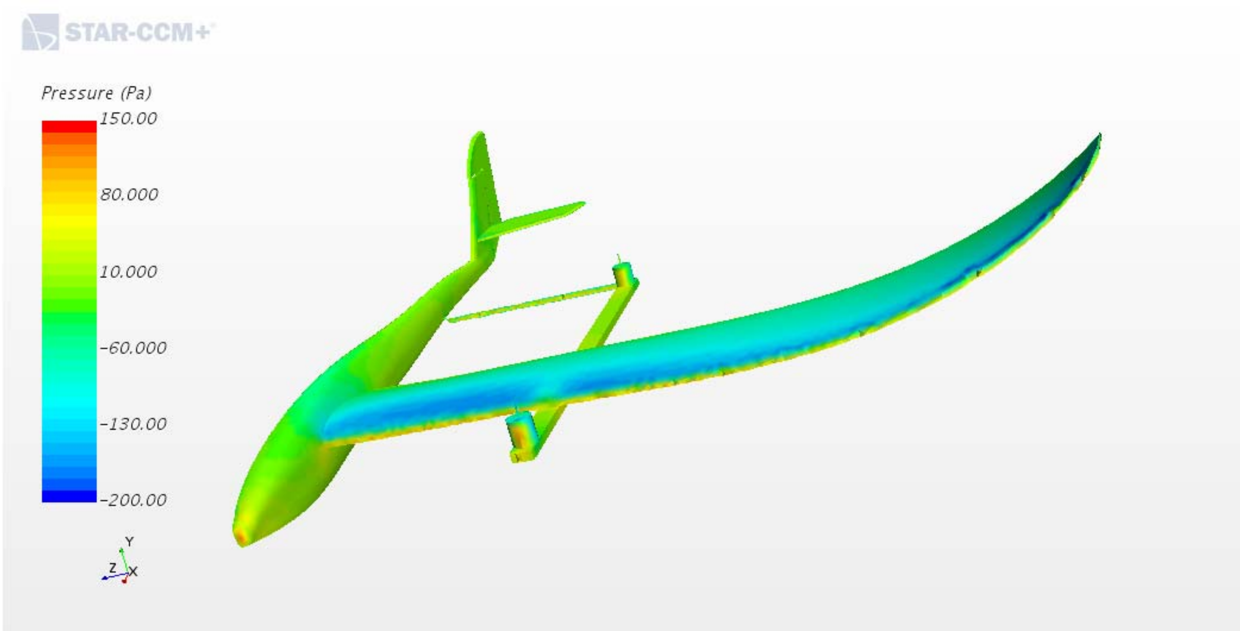


Figure H.5: The pressure distribution from the half model simulation

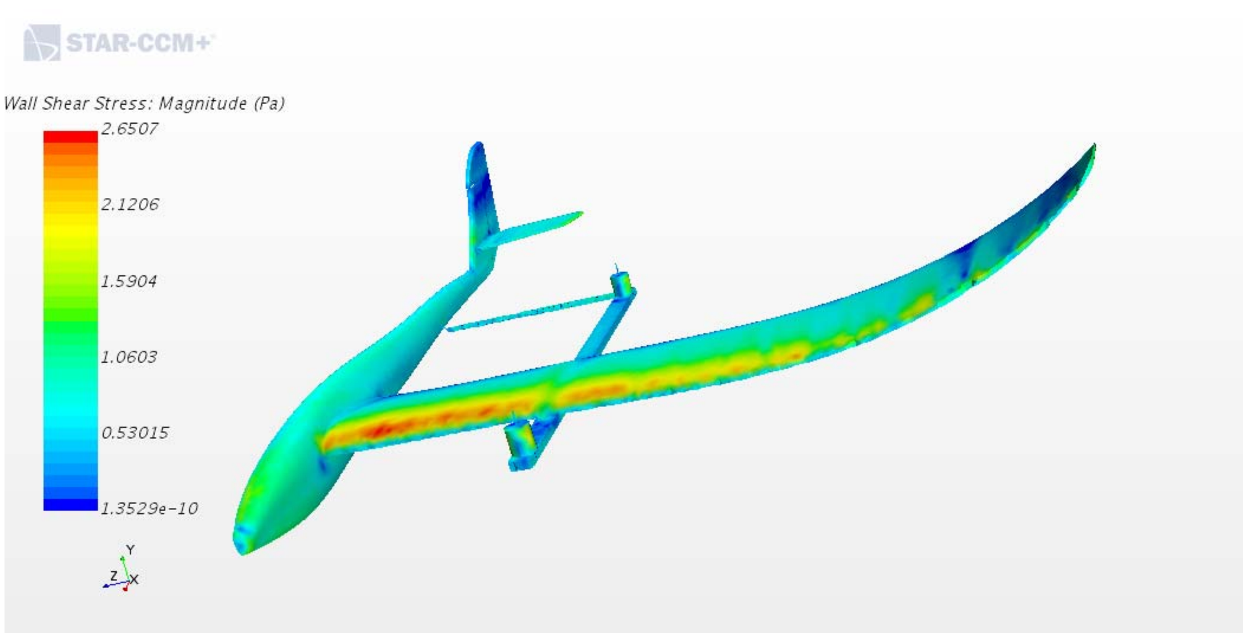


Figure H.6: The shear stress distribution from the half model simulation

Appendix I: Detail and Assembly Drawings

Number	Subsystem	Component Description	Part #	Number of Items
1	Airframe	Fuselage and Wings	A001/002	1
2	Airframe	Back Support	A006	1
3	Propulsion System	Quadcopter Brushless Motors	P001	4
4	Airframe	Carbon Fiber Strut	A003	1
5	Airframe	Cap	A004	1
6	Propulsion System	Quadcopter Brushless Motors	P001	5
7	On-Board Avionics	Electronic Speed Controller	E004	5
8	On-Board Avionics	Battery	E008	1
9	On-Board Avionics	Flight Controller	E001	1
10	On-Board Avionics	Receiver	E002	1
11	On-Board Avionics	Groundstation Telemetry	E009	1
12	On-Board Avionics	Power Distribution Board	E007	1
13	On-Board Avionics	GPS Module	E010	1
14	On-Board Avionics	Gimbal	E014	1
15	On-Board Avionics	Power Module	E006	1

Figure I.1: The subsystem, component and corresponding number for the assembly drawings

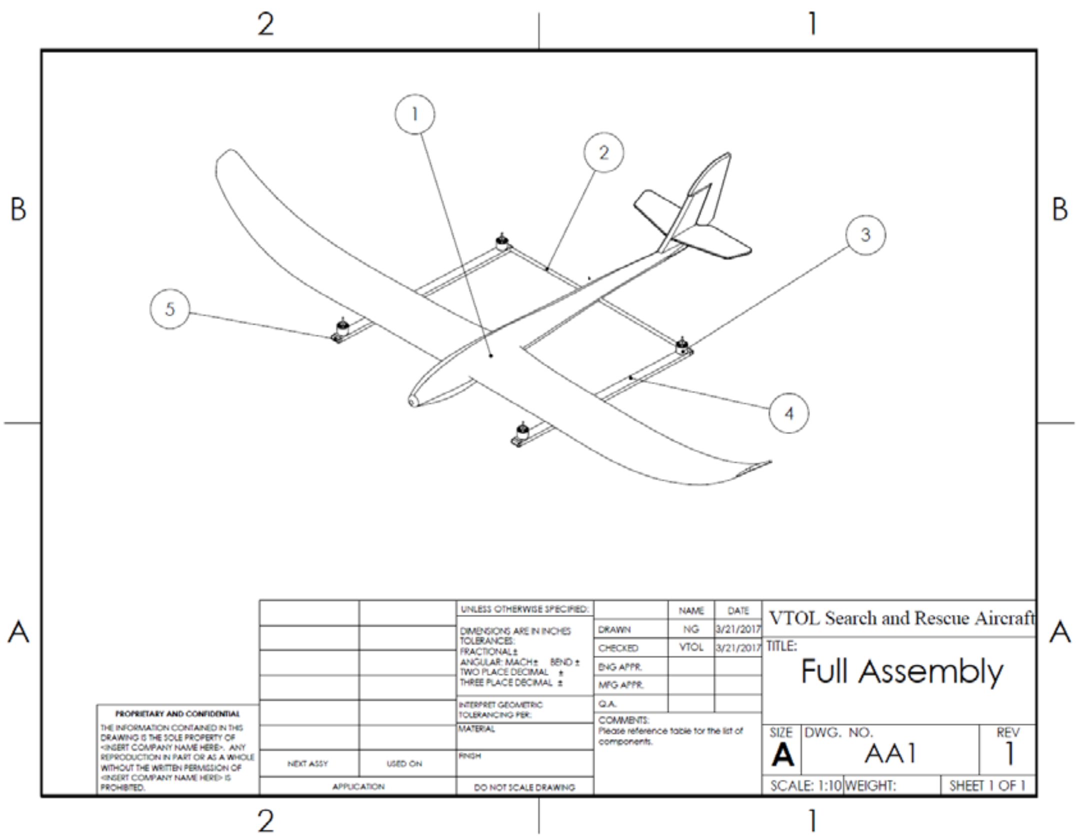


Figure I.2: The airframe subsystem with all major parts labeled

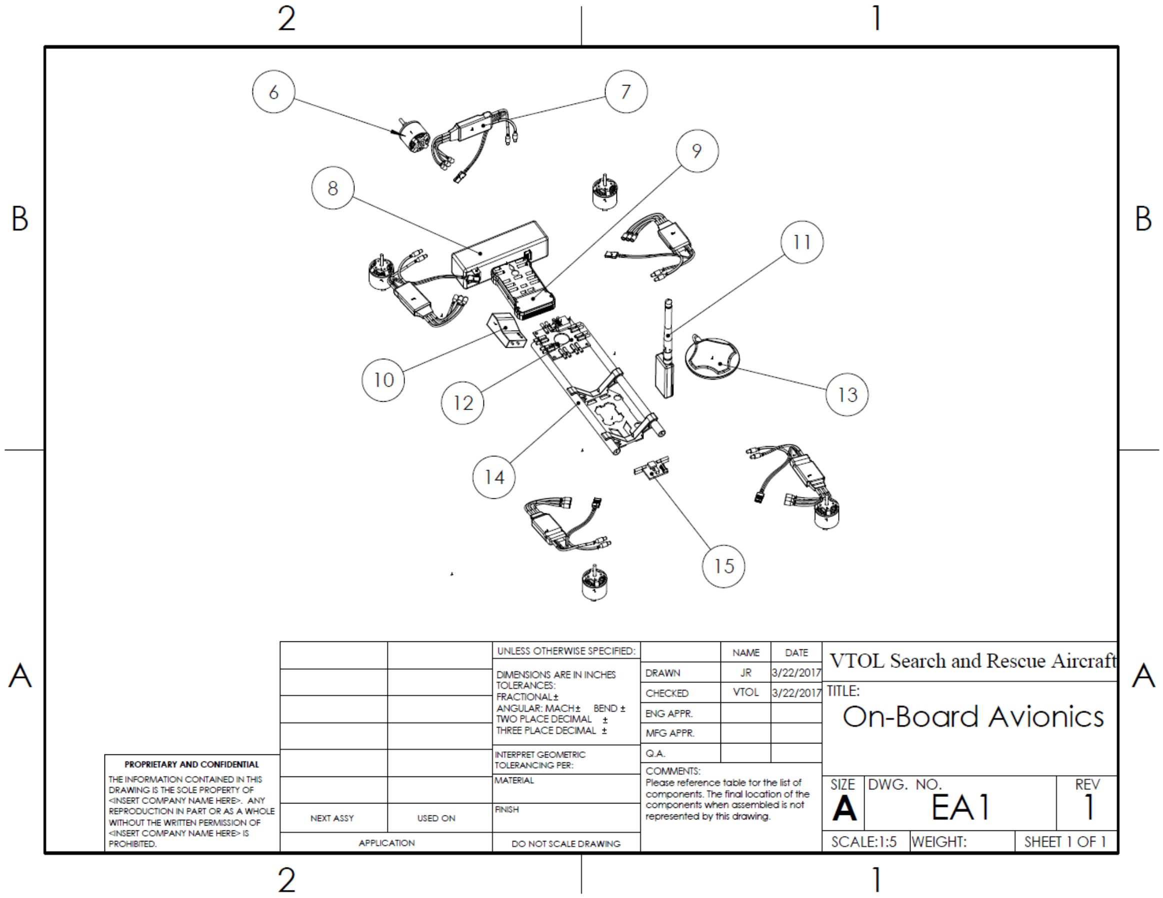


Figure I.3: The on-board avionics of the aircraft

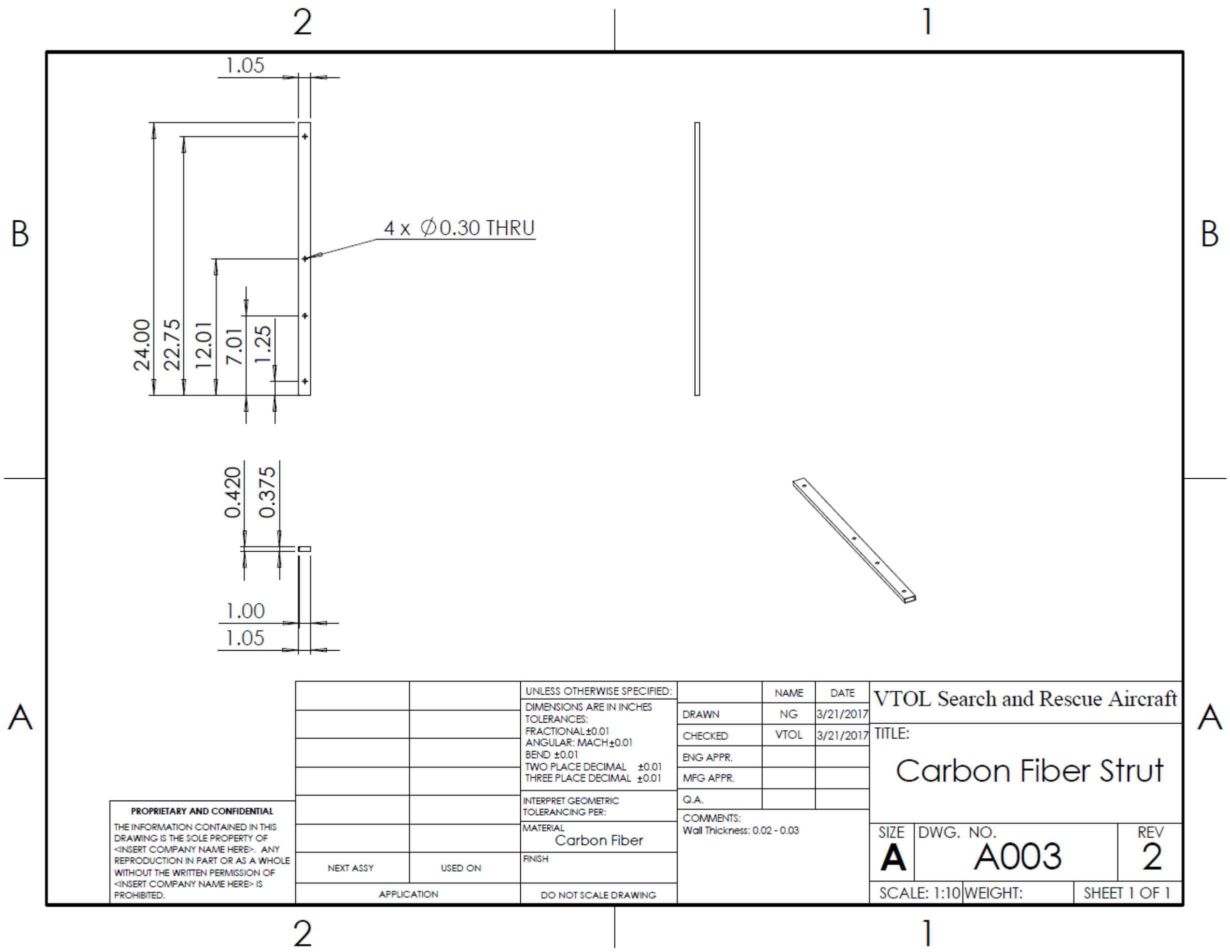


Figure I.4: The carbon fiber struts

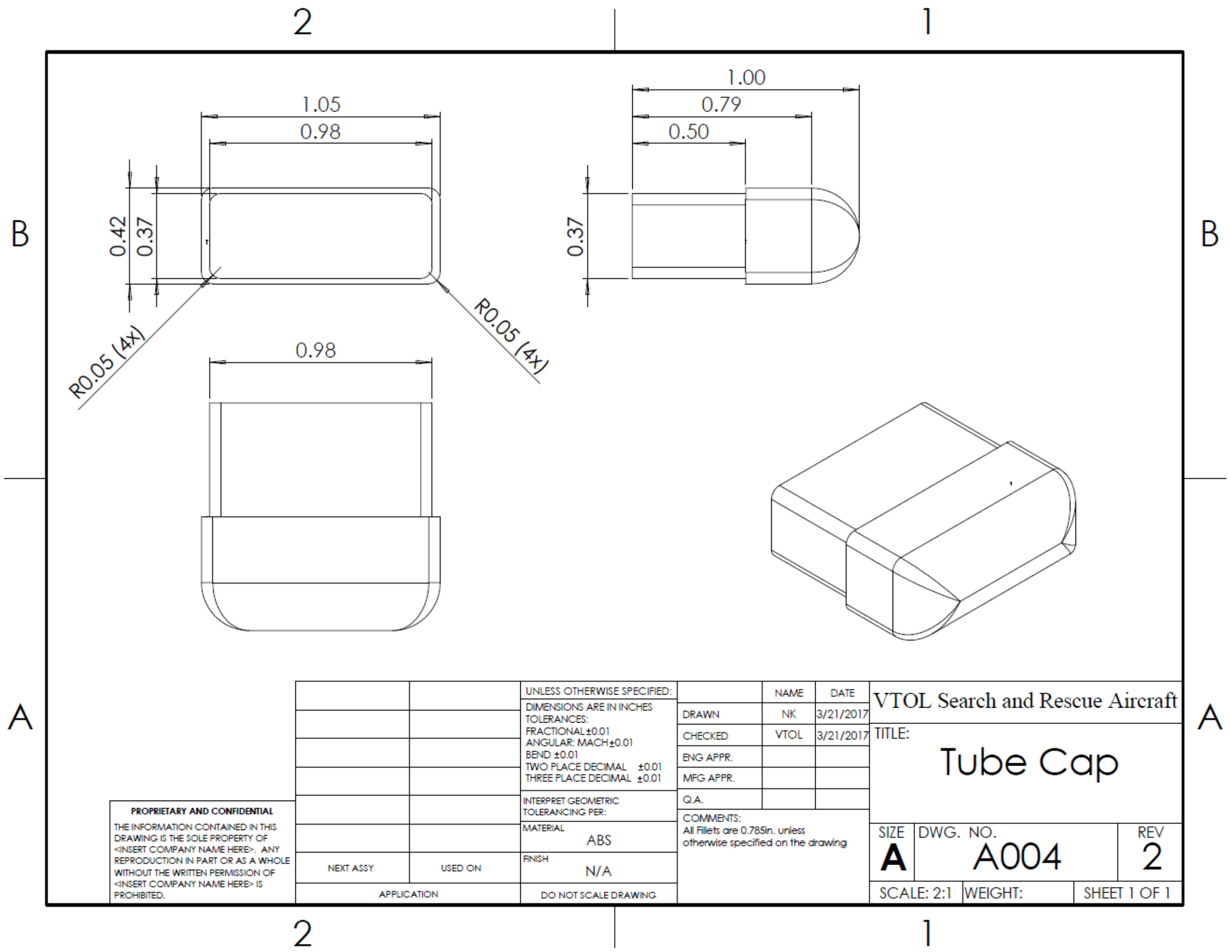


Figure I.5: The 3-D printed caps that were put in the ends of the carbon fiber struts

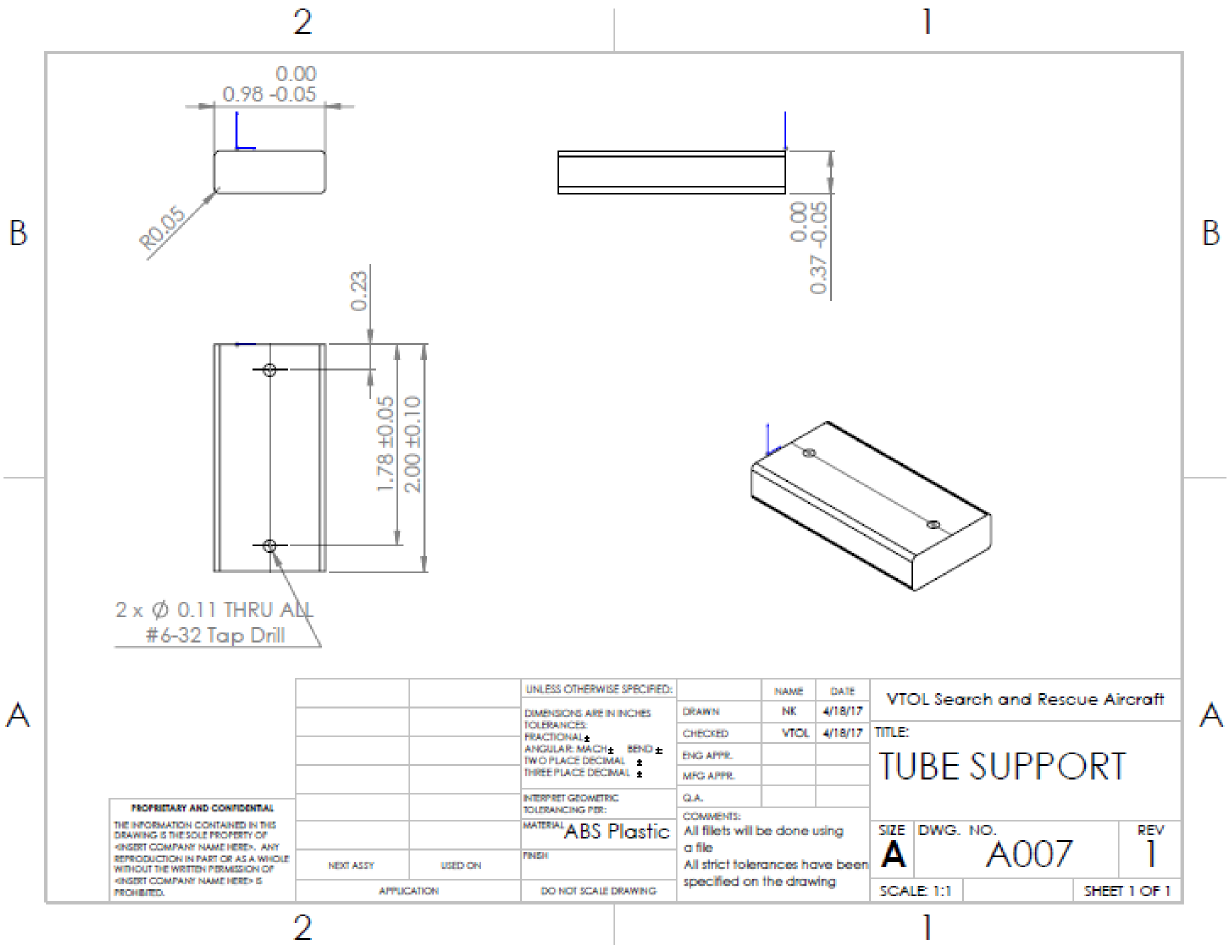
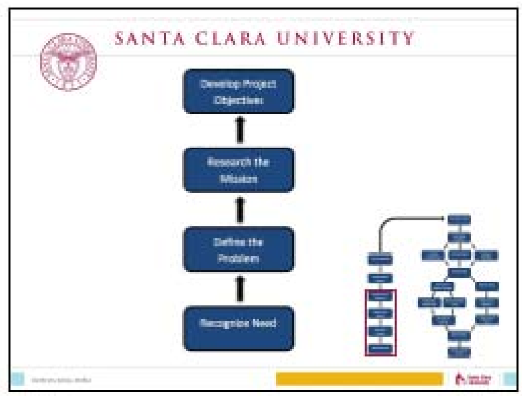
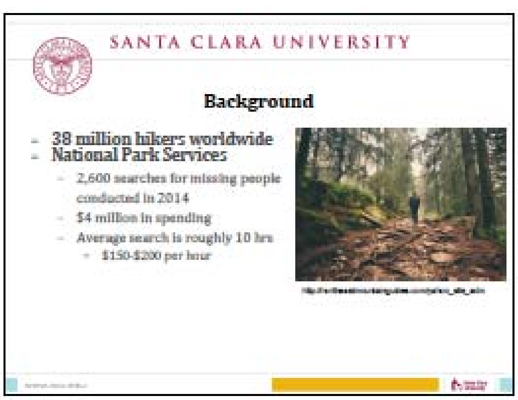


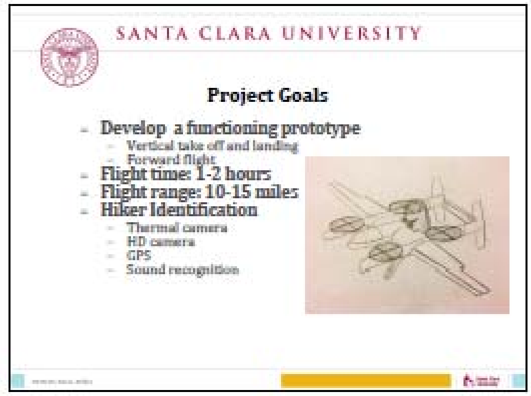
Figure I.6: The 3-D printed supports that were used to attach the motors to the carbon fiber struts

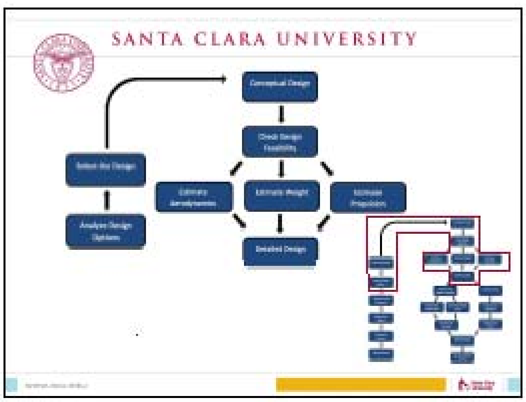
Appendix J: Final Presentation






SANTA CLARA UNIVERSITY
Current Solutions
Problems
Human risk
Functionality
Cost
Performance


SANTA CLARA UNIVERSITY
Project Goals
Develop a functioning prototype
Vertical take off and landing
Forward flight
Flight time: 1-2 hours
Flight range: 10-15 miles
Hiker Identification
Thermal camera
HD camera
GPS
Sound recognition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Proposed Design Solution


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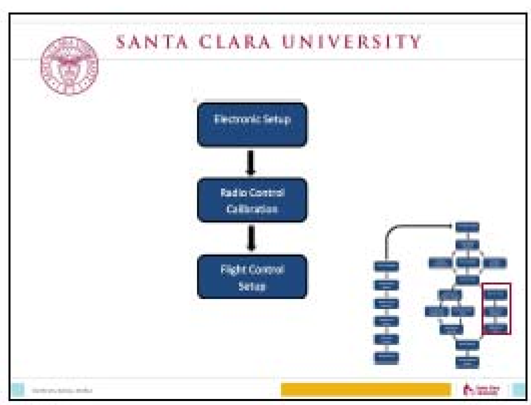
Final Design


SANTA CLARA UNIVERSITY
Electronic Setup
Radio Control Calibration
Flight Control Setup

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Electronic Setup

- Angelfire motors
- Turnigy ESC's, & battery
- Taranis radio controller
- Pixhawk

	Tested with Angel 20A ESC				
Prop	Volts (V)	Amps (A)	Watts (W)	Thrust (g)	Efficiency (g/W)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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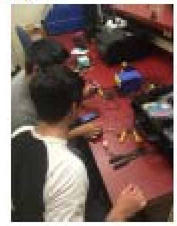
Pixhawk Flight Controller



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Ground Control Application

- Mission Planner software
  - Firmware upload
  - Flight control readings
    - Altitude
    - Orientation
  - Accelerometer, radio, & flight calibration
  - PID tuning

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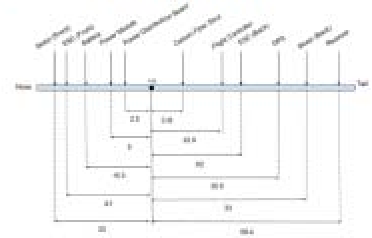
Mass Distribution



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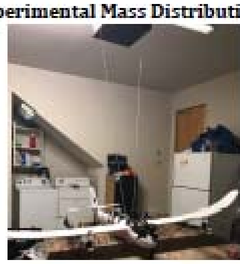
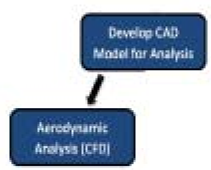
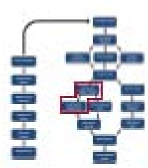
Experimental Mass Distribution

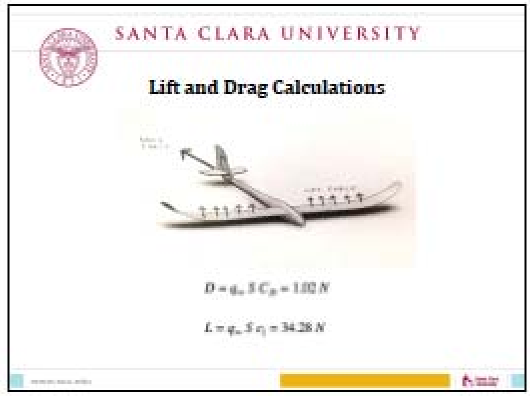


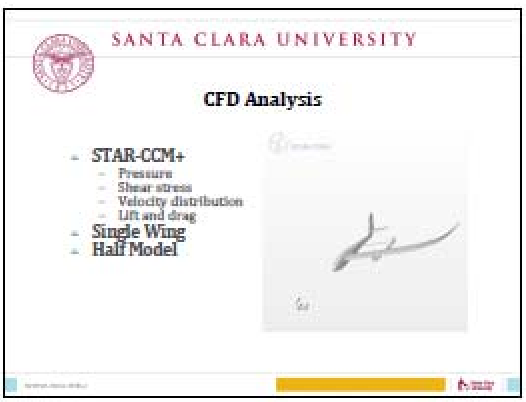
SANTA CLARA UNIVERSITY



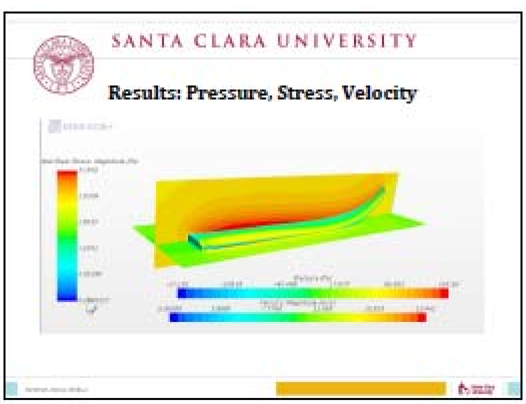


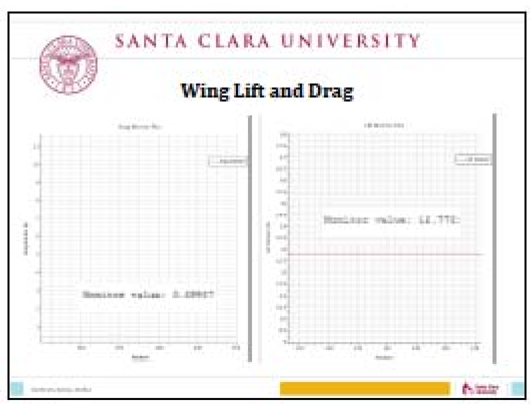

SANTA CLARA UNIVERSITY
Analysis
Hand Calculations
CFD analysis
STAR-CCM+
FEA
ABAQUS
ANSYS Mechanical
Experimental Testing Verification
STAR-CCM+
ANSYS
ABAQUS


SANTA CLARA UNIVERSITY
Lift and Drag Calculations
$D = q_\infty S C_D = 1.02\ N$
$L = q_\infty S c_l = 34.28\ N$


SANTA CLARA UNIVERSITY
CFD Analysis
STAR-CCM+
Pressure
Shear stress
Velocity distribution
Lift and drag
Single Wing
Half Model


SANTA CLARA UNIVERSITY
Wing Meshing


SANTA CLARA UNIVERSITY
Results: Pressure, Stress, Velocity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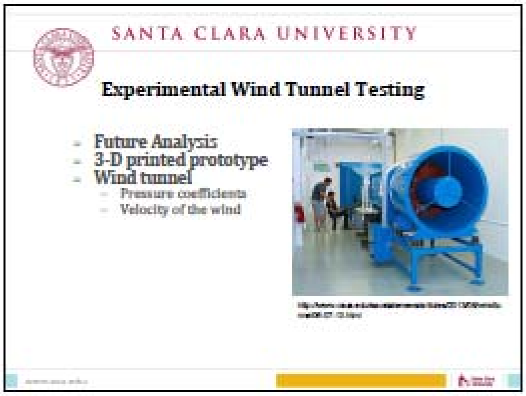
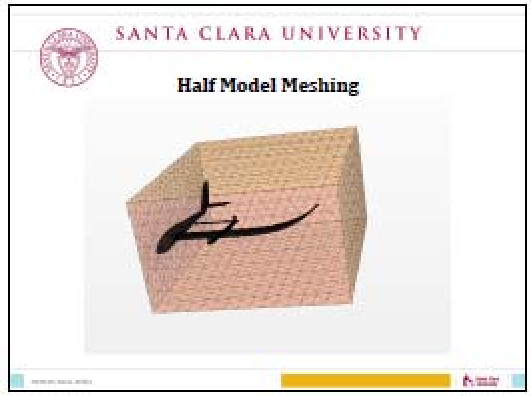
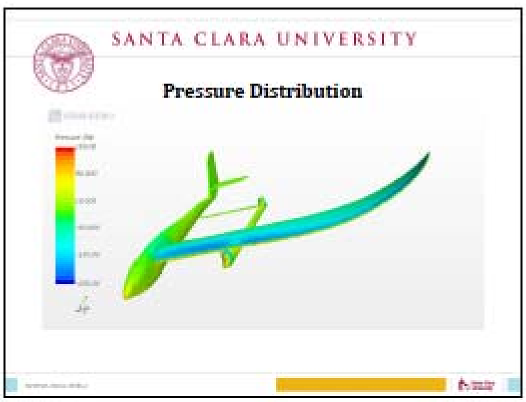
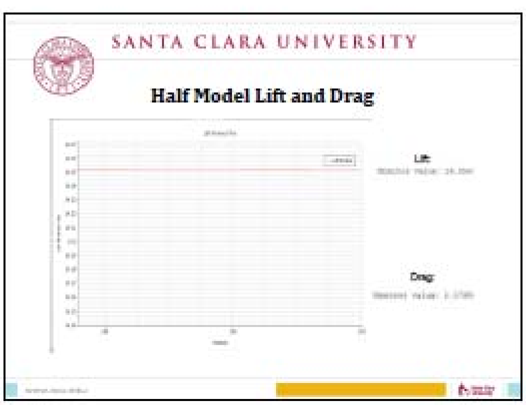
Wing Lift and Drag

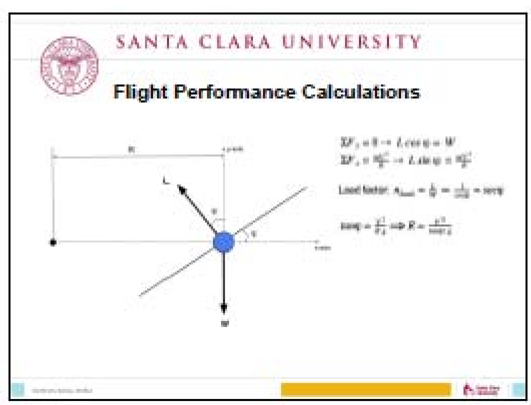

SANTA CLARA UNIVERSITY
Experimental Wind Tunnel Testing
- Future Analysis
- 3-D printed prototype
- Wind tunnel
- Pressure coefficients
- Velocity of the wind

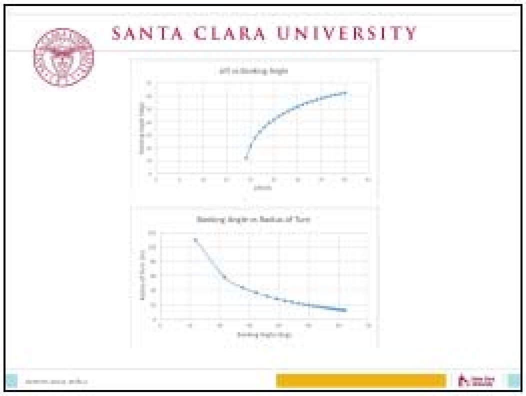

SANTA CLARA UNIVERSITY
Half Model Meshing


SANTA CLARA UNIVERSITY
Pressure Distribution


SANTA CLARA UNIVERSITY
Shear Stress Distribution


SANTA CLARA UNIVERSITY
Half Model Lift and Drag
Lift:
Drag:


SANTA CLARA UNIVERSITY
Flight Performance Calculations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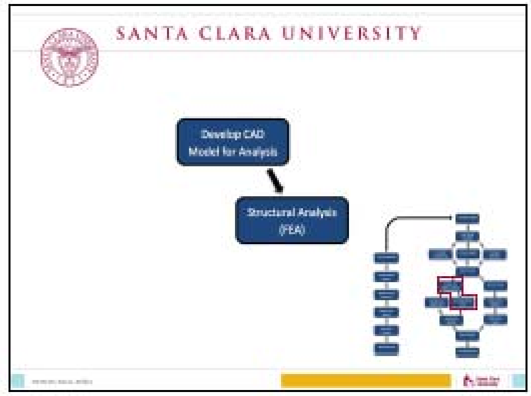
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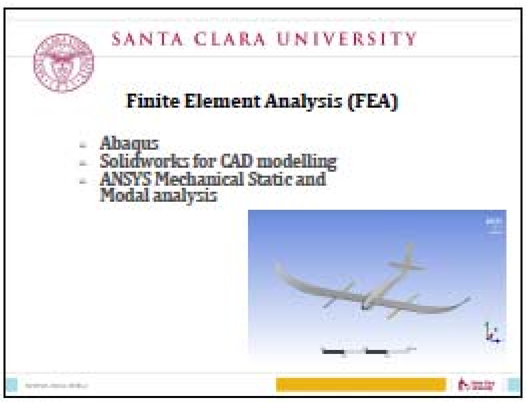
Develop CAD Model for Analysis
Structural Analysis (FEA)


SANTA CLARA UNIVERSITY
Finite Element Analysis (FEA)
Abaqus
Solidworks for CAD modelling
ANSYS Mechanical Static and Modal analysis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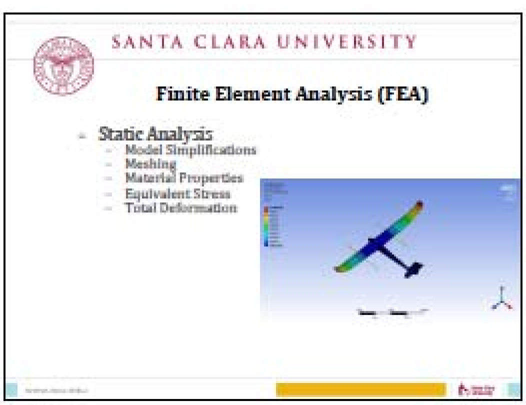
Single Wing Pressure Results


SANTA CLARA UNIVERSITY
Finite Element Analysis (FEA)
Static Analysis
Model Simplifications
Meshing
Material Properties
Equivalent Stress
Total Deformation


SANTA CLARA UNIVERSITY
Result
Total Deformation
Max = 1.47 cm
Equivalent Stress
Max on wing = 500 kPa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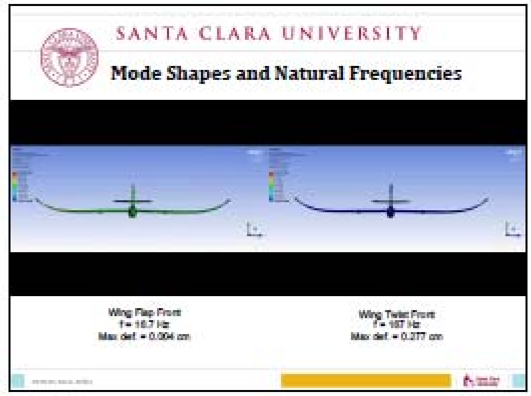
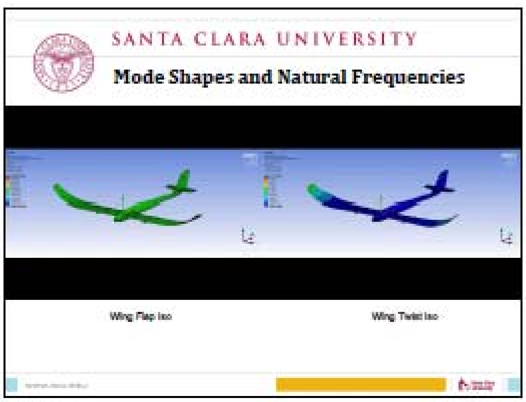
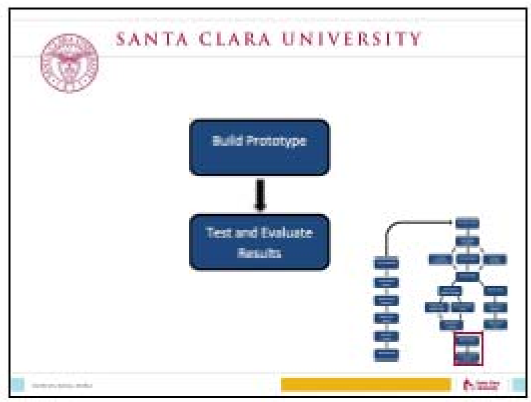
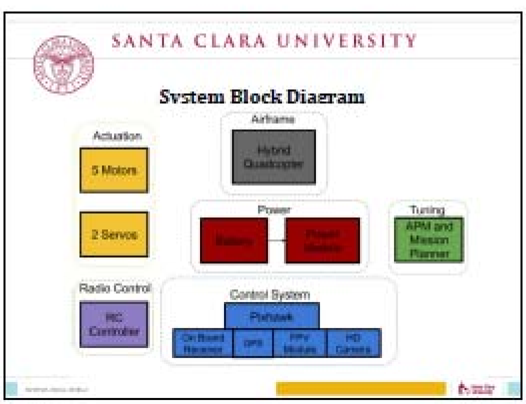
Vibrational Analysis
Modal Analysis
– Model Simplifications
– Meshing
– Material Properties
– Mode Shapes
– Natural Frequencies
– Deformations


SANTA CLARA UNIVERSITY
Mode Shapes and Natural Frequencies
Wing Flap Front
f= 16.7 Hz
Max def. = 0.004 cm
Wing Twist Front
f= 187 Hz
Max def. = 0.277 cm


SANTA CLARA UNIVERSITY
Mode Shapes and Natural Frequencies
Wing Flap Iso
Wing Twist Iso

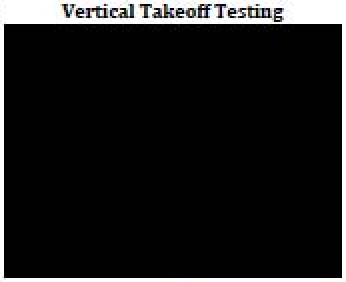

SANTA CLARA UNIVERSITY
Build Prototype
Test and Evaluate Results


SANTA CLARA UNIVERSITY
System Block Diagram
Airframe
Hybrid Quadcopter
Actuation
5 Motors
2 Servos
Power
Tuning
APM and Mission Planner
Radio Control
RC Controller
Control System
Pixhawk
On Board Receiver
GPS
FPV Module
HD Camera


SANTA CLARA UNIVERSITY
Prototype

SANTA CLARA UNIVERSITY

Vertical Takeoff Testing



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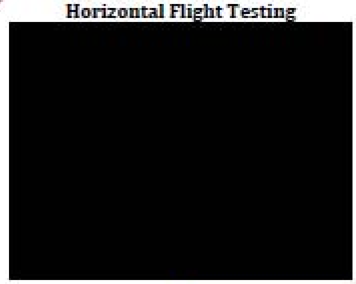
Horizontal Flight Testing



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Conclusions

- Project Goals
  - Design and create a fixed-wing UA prototype
  - Vertical takeoff and landing
  - Horizontal flight
  - Transition
  - Theoretically help SAR teams

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Next Steps

- Finish individual mode testing and tuning
- In-flight transitioning
- Produce a finalized model
- Add attachments
  - FPV HD camera
  - Thermal camera
  - Sound recognition

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Questions?

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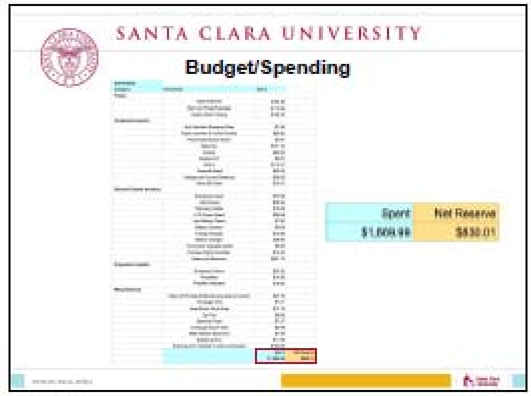
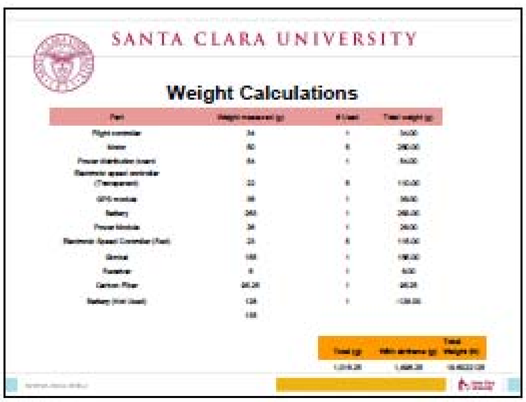
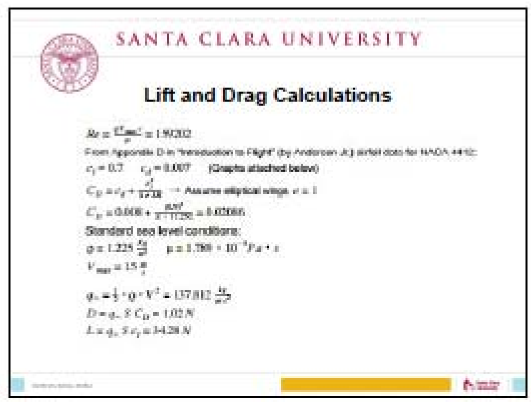
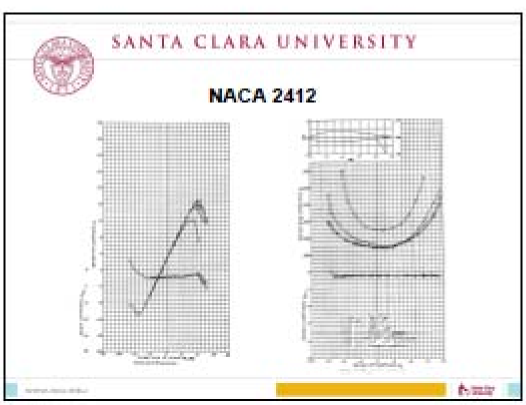
References

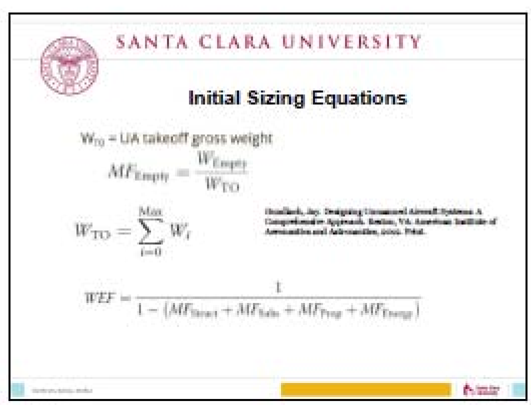

SANTA CLARA UNIVERSITY
Funding
Applied for School of Engineering funding
Received a grant for $500 per team member
Santa Clara University
School of Engineering

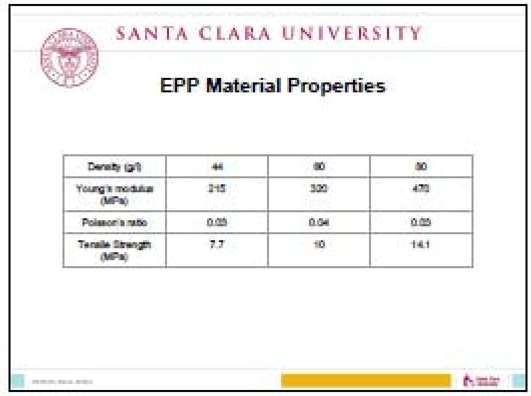

SANTA CLARA UNIVERSITY
Budget/Spending
Spent
Net Reserve
$1,869.99
$830.01


SANTA CLARA UNIVERSITY
Weight Calculations


SANTA CLARA UNIVERSITY
Lift and Drag Calculations
(Graphs attached below)
Standard sea level conditions:


SANTA CLARA UNIVERSITY
NACA 2412


SANTA CLARA UNIVERSITY
Initial Sizing Equations



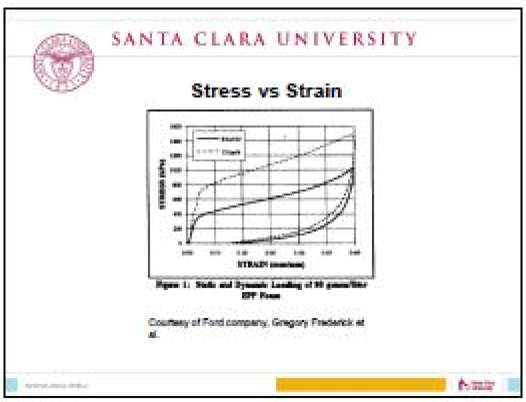


Figure J.1: Final presentation slides

Appendix K: Executive Summary from Final Presentation

VTOL SEARCH AND RESCUE AIRCRAFT

Executive Summary

Group: Nick Gagliardi, Nick Keyes, Joshua Ramayrat, Francesca Caruso, Kia Moazzami

Advisor: Dr. Mohammad Ayoubi

Issue: In the United States, roughly 44 million people hike each year. National park services conducts around 2,600 search and rescue missions each year, resulting in $4 million of spending. In addition, each mission takes an average of 10 hours, and it costs roughly $150-$200 per hour of search time.

Problem Statement	**Solution**
To cut down on the costs of these missions and to guarantee less exposure to the rescue team, there needs to be a vehicle that can help to find lost hikers more efficiently.	We designed and built a remote controlled, hybrid, search and rescue aircraft that will relay information back to the rescue team and keep them out of harm's way.

The main advantage of a VTOL aircraft over a drone is that the fixed-wing, horizontal flight increases battery life, and therefore can cover a wider range.

Due to the expansiveness of national parks, the aircraft needed to be able to cover a large area, but still be able to locate the lost hiker.

The hover functionality of the aircraft will allow the thermal camera and HD camera to thoroughly search the area. The aircraft was designed to have a range of 15 miles and a battery life of 1 hour.

This hybrid search and rescue vehicle will be remote controlled with two systems of propulsion - one for drone-hovering mode and another for horizontal, long distance flight. The transition between hover and horizontal flight mode is automated using one of the toggles of our controller.

In order for the software to communicate with the aircraft, Mission Planner, a GUI developed by Ardupilot, was used. This software incorporates the hybrid transition. Currently, the aircraft has been tuned for vertical takeoff, and the other modes are under development.

Figure K.1: The executive summary from the final presentation

Vita

The VTOL Search and Rescue team is comprised of Nicholas Keyes, Nick Gagliardi, Francesca Caruso, Joshua Ramayrat, and Kiavash Moazzami. As a group they have developed strong camaraderie and team working dynamics. They have been tested over the course of the year and proven themselves in the success of this project. The team has blended their individual skills and experiences into designing and building a quality finished product that met and exceeded their high standards and expectations.

Nicholas Keyes (Mechanical Engineer)

From Saratoga, CA.
I am very close with my family. In my free time I enjoy hiking, biking, and any outdoor activities. On top of this I love playing just about every sport especially basketball. After my undergraduate career I will be pursuing a Master's degree and will be working in robotics for Kindred Ai in San Francisco.

Nicholas Gagliardi (Mechanical Engineer)

From Fox Island, WA.
I spent two years on the baseball team at Santa Clara University. I enjoy playing sports, fishing, and any activities with my two brothers. After college, I will be working for ACCO Engineered Systems in San Leandro, CA.

Francesca Caruso (Mechanical Engineer, Aerospace Engineering Minor)

From Rome, Italy.
In my free time I like to read and go swimming. I currently work for ACCO Engineered Systems, an HVAC company in the bay area, and will continue with them after graduation.

Joshua Ramayrat (Mechanical Engineer)

From San Jose, CA.
A native from the Bay Area, I grew up with an affinity for physics, robotics, art, and riding/maintaining BMX bikes. It was only natural to specialize in a field that encompasses my interests and hobbies. I will be pursuing a career in mechatronics as my interests vary from mechanical to electrical and software engineering.

Kiavash Moazzami (Mechanical Engineer)

From Tehran, Iran.
I enjoy traveling, learning more about the world and its people, their cultures and languages. An avid fan of sports, namely Tennis and Soccer. I will be pursuing a career in structural design and analysis in aerospace industry.