Black Mamba

Submitted in Response to the Real World Design Challenge

Submitted By

First Class

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Submission Date: **4/5/2013**
Objective Function Value: **463,594.69** hour*dollar

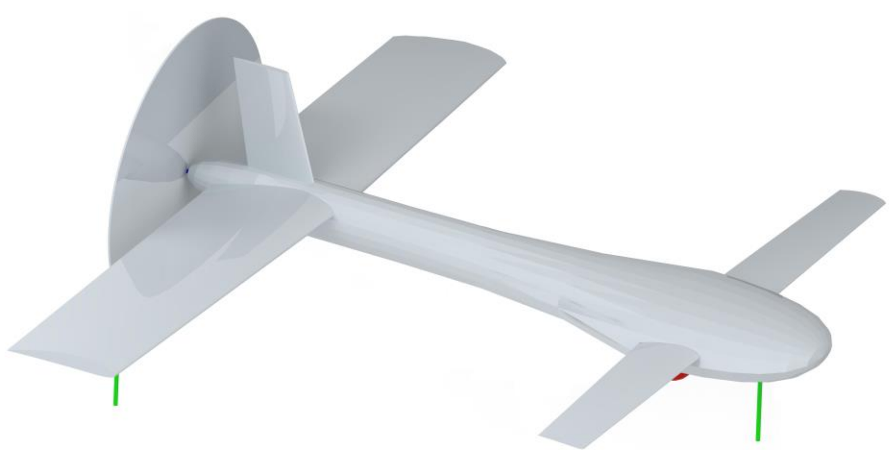

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Table of Contents

Abstract

The Federal Aviation Administration (FAA) indicates imminent growth in the industry of small Unmanned Aircraft Systems (sUAS) due to their wide assortment of government and civilian applications. In accordance to the aircraft constraints set forth in the National Real World Design Challenge, the team designed a system to locate a missing child with small Unmanned Aerial Vehicles (sUAVs), focusing on engineering, innovation, and scientific process. To strategically craft a design optimized for both time and cost, the team used a design strategy employing Conceptual, Preliminary, and Detailed Design processes.

The Conceptual Design Phase consisted of identifying and evaluating mission requirements, design variables, and commonly utilized sensor considerations to select sensor candidates that would move on to the next design phase. The team built the UAV around the sensors, which were selected based on the mission requirements. To efficiently examine all options and eliminate those that are impractical for real world application, the team followed a continuous process researching, critiquing, and collaborating with mentors until they obtained a subjectively refined selection. By doing so, the team developed four possible solution candidates: Option 1, one large plane with two X3000 sensors; Option 2, two smaller planes, each with two X2000 sensors; Option 3, another large plane, but with four X2000 sensors; and Option 4, four small planes, each with a single X2000 sensor.

In the Preliminary Design Phase, the team continued to explore and refine the sensors to obtain a singular selection of UAVs, personnel, and search patterns. Four different configurations, involving sensor payload options and number of aircraft, were tested and compared for speed of aircraft, total time required for mission, and cost of aircraft and sensor payloads. Furthermore, utilizing knowledge obtained through research and mentor suggestion, each possible combination was then holistically evaluated for its positive and negative factors. As it turned out through down-selection, one UAV with two X3000 sensors appeared to be the sensor configuration worth of final exploration. Based on said sensor configuration, the team assessed the effect of the different variables on the cost, search time, and the Objective Function.

The Detailed Design Phase involved optimization of the final design along with the aircraft that it would utilize in the proposed mission. Aspects of the design, such as the wing, tail, fuselage, as well as the aerodynamic properties and placement of each of these, were assessed and refined. The sensors and placements chosen in the previous design phases were placed onto the assembly of the aircraft in their respective positions, corresponding with the determined search pattern, speed, and altitude of the aircraft. In an innovative twist, the team integrated model calculus to calculate the gimbaling of the sensors. Upon re-examining the number of UAV's in our final sUAS, we found that adding a second UAV significantly reduced our Objective Function. Once these variables were optimized, the team had produced a complete sUAS that could be effectively utilized in the search mission.

Reaching a final optimized aircraft and search pattern configuration, the team focused on maximizing its real world applicability as modeled by the challenge scenario. Supported by the team's initial ($202,829.64) and amortized ($12,379.08) cost values produced in their cost analysis, the team sought ways to attract angel investors and obtain a contract from the Department of Homeland Security to manufacture the UAV system.

Projects in the real world stress feasibility, usability, and sustainability. The real world is not an engineering utopia, and thus there is no perfect design. However, the significance is placed on the iterative process used in designing the aircraft and in maximizing its capabilities in the given amount of time. Through a structured approach that integrated scientific process and project management, the First Class Real World Design Team developed a sUAS design that most effectively minimizes the Objective Function and maximizes real world application with the final Objective Function of: 463,594.69 hour*dollar.

1.0 Team Engagement

1.1 Team Formation and Project Operation

A successful Real World Design Challenge team is a conglomerate of synergistic students interested in the field of science, technology, engineering, mathematics, and business (STEMB). Background knowledge of aircraft, engineering, scientific writing, and marketing is vital to develop a presentable final product. Our team is composed of members who possess talents in various areas. Having participated in the challenge in previous years, we each took on individual roles, taking into account our skills, experiences, and interests. However, this is not to say that we were restricted to our roles. Together, we worked as a team to keep everyone up-to-date as we progressed through the challenge.

Figure 1 – Process of Establishing Team Roles

Each member of the team was chosen for the specific skills they brought to the table. Matt Gilmartin took charge in gathering potential candidates for the team and presenting everyone with an outlined approach for the challenge; given his previous experience in the challenge, the team unanimously nominated him as the project manager. Neel Desai, a former writer, engineer, and project manager, is an expert in marketing and communication and was the best person to push the team forward by serving as a bridge between the engineering and writing teams. Vishnu Premsankar has been an engineer for the past three challenges and has the most knowledge with the design workflow; he was chosen to lead the engineering team. Noah Bugbee committed to the team as an engineer due to his strong abilities in mathematics and familiarity with CAD software. Raihan Kabir has participated in the challenge as a project writer for the past two years and he led the writing team. Forrest Scharmer, having worked between the engineering and writing teams in previous years, he was chosen to be the project communicator to help craft a well-rounded report. Ronak Bhagat is proactive and a strong team player; having taken part in the challenge for the past two years as well as helping out in every aspect of the challenge, he filled the final position on the team by serving as an extra pair of hands. Even though the members were recruited for experience in their respective fields, everyone had been through the challenge and was ready to jump into any given task.

Matt Gilmartin	•Three Years in RWDC + Organization / Management Skills •Leading Design Process + Ensuring Proper Execution
Neel Desai	•Three Years in RWDC + Strong Communicator / Analyst •Bridging between Writers and Engineers + Market Assessment
Vishnu Premsankar	•Three Years in RWDC + Strong in Mathematics / Engineering •Providing Directions to Engineer + Reviewing Test Cases
Noah Bugbee	•Two Years in RWDC + Strong in Mathematics / Engineering •Engineering Design + Performing Calculations
Raihan Kabir	•Two Years in RWDC + Strong Writer •Writing + Planning / Condensing the Report
Forrest Scharmer	•Two Years in RWDC + Strong Communicator + Detailed •Writing the Report + Communicating with Mentors / Members
Ronak Bhagat	•Two Years in RWDC + Organized + Data Analyst •Working with everyone to Finish the Job

Figure 2 – Team Skillset and Responsibilities

Appropriate team roles were derived from the outlined skillset and responsibilities, and they were then assigned to each respective member. By doing so, everyone intuitively understood their place on the team, and thus everyone was in a position to assume and effectively complete tasks.

<u>Matt Gilmartin – Project Manager</u>

Matt Gilmartin was the initial driving force behind recruiting a winning team and leading a strategic design process, so he was chosen to be the project manager. He consistently and successfully managed the project plan, ensuring that all project team members had the necessary instructions to effectively execute project tasks. He monitored all interrelated sub-project activities and reported the status of the team and completion of the challenge through various organizational spreadsheets. By continually checking in with everyone and pushing through the project plan, Matt led the team through the path of success.

Neel Desai – Design Coordinator

Neel Desai attacked the challenge with a holistic perspective and because of his understanding of the engineering, documenting, and marketing perspectives, he was chosen to be the design coordinator. He served as the liaison between internal teams and as a right-hand man for each member of the team. He took the design data and integrated it into the overall business case. While doing so, he consulted various resources throughout the school and mentors to obtain key guidance, Neel maintained a fluid integrity of communication in the team.

Vishnu Premsankar – Test and Systems Engineer

Vishnu Premsankar has extensive background in the models and interfaces involved in product engineering and architecture, and in the past years of the challenge, he gained experience generating and reviewing test cases. For these reasons, he was chosen to be the systems and test engineer. Vishnu had to ensure a working product after the various parts were put together and assembled as a whole. He provided directions to the design engineer and reviewed the final product, documenting the steps taken throughout. By assisting the team with the incorporation of engineering advice from mentors, Vishnu lead the engineering team.

Noah Bugbee – Simulation Engineer

Noah Bugbee is proficient in 3D CAD, and he's a connoisseur of physics and calculus, so he was chosen to be the simulation engineer and mathematician. By designing the entire UAV he became an expert in authentic simulation and modeling tools, including but not limited to OpenVSP, CreoElements Pro, and Mathcad. His role was critical in analyzing design flaws and structural integrity of the system within the context of design software.

Raihan Kabir - Project Documentor

Raihan Kabir is a well-versed writer of all works, and having participated in previous challenges, he was chosen to be the project documenter and lead the writing team. He assigned roles for the writing process, and in collaboration with the project leader and design coordinator, he ensured that everyone on the team met their writing task goals. After synthesizing team writing assignments onto one working document, and guaranteeing that every member took part in the editing of the final document, Raihan maintained an organized approach to the design notebook.

Forrest Scharmer - Project Communicator

Forrest Scharmer is a hard worker and dedicated to following through with everything he starts, so he was chosen to be the project communicator. He helped the writers modify the plan based on the progress and results of the engineering team. He integrated the ideas, approaches, and applications from the design team into the report. He was responsible for contacting mentors and maintaining the team's collaboration with one another. Taking part in both the engineering and writing parts of the challenge, Forrest documented all communication with the team and the mentors to drive the team's progress in the challenge.

Ronak Bhagat – Project Scientist

Ronak Bhagat is an effective team player, and because of the thoroughness in his work and experience handling bits of every aspect of the challenge, he was chosen to be the project scientist. By obtaining a thorough understanding of the challenge, he documented the progress and results of the engineering team.

1.2 Acquiring and Engaging Mentors

Mentors have years of valuable professional experience and our interactions with them throughout the challenge helped us move along with our writing and engineering processes. They answered our questions to the extent of their knowledge, provided us with other resources to obtain necessary information, and gave feedback on each part of our report. The interactions with mentors made the entire process a thorough learning experience. To most effectively utilize every mentor, the team developed and followed a framework for mentor interaction.

We focused our collaboration on the email platform with a new team designated email that every member was able to access so everyone could have firsthand contact with the mentors. Communication was mostly made via email with a few teleconferences when we had urgent questions. Every member was encouraged to take initiative and ask questions when they needed assistance, which helped us work more independently while enhancing the overall effectiveness and progress of the team.

When choosing our mentors, we made sure that we ended up with a broad range of skillsets in order to get the most out of this challenge. We focused on getting help with search patterns, business plans, and sensor dynamics to compliment what we already knew and got a few mentors to supplement our skills in aerodynamics and UAV design to be sure we stayed on the right track. First contact with mentors was on October 26, 2012. We initially had many mentors but as we progressed with the challenge we found that some were more informative than others. About seven or eight of them stood out to us because they provided the most valuable advice. We focused our communication with them to get the most information as possible. To make sure that the information was not lost and to make comparisons between mentors' advice for our own judgments, we took notes of all the helpful information from the emails and teleconferences. With these notes we could make very educated steps forward with the challenge. When we reached the national challenge, to ease into using the mentors again, we re-assessed our needs and determined the mentors that would help us the most. We knew which mentors were the most helpful so we asked them if they would be willing to continue helping us through the national challenge. It wasn't a difficult transition because we kept in contact often. The biggest change was how they helped us. Because of the changes to the National Challenge, we needed to focus more on the process and refinement, in addition to becoming educated on the topics.

Mentors often changed our course during the challenge and helped us make great progress that could not have been accomplished without their help. During the beginning of the challenge, mentors mostly gave us starting questions regarding sensor selection, altitude and speed, number of aircraft, and more so we spent a lot of time on those to ensure that we had a knowledgeable base to start the challenge. The most significant question we needed to answer at the beginning was the number of aircraft. Our mentors helped us see the pros and cons of both options, one UAV or multiple. They made it very clear to us that we needed to think about how the number of UAVs would affect the search pattern, search time, and personnel cost. We brainstormed the trade-offs with all of these to come up with the best option. We decided to go with one UAV because there are lower personnel costs, lower initial costs, and simpler configurations.

At the beginning, we thought that the search pattern was an important thing to figure out in order to work backwards to determine the best sensor configuration. Once we realized that this was not possible, we eased off the importance of figuring it out until after we had a plane built. However, we did learn a lot about the relationships between the search pattern and the plane and sensors from our mentors and by simply brainstorming about it. Many of our mentors suggested the spiral search pattern because it covers the entire search area quickly with minimal overlap. Yet, surprisingly, with all of the search pattern advice from mentors, we ended up making our own decisions based on other variables that were affected. We went through an incredibly long process of determining the right search pattern using many sketches, intricate calculations, and interwoven concepts.

One of the biggest pieces of advice that transformed our challenge was the introduction of gimbaling, a specific method of transitioning from detection to identification, by one of our mentors. It was presented in the Detailed Background, but our mentor helped us see its potential. He told us what we needed to look for when doing the calculations, and we carried it through. The Footprint Excel Sheet is easy to use, but deceptively hard to understand. Hours were spent conceptualizing, calculating, and recalculating, mostly because we sought the very best. We looked for what shape would provide the biggest footprint—which we soon found to be not so intuitive. We simplified the sheet to the variables altitude, speed, and zoom to again, try and find the most optimal scenario. It was decided that altitude and speed were not to be compromised. Gimbaling allows us to zoom in and follow the child so the plane doesn't have to change altitude or speed. Without this mentor's initial introduction of this concept, and regular check-ins, we wouldn't have been able to develop the most effective search strategy for our sUAS.

The most innovative change we made after the state challenge was the addition of canards. With such a major addition, we had to be 100% sure that we were making the right decision, but our mentors gave us the confidence we needed to push the idea forward. All of our mentors said that canards would be beneficial to our UAV and with such a heavy aircraft, we needed the extra efficiency. One of our mentors actually suggested that we should focus on the UAV we already had in order to run many tests and make it the best possible solution. However, the benefits such as better efficiency outweighed the negatives like added weight. As an ambitious group of students, we embraced the change and set out to drive this futuristic concept of UAV design.

We needed guidance with many aspects of the mission planning and mentors did not disappoint when we were concerned about our bank angle. There were many turns in our search pattern so we needed to analyze every aspect of the turn to make sure that our UAV would be able to perform appropriately. One of our mentors gave us a lot of information pertaining to the bank angle, and other factors of an aircraft turn such as reduced vertical lift. A lot of the time, mentors didn't give us the information we wanted, but were able to make our own discoveries based on what they said. An example was when one mentor suggested we use a really high bank angle so that the almost sideways fuselage began to produce the lift to remain in level flight. We exercised this idea for a while, but after we realized it wasn't going to work for us, we found ways that the concept could actually help us. We discovered that a steep bank angle would require a big angle of attack so we pondered whether there was a limit. This helped us discover the concept of critical angle of attack which we realized was very important for the correct bank angle and to determine if our UAV could make the turns we made for it. After many hand-drawn, physics calculations, and some concept advice from mentors, we successfully incorporated critical angle of attack into our system.

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Figure 3 - List of Mentors. *denotes National mentor

1.3 State the Project Goal

The Real World Design team is on a mission to locate a missing immobilized child within a two-mile radius by designing optimized small Unmanned Aircraft Systems (sUAS). This specific class of vehicles is likely to experience civil and commercial growth for its various applications.

The design should satisfy the following variables to optimize the efficiency of the aircraft: wing and tail geometry (including area, aspect ratio, taper ratio, sweep, dihedral, twist, angle of attack, and airfoil selection); propulsion system selection; fuselage layout (including the location of sensor payloads, transmitters, fuel tank, battery, autopilot, and other electronics); sensor payload; telemetry selection; UAV search pattern; mission computer selection and other ground-based components. The final design concept should minimize operating time and cost while staying within the following constraints: a 55 lb. maximum gross takeoff weight; 18 in. separated antennae (to avoid destructive interference); 150 ft. – 1,000 ft. operating altitude range above ground level (AGL); and the ability to clear a 50 ft. obstacle within 300 linear ft. from the starting position.

The Objective Function combines the technical and business aspects of the challenge in its simple multiplication of time and cost. The team that most effectively derives and minimizes these values will produce the most successful design. A high lift to drag ratio improves the efficiency of the aircraft's wing which is a main aspect of the challenge. The propulsion system is another aspect that affects the efficiency of the aircraft. Teams have to choose between the two main categories of propulsion systems: electric and gas. The decision they will make is based on the cost of fuel or batteries, the power of each system, and whether or not refueling and recharging would be a problem. The fuselage design would have to take into consideration the sensor payload and the propulsion system to make sure that the shape and size fits these important components. These are the internal variables that must be considered, however, there are also external variables that will affect the efficiency of the search mission. The search pattern is one of these external variables that would affect both the efficiency and the cost of our Objective Function. An inefficient search pattern would diminish the positive impact of the efficient aircraft. Cost is also a dominant driver of the Objective Function score, which shall be deduced from the total operational and flight costs associated with the sUAS. All of these factors affect the time the aircraft takes to find the child and the cost of maintaining the aircraft, overall determining the quality of our Objective Function and the efficiency of our mission plan.

Challenge Statement	Objective Function
Design a sUAS, which includes one or more fixed-wing UAV	The successful team will minimize the Objective Function (Of): Of = T * C
Develop a business case for that system to be used in support of commercial applications based on the following mission scenario:	Where T is the total time required to find the missing child for the example mission
Search for a missing, injured and immobilized child at the Philmont Ranch in a designated 2-mile radius circular search area	Where C is the fully loaded cost of building the system and completing the above mission fifty times.

1.4 Tool Set-up / Learning / Validation

We ran into a variety of technical issues that were worked through by reviewing webinars, utilizing mentors, and conducting research. Each phase of the challenge required us to use different programs and brought about their own unique technical challenges. We used OpenVSP in the Conceptual Design of the challenge and for the creation of our model fuselage. It allowed us to quickly observe the geometry and later transfer to Creo Elements. This program was new to the engineers. Because in the past they had only used Creo Elements Pro for the design process, the learning curve involved in familiarizing themselves with OpenVSP was a challenge. The team visited the program website to clarify questions and learn more about using the software. From there, the engineers were able to successfully work with OpenVSP during the Preliminary Design Phase. Using this program, they were able to obtain the required information for weight estimates in the configurator spreadsheet which was used to determine the overall cost and weight of our system. It was also very helpful for creating and exporting a fuselage for the Detailed Design.

Another important tool used throughout the challenge was PTC's Mathcad. We did not face many issues surrounding this program due to proficiency with the wing-designing worksheets, which we used to create output points in Creo Elements Pro in the Detailed Design Phase. There were little to no problems when using the Wing Definition, Horizontal Tail Definition, and Vertical Tail Definition worksheets. The main challenge was ensuring the input of the right values from the excel spreadsheets into the Mathcad worksheets. Most Mathcad problems were resolved when we went back through all of the interconnected worksheets and made sure they were all filled out the right way.

Our use of Creo Elements Pro was perhaps the most important part of the design process. There was not a significant learning curve because both engineers were extremely experienced with using the software. A minor problem that occurred when building the wing was when we created a curve through the root and the tip points. This was resolved by going back into the wing definition sheet and making sure the correct cells were selected for the link to the airfoil spreadsheet. The most difficult part of using Creo in the Detailed Design process was placing the sensors. However, Noah, the team simulation engineer, worked diligently to maneuver the sensors around using offset data planes and adjusting the placement definitions until they fit flush with the fuselage surface. Creo Elements Pro was certainly the most useful and problem-free software in the entire challenge.

FloEFD was a new tool used for the National Challenge that was not used in the State Challenge. Early issues with this program occurred primarily due to not setting up the right kinds of tests. The webinar was very helpful in explaining the use of CFD models to test airfoils and angle of attack. From that point on, the use of FloEFD was fairly problem-free. The main problem was making sure that the tests didn't stop running and that the computers didn't shut down in the middle of testing. We found it very useful to use remote-access software to control the computers at the school that we were using for testing. Team members accessed our FloEFD tests from Vermont, India, Spain, and California. A large portion of the team was able to learn how to setup the tests we ran on our models, which made our testing phase of the challenge very efficient.

1.5 Impact on STEM

Though we had much experience with STEM topics entering the challenge, the very applicable business perspective added a real world dimension that each member had to keep in mind. For this reason, we felt the need to add a "B" to STEM, recreating the term as STEMB (the B is silent). We all strengthened our skills in mathematics, science, technology, engineering, and business. This challenge required us to utilize related rates from calculus, key concepts from physics, and new software in engineering. However, integral to the challenge was taking a real world perspective and factoring in the marketing aspect. Our knowledge of the engineering process increased throughout the course of the challenge, and members were aware of all of the different phases from research to design in terms of utilizing the final product in the real world. Just as scientists, mathematicians, and engineers given this task do not have time to test the possibilities of every variable, we followed similar processes and gained valuable insight doing so. Our ability to work together has improved tremendously knowing the importance of communication, and the success of the team is attributed to its synergy, as no major problems go unsolved in a united team.

With most RWDC members of South Burlington High School graduating this year, we noticed a strong correlation between challenge participation and career interest. Noah was initially interested in following the traditional pre-medical undergraduate route to becoming a primary physician, but after diving into the challenge as the lead engineer this year, he realigned his sights on pursuing a biomedical engineering major. Neel was determined to go into the political realm, but after taking part in an increasingly marketability-focused challenge, he decided on including an economics major. Matt and Forrest, who were initially rather ambivalent about their future, became greatly invested in the challenge this year and ended up applying to major in aerospace engineering. For Vishnu, this challenge was another great reason to pursue his interest in the engineering field, and he ended up applying for an electrical and computer engineering major. And for juniors Ronak and Raihan, who thoroughly enjoyed taking part in the challenge, this opportunity gave them key STEMB-related and lifelong skills that they would bring into the medical field, or whatever they choose to pursue.

2.0 System Design

2.1 Conceptual, Preliminary, and Detailed Design

2.1.1 Conceptual Design

The Conceptual Design Phase involved identifying design variables and synthesizing a series of candidates to bring into the Preliminary Design Phase. We utilized a down-select process to take the multitude of possible solutions and condense them into a few viable options. This process allowed us to examine all options and quickly eliminate those that are unrealistic in real world conditions.

We established a list of features we needed to focus on after detailed research and mentor consultation. Our design had to minimize both time and cost to obtain an optimized Objective Function value, so we focused on minimizing weight and aircraft expenses. Many of the design variables (size, weight, power consumption, etc.) were found to be largely dependent on the sensor configuration, so we decided to build the plane around the sensors. For this reason, our next steps revolved around developing a series of viable sensor configurations.

We noticed several trends after completing initial research:

- A larger plane with more sensors would cost less than several smaller planes
    - This would compromise time taken to find the child

- A sUAS with more planes and smaller sensors would take less time to find the child
    - This has higher initial and personnel costs
- The breakeven point between these two factors, where the number of planes and the cost of sensors compensates for the additional mission time is integral in solving the challenge.

We continued in the Conceptual Design Phase by narrowing down our sensor options. The X5000 had a 30x zoom, which is quite significant for a maximum of 1000 ft. altitude; the X4000 has high roll and pitch limits, which seemed excessive for the speeds that we are flying at; and the X1000 didn't have sufficient capabilities. We needed a balance between features and cost—something that could get the job done yet be cost effective. After determining that a balance of cost and capabilities provides the most optimal design, a comparison of height and pixel calculations eliminated all but the X2000 and X3000 sensors. By our calculations, the maximum detection distance is far larger for the X2000 and X3000 sensors than the X4000. This means that it is harder, relatively speaking, to detect and confirm using the X4000 sensor. This was the final factor that led us to eliminate the X4000 from consideration.

After narrowing our sensor options, we formulated a series of plane-sensor configurations. We wanted to test the possibility for multiple aircraft and multiple sensors per plane. As a result, we ended up with the following solution candidates that we brought further: Option 1, one large plane with two X3000 sensors; Option 2, two smaller planes, each with two X2000 sensors; Option 3, another large plane, but with four X2000 sensors; and Option 4, four small planes, each with a single X2000 sensor. By examining the rough Objective Function values of each option, we down-selected to Option 3: one UAV with two X3000 sensors.

In the Conceptual Design, we also researched tail designs. We began by looking at the conventional T-tail design. This configuration is a very tried and true design, since it is very easy to build and test. In addition because its 90 degree control surfaces, the T-tail is very easy to control, and is usually very stable during flight. Easy construction, and stability come at a cost; T-tails are generally relatively heavy, as they require sizable surface area. Another design we examined was the V-tail. These tails have less surface area, and thus are lighter. However, because the stabilizers are skewed off of the vertical axis, they make the plane significantly harder to control. We were initially drawn to this design because of its modified usage on the MQ-9 Reaper. Our analysis of the challenge led us to the conclusion that neither option would significantly affect our Objective Function so both continued onto the Preliminary Design to be narrowed down solely based on aerodynamic testing.

In addition to the standard T-tail and V-tail designs, we also came across a canard-based design, which initially proved to be a very promising concept. Because the center of gravity is in front of the wings, closer to the nose, a traditional tail generally provides negative lift in order to balance out the torque coming from the wings that is caused by the pitching moment, which would cause the plane to turn downward towards the ground. In a canard design, there is vertical stabilizer, but there is a smaller set of wings, called canards, placed near the front of the aircraft. Unlike a traditional tail, canards provide positive lift, while still balancing out the plane due to their position in front of the center of gravity. By providing positive lift, they create significantly less drag, which would increase the overall efficiency of our aircraft.

Another important consideration was our fuselage geometry. The combination of intuition and mentor input led us to two fuselage candidates. One would be a typical fuselage, essentially a long cylinder, except with a widened forward section, to account for the large X3000 sensors. By tapering the aft section of the aircraft we greatly reduced the weight of our aircraft, though we would lose some structural stability, but not enough to cause massive structural failure.

Our second design was a bit more complex. The idea would be to take a symmetrical airfoil and spin it around the x-axis. This would yield a shape resembling a falling water droplet. We were drawn to this idea due to its sleek and innovative design. We also considered widening the fuselage to increase space for the X3000 sensors. In addition to creating more internal space, it would also theoretically allow us to generate additional lift at certain angles of attack. We scrapped this idea moving into the Preliminary Design because additional lift generated by the fuselage would also increase the drag on the aircraft. More importantly, this design is large and very heavy. Because the first design was smaller, yet still had the structural and spatial capacity to support our system, it was the design we ultimately brought to the Preliminary Design.

After narrowing our aircraft's design, we examined our search maneuvers. We found five initial search patterns: the Ring of Theodorus, the United States Coast Guard's Spectre pattern, a sweeping pattern, a large spiral, and a tri-spiral. We eliminated the Ring of Theodorus, due to the limitations of the mission planning software provided. We then eliminated the Spectre pattern due to a great deal of overlap as it assumes that you have a greater idea of the target's location, one smaller than the challenge's two mile radius. This left us with the lawn mower and spiral patterns.

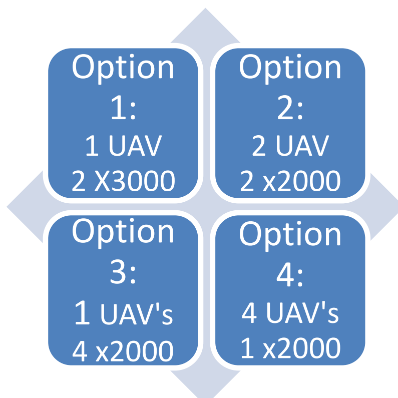
We were initially attracted to the tri-spiral due to the National Challenge's three zones. Because changing zones forces us to change our confirmation technique, and possibly speed or altitude, we devised this pattern so as to change zones as little as possible. The drawback, of the tri-spiral is that there is a great deal of overlap. This is largely due to the need to fly from the center of one zone to the center of another, over area that has already been searched. Additionally the large turns tend to cause gaps in our pattern, which would require us to create even more overlap. A single large spiral would be optimal, having minimal overlap, and simple to design, however it requires all variables, including footprint to be constant over the entire search area. Because of the addition of trees in the various zones, we must use different footprints for the each zone. Since we have differing footprints, each zone would require a different number of passes, which would create an odd and distorted spiral pattern. This odd pattern requires a series of sharp turns, each one of which requires a great deal of overlap to eliminate all gaps. Our third option would consist of three large sweeping lawnmower patterns, one in each zone. It would allow us to cover each zone individually with minimal overlap. However it also relies on complete 180 degree turns that stress the capabilities of our design. It was these three possibilities that we later brought into our Preliminary Design.

Another possibility we explored during the Conceptual Design was the possibility of an almost 90 degree bank. Any intro to physics class would tell you that this feat is impossible, as the lift created by the wings would be perpendicular to the force of gravity, meaning the weight would not be supported, and the plane would fall out of the sky. However, one of our mentors suggested a way that we could make it work and after extensive research, we decide to look into this idea. As the plane banks into the turn, we would turn the rudder causing the aircraft to gain angle of attack. By doing this we would create differing airflow on the top and bottom of the aircraft, which by Bernoulli's principle, would create lift. Ideally, the fuselage would provide us enough lift to make up for the fact that the wings are not providing any lift. This would allow us to minimize our turning radius. After examining the requirements of our search pattern and confirmation maneuvers, we decided that we would not need an extremely tight turning radius. We then abandoned this idea to examine other possible innovations.

2.1.2 Preliminary Design

The Preliminary Design phase consists of cutting down the multitude of brainstormed UAV options into one final scenario which will be used to proceed into the Detailed Design. Just as in the real world, it would not be feasible cost-wise and time-wise to extensively test each design. In a hypothetical engineering utopia, one would test all possibilities of each variable, but this was simply not an option. Therefore, rough estimates of the Objective Function value were derived from each option to objectively down select our options.

Consequently, our engineers prepared to calculate rough time and cost estimates for each option. It was critical we did not set any of our variables in stone as the Detailed Design, later in our engineering process, would serve to maximize efficiency for that given UAV option. For the sake of comparison, we kept variables either constant or generic, derived from mentor suggestion and or commercial UAV values. Following the Conceptual Design, our team generated the following options:



The Preliminary Design gave us the perfect opportunity to take advantage of the new software: OpenVSP. We would be able to “sketch” our designs quickly, and generate rough weight estimates, which would in turn yield us cost estimates. To familiarize ourselves with OpenVSP, our engineers used the tutorials on the OpenVSP website. This provided us with additional assistance, as OpenVSP was new to each member of the team.

Going into analyzing each option, we all had strong feelings, either positive or negative about them. There were many things to consider, and we were each asking ourselves several fundamental questions that would dictate where our design would go next. We didn’t want to compromise on sensor quality, yet the added weight could slow us down. However, we then had to examine whether or not it was worth yielding a better time if it meant sacrificing cost efficiency. This vicious cycle of questions going into the Preliminary Design left the team a bit unsure, but we trusted the numbers, and hoped to eventually get an Objective Function value estimate. Most numbers needed to calculate the Objective Function value are very roughly estimated. We weren’t concerned with a completely accurate value but more with figuring out which option was the best. Although we believe we estimated correctly, we may have been wrong. Either way, these were the results we used to determine the best option and move on to the refinement process in the Detailed Design Phase. We didn't spend too much time getting the most accurate values because it would've been illogical to follow each option to its end, and then decide the best one. We needed to narrow down our options so that we could focus most of our time on refining it. Once we refined the one option, we could use the accurate values to get very good estimates of our other options and then we could decide whether to move to a different option based on the Objective Function. If we do switch, most of the plane and search pattern would already be refined so there wouldn't be very many changes.

The following are pros and cons we ultimately decided for each option. Additionally, we compared each sketch and sensor footprint to gauge which option we may want to proceed with. Furthermore, we ran cost calculations through the configurator to determine payroll costs for each UAV option scenario if carried through.

Option 1

Pros	Cons
Inexpensive	Middle OF
High quality sensors	Heavy aircraft (~27.1 lbs.)
Easy confirmation and identification	Expensive sensors
Large footprint	Only one UAV
Less people required	
Good zoom	

The configuration of Option 1 is one UAV with two X3000 sensors

<u>Estimated Mission Values for State Challenge</u>

Time for One Mission: 0.345 hours

Estimated mission times were calculated by first finding the area of a footprint during cruise and calculating how long it takes for the UAV to travel through the footprint in the forward direction. This was used to obtain area covered per second. Dividing the total area of the search by the rate of change of area covered gives a rough estimation of how long the search will take.

Extra Time: 2 * 3.5 + 2 * 0.5 hours = 8 hours

Extra time is given by the challenge background document. 3.5 hours are required for travel each way and 0.5 hours is required for setup and tear down.

Time per Mission: 8.345 hours

Personnel Cost: $625/hr

This value was found by utilizing the values given for each job and each mission's required number of jobs found in the main excel sheet and the background to determine the overall cost of the personnel.

Personnel Cost for One Mission: $4278.13

Mission time multiplied by the personnel cost.

Personnel Cost for Fifty Missions: $213,906.50

The aforementioned value multiplied by fifty.

Initial Cost: $119,503.63

TOTAL COST: $333,410.13

<u>Estimated</u> Objective Function Value: 2,280,190.63

This value was obtained by multiplying the cost of our mission and the time our UAV takes to complete it. Time is the amount of time spent in the air (.345 hours) and cost is the cost of building the UAV and completing the mission 50 times.

One of the many factors that we worked with during the State Challenge was altitude. We wanted to go high enough to maximize our footprint, but low enough to be able to detect. As depicted by the camera footprint image above, we found a "sweet spot" at 350 feet—this value as well as the above Objective Function estimate was reexamined in the National Challenge. While altitude was later changed, the value of 350 ft still allowed us to get a relatively accurate estimate, so as to narrow our solution candidates.

Our team also liked Option 1 due to its low personnel costs. The Objective Function requires us to simulate cost for 50 total missions. However, the UAVs only need to be purchased once, which resulted in lower personnel costs over the course of 50 missions. In spite of having a high initial cost, this was better in the long run. This can be compared to the everyday scenario of buying a hybrid car. While they are a greater initial cost, if used for x number of years, you will ultimately save on gas. Finding this balance was critical among all elements of our UAV option.

The estimated Objective Function value for this option would ultimately come out to be the lowest among all three options – more on selection below.

	Pros	Cons
Option 2	Second fastest search time	Weak X2000 sensors
	Light planes	Twice the initial costs
	Innovative 2 plane system	Higher personnel costs

The configuration for Option 2 is two UAVs with two X2000 sensors each

<u>Estimated Mission Values for State Challenge</u>

Flight Time: 0.247 hours

Extra Time: 2 * 3.5 + 2 * 0.5 hours = 8 hours

Total Time for One Mission: 8.247 hours

Personnel Cost: $725/hr

Personnel Cost for One Mission: $4891.58

Personnel Cost for Fifty Missions: $244,578.75

Initial Cost: $153,728.10

<u>Estimated</u> Objective Function Value: 2,687,376.32 hour*$

Having two UAV's was a very intriguing idea to our team, due to potentially having an innovative search pattern, and drastically reducing our search time. After discussing it with one of our mentors, we even considered having one go faster that could only detect, and a slower one that could do both. However, after considering the worst case scenario of running that UAV option, the numbers simply did not work in its favor.

The weaker X2000 sensors proposed a number of issues. These sensors, while cheaper individually, the total cost of four X2000 sensors in our configuration, was greater than that of two X3000 sensors. Another issue was the fact that the X2000 sensors only had two times zoom. This meant that we would have to fly lower because we could not zoom in enough to identify the object if we flew at 350 feet.

Lastly, the inclusion of two planes also created several issues that would later lead to its elimination from consideration. First and foremost, having multiple planes requires higher production costs and more personnel to run the system.

	Pros	Cons
Option 3	Large footprint	Weak X2000 sensors
	fastest detection time	Complicated identification
	innovative plane system	Irregular footprint

The system has one UAV with four X2000 sensors

<u>Estimated Mission Values for State Challenge</u>
Flight Time: 0.314 hours
Extra Time: 2 * 3.5 + 2 * 0.5 hours = 8 hours
Total Time for ONE Mission: 8.314 hours
Personnel Cost: $625/hr
Personnel Cost for One Mission: $4258.75
Personnel Cost for Fifty missions: $212,937.50
Initial Cost: $141,782.09
TOTAL COST: $354,719.59
<u>Estimated</u> Objective Function Value: 2,417,059.29

Option 3 originally was designed in hopes of reducing search time with the added number of sensors. However, it was astoundingly close to the search time of option 1. However, the added cost increased it’s OF value and was not worth it in the long run. Having four lesser powerful sensors, X2000, ultimately gave us a little faster time, but was much more expensive. This was hard to digest for some of our team members, as basic logic leads one to believe that if doubled, the less powerful sensors could significantly reduce search time. While it did not please the entirety of the team, we trust the numbers, and the principles underlying our design.

The issues we faced regarding sensors for Option 3 were mostly the same as in Option 2. The X2000 sensors in combination were very expensive, and they had minimal zoom. Additionally, the pitch, and roll required to create a footprint with little to no overlap using four sensors created very irregular footprint patterns. When combined with the low Objective Function values, and complexity of engineering required, we decided against option 3.

Option 4 was immediately elimniated due to the impracticality of having 4 UAVs. After making some initial cost calculations, we determined that the initial costs alone would be extremely hard to justify from a business perspective. We also found that the personel costs associated with operating four UAVs simultaneously, are incredibly high. Despite the time reduction associated with a large number of UAVs, our initial cost calculations were simply too high to even consider four UAVs as a viable option.

Option 1: 2,282,190.63 hour*$

TOTAL COST: $333,410.13

Total Time for ONE Mission: 6.845 hours

Option 2: 2,687,376.32 hour*$

TOTAL COST: $398,306.85

Total Time for ONE Mission: 6.747 hours

Option 3: 2,417,059.29 hour*$

TOTAL COST: $354,719.59

Total Time for ONE Mission: 6.814 hours

Option 1: Winner

After analyzing the Objective Function for each option, and weighing in the feasability of constructing each option, we decided to proceed with Option 1 into the Detailed Design Phase during the State Challenge. We then went on to re-vamp the entire plane, adjusting every variable to minimize search time and reduce cost as much as possible. We were confident that the one UAV two X3000 sensors would provide us with the needed camera footprint to detect and confirm, while still minimizing cost. As mentioned above, there was quite some internal deliberation among our team while constucting these sketches. We had to modify our project plan substantialy, and allow more time to ensure we proceeded with the “right option.” The idea that there is no “right answer,” and that each option could ultimately be made efficent was tough to swallow, but flexibility and teamwork prevailed. The Preliminary Design phase in total took about three times the amount of time originally allocated due to the varying viewpoints of the members on the team, however after researching cost analysis,and marketability, and with the backing of strong mentors, we were able to wittle our options down into one. Our engineers would now bring our design into Creo Elements Pro and finalize our design. From here, we would go on and optimize the wing placement, sensor placment, fusualge shape, and wing definition.

Taking these Objective Function estimates from our state design, we were confident in our design to take into the Detailed Design Phase. We then optimized and made the necessary modifications to improve upon it. The one UAV with the two X3000 sensors provided us with our best estimated Objective Function for the state design. While our State Challenge estimates may not be the most accurate, we believe our process was solid, and that our cost and marketability justifications still hold true. Because of this we retained our solution candidate from the State Challenge, bringing it to our National Challenge solution to be refined. Since our values were only estimates, we planned to reconsider our options after we got a final, accurate Objective Function in the Detailed Designed. We knew that we would have better estimates after we optimized our two UAV, two X3000 option.

In addition to finalizing our sensor selection, we decided to move forward with our design with canards instead of a conventional T-tail. Canards would provide the lift necessary to account for the forward pitching moment of the nose, creating a more balanced aircraft. We then moved our propeller to the back of the UAV to not disturb the airflow hitting the canards. We would need to run tests to see how the addition of canards would affect the airflow as a whole. We allotted time for the Detailed Design Phase to perfect the addition of canards. Lastly, we didn’t shut out the option of adding more UAV’s during the Detailed Design Phase. Our rough Objective Function estimates during the State Challenge illustrated that Option 1 was the best. It wouldn’t be until after knowing more variables and resulting in a more accurate Objective Function that we would be able to make the decision of adding more UAVs during the Detailed Design Phase.

2.1.3 Detailed Design

Most values in the Preliminary Design were estimated so that during the Detailed Design we had to go back to finalize them with optimized them. After thorough research and advice from mentors acquired in the Preliminary and Conceptual phases of the challenge, we were able to design a base aircraft configuration. In starting with airfoils, we found that the NACA 4412 and NACA 4415 airfoils were common airfoils utilized for the wings of UAVs. These airfoils are more cambered giving them a higher lift value, and they are slightly thicker making, them stall at higher angles-of-attack than many other airfoils. For canards, we used the same airfoil and then we used a number of equations to get the right size, position, and shape. From mentor advice and research we knew canards would be a good option to look into and our tests proved that they make our UAV more efficient than a traditional tail. With the addition of canards, we could remove the horizontal stabilizers but still have the vertical stabilizer.

A challenge we faced during this phase was understanding how the footprint relates to the detection and identification of the child. We misunderstood the meaning of the green detection circle in the Footprint Excel Sheet and thought that it confirmed if we were flying at the correct speed and altitude. We thought that the optimized altitude was found when the footprint fit perfectly into the detection circle. With our mentors' help we figured out that the green detection circle only tells us if we can see enough pixels at the altitude we entered. We then found out that our speed was too fast for the X3000 sensor at 350 feet—the altitude we had at the time. Our mentor reminded us that the forward length of our footprint needed to be longer than the distance required for identification. With this knowledge, we figured out that we could not arrange the variables at 350 feet to make our footprint distance longer than the distance required for identification, which is dependent on speed and altitude. Without the proper length, we had to find another way to identify the child because we still planned to stay at the same altitude for the entire search. Our mentors told us about a search strategy that involves gimbaling the sensors, which simply means moving the camera to follow the object after we detect it. With gimbaling, we can have a smaller footprint with a faster speed and still identify the object. We had to recalculate our speed and altitude to allow for the best possible scenario and still have detection and identification possible. We figured that the best altitude would be at the maximum 1000 feet because it is well within the capabilities of the UAV and it gives us the biggest detection footprint possible. Staying at a consistent altitude is beneficial because it allows us to optimize our wing efficiency and aircraft trim settings for that single altitude. We also wanted to fly at the fastest speed possible to give us the shortest search time so we chose 80 mph which is the FAA regulated maximum.

Continuing with the optimization of our footprint with two X3000 sensors, there were many things that we needed to edit with our new speed and altitude values. First, we had to use the footprint excel sheet to make sure that our optimal altitude and speed allow for detection and identification. We started with the Horizontal Field of View (HFOV) to ensure that the distance we can gimbal is longer than the distance required for identification. Then we got an estimated distance that the camera could cover within that circle using the top inside coordinate of the footprint. These distances were compared to distance required for identification, which is 587 feet for 80 mph.

To find the rate that the camera was gimbaling we sought help from our school's math teachers. They helped us find the equation using related rates to find our angle's rate of change per second. Once we had the equation, we did the calculations but found that the number didn't seem correct. This started hours of brainstorming as we tried to prove why our methodology was correct. Our coach helped us conceptualize gimbaling by showing us a gimbal and how it can be pointed in any location. We still did not understand the problem when we had to leave school so we went over to Neel's house to figure it out. Neel solicited assistance from a friend in Kentucky who specializes in calculus. With his help we found a different equation that made more sense because of a concept that we realized during our brainstorm session. We noticed that the camera needs to move slower when it is at a greater pitch and faster when it is pointing directly under the UAV. Just like when you are in a moving car, a tree up ahead seems to be moving slower than a tree that is directly next to your car. Our math teacher did not solve the equation using the right variables which led to an incorrect value. Our friend helped us find the right variables to use and we got an expression that accounts for the change in speed of the camera as it is tilted. With derivatives and related rates we found the expression for the change in degrees per second to be (speed)/(1000+((x)^2)/1000)). Speed needed to be in feet per second because our distances are measured in feet. 80 mph is 117.33 feet/second. The variable x is the distance on the ground the sensor needs to travel, starting at the top of the footprint which is situated on an x-y coordinate plane. Plugging in the values we get:

$$\frac{d\theta}{dt} = \frac{117.33\ {}^{ft}/_{s}}{1000 + \frac{x^2}{1000}}$$

After all this work we noticed a flaw in our gimbaling procedure. The detection footprint expanded to the left and right 567 feet. The identification circle expanded to the left and right about 350 feet. So if the child was detected 567 feet to the left, we would not be able to identify because the identification circle only expands about 350 feet. Nonetheless, this only meant that we are at the incorrect HFOV for identification. A quick edit of the footprint excel sheet shows that a zoom of 5.695 degrees HFOV instead of 6.95 would allow us to identify 567 feet to the left and right, and anywhere in between. Because the footprint is smaller, this means that the gimbal rate would increase as it has to cover more distance than before. A quick calculation using our equation shows that the gimbal rate would still be much less than 200 degrees per second, the only challenge constraint we have for gimbaling. Our method of gimbaling remained unchanged in the National Challenge and the calculation process is the same, however the National Challenge conditions yielded slightly different numbers. The exact specifications are found in the System Detection and Identification section.

In the state challenge, we had a large spiral search pattern. This pattern allowed us to search the entire area with very little overlap which could give us a shorter flight distance and search time. Furthermore, the low search time decreased our Objective Function. The national challenge forced us to reconsider our search pattern options. Because of the new zones, the large spiral was not possible since the camera footprints needed to be different sizes. The next option we considered was a spiral within each zone. We tried to mix the benefits of a spiral with the zone constraints of the challenge but we found that it was incredibly difficult to program. Every turn we made required a complex calculation and we ended up with many triangles of area that are missed in the search pattern. We brainstormed for other patterns and decided on a sweeping pattern within each zone because it was the next best option that minimized overlap. The programming was much easier and calculating the variables of the turns was more straightforward. We had the layout of this pattern set up when we changed to two UAVs so it was easy to make the adjustment. The extra UAV reduced our search time significantly, from 82 minutes to 45 minutes. It isn’t directly half the search time for one UAV because it made sense to have one UAV search only Zone 3 since it took the longest, and the other to search both Zones 1 and 2. After selecting a general search pattern, we began the process of refining it. Our initial plot covered the area, but upon closer examination, we discovered a number of sizable gaps. We then went about searching for gaps, and closing them by making small adjustments to our waypoints. We looked in excruciating detail to find every tiny gap for fear that the child might be residing in the tiniest hole in our search pattern. Any chance that the child would go undetected was unacceptable. We increased our magnification to hundreds of times the standard, even going so far as to put our search pattern plot on a huge 70 inch screen to be certain no gap went unseen.

Another aspect of our search pattern that we needed to account for was stall speed. It needed to be low enough so that we wouldn't stall easily if we needed to make sharp turns. We didn't know how to calculate it so we researched how stall speed was affected by our plane. We learned that stall speed is actually caused by the critical angle of attack. There is a limit to how high the critical angle of attack can be because eventually the lift from the wing will start to decrease. The boundary layer of air on the wing starts to separate from the wing at high angles of attack making the airflow and lift unpredictable. We also found that the only way to get accurate data related to stall is to test the airfoil using simulation programs like FloEFD or Javafoil—there is no mathematical formula. Since we are using the Javafoil results, we have a well-defined graph which made it easy to see that the critical angle of attack is 13 degrees. We are only using Javafoil because our test results with the CFD models in FloEFD were not accurate. We got coefficients of lift more than 20% different from Javafoil meaning we couldn't use those test results. After we derived the critical angle of attack, we had to make sure that during turns, the UAV would not have to exceed 13 degrees angle of attack. The UAV has to increase the angle of attack to provide enough vertical lift to stay up. We found that we would only have to fly at 9 degrees angle of attack during a 45 degree bank turn which is the highest bank turn that was reasonable for our UAV based on mentor feedback.

In relation to the mission planning, we figured out that we could benefit from making a minor change in the Mission Planning sheet. We calculated that our UAV could make 45 degree turns because our wings generated enough vertical lift. Once we realized this, we wanted to take advantage of that by changing how the Mission Planning makes its calculations. It was initially made so that we could only turn with a maximum 30 degree bank angle, but we knew our plane could handle 45 degrees. When we turned with 45 degrees of bank, we needed about a 1.45 coefficient of lift which meant that the angle of attack of our wing needed to increase to 9 degrees. This was possible because our Javafoil graph of coefficient of lift versus angle of attack shows that our critical angle of attack is 13 degrees. Since we knew it was possible, we asked the creator of the Mission Planning sheet to change the code of the program. This change in code, Change:

```
wp%turn=max(turn,(MPH2FPS*wp%sv)**2/(G*tan(30d0/RD)))
```

To:

```
wp%turn=max(turn,(MPH2FPS*wp%sv)**2/(G*tan(45d0/RD)))
```

in the Fortran source code allowed us to make smaller turns and ultimately lower our search time. It was necessary because our search pattern is affected by our small footprint widths in Zones 2 and 3. If we couldn't make this change, we would've had to slow down for every turn.

The final step was to determine the Objective Function for one UAV. Once we got this value for our one UAV option, we then looked again at the possibility of adding more UAVs. We expected one UAV to still be the best because it had the least amount of hourly personnel cost but we were surprised to find that two UAVs had a lower Objective Function by about 85,000, which is very significant. It also had other benefits that made it a better option such as a significantly reduced search time and lower per-UAV personnel costs. We chose not to go with three or four UAVs because the initial and per-mission cost would be too high for our small startup business to gain any market share. The high initial costs and per-mission costs make getting initial investors and future consumers difficult. Further explanation about the business aspect of all our decisions is found in Section 4. We needed to find a balance between long-term cost and search time that allows our business to thrive.

At the end of this phase of the challenge, we had created an optimal aircraft, chose an efficient search pattern, and an appropriate sensor payload configuration. The geometry of the aircraft was created using airfoils and aerodynamic aspects that we optimized, the sensors and a gimbaling plan were put into place to ensure our aircraft's detection and identification abilities, and our search pattern was customized to ensure an efficient search time. Individual research and collaboration with mentors led us to this final design and plan for our mission concluding the Detailed Design of the challenge.

2.1.4 Lessons Learned

Early on in the challenge we realized the importance of mentor collaboration. Despite our combined experience with this challenge, the additions of telemetry, search patterns, and fuselage geometry were new aspects for all of us. We quickly found ourselves overwhelmed with the multitude of new considerations to take in, and we struggled to find a starting point. Luckily we had contacted several mentors and acquired their help. Their assistance guided us to use sensor selection as the focal point of our design. Mentors helped us break apart the many new aspects of the challenge so that we could then prioritize them, and find a suitable starting point. Without their assistance we would have stumbled early in the challenge, which would have left us less time to design and possibly decrease the quality of our final submission.

One of the hardest lessons for us to learn was the fact that there is no “right answer” to this challenge. We had been stuck for weeks trying to derive the best answer using the constraints and our own estimations, but we weren’t making any progress. We wanted to look ahead in the Workflow to figure out how the constraints would affect our sensor choices, but we soon realized that this method was not possible. Common sense would lead one to believe that if one answer is better than another, then there must be a best answer. After a great deal of frustration, and dozens of emails with mentors, we finally came to accept that there was no right answer. We realized that because of the huge scope of the challenge, all the issues can be approached from a myriad way, each with their own positives and negatives. Instead of focusing on making the “perfect design” we focused on making a design that had the best balance of factors to minimize the Objective Function while also being marketable. This also ties into a problem we had of trying to come up with as many options as possible and follow a good chunk of them to a refined product. It took us plenty of hours to realize that it was simply impossible to compare every variable in relation to every other variable to try and get the best product. For example, we initially wanted to conceptualize many different sensor configurations without much thought of how exactly they would help us. It was essential that we finally realized our mistake and took on a down-select process. It allowed us to focus on our determined necessities in relation to what we wanted for search time and cost.

Another important lesson we learned through working together on this challenge was the benefit of having a team of friends. This generated an atmosphere of open communication and one in which each team member was comfortable confronting one another. Confrontation inevitably leads to a higher degree of teamwork. Being able to be open, honest, and frank with one another inherently made the end goal more doable. Everyone was accountable for their responsibilities and we kept each other on track. We were comfortable making mistakes with our work. One example of this was when our team was divided on whether or not to proceed with our Javafoil data or CFD data when we were analyzing the aerodynamics of our wing. We realized that we needed to have each other’s back and remind one another to always stay motivated and hungry to reach that end goal of having the most optimized design.

One of the last and most important lessons we learned was how to resolve conflict. Our team was made up of seven individual people, all with their own ways of thinking. Because of this it was nearly inevitable that we would come into conflict at some point in the Challenge. In some respects this is a good thing as it means as a team we can look at a problem from more angles and ensure nothing is overlooked. These differing views can also create conflicts, which if left unresolved, can threaten to hinder our progress. Each team member was proactive in being aware of conflicts and found ways to effectively solve them through compassion and empathy.

2.1.5 Project Plan Updates and Modifications

Early on we decided that if we were to succeed we needed a project plan, with deadlines for each of the various design phases. As we progressed through the challenge we found it necessary to modify this plan for a multitude of reasons. The primary reason was due to delays from challenges or sections of the design process that took longer than we initially anticipated. For example, we initially allotted a week to the construction of our aircraft geometry in OpenVSP. Our engineers realized however that they were unfamiliar with this program, thus we would need to spend additional time for them to familiarize themselves with it. We then readjusted our deadlines so as to allow for time to learn OpenVSP, while ensuring we still had time to complete the entire challenge.

During the National section of the challenge this became very important. About two weeks into the challenge, the majority of our team members left the state on various trips because of the school vacation. This meant our team would be separated by thousands of miles. Traditionally we have found ourselves at a reduced working and engineering capacity, however, we anticipated this early on in the challenge and utilized Google Drive cloud-based office tools and the TeamViewer remote access program. This allowed us to work on our design collaboratively, regardless of location.

When we first started the challenge we were extremely focused on the search pattern because we thought that it would affect our initial sensor choices. We tried to look ahead in the Workflow and figure out estimations for the variables so we could choose the best design. Our mentors helped us realize that the search pattern is interrelated with the footprint and camera placement, the things that we initially tried to use to determine the “best” sensor selection. We needed to change our plan of action to focus on optimizing the footprint with the altitude and speed.

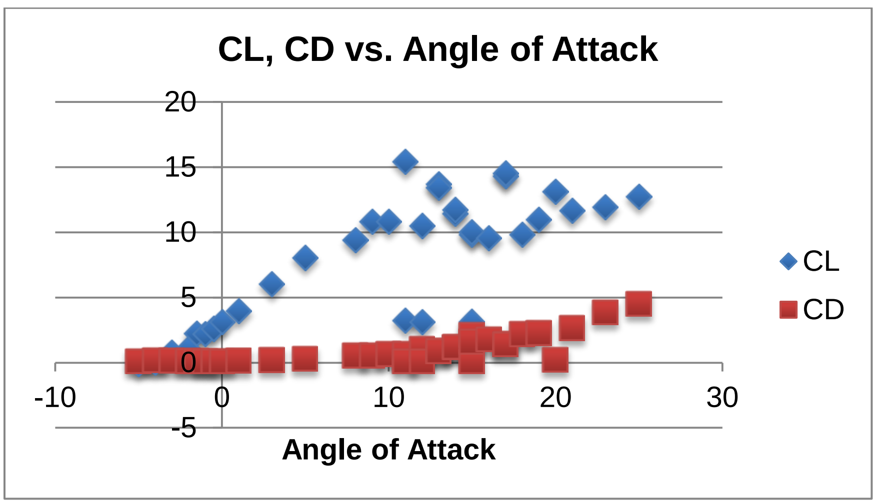
After the State Challenge we again set about determining the best plan to approach completing our design. The addition of FloEFD program meant we would have to dedicate additional resources to determine the efficiency of our aircraft. Because of the lack of aerodynamic analysis in the State Challenge, we immediately recognized the need to reexamine our airfoil selection and look at additional innovations to maximize efficiency. Initially we planned to have this Preliminary Design work done by the end of our February vacation. After running into significant testing errors, we had to modify our project plan, allotting time to solve the problem, while managing enough time to ensure the completion of the remaining components of the challenge. After consulting with our coach and reviewing the resources provided by the Real World Design Challenge administrators, especially the webinars, we were able to resume testing our design and finish in accordance with our new adjusted schedule.

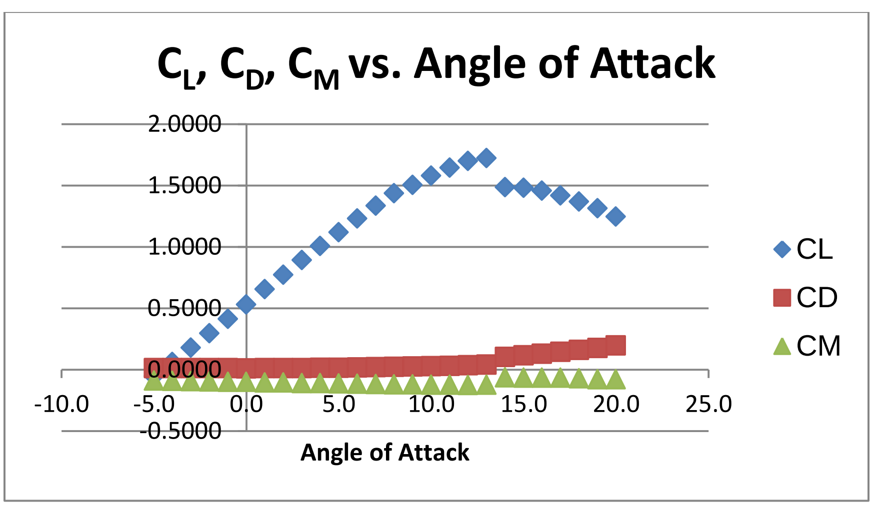
As the challenge started to come to a close, we needed to put more focus on writing. Some of the writing was already started but most of it could not be done until the end of the challenge. To make this adjustment from research and designing to writing, we created a "loose" task list which divided all of the writing sections to members with the appropriate experience. It was "loose" because the expectation was that everyone was supposed to help others and that no one was done writing until the challenge was over, even if they completed their task. For the parts that could not be written about due to an unfinished sUAS, we wrote drafts that would make it easy to finish once we got the necessary information. Most of our preliminary research, down select process, and iterations were completed so we moved our attention to writing everything down into the notebook. To ensure we had created a high quality document we decided it would be imperative to allocate additional time for editing and revision. We also determined that it would be advantageous to allow our mentors, coaches, and science teachers review our notebook so as to accumulate as much feedback as possible. We then allocated the entirety of the last week of the challenge to review our design notebook and ensure we had the best solution possible. In addition by acquiring feedback from multiple sources we minimized the chance that something was missed or overlooked.

2.2 Aerodynamic Characterization

2.2.1 AeroData Characterization

The purpose of our wing is to provide lift, and successfully raise our aircraft into the air. The amount of lift we need depends on multiple factors, but during straight flight (when the aircraft is not banking), the value should be equal to the weight of our aircraft. This is a very basic principle of physics that correlates to all forms of work being done. For example, the force needed to pull a box up off the floor is equal to the weight of the box. Understanding this concept, we could pinpoint a certain lift value we wanted and change aspects of our aircraft such as the angle of attack and the size of our wing. While the aircraft was being built, we set up CFD models with different angles of attack and tested them in FloEFD to find the different lift coefficients so that when we found the weight of our aircraft and the appropriate lift that we needed, we would have a table set of lift coefficients for different AOA's that we could pick and choose from. When we graphed the lift coefficients across from the angles of attack we were not able to find the accepted curve that would tell us what our stall angle of attack (the angle of attack at which our aircraft would stall and not fly anymore). Initially we tested all of the different angle of attack by building CFD models and testing them in FloEFD. By graphing our test results, with angle of attack on the x-axis and lift coefficient on the y-axis, we hoped to find the stall angle which would appear at the point in the graph when the line starts to curve. However, our data from FloEFD was incorrect (way more than 20% different from the Javafoil values) and even after retesting many of the models the incorrect data did not change. Because of this, we decided to use the data retrieved from Javafoil instead.





This stall AOA was very important for us to find, because while maneuvering through our search pattern we had to bank at up to 45 degrees during which we would have to increase our angle of attack to maintain the lift we needed. A series of calculations (as seen below) were done to find the angle of attack we would need in different parts of our trajectory. The coefficient of drag values affected how much battery we needed, affecting the weight of our aircraft. As we can see here, whenever the weight was increased we would have to find an angle of attack that would give more lift to counterbalance the extra weight. This is the relationship between these three important concepts. The coefficient of moment was related to the pitching moment of the aircraft. By making sure that our center of gravity was correctly positioned and that the lift was appropriate we could make sure that our coefficient of moment was not a problem.

$$C_L = \frac{2L}{pv^2A}$$

<u>UAV One</u>

No bank:

$$C_L = \frac{2(33.45\ lb)}{\left(0.0544\ {}^{lb}/_{ft^3}\right)\left(80\,{}^{mi}/_{hr}\right)^2(400\ in^2)} = \frac{2(148.793\ N)}{\left(0.8714\ {}^{kg}/_{m^3}\right)(35.76\,{}^{m}/_{s})^2(0.2581\ m^2)}$$

$$= 1.0346479811919$$

45° bank:

$$C_L = \frac{2({}^{33.45\ lb}/_{\cos 45°})}{\left(0.0544\ {}^{lb}/_{ft^3}\right)\left(80\,{}^{mi}/_{hr}\right)^2(400\ in^2)} = \frac{2(210.425\ N)}{\left(0.8714\ {}^{kg}/_{m^3}\right)(35.76\,{}^{m}/_{s})^2(0.2581\ m^2)}$$

$$= 1.4632118567855$$

AoA_{min} = 5° → 1.1180 C_L 0.01368 C_D

$AoA_{45°}$ = 9° → 1.5020 C_L 0.02491 C_D

AoA_{stall} = 13° → 1.7230 C_L 0.03929 C_D

UAV Two

No bank:

$$C_L = \frac{2(32.45\ lb)}{\left(0.0544\ {}^{lb}/_{ft^3}\right)\left(80\ {}^{mi}/_{hr}\right)^2(400\ in^2)} = \frac{2(144.345\ N)}{\left(0.8714\ {}^{kg}/_{m^3}\right)(35.76\ {}^{m}/_{s})^2(0.2581\ m^2)}$$

$$= 1.0037168008872$$

45° bank:

$$C_L = \frac{2\left({}^{32.45\ lb}/_{\cos 45°}\right)}{\left(0.0544\ {}^{lb}/_{ft^3}\right)\left(80\ {}^{mi}/_{hr}\right)^2(400\ in^2)} = \frac{2(204.134\ N)}{\left(0.8714\ {}^{kg}/_{m^3}\right)(35.76\ {}^{m}/_{s})^2(0.2581\ m^2)}$$

$$= 1.4194689815986$$

AoA_{min} = 4° → 1.0050 C_L 0.01283 C_D

$AoA_{45°}$ = 8° → 1.4350 C_L 0.02264 C_D

AoA_{stall} = 13° → 1.7230 C_L 0.03929 C_D

2.2.2 Airfoil Validation

A very important aspect of our aircraft is the wing, and it is imperative that it is designed in an efficient manner. An optimal wing is one that brings great efficiency to the flight, allowing us to fly the search pattern in smaller amount of time and forming a low Objective Function. A key aspect of the wing was the airfoil selection, as airfoils of different classes and shapes have different effects on the aircraft and work well with certain types of aircraft. Features of aircraft like wing size, air speed, and air density determine the Reynolds number, a value that quantifies the importance of the inertial and viscous forces on the airfoil. The equation below shows the relationship between these variables, where ρ is the density of the surrounding fluid (air) is, v is the mean velocity of the object, L is the length of the wing, and μ is the dynamic viscosity of the fluid.

$$Re = \frac{\rho v L}{\mu}$$

For a small sized UAV flying at relatively slow speeds (80mph is the max speed), our airfoil needed to offer a small Reynolds number, in the low hundreds of thousands. Understanding this, we based our airfoil choices around selections that would offer a Reynolds number of round 300 to 400 thousand (Our final Reynolds number was 378,000).

After conducting research we determined that airfoils that are slightly thicker and those that sport a higher camber would be optimal for the wing of a UAV due to the sufficient lift and appropriate stability that it offers. Using this information we browsed through the UIUC database, looking for airfoils that met this description. We came up with 9 different plausible candidates, and used Javafoil to collect information on each airfoil's performance. The airfoil we found that met our considerations were the Clark Y, NACA XX12, XFLR5, FC 60-126, Selig Donovon, NACA 4412, NACA 4415, Raskins 4-40, and Vans RV-6. Using this information we narrowed our airfoil down select choice to one of two airfoils: the NACA-4412 and the NACA-4415. Once we knew this we built the CFD models in Creo and then put them into FloEFD so that we could test them in the virtual wind tunnel. Once we got the results we judged them based mostly on the lift to drag ratios. Knowing that the lift coefficient was directly proportional to the values of lift, we simply found the ratio between the lift coefficient (labeled SG Force (Z) 1 below) and the drag coefficient (labeled SG Force (X) 1 below). From this calculation we found the best airfoil for our UAV's wings would be the NACA 4412. Force X is coefficient of drag and Force Z is coefficient of lift.

CFD_NACA4412_AOA0.ASM [CFD_NA

Goal Name	Unit	Value	Averaged Value
SG Force (X) 1	[lbf]	0.115016045	0.105940532
SG Force (Z) 1	[lbf]	3.072963482	3.248877548

Figure 4 - Cd and Cl results for NACA 4412

CFD_NACA4415_AOA0.ASM [CFD_NA

Goal Name	Unit	Value	Averaged Value
SG Force (X) 1	[lbf]	0.194435033	0.189884198
SG Force (Z) 1	[lbf]	0.630129792	0.618239845

Figure 5 - Cd and Cl Results for NACA 4415

2.3 Selection of System Components

2.3.1 Propulsion System

We commenced by identifying the characteristics we wanted in our propulsion system. The main deciding factors we established were the thrust output, and the fuel type. After sizing our aircraft we determined that a thrust output of around 13 pounds would be sufficient to attain and maintain our altitude, as well as any necessary maneuvers. We did not want too little lift, as we wouldn't be able to perform necessary maneuvers, but at the same time we didn't want too powerful of a system, because a large system would add additional weight and cost. This limited our solutions to the E-20, and GL-25 systems as any other system would either be too large, weighing our plane down, or would require multiple systems, increasing our cost, and weight.

This down select left us with one last characteristic to choose from: gas or electric. In order to accurately choose between the two options we did additional research and continued on to side-by-side comparison. After careful examination of these factors we ultimately decided on the electric E-20 propulsion system. First and foremost, we chose this system because it was almost half as expensive, and half as heavy as the comparable GL-25 system. The ease of battery use is also a benefit because it would allow them to be swapped out quickly, if needed. In addition, the consistency of the power source between all systems makes the overall process of providing power to the UAV simpler, as all of our systems rely on the same technology. Lastly, we sided with electric because the weight of the system does not noticeably change as energy is used, whereas in gasoline systems, the burning of fuel causes the system to get lighter. An in-flight weight change means that the aircraft would have to adjust its angle of attack in order to maintain a state of equilibrium. Such a process would allow for additional inefficiencies that were avoided by choosing an electric system.

Another consideration we had to make while choosing propulsion was placement. Because we decided to use canards, a conventional tractor configuration would not be ideal. Since the canards are so close to the front of the aircraft, the propulsion system had to be moved to the back so as not to disturb the laminar flow over the canards. With this new design, the engine would not be in the front, allowing us to place our sensors and antennae in the front of our fuselage without obstruction. Also a pusher propulsion system design would incorporate a smaller fuselage, effectively decreasing our weight and therefore cost and Objective Function. The system with a propulsion system in the back of the fuselage also increases the stability of our aircraft and also reduces the form drag by keeping the flow of air over the UAV attached to the fuselage. The design also is optimal in safety. If there were a fuel leak from the engine it would stream away from the aircraft

Incorporating the E-20 propulsion system into the Creo Elements Pro required a couple extra steps than usual because of our use of a pusher propulsion configuration. In order to accomplish this, we imported the E-20 part into the assembly and mirrored it across the right plane. Now the propeller is facing out the back of the fuselage allowing for its pushing function in our design to work.

2.3.2 Sensor Payload Selection

The Real World Design Challenge initially gave us five sensors to choose from. In order to thoroughly, and accurately eliminate impractical sensors we created charts and side-by-side comparisons to differentiate between the many options.

We almost immediately realized that for an optimized UAV, we wanted to balance each of the variables that affect the design. Therefore, sensors like X1000 and X5000 were eliminated right away. X1000 was extremely light, but was a very weak sensor. While it was the most inexpensive, it was not worth it when considered with the full design. Consequently, X5000 was heavy, required a great deal of electricity and was very expensive. This elimination of two of the five sensors we were given allowed our team to proceed with more efficiency. We then calculated several numbers such as the maximum detection distance, and found that the X4000 was too expensive compared to the X3000, while not providing enough additional features. This left us with the X3000, and X2000 sensors. We then used these two sensors to form our initial solution candidates. Those candidates were: Option 1, one large plane with two X3000 sensors; Option 2, two smaller planes, each with two X2000 sensors; Option 3, another large plane, but with four X2000 sensors; and Option 4, four small planes, each with a single X2000 sensor.

We compared the differing features of our various design candidates. After extensive side-by-side examination, including Objective Function analysis, we found that the cost and weight of the three X2000 configurations were considerably higher than that of our X3000 option. After further analysis, we calculated the Objective Function with two X3000, but with two planes. We found this value to be lower than the Objective Function for our original configuration. As a result we finally settled on a sUAS with two planes and two X3000 sensors.

Before the sensors could be added to the UAV, the front of the fuselage had to be widened to accommodate them. Once that was accomplished, the sensors were moved to 8.50 inches from the front of the UAV. In order to fit flush with the surface of the fuselage, it was necessary to tilt each sensor out 18.5 degrees. This was done by creating an angled datum from the front plane and offsetting a sensor. The other sensor was created by mirroring the first across the top plane.

2.3.3 Ground Station Equipment Selection

The ground station equipment is a vital element of our sUAS. Without it we would not be able to remotely operate our plane, because of this it is imperative that we have the proper equipment to complete our missions. The majority of our ground equipment was predetermined for us, such as transceivers and our catapult. Aside from determining the necessary quantity of ground assets, we had one large decision to make, whether to opt for four smaller, cheaper Workstation A's or one larger, more powerful, and more expensive Workstation B. After analyzing our sUAS configuration with two X3000 sensors, we decided to use Workstation B.

We chose Workstation B to serve as our ground station for many reasons. The primary reason was time. Workstation B included detection software, a characteristic that we determined to be absolutely necessary. The software allowed us to greatly reduce the time, and pixels required to detect the child. This small detection time is just small enough that when used in combination with our gimbaling system, we can detect and identify the child quickly enough so as to never need to alter our flight path, until the child is found while in zones 1 and 2. This means that we do not have to waste time by performing time-demanding confirmation maneuvers, such as dropping altitude, or circling the detected object.

The second reason for choosing Workstation B is cost. While initially more expensive, Workstation B allows for multiple sensors to be displayed on a single ground station. Because our system includes multiple sensors which must be monitored, the ability to display feeds from more than one sensor on a single unit means that we can greatly reduce our personnel costs, as only one person is needed, rather than one per sensor or a total of four. This is especially advantageous as personnel costs are calculated for each mission whereas the initial cost of the workstation is only added to our costs once. After a quick calculation we determined that we would make up the additional cost of our workstation from personnel cost savings after about 5 missions. Therefore in the long run we would save money by opting for the larger workstation, which would further reduce our Objective Function value.

We selected the following ground equipment for our sUAS:

- 4 Video Data link Ground Receiver
- 2 Command Datalink Ground Transceiver

- 2 Safety Pilot Flight Box
- 1 Sensor Payload Workstation Computer- Version B
- 1 Trailer/Shelter- Streamline
- 1 Launch Catapult

2.3.4 Additional UAV/sUAS Equipment

Our goal when selecting the remainder of our equipment was to minimize cost and weight while still providing the necessary system functionality that would be required to complete our mission. We chose to include vital system components such as the flight control system, and the datalink transmitter and datalink transceiver, as they allow us to transmit our UAV's flight data back to the base camp, a necessary functionality in order to analyze our data in real-time. We did not include a plane-mounted video recorder as it does not aid our ability to process data in real time, nor is it a mission critical component. Because it would add unnecessary cost and weight to our aircraft, it was not included into our final design.

We selected the following additional equipment for our sUAS:

- 4 Video Datalink UAV Transmitter
- 2 Command Datalink UAV Transceiver
- 2 Flight Control System

The placement of additional components was the same for each UAV. The flight control system was placed 18.0 inches from the front of the plane, the datalink transceiver was placed 4.0 inches from the front, and the datalink transmitters were each placed 32.50 inches from the front but on opposite ends of each wing. Therefore, we were able to comply with the major additional equipment constraint of the challenge in making our antennae more than 18.0 inches apart.

2.4 Aircraft Geometric Details

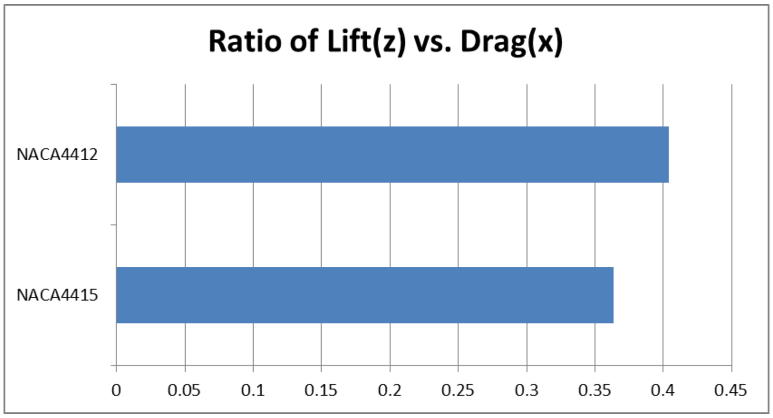
2.4.1 Wing Configuration

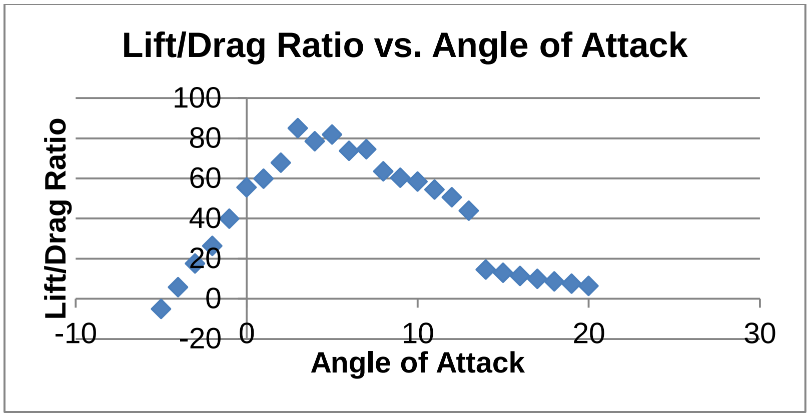
As we entered the Detailed Design Phase of refinement, we had to have a complete aircraft design. The first aspect of our UAV that we worked on was the wing geometry. Initial research and a few conferences with mentors, had put us on a path towards the airfoil we would end up utilizing. We started the research by considering certain characteristics of airfoils and the effect that they would have on the efficiency on our wing design. In particular we considered the shape and camber of the airfoils. Through research we had discovered that airfoils that are slightly thicker and those that sport a higher camber would be optimal for the wing of a UAV due to the sufficient lift and appropriate stability that it offers. Using this information we narrowed our airfoil down select choice to one of two airfoils: the NACA-4412 and the NACA-4415. At this point, we used Flo EFD, a virtual wing tunnel program that conducts fluid analysis, to decide which one we would continue to incorporate in our wing design. The airfoil that gave us the highest lift to drag ratio was the one we chose: NACA-4412. Once we had decided the airfoil that we were going to use, it was crucial for us to determine the specific shape and size of our wing. For this step we had to consider the aspect ratio, taper ratio, and position of our wing. By the time we arrived at this point in the designing, we had already done research on these values. Observing the well-performing UAVs that were in use today, we were able to find certain ranges for the values that we would choose. Our research also showed that a smaller wing is a more stable wing that is less likely to flutter but also produce more induced drag and pushes down on the air less. However, a larger wing would increase the force applied on the general cylinder of air that our aircraft occupies, but be less sturdy. Seeing the two sides of the decision, we decided to find the happy medium that would optimize our aircraft's strength to L/D ratio. We ended up with our final aspect ratio of 7 and a taper ratio of .867 to meet the needs of the geometry of our wing.

Once the main placement and size factors were finalized, we moved onto the aspects of angle of attack, dihedral angle, incidence angle, Sweep angle, and the twist angle. To find the angle of attack, we followed a very efficient down select process. We knew that our stall angle of attack would be somewhere between 10 and 20, so we tested up to angle of attack 20. Our range of angle of attack values that we initially selected to test went from -5 to 20 in large 5 degree intervals. After building CFD models for each angle of attack scenario, we put the models into FloEFD. Before we looked at the results for the tests we had to calculate the lift we would need to fly our UAV. Using classical physics we determined that the lift value would have to be equal to the weight of our aircraft (and a little more to make sure that our plane had some room for error). With our lift value we could use the equation below to calculate the coefficient of lift that we would be looking for when we looked at the results of our tests. After viewing our results we noticed that the CFD model with the angle attack value 0 had the closest lift coefficient to the one we needed. Seeing this, we scoped in in our testing process, and test from -3 to 3 in intervals of 1. Each time we ran the next set of batch runs, we got closer and closer to that perfect coefficient of lift; the coefficient turned out to be optimal at -1 angle of attack. Starting at larger intervals allowed us to be efficient by not testing angle of attack values that wouldn't have even close to 0. We tested using this particular testing process so that we could run as few tests as possible. This was the correct process for finding optimum angle of attack, but our final results turned out different when we decided to use Javafoil data rather than CFD data. In the end, we found that our wing would need to fly at an angle of attack between 4 degrees and 9 degrees, depending on which UAV it was and the bank angle.

We moved on to the dihedral angle and conducted some preliminary research so that we could understand the effect of the angle. From what we learned, we noticed that the main purpose of it was to increase the stability of our aircraft. After consulting with our mentors we decided that a relatively low dihedral (relative to the angle's present in modern aircraft) would benefit the overall performance of our UAV. This is why we had our final wing design incorporate a dihedral angle of 2 degrees. We then moved on to understand the effect of our incidence angle, what we understood would help our aircraft gain more lift to give our aircraft the appropriate thrust. We decided to incorporate an angle of 3 degrees to provide our aircraft some extra support in the case that the efficiency of either the propulsion system or the tail decreases*. Sweep and twist angle were not tested in the design of our wing because we noticed that they would not benefit or hurt our performance too much, so we focused more on the other aspects that would have immense effects. Sweep could simply be zero because of the low maximum speed of our aircraft and twist was set to zero because there were no abnormal conditions that indicated it would need to be anything otherwise.

This concluded the design of our wing, from the shape and size design aspects, to the specific aeronautical factors of the position.





2.4.2 Tail Configuration

The idea of a UAV design that incorporated canards was new to the team. It was a design feature that we had not looked into in previous years, which made it an aspect of the aircraft that made us curious. While researching modern aircraft and new concept ideas for 21st century UAVs, we came by a design that would in essence bring the canards, our substitute for a horizontal stabilizer, to the front of the fuselage and move the wing to the rear of the fuselage. To make this design work efficiently, one of our mentors mentioned that we would have to use a pusher propulsion system. The canard design was our team's innovative step toward finding the solution for this challenge. The design is meant to be ultimately efficient, because it offers lift in the same direction the wing, balances the pitching movement, and doesn't have negative or downward lift as the horizontal stabilizer would. There were many benefits to the canard design. An important benefit of the canard design is that it would make it harder for the UAV to stall. This is because the canard wing will stall before the main wing, so the nose will drop, increasing airspeed before the main wing stalls. Another benefit is that the canard design offers a lot more aircraft maneuverability. The system with a canard design also is beneficial to our UAV because of the parallel structure of the canard to the wing adds lift when it needs to climb and drag when it needs to dip during maneuvers such as banking. As evident, the canard and pusher propulsion system design has many benefits, which was the reason for our decision to move forth with it.

The process of building the canards required a significant deal of innovation and thinking outside the box. Since a canard definition worksheet was not made available through the Real World Design Challenge, we had to utilize the horizontal tail definition sheet and make some modifications to allow us to incorporate canards into the design. The root leading edge waterline and fuselage station of the quarter chord were quite different for canards than they would be for wing. Therefore, the calculation for tail arm in the Mathcad sheet had to be adjusted so that it would not produce a negative result.

2.4.3 Fuselage

The fuselage was the first aspect of our aircraft's design that we constructed. Using OpenVSP, we started with a base model that was given to us by the challenge administrators and then changed the size and shape of certain parts to make it work with the design that we decided to construct in the Conceptual Design Phase. A few things that we had to take into consideration were the overall aerodynamic shape of the fuselage, the size and fit of the sensors, and the weight that would affect our overall efficiency. We started off by trimming down the back of the fuselage, in an effort to decrease the fuselage depth in an area that didn't necessarily need a lot. The back of the aircraft would serve the purpose of holding our wing. After the trimming, we made the front of the fuselage wider to make sure that our sensor payload would fit appropriately. Our first design did not allow us to fit both of the X3000 sensors that we had decided to incorporate in the Preliminary Design phase. To accommodate for this, we made our front flatter and wider, to increase the surface area on which we could place the sensors and still maintain a reasonable weight value. The wide front also helped in the National Challenge because of our addition of canards, which were placed close to the nose of each UAV. The back of the fuselage had to be made slightly larger for the National Challenge than in the State Challenge because our wing was placed there rather than a horizontal stabilizer, in addition to our pusher propulsion system. Once this design change was made, we checked that all of our parts, including the wing, the canards, the sensors, and the antennas would fit correctly. Overall, the fuselage in the National Challenge was very similar to that used in the State Challenge, but it was shorter in length and wider at the end to account for moving the wing to the back of the aircraft.

The length of our fuselage is 41.257 inches. This was found in OpenVSP after the final version of the fuselage was created. This was entered into our configurator sheet, vertical tail definition sheet, and horizontal tail definition sheet. The vertical and horizontal tail definition sheets also required the input of fuselage height and width. Since our fuselage is irregularly shaped, these values varied along the length of the fuselage. In OpenVSP, the length and width were defined at five different points along the fuselage, spread out relatively evenly. The five values for height and width were averaged to produce a height value of 3.533 inches and a width value of 5.1455 inches. These could then be averaged together to find our fuselage depth of 4.339 inches, which was needed for the configurator sheet. Finally, our wetted area, the total area covering the external part of our fuselage, is 569.11 square inches. This was easily calculated using the measure area tool in Creo Elements Pro. Seeing an aerodynamic and accommodating design, we decided that our fuselage was completed and moved on to the next step of the challenge.

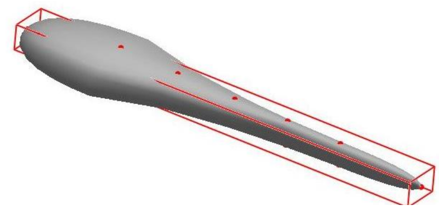


Figure 6 - Model of Fuselage

2.5 System and Operational Considerations

During the Detailed Design process, after the down select process in the Preliminary Design had been completed, we decided that our optimal search mission would incorporate a two-plane design. This design was chosen over a single-plane option that would be significantly cheaper than having two planes, because a single plane would take almost twice the amount of time to cover the search area. We didn't use more than two UAVs because as the number of planes increase, the initial and personnel costs increase exponentially. We could minimize our search time significantly, but the increased costs make such an option impractical. Instead we opted for a balanced approach, with a middle of the road cost and time, one that would find the child in a reasonable amount of time, without costing a large amount of money per mission. We found that a system with two UAVs was the superior configuration for our given conditions.

Another major design decision we made was the inclusion of canards. We found the idea particularly attractive because they serve the same function as the horizontal stabilizer, but while providing positive lift and significantly less drag. We did have to make some tradeoffs, however, to make this design work. Because the canards are so close to the nose of the aircraft the propellers on a conventional nose-mounted propulsion system would disrupt the laminar flow over the canards, and causing them to be ineffective. To counteract this effect, we moved the propulsion system into a "pusher" configuration. This became advantageous because it allowed for laminar flow over the canards and wings, while also creating a more even weight distribution over the aircraft. This configuration also has a number of tradeoffs. Because the propellers are behind the aircraft, the air passing through the system is turbulent as it lies in the aircraft's wake. This decreases the efficiency of our system, causing us to use more energy to move the plane. Additionally, because of the loss of propeller wash over the wings, the aircraft can experience a slight loss of lift which during takeoff requires higher speeds and longer distances to reach the same level flight as a tractor propulsion system. This means that we will have to spend more energy to reach our desired altitude than would be required of a conventional system. In the end the added efficiency of the canards more than make up for the slight loss of efficiency from switching to a pusher configuration instead of a conventional tractor configuration.

Perhaps the largest single engineering decision we made was sensor selection. We wanted a sensor that would give us good visibility without using too much electricity or costing too much money. Ultimately we chose to use two X3000 sensors. This configuration has ample zoom and a fast enough gimbal speed to allow us to perform all of our search maneuvers. The tradeoff to this functionality is that the X3000 sensors were fairly expensive. However, the time made up by our search maneuvers, such as our gimbaling in Zones 1 and 2, allow us to make up for the additional cost of the larger sensors.

During the remainder of the system components selection process, we decided on utilizing an electric propulsion system in our final design. This decision allowed us to lower the cost of our aircraft, as the electric E-20 was $250 cheaper than the comparable GL-25. However in opting for a cheaper engine, we did have to sacrifice some of the power and reliability of a gas powered engine. In order to compensate for the shorter endurance of the electric engine, we had to add 5 lbs. of batteries to ensure we didn’t have to refuel mid-mission. This increased our cost a small amount but this additional cost was still less than that of a gasoline fueled engine.

2.6 Component and Complete Flight Vehicle Weight and Balance

	UAV (Zone 1,2)	**UAV (Zone 3)**
Batteries	6.5 lb	5.5 lb
Electrical	0.5 lb	0.5
Fuselage	4.59 lb	4.59 lb
Wing(canards)	1.6 lb	1.6 lb
Horizontal Tail	0.49 lb	.49 lb
Vertical tail	14.42 lb	14.42 lb
(2) X3000 sensor	2(2.1lb) = 4.2 lb	2(2.1lb)= 4.2 lb
E-20 Propulsion system	1.1 lb	1.1 lb
(2) Video Datalink UAV Transmitters	2(0.05) = .1 lb	2(0.05) = .1 lb
Command Datalink UAV Transceiver	0.1 lb	0.1 lb
Flight Control System	0.1 lb	0.1 lb
Total Weight	33.7 lb	32.7 lb

On a normal commercial aircraft, like a Boeing 747, the center of gravity is right above the wing as far as placement goes on the fuselage. For our canard design, we have the wing in the back of the fuselage so using the configurator we confirmed that the COG was in the middle of the aircraft, successfully balancing the weights on the aircraft and ensuring proper flight of our UAV. The first UAV's COG was 19.86 inches from the front of the fuselage, while the second UAV's COG was 19.92 inches from the front of the fuselage.

2.7 Maneuver Analysis

An important part of the challenge was that the aircraft must be able to take-off and clear a 50 foot obstacle within 300 linear feet from the starting position. The Mathcad Performance worksheet was a very useful tool in making sure this could happen. Using this tool, we found that our aircraft clears that 50 foot obstacle at 280.355 linear feet from its starting position. A key part of our system maneuvers involves the climb of both UAVs as they travel to the outside of the circle before starting the search. The first UAV travels out 1.9 miles along the edge of zone one at a constant climb rate of 701.75 feet per minute. The second UAV travels out 1.954 miles along the edge of zone three at a constant climb rate of 682.35 feet per minute. Our search pattern does not require any maneuvers for speed or altitude changes during the process of search because of the way our identification technique utilizes gimbaling in zone one and two and a circling maneuver in zone three. A normal flight path is used during gimbaling and a turn with bank below 45 degrees is used for the circling maneuver.

The aircraft can also perform the maneuvers required by the search pattern. It is a spiral pattern that requires an angle of bank of up to 45°. We had the code for the mission planning worksheet changed so that we are alerted if any turn banks more than 45°. The search pattern was created based on the footprint widths determining how far apart the flight paths had to be from one another. When moving closer to the search center, the pattern had to be changed from a sweeping pattern to a more zamboni-esque pattern so that the turn radius would not be too low. Part of the process of banking involves a change in angle of attack. Since the bank angle changes throughout the flight, depending on the size of the turn radius, the angle of attack is constantly being adjusted. The first UAV varies its angle of attack between 5 degrees, when it is not banking at all, and 9 degrees, when it is at the maximum bank of 45 degrees. The second UAV varies its angle of attack between 4 degrees, when it is not banking at all, and 8 degrees, when it is at 45 degrees bank. It is absolutely necessary that both UAVs maintain an angle of attack below 13 degrees, as to not stall in mid-flight.

2.8 CAD Models

	Wing	Canards	Vertical Stabilizer
Area	400 in^2	98.10 in^2	26.75 in^2
Aspect Ratio	7	8.4	1.6818
Taper Ratio	0.867	0.7742	0.8258
Postions from tip of Aircraft	31 in	6.5 in	35
Dihedral Angle	2 degrees	0	-
Incidence Angle	3 degrees	0	-
Sweep Angle	0	0	15 degrees
Twist Angle	0	0	-
Angle of Attack	*Varies based on bank angle during flight	*Varies based on bank angle during flight	-
Airfoil	NACA 4412	NACA 4412 upside down	NACA 0010

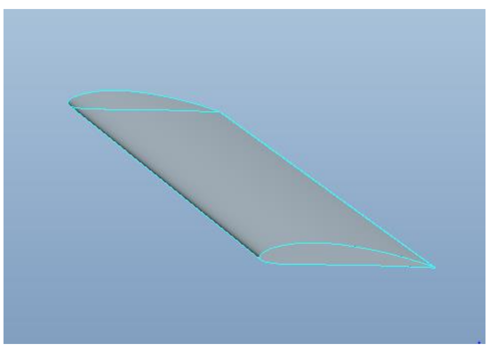


Figure 7 - Model of Wing

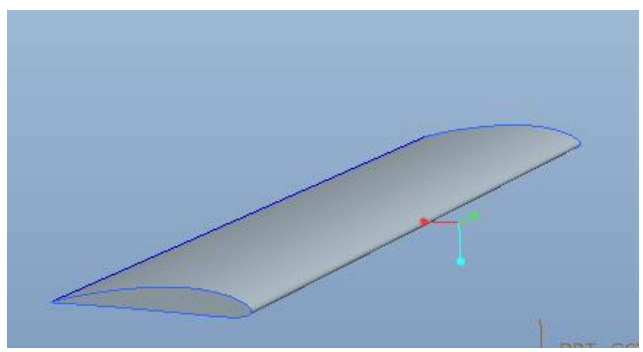


Figure 8 - Model of Canard

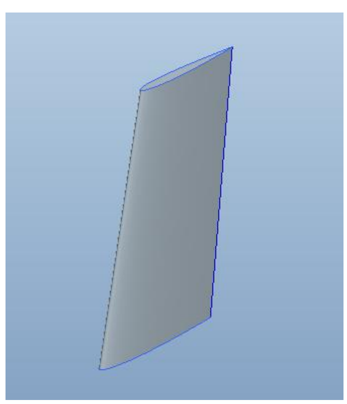


Figure 7 - Model of Vertical Stabilizer

2.9 Three View of Final Design

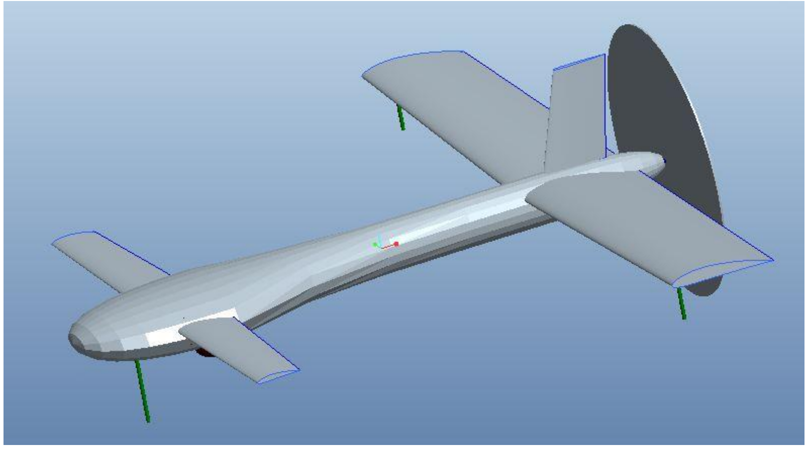


Figure 8 - Top View

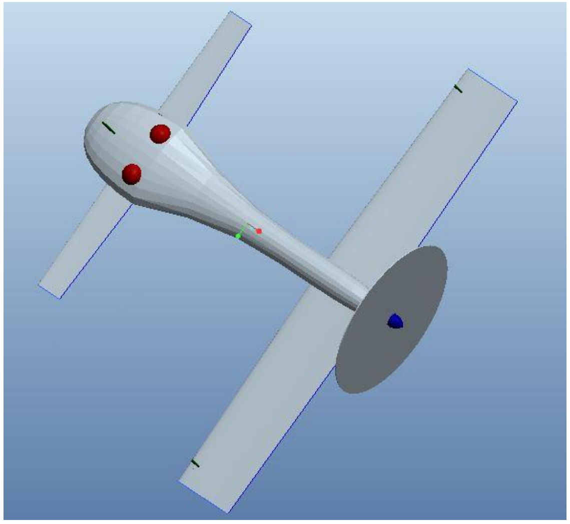


Figure 9 - Bottom View

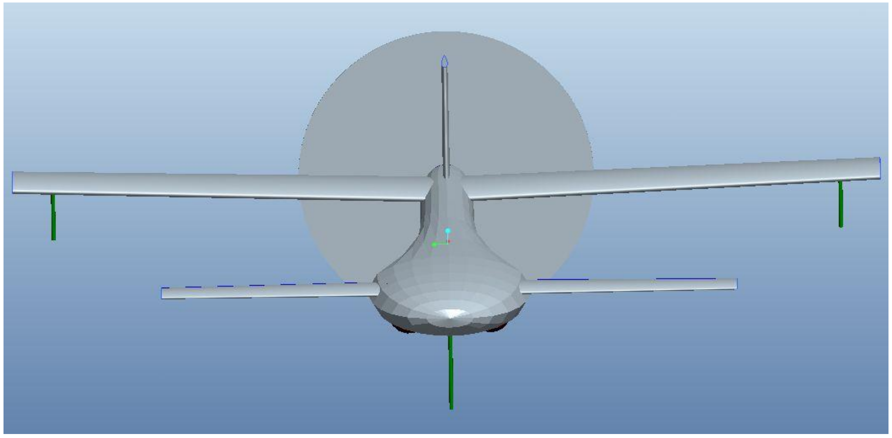


Figure 10 - Front View

3.0 Mission Plan

3.1 Search Pattern

The efficiency of our aircraft depends on two things: the time it takes for our aircraft to find the lost and injured child and the cost of our sUAS including acquisition cost and operational cost considerations. Even if our aircraft were completely optimized, an inefficient search pattern could hurt the overall Objective Function. Seeing the need for an effective search pattern, we did a great deal of preliminary research on them. We settled on a sweeping pattern within each zone after a great deal of deliberation as it provided minimal overlap and thoroughly covered the search area.

One of our UAVs is launched from base camp, then immediately moves to the outside of Zone 1. From there it sweeps back and forth across the zone moving in the direction of base camp. Once Zone1 is complete, the aircraft will then adjust its orientation and proceed to the outside of Zone 2. Once it reaches the edge of Zone 2, it will sweep back and forth similar to Zone 1. The only difference is, because of the limited view from the brush, the footprint is slightly smaller. Just after the first UAV was launched, a second plane was launched. This plane moved to the edge of Zone 3 and made the same sweeping pattern as the other plane, moving back and forth in the direction of base camp. The two aircraft are coordinated so that they each finish their designated areas in approximately the same amount of time.

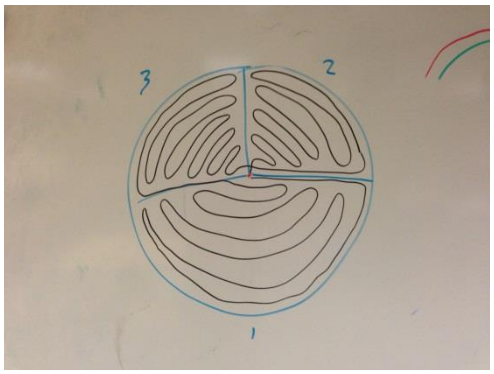


Figure 11 - Sketch of Sweeping Pattern

There are a couple turn-around loops that we need to have in order to identify the child. In Zone 3, we put in two loops because our camera can't gimbal to identify the child. We have to circle around the child to see it for the required 5 seconds. Because search time is so important when the life of a child is at stake, we created an excel sheet that compared the values of the bank angle, speed, and turning radius to find the corresponding values of time to fly the circle and lift required to make the turn. We could then look at the most important value, time, to see what it would take to fulfill the other variables. We saw that the highest bank angle our plane could manage, 45 degrees as suggested by our mentors and research, gave the shortest flight time around the circle. Then we looked at the required wing lift and saw that our plane had enough lift at the maximum 80 mph. The circle would actually be a few seconds quicker if we slowed down, but that meant that we would’ve had to add airbrakes which would’ve added weight to the aircraft. A heavier aircraft needs more batteries which increases the cost and wasn’t worth the extra few seconds of search time.

3.2 Camera Footprint

Our camera footprint is engineered to see the widest area possible, while still being capable of gimbaling, our main detection and identification strategy. We started off with a footprint that was completely in the desired circle, whether it be the detection, identification, or any of the zone circles. But we had no basis to make the footprint entirely in the circle. In other words, we didn’t know if the footprint was the biggest or widest possible. We thought about the basics of our gimbaling strategy and determined that in order to gimbal, the footprint needed to be tall enough (expand in front of the UAV enough). Since speed was constant for the entire search, we could use the “distance traveled during detection time” value, 59 feet, and the “distance traveled during identification time” value, 587 feet, for all of our gimbaling calculations. This means that there must be 646 feet of forward plus backward distance in order to gimbal and see the child for the necessary 5.5 seconds of detection and identification time. The camera is supposed to follow the child on the ground, wherever it is in the footprint so that it can see the child for the necessary time to make a detection and identification. Now that we had the vertical distance figured out, we needed to figure out the width of the footprint to try and get the biggest possible footprint in order to reduce our search time. It was determined that the widest footprint would allow just enough room on the sides to detect and identify. We ended up with footprint in which a small corner of the footprint lies just outside the circle. This means that we cannot detect or identify in that small corner, however, we didn’t need that space and we were able to make our footprint the widest possible.

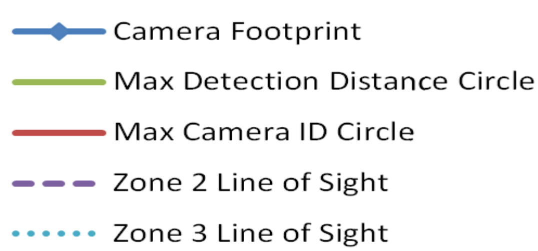


Figure 12 - Legend for Footprints

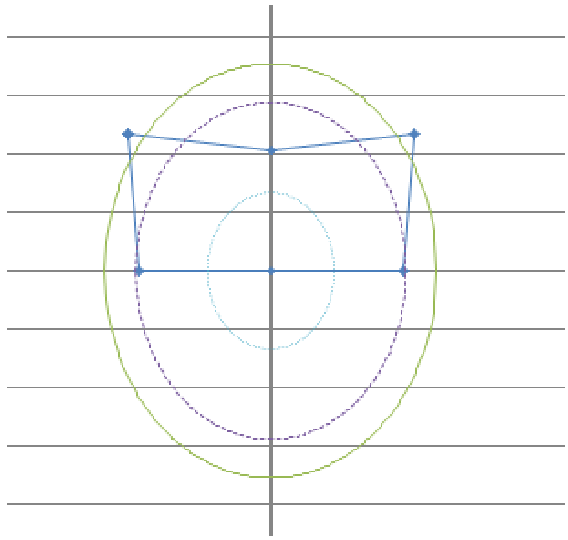


Figure 13 - Zone 1 Detection Footprint

UAV Info		
camera model	X2000	
aircraft altitude	1000	ft AGL
aircraft speed	80	mph

Instructions:
- Enter the values relevant to your aircaft and the flight condition in yellow.
- Pay special attention to the HFOV - this is how you select zoom
- The plot of the camera footprint and lines of sight as well as detect/identify ranges will appear to the right.

Camera Footprint			
Field of View	HFOV	VFOV	
field of view	29.9	22.425	deg
resolution	640	480	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	14.6	11.15	deg
Corner Angles	roll	pitch	
top left	29.55	22.3625	deg
top right	-0.35	22.3625	deg
bottom right	-0.35	-0.0625	deg
bottom left	29.55	-0.0625	deg
Corner Locations	y right wing	x forward	
top left	-613	473	ft
top right	7	411	ft
bottom right	6	-1	ft
bottom left	-567	-1	ft
top left (repeated)	-613	473	ft

Detection		
pixels required for detection	4	pixels
angular diameter required for detection	0.18688	degrees
maximum distance from camera for detection	1226	ft
time required for detection	0.5	sec
detection radius on ground	710	ft
distance travelled during detection time	59	ft
Identification		
pixels required for ID	20	pixels
angular diameter required for ID	0.93438	degrees
maximum distance from camera for ID	245	ft
detection radius on ground	Too high!	ft
time required for ID	5	sec
distance travelled during ID time	587	ft
Trees		
Zone 2 Line-of-sight radius	577	ft
Zone 3 Line-of-sight radius	268	ft

Figure 14 - Zone 1 Detection Specifications

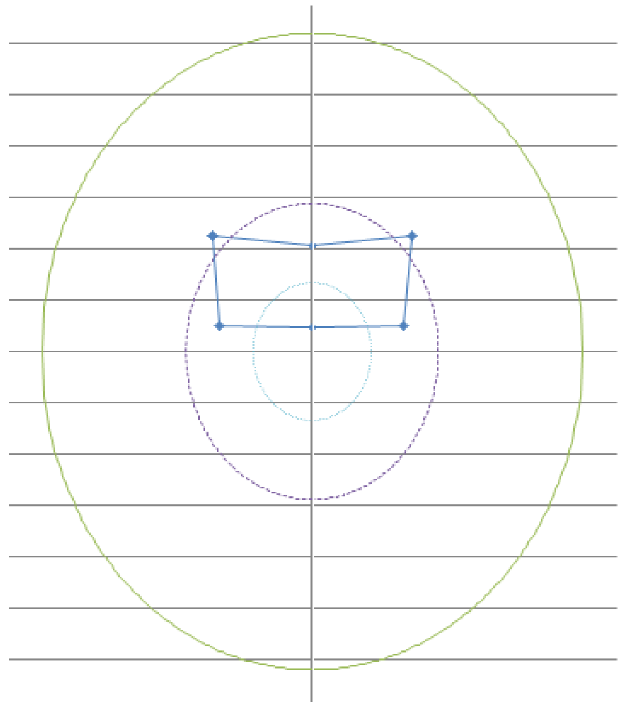


Figure 15 - Zone 2 Detection Footprint

UAV Info		
camera model	X2000	
aircraft altitude	1000	ft AGL
aircraft speed	80	mph

Instructions:
- Enter the values relevant to your aircaft and the flight condition in yellow.
- Pay special attention to the HFOV - this is how you select zoom
- The plot of the camera footprint and lines of sight as well as detect/identify ranges will appear to the right.

Camera Footprint			
Field of View	HFOV	VFOV	
field of view	23	17.25	deg
resolution	640	480	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	**11.2**	**14**	deg
Corner Angles	roll	pitch	
top left	22.7	22.625	deg
top right	-0.3	22.625	deg
bottom right	-0.3	5.375	deg
bottom left	22.7	5.375	deg
Corner Locations	y right wing	x forward	
top left	-453	452	ft
top right	6	417	ft
bottom right	5	94	ft
bottom left	-420	102	ft
top left (repeated)	-453	452	ft

Detection		
pixels required for detection	4	pixels
angular diameter required for detection	0.14375	degrees
maximum distance from camera for detection	1594	ft
time required for detection	0.5	sec
detection radius on ground	1242	ft
distance travelled during detection time	59	ft
Identification		
pixels required for ID	20	pixels
angular diameter required for ID	0.71875	degrees
maximum distance from camera for ID	319	ft
detection radius on ground	Too high!	ft
time required for ID	5	sec
distance travelled during ID time	587	ft
Trees		
Zone 2 Line-of-sight radius	577	ft
Zone 3 Line-of-sight radius	268	ft

Figure 16 - Zone 2 Detection Specifications

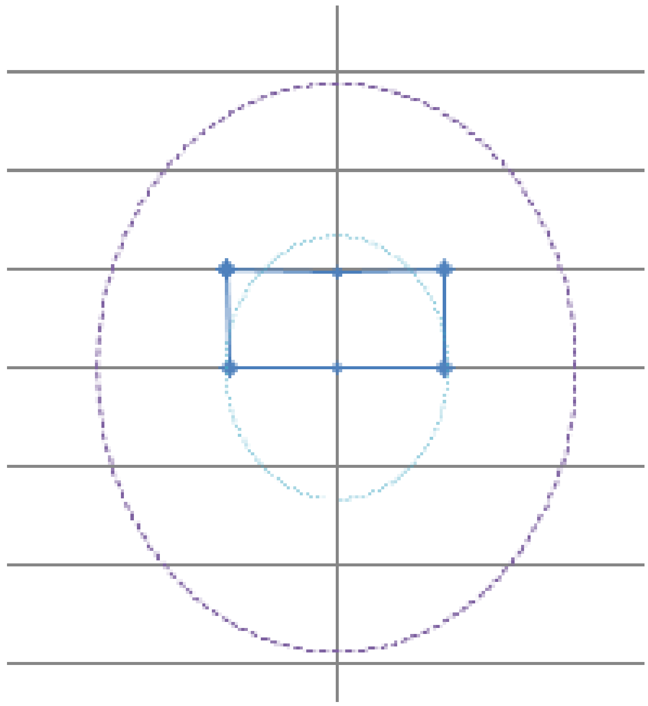


Figure 17 - Zone 3 Detection Footprint

UAV Info		
camera model	X2000	
aircraft altitude	1000	ft AGL
aircraft speed	80	mph

Instructions:
- Enter the values relevant to your aircaft and the flight condition in yellow.
- Pay special attention to the HFOV - this is how you select zoom
- The plot of the camera footprint and lines of sight as well as detect/identify ranges will appear to the right.

Camera Footprint			
Field of View	HFOV	VFOV	
field of view	14.8	11.1	deg
resolution	640	480	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	7.1	5.55	deg
Corner Angles	roll	pitch	
top left	14.5	11.1	deg
top right	-0.3	11.1	deg
bottom right	-0.3	0	deg
bottom left	14.5	0	deg
Corner Locations	y right wing	x forward	
top left	-264	203	ft
top right	5	196	ft
bottom right	5	0	ft
bottom left	-259	0	ft
top left (repeated)	-264	203	ft

Detection		
pixels required for detection	4	pixels
angular diameter required for detection	0.0925	degrees
maximum distance from camera for detection	2478	ft
time required for detection	0.5	sec
detection radius on ground	2267	ft
distance travelled during detection time	59	ft
Identification		
pixels required for ID	20	pixels
angular diameter required for ID	0.4625	degrees
maximum distance from camera for ID	496	ft
detection radius on ground	Too high!	ft
time required for ID	5	sec
distance travelled during ID time	587	ft
Trees		
Zone 2 Line-of-sight radius	577	ft
Zone 3 Line-of-sight radius	268	ft

Figure 18 - Zone 3 Detection Specifications

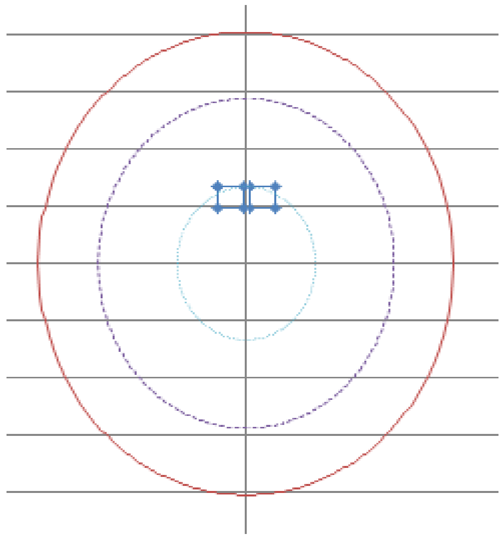


Figure 19 - Zone 1, 2, 3 Identification Footprint

UAV Info		
camera model	X2000	
aircraft altitude	1000	ft AGL
aircraft speed	72	mph

Instructions:
- Enter the values relevant to your aircaft and the flight condition in yellow.
- Pay special attention to the HFOV - this is how you select zoom
- The plot of the camera footprint and lines of sight as well as detect/identify ranges will appear to the right.

Camera Footprint

Field of View	HFOV	VFOV	
field of view	5.695	4.27125	deg
resolution	640	480	pixels
	roll right (pan left)	pitch up (tilt up)	
Camera Pointing	3.2	13	deg

Corner Angles	roll	pitch	
top left	6.0475	15.135625	deg
top right	0.3525	15.135625	deg
bottom right	0.3525	10.864375	deg
bottom left	6.0475	10.864375	deg

Corner Locations	y right wing	x forward	
top left	-110	272	ft
top right	-6	270	ft
bottom right	-6	192	ft
bottom left	-108	193	ft
top left (repeated)	-110	272	ft

Detection		
pixels required for detection	4	pixels
angular diameter required for detection	0.03559	degrees
maximum distance from camera for detection	6439	ft
time required for detection	0.5	sec
detection radius on ground	6361	ft
distance travelled during detection time	53	ft

Identification		
pixels required for ID	20	pixels
angular diameter required for ID	0.17797	degrees
maximum distance from camera for ID	1288	ft
detection radius on ground	811	ft
time required for ID	5	sec
distance travelled during ID time	528	ft

Trees		
Zone 2 Line-of-sight radius	577	ft
Zone 3 Line-of-sight radius	268	ft

Figure 20 - Zone 1, 2, 3 Identification Footprint

The footprints for all three zones are different because of the new constraint regarding terrain. The terrain restricted us from seeing the child at any angle above 30 degrees in Zone 2 and any angle above 15 degrees in Zone 3. In Zone 2, this limited our footprint width to 840 feet, but we still had enough vertical distance to gimbal. The restriction in Zone 3 didn't allow us to gimbal so we planned on circling around the child as shown in the search pattern diagram. Also shown is a visual of how the terrain affected how we could detect. The water bottles are trees and the meter stick is the line of sight from the UAV. The UAV theoretically can't see the child if the camera looks outside the 15 and 30 degree circle.

Figure 21 - Demonstration of the Effects of the Terrain in Zones 2 and 3

The detection footprint in Zone 1 extends to the side 567 feet on both sides of the flight path and 411 feet in front of the UAV. The detection footprint in Zone 2 extends to the side 420 feet on both sides of the flight path and 94 to 417 feet in front of the UAV. The detection footprint in Zone 3 extends to the side 259 feet on both sides of the flight path and 196 feet in front of the UAV. The identification footprint is the same for all three zones. The only differences between the identification processes in each zone are the limits at which they can rotate due to the terrain.

The detection footprint for Zone 2 is the only one that doesn't originate from the origin directly under the UAV because we needed the left and right sides of the footprint to have enough forward and backward length to allow for gimbaling. All of these dimensions use the smallest dimensions on the sheet because the footprint is distorted when it is turned to the side. We also made sure to add at least a 4 foot overlap over each camera's footprint on the UAV which is the size of the child. Each footprint shown is how it will be on the ground no matter how much the UAV banks.

3.3 System Detection and Identification

Gimbaling allows us to identify the child without any disruption to our search strategy, thus reducing search time. We are able to gimbal in Zones 1 and 2 since the footprint is big enough. Zone 3, however, doesn't allow us to gimbal since the terrain makes the footprint small. For this we proposed a turn around, which one of our mentors suggested. We didn't pursue the idea before but now it makes sense to use it. He showed us real live footage from Iraq of a UAV making a turnaround maneuver which allows the camera to see the child at all angles, as well as for the necessary identification time. There is just enough footprint area in Zone 3 to detect, so after the child is detected, the UAV will circle around the child while keeping visual contact. We found that we are able to bank at a higher degree without violating the terrain constraints because the camera is always looking at the ground the same way. For example, if we have a 45 degree bank angle, and the camera is rotated 45 degrees, it would be looking straight down.

During normal flight, the camera is zoomed out to a specific zoom to give us the biggest footprint for detection. Once the child is detected in Zone 2 and 3, the camera zooms in, rotates to the location of the child since the footprint is now smaller, and then follows the child straight down adjusting for turns in our search pattern. If the child is detected when the UAV is flying straight, the camera just gimbals down. If it is detected on a turn, then the camera gimbals down with the orientation of the turn to keep the child in view.

One other aspect of the gimbaling and identification process that we needed to consider was what to do when we zoomed in. More specifically, the identification footprint is much smaller than the detection footprint. So when we zoom in, we are missing a lot of ground because we are still moving forward. If there is another object in front of us while we are zoomed in identifying the first object, it would be on ground that our camera hasn't seen yet in front of the UAV. After we identify the first object, the camera is facing backward so it needs to move forward again. In order to catch the camera up to its original detection position, it would have to zoom out, then gimbal forward. We calculated that there would be plenty of time to detect the child when we gimbaled forward, but not enough time to identify. If we did detect a child while gimbaling forward, we would have to circle around the child, even if it's in Zones 1 and 2. Our search time wouldn't be affected because the turn-around maneuver would be the same one that we have in Zone 3. Knowing that we can gimbal forward and still have a method for detecting and identifying no matter what situation we get gives us confidence in being able to cover the entire search pattern.

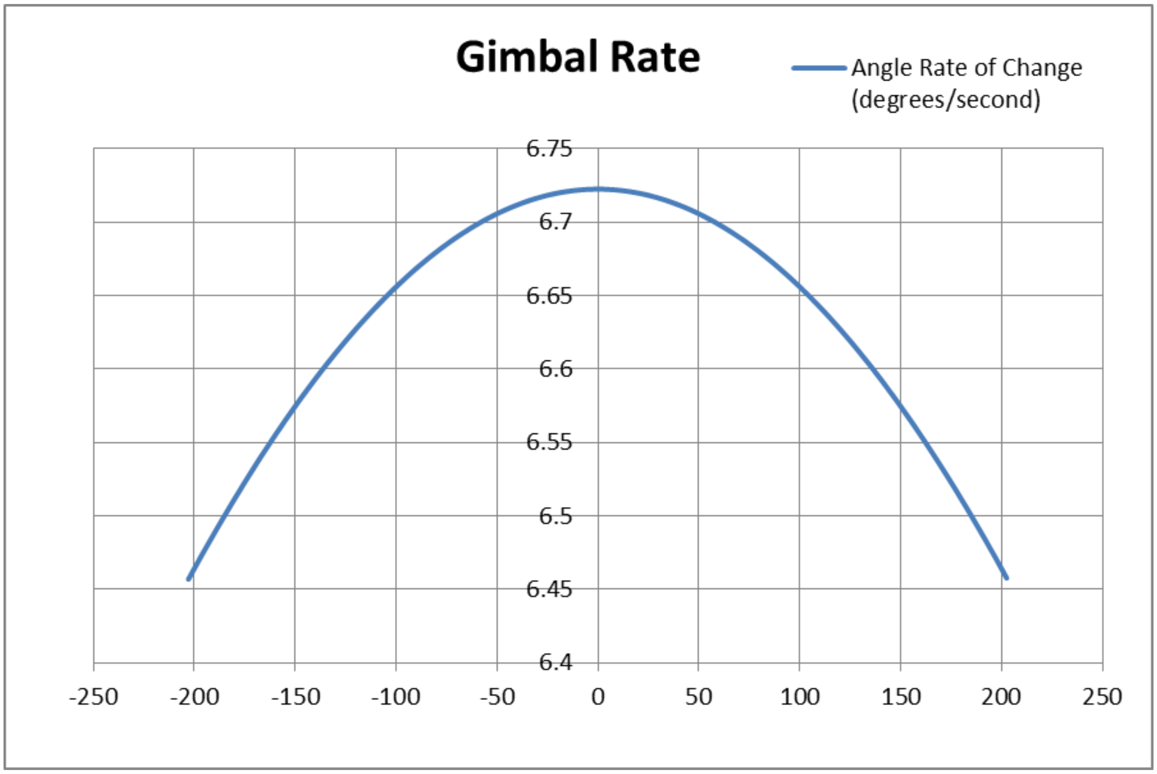


Figure 23 - Graph of angle rate over the distance the camera needs to gimbal

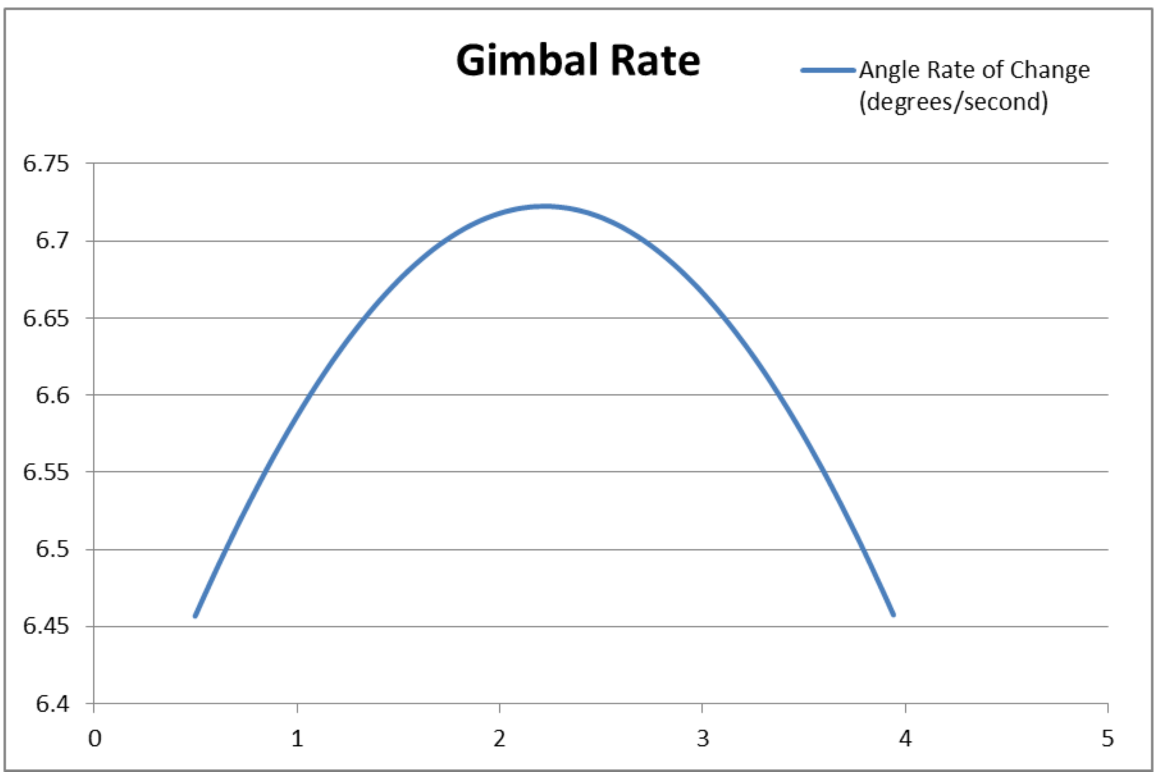


Figure 22 - Graph of angle rate over the amount of time the camera needs to gimbal

3.4 Example Mission

A call goes out to First Class Enterprises. A skier has wandered off the marked trails at Stowe Mountain Resort. The Search and Rescue squad is soon mobilized to assist local authorities with the search for the missing skier. After approximately three and a half hours of travel from the team's regional headquarters in Boston, the team arrives on site with their state-of-the-art Black Mamba small Unmanned Aircraft System. The system specially designed by First Class Enterprises is comprised of two medium-sized UAVs each with two X3000 sensors, video transmitters, real-time target detection software, and specialized gimbal techniques. Half an hour later, the base camp has been set up at the center of the search area and the Black Mamba sUAS is quickly sent to search for the stranded soul.

A ground team consists of:

- 1 Payload Operator ($150/hr)
- 2 Safety Pilot ($100/hr)
- 2 Operational Pilot ($150/hr)
- 1 Range Safety/Maintenance officer ($175/hr)
- 2 Launch and recovery Assistant ($50/hr)

Soon after the Black Mamba sUAS is launched by the catapult it begins executing its search commands. Because of the differing terrain, the search area has been split into three zones of differing brush size. The first UAV begins by moving to the outside of the first zone, and then sweeps back and forth towards the base camp. This zone has no brush and thus is the easiest to detect and confirm in. Not long after, the UAV has potentially targeted the skier. The ground personnel are immediately called into action. The high-tech sensors on-board the aircraft gimbal to maintain constant visual contact with the detected object, meanwhile video technicians monitor the video feed to positively identify the lost skier. The great zoom capabilities of the powerful X3000 sensors allow the operator to clearly see the object in question. Unfortunately, this time, the object detected was merely a rock. As programmed, however, the plane never left its initial flight pattern, and after the object is identified as a false positive, the UAV wastes no time at all, resetting the sensors to their default position and continuing on its way.

The aircraft quickly finishes searching the first zone, then quickly transitions to the next zone. Again moving to the outside, and then sweeping back and forth towards the center. The second zone has medium level brush, meaning detection and confirmation is obstructed. To compensate the UAV must zoom in, readjusting the footprint of the sensors, in order to ensure that any objects in view can be successfully identified.

At the beginning of the search, the team from First Class Enterprises deployed a second UAV. This plane is sent to the third and most obstructed zone. Because of the large brush, the second plane must zoom in, creating a very small footprint, to account for the loss of visibility. Another object is soon detected. Because of the extremely limited visibility in the third zone, the gimbal techniques will not be enough. The aircraft quickly banks to the side, spiraling around the detected object. The object is quickly identified as a false positive, and the plane simply continues its spiral around the object until it has returned to the original search pattern.

At a blistering 80 miles per hour, the two aircraft quickly sweep across the search area. Another object is detected by the first aircraft, this time in the second zone. The first UAV quickly gimbals and confirms that the object is another false detection. However, at no point during the false detections did the first UAV leave its search pattern. The advanced gimbal techniques allow it to rotate sensors to keep visual contact while allowing constant flight altitude and airspeed, eliminating any time wasted by leaving the search pattern to identify objects.

After multiple false detections, the second aircraft spots and identifies the helpless skier in the third zone, transmitting his or her coordinates to a crack team of rescue volunteers. 44.9307 minutes have passed since the Black Mamba sUAS was deployed. $12,379.75 was spent ensuring the skier's safety, and it was luckily covered by their insurance. Within minutes the skier is found and returned to base camp, where they are quickly taken to the nearby Copely Hospital for examination. First Class Enterprises and the Black Mamba sUAS save the day yet again.

3.5 Mission Time and Resource Requirements

First Class Enterprises' Black Mamba sUAS completes the example Search and Rescue Operation as follows:

The ground team consists of:
1 Payload Operator ($150/hr)
2 Safety Pilot ($100/hr)
2 Operational Pilot ($150/hr)
1 Range Safety/Maintenance officer ($175/hr)
2 Launch and Recovery Assistant ($50/hr)

Travel Time from Headquarters: 3.5 hours

Set-up Time: 0.5 hours

Flight Time: 0.7488 hours

Total Operational Time: 8.7488 hours

Operational Cost Per Hour: $925/hr

Initial Cost: $202,829.64

Total Operational Cost per Mission: $8325.00

Amortized Cost per mission: $12,379.75

Objective Function Value: $463,594.69 hour*$

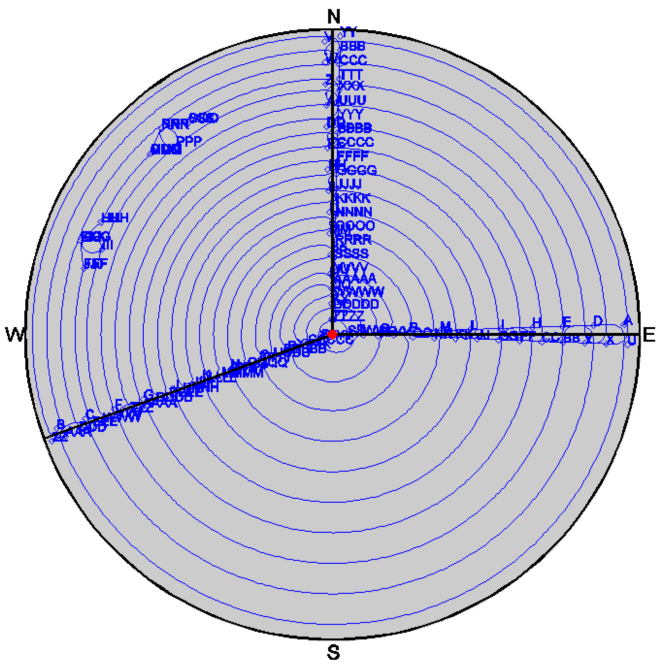


Figure 24 - Mission Profile

4.0 Business Case

4.1 Target Commercial Applications

While UAVs have primarily taken off in the military and defense industries, there are a variety of other civilian uses if regulatory restrictions were to be eased. From conventional applications such as border patrol, crowd control, traffic monitoring, forest fire detection, and oil, gas and mineral exploration/production, to more radical uses such as transporting goods such as food—the possibilities are endless.

UAVs offer a more reliable and cost-efficient method of doing common tasks. However, reliability is a key issue for these planes aimed at civilian use, as the industry lobbies to aviation regulators to gain access to skies that have remained off limits. For example, instead of using people to patrol an area by foot (like the country's border), we can use UAVs piloted by a computer—it's much cheaper, and often more reliable. If the air space around these areas were eased and open to unmanned systems, we would be able to monitor our border much more effectively. Our UAV would be fit to do such a task as it has a large detection footprint, effective search pattern, and can search an area of 12 square miles in less than 45 minutes. Additionally, the cost would be considerably low, compared to having people on foot patrolling the border. As development of automated object detection increases, commercial production of a "border patrol" UAV is highly likely. The one barrier that is preventing us from modifying UAVs (like ours) are the current FAA guidelines. We are prohibited from flying our plane during night time –an advantageous time to patrol the border. Additionally, flying over private property invites a series of legal complications that must be dealt with, if adjacent to the border.

As the price of gas is rapidly increasing and our supply is decreasing, it is critical we find more effective methods of oil, gas and mineral exploration/production. UAVs can be used to perform geophysical surveys—in particular geomagnetic surveys. Our current system of oil and gas production requires a constant monitoring of the integrity of the respective pipelines and related installations. Consequently, these pipelines that are above-ground could be very easily monitored with an assortment of cameras. Thus, our UAV could in essence fly above these pipes and save hundreds of hours of monitoring and inspecting. If a problem is detected, it would alert the respective oil company and it could be pinpointed and fixed. Prevention in leaks can especially save money and protect the environment. Again, using a UAV to do this task would save money, time, and is a win-win situation for everyone even the consumer of gas. As FAA regulations ease up, this is increasingly feasible.

It is evident that monitoring and surveillance in various methods could be quite easily adapted to a multitude of UAV designs. There are also more radical uses such as the transportation of goods including food. There are endless scenarios, both in developing countries and search and rescue missions, where it is not possible to deliver food and other items that can help prolong life. Most payloads can be stored in the internal payload bay inside the airframe. There are already many existing helicopter configurations, in which external payloads are tethered to the bottom of the airframe. With our fixed wing design, payloads can be attached to the airframe, granted it can still maintain steady flight. Additionally, payloads that are enclosed in aerodynamic pods can be developed. It is clear that our UAV system has many more uses than simply search and rescue. With our dual plane sUAS, we are able to cover a great amount of area, very quickly and efficiently.

There are several emerging trends in the current UAV market that we wish to explore.

Emerging Trends in UAV Markets	
Trend A	Growth in Unmanned Combat Aerial Vehicles (UCAV)
Trend B	Increase in endurance limit
Trend C	Increase in mission capabilities of UAVs
Trend D	Increase in awareness of UAVs
Trend E	Increase in HALE (High Altitude, Long Endurance) UAVS

As UAV's become more mainstream, lots of money is being poured into research and development—specifically to improve the technology itself. Scientists all around the world are making an effort to improve certain aspects of UAV's. Illustrated above are the many trends that are emerging in the UAV markets. Many things such as endurance limit and awareness would drastically improve First Class Enterprise's sUAS. An increase in endurance would allow much longer search and rescue missions. Consequently, an increase in awareness would ultimately lead to less cynicism among people. It is important to understand the growth and direction of the competition and general sector of UAV's in order to plan the future for First Class Enterprise.

In addition to specific trends, it is critical we take note of what sectors of the economy are utilizing UAV technology. UAV's have significantly taken off in the civil, commercial, military, science and economic realms. They are emerging to be a primary tool in solving many prevalent problems we face daily.

UAV Involvement in Various Sectors of Economy				
Segments		**UAV**	**Rigid lighter-than-air**	**Semi-rigid lighter-than-air**
Civil	Natural Disasters	Low	Medium	Medium
	Humanitarian Relief	Medium	Least	Least
Commercial	Environment	Low	Medium	Medium
	Weather & Storm Tracking	Low	Medium to High	Medium
	Advertisement	Least	Medium to High	Medium
Military / Security	Defense	Medium to High	Medium	Low
Science	Wireless communications	Medium to High	Medium	Medium
	Precision Agriculture	Low	Low	Low
	Cargo Transport	Low	Medium	Medium

UAV technology has tremendous potential. They can be used to do a lot of things faster and more efficiently. After analyzing what is already being done, and what we are moving towards, we will have a better understanding of how to proceed with practical and commercial uses for our UAV.

4.2 Amortized System Costs

In order to successfully carry out 50 missions, we need to ensure we have the necessary capital. Amortized cost is calculated by dividing the total cost including initial costs (the T variable in the Objective Function) by 50.

Amortized Cost Per Mission: $12,379.08

Total Cost: $618,953.75

4.2.1 Initial Costs

In order to mass produce our sUAS, we will need to build one initial system to prove its worth. (More on how we raise the necessary capital further down.) The System Initial Cost is $202,829.64. During the actual mission, the System Per-Hour Cost: $925.00. The following is a specific breakdown of our initial costs.

Airframe				
Component	Fuselage Station (inches)	Moment (inch-lbs)	Weight (lbs)	Per Item Cost
Fuel tank	0.00	0.0	0.00	$12.50
Batteries	18.00	99.0	5.50	$385.00
Electrical	24.00	12.0	0.50	$5.00
Fuselage	31.00	142.3	4.59	$229.30
Wing	6.50	10.4	1.60	$80.09
Horizontal Tail	35.00	17.2	0.49	$24.61
Vertical Tail	20.00	288.4	14.42	$721.05
Total Airframe	21.01	569.2	27.10	$1,457.55

Sensor Payload Options							
Model	Fuselage Station (inches)	Moment (inch-lbs)	Weight Per Unit (lbs)	Cost Per Unit	Nominal Power (Watts)	Maximum Power (Watts)	Quantity
X3000	8.25	34.7	2.10	$38,000.00	10.0	14.0	2
Total Sensor Payload	8.25	34.7	4.20	$76,000.00	20.0	28.0	

Propulsion System Options								
Fuselage Station (inches)	Moment (inch-lbs)	Weight Per Unit (lbs)	Per Item Cost	Maximum Power (Watts)	Static Thrust (lbs)	Engine Efficiency	Propeller Efficiency	Quantity
38.15	42.0	1.10	$295.00	1,800	13.0	96%	80%	1
38.15	42.0	1.10	$295.00	1,800	13.0	96%	80%	

Additional UAV Components							
Component	Fuselage Station (inches)	Moment (inch-lbs)	Weight (lbs)	Per Item Cost	Required Power (Watts)	Required Quantity	Quantity
Video Datalink UAV Transmitter	32.50	3.3	0.05	$200.00	0.4	Up to 1 per sensor payload	2
Command Datalink UAV Tranceiver	4.00	0.4	0.10	$300.00	0.3	Up to 1 per UAV	1
Onboard Video Recorder		0.0	0.35	$600.00	0.3	Up to 1 per sensor payload	0
Flight Control System	18.00	1.8	0.10	$2,000.00	0.1	1 per UAV	1
Total Additions	18.17	5.5	0.30	$2,700.00	1.20		

Ground Station Options			
Component	Per Item Cost	Required Quantity	Quantity
Safety Pilot Flight Box	$200.00	1 per UAV	2
Operational Pilot Workstation Computer	$1,500.00	1 per UAV	2
Sensor Payload Workstation Computer - Version A	$2,000.00	1 per sensor payload	0
Sensor Payload Workstation Computer - Version B	$12,000.00	1 per set of 4 sensor payloads	1
Command Datalink Ground Transceiver	$300.00	1 per UAV	2
Video Datalink Ground Receiver	$400.00	1 per sensor payload	4
Shelter/Trailer - Streamline	$12,000.00	1 per sUAS	1
Shelter/Trailer - Fleet	$14,000.00	1 per sUAS	0
Shelter/Trailer - Armada	$16,000.00	1 per sUAS	0
Launch Catapult/Snag Line	$12,254.55	1 per sUAS	1
Ground Station Total	$41,854.55		

These tables show the specific costs needed to make one UAV and a complete sUAS. Adding up the airframe ($1,457.55), the sensor payload options ($76,000), the propulsion system options ($295.00), and the additional UAV components ($2,700.00), we get a total of $80,452.55 for one UAV. The second UAV has an extra pound of battery ($70.00) so its cost is $80,522.55. If we add those two UAV costs together, we get the total cost of two UAVs,

$160,975.10. Then when we add the ground station options ($41,854.55), we get the total sUAS cost of $202,829.65. All these cost must be covered prior to commencing our first mission.

4.2.2 Direct Operational Cost per Mission

For the example mission illustrated above, the total operational cost for the example mission is $8,325.

Our cost per mission is the price our consumers or the government pays to ultimately find the missing person. It is critical we minimize this in order to edge out our competition. Operational costs are reoccurring so you must have enough capital to sustain that. We plan on having a profit margin of 25% to begin which is a reasonable estimate for a startup.

Operational Personnel		
Resource	Resource Cost Per Hour	Number of Positions Required
Payload Operator	$150.00	1
Data Analyst	$150.00	0
Ground Search Personnel	$0.00	3
Range Safety/ Aircraft Launch & Recovery/ Maintenance	$175.00	1
Launch & Recovery Assistants	$50.00	2
Safety Pilot	$100.00	2
Operational Pilot	$150.00	2
Personnel Total	$925.00	

4.2.3 Amortization

In order to mass produce our sUAS and begin using it for search and rescue missions, we will need to raise some initial capital, to fund the manufacturing of the system and payroll. The system will be in action for some time before enough revenue is generated to profit from the operations. There are many ways of raising capital, including taking a loan from a bank, bringing in investors and/or selling equity of the company.

We would like to ultimately have strong nationwide and region wide coverage. Our sUAS will be distributed across America proportional to the area of each state—with an emphasis on national parks. Our long term goal is having 100 sUAS' manufactured to maximize coverage and to minimize the travel time to the operational location. However, we will first build one system to prove its worth. To raise this capital, we will recruit a few private angel investors to manufacture one system. This system will be demonstrated to banks in order to secure a loan for the full production and rollout of our system. This demonstration will likely secure a contract with Homeland Services or the National Forest Service to serve as collateral from the loan.

The cost of one sUAS is $202,829.64. However, after factoring in payroll for 50 missions, we will need an initial investment from investors of $619,079.64. In return, we will offer them x percent equity in our company. The benefits of having investors would not only be their financial backing and funding from the back end if there is business, but their valuable skills, connections and experience to advance our company. We will also consider a buyout option for our investors at that time to prevent losing profits from their equity for life.

In time, our SAR missions will begin to generate profit and we will be able to sustain on our own. As the population of America rises, there will be inherently more lost people. There is a tremendous amount of potential as the costs and operating expenses decrease and the demand increases.

Overall Cost: $619,079.64
Cost of One UAV: $80,452.55

4.3 Market Assessment

The UAV is an emerging sector of the aerospace industry with great opportunity and market demand that can be leveraged for high profitability in the coming years. About 70% of global growth and market share belong to the US and is up a new 15% this past year. UAV expenditures reached more than $3 billion this past year, with over half dedicated to research and development. An increase in awareness and mission capabilities of UAVs is driving innovations and many new applications. However, to ensure customers are receiving top notch quality, we must conduct some studies. To properly assess the capabilities of our UAV, we have conducted a thorough market analysis for comparison.

There are many types of UAV’s out in the market. As seen above, UAV’s are used in many economic sectors and thus have different technical requirements. The following is an illustration of the classifications of commercial UAV’s.

Classes	UAV-Close Range	UAV-Short Range	UAV-Endurance
Range	Approx. 50 KM	200 KM	More than 200 KM
Endurance	30 min - 2 hours	8 to 10 hours	Minimum 24 hours
Weight	2 - 10 lbs	< 10,000 lbs	< 229,000 lbs
Speed	-	<300 mph	< 454 mph
Altitude	<1000 ft	< 50,000 ft	< 65,000 ft
Pay load	-	<3800 lb	< 1,900 lb
Cost	$500 - $1500	< $8,000,000	< $123,000,000

For the requirements in our mission, our UAV fits in the “close-range” category. Our UAV would be able to adapt to different situations if need be, but our current configuration is geared toward close range, search and rescue missions. The technical merits of each UAV are geared towards its use.

An estimated 300,000 people are reported to be lost annually. For each case, a search and rescue UAV can be used to effectively and efficiently find the person. The time of a typical search and rescue (SAR) operation ranges from a few hours to spread over many days using helicopters, boats, and teams of employees. The United States Coast Guard is the leader in SAR operations, averaging 114 people per day, at a total annual cost of $680 million. There are various different types of land and air vehicles that assist in these SAR operations, many being UAVs. The Black Mamba will serve as an inexpensive and efficient alternative for many SAR missions.

UAV	Cost	Use	Top Speed
Boeing Insitu ScanEagle	US$100,000	UAV United States Navy	55-80 mph
Eurocopter HH-65 Dolphin	US$9 million	Search and Rescue Helicopter	201 mph
Sikorsky HH-60 Pave Hawk	US$15.8 million	Combat Search and Rescue helicopter	224 mph
MQ-9 Reaper	US$36.8 million	Combat Air Vehicle	300 mph
MQ-1C Grey Eagle	US$90.9 million	UAV combat	170 mph
Black Mamba	US $80,452.55	SAR	80 mph

It can be concluded for SAR, the Black Mamba would be the way to go. The other military UAVs have many necessary functions for SAR. Comparing our design to the Boeing Insitu Scan Eagle, it is approximately $20,000 cheaper. Additionally, the operational costs of the Black Mamba are significantly less than other military equivalent aircraft. Our UAV is the most competitive design on the market because it has much functionality for its price tag.

4.4 Cost / Benefit Analysis and Justification

In order to properly justify the credibility of our sUAS, we must ensure that we meet the vision, mission, and values of our consumers. Our number one priority is to be able to accomplish the desired mission as quickly as possible. As illustrated by our system specifications, our sUAS is capable of doing this in a multitude of scenarios.

We firmly believe that in today's global market and economy, businesses should prioritize reducing costs. Thus, we placed great emphasis on cutting costs while not sacrificing quality and capability in our design. Each state of our design process was conducted with this principle in mind. Consequently, half of the Objective Function, which must be lowered as much as possible, is cost. Therefore, it was important that we find a balance between time and cost and make sure the trade-off is well worthwhile in the long run.

This can be seen in our design workflow right from the beginning when brainstorming sensor payload scenarios. We wanted to have a powerful sensor, while not spending too much money. X3000, which we would later find out, had the perfect amount of zoom needed at our altitude. We didn't overspend, but got the necessary functionality out of the sensor. Another key aspect of our design in which we save money is our gimbaling system. Without needing to change altitude or slow down while confirming a target, we could simply continue our search pattern and save battery life and time in the process. The sensors would simply gimbal and track the target as we flew over the footprint. This saves us a tremendous amount of money over the 50 missions. Thus, we are able to do the same mission, same SAR, same target, with less time and less cost with our sUAS.

One of the biggest decisions our team faced was the number of UAV's we wanted in our system. There is a significant tradeoff between time and cost. It is intuitive to believe that the addition of a UAV decreases our search time but we must consider our costs. To successfully decrease the Objective Function, we must also decrease cost. Additionally, it is essential we are able to sell our services and be able to have angel investors to purchase our initial system. Finding this balance came from research and testing to be able to determine a sweet spot between time and cost. We are confident we are at a price point that appeals to our consumers, yet still remaining competitive with our search time of 45 minutes.

In addition to our actual sUAS, our company as a whole, First Class Enterprises, serves a greater humanitarian need through its various "green" and outreach programs. Our culture is one that values innovation, and we are not afraid of change. We ensure our companies long-term sustainability through its ability to adapt and modify its processes according to its needs—even if it means cannibalizing our own products. Our company is bigger than our sUAS, and our scientists have developed a series of technologies and programs we would like to develop/explore. Additionally, in order to remain competitive in the UAV market, it is critical we stay on top of the latest aeronautical technologies. First Class Enterprise is exploring the following to implement within our design and infrastructure:

Ethics about drones and appearance of it in cultures; reducing bad stigma

One of the fundamental limitations of the usage of UAV's today, are the stereotypes and negative stigma that come with it. With technology advancing at such a high rate, many people develop a generic fear of being watched, especially by the government. When legislation regarding the use of UAV's is brought up, many are quick to turn it down simply due to privacy issues. It is essential for federal regulations to relax if commercial use of UAV's is to take off. Thus, our company proposes an outreach program, targeting young adults to spearhead a "pro-UAV" movement. This would obviously have to be strictly controlled as we too understand the dangerous potential of everyday civilians getting their hands on UAV technology. However, after careful risk analysis, it is deemed that the benefits of commercial use of UAV's can be used to increase productivity and improve everyday lives. UAV's are inevitable, and it is critical we seize the moment before the technology is abused.

Infrared:

One of the limitations imposed by the challenge was the limited amount of sensors we had available for selection. If given the chance, our team would have liked to explore infrared sensor technologies—especially with the addition of trees in the National Challenge. Being able to sense heat, infrared sensors would be in essence able to "scan" through the trees. Once detecting an increase in heat—related to the average human body, the UAV would immediately know where the missing child is. While infrared would surely increase the total cost of our sUAS, it has the potential for reducing time and should surely be explored in a real life scenario.

Hydrogen Fuel Cells/Solar Energy

As climate change increases, industries are becoming increasingly more aware to go "green." Going in line with these efforts, our team pondered alternative energy technologies. The one thing that will always limit the performance of an aircraft is how much of its energy source it can carry at once. For a petroleum aircraft, this happens to be the fuel tanks, and for electric airplanes, it is typically the batteries. The modern day lithium polymer batteries are the best power to weight batteries ever made. We wanted to find a way to recharge the batteries during flight. Every second that passes, our sun emits more energy than all of the energy ever used in mankind's history. As a result, we turned to harnessing solar energy as a possible efficiency booster. With the recent accomplishments in flexibility of solar cells, we decided to look into the possibility of incorporating solar panels into our own aircraft's surfaces.

Just like with the electric car market, you may find that range is being slowly extended with new battery technologies, but one issue still remains. The time it takes to recharge batteries is simply too slow. For this reason alone most people would probably choose a petroleum aircraft over an electric aircraft simply because cross country trips, with multiple refueling/recharging stops, would take much more time in the electrically powered aircraft. And even though the solar cells would create some extra power, it alone doesn't add enough extra range to go up against the petroleum competitors. To overcome this dilemma we had to review the car market once again.

There are three main types of electric motor cars on the roads right now. The first is powered by a battery pack such as the Nissan Leaf but this obviously has the low range, and long recharging time as previously talked about. In an effort to overcome this range problem, General Motors came out with their range extender, the long awaited Chevrolet Volt. This car's electric power plant is powered by a small battery array that is constantly being recharged by a petroleum powered generator. That design definitely increased the effective range of the vehicle while cutting down on recharge/refuel time due to the generator, though a large issue still exists with this design. The Volt still uses petroleum. In order for us to have a technologically superior design, and separate ourselves from other teams, we had to find a way to push the innovation envelope even more-so than Nissan and even GM had.

That is when our attention was turned to a futuristic experiment going on in California. The state government in California called for hydrogen refueling stations to be built along a few major road networks. Honda made the first commercially available hydrogen fuel cell electric car called the FCX Clarity. For the first time in automotive history a car with no emissions other than pure H_2O was able to drive like a normal car, and achieve the range of a normal car. Finally we found the technology needed to help our electric design better compete head to head with the standard petroleum aircraft.

With the decision to use hydrogen fuel cell technology, we wanted to come up with a way to still utilize solar cells. Our solution to this problem involved us going back and taking another look at Chevrolets Volt. If we take the Volt's topology of a generator powering a battery pack which then feeds energy to the motor, we were able to incorporate out solar cells again. Our hydrogen fuel cell will act as the generator that feeds into a Lithium Polymer battery. The solar cells also feed into the battery so as to add a little bit more power and improve the range.

Systematic Ground Search Team of Volunteers:

We want to create a system in which we leverage social media to have a group of volunteers that are essentially “on-call” to partake in ground search missions. During a situation in which a child is missing, we can generate traffic on Facebook and Twitter to easily recruit volunteers to help find the missing child. In each town, an existing group of volunteers would surely speed up finding the child. Being able to use tools that young people are on daily, we could easily access millions of people very quickly to aid in these search and rescue missions.

Everything once in a while, a product comes along so great, it’s almost magical. But with all things, a great product is worthless unless it is properly delivered to its consumers. We have developed a play to attract investors and gain a contract to mass-produce our sUAS. We firmly believe that we can advance UAV technology and begin to take market share in our sector. Additionally, our company is one that values innovation and progress, and we firmly believe we have a product capable of conducting great search and rescue missions.

5.0 Appendix

5.1 Final Test

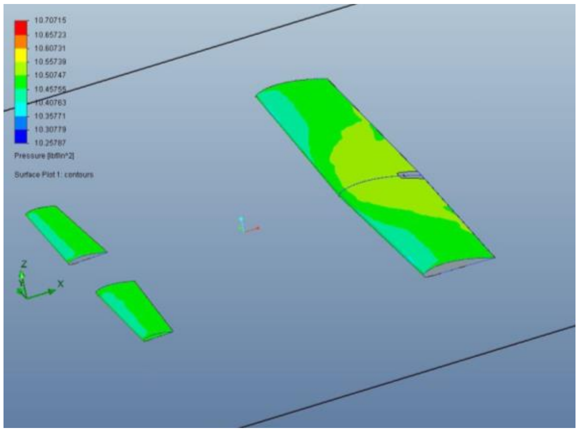


Figure 25 - Top View of Pressure Gradient of Final Wing and Canard Configuration

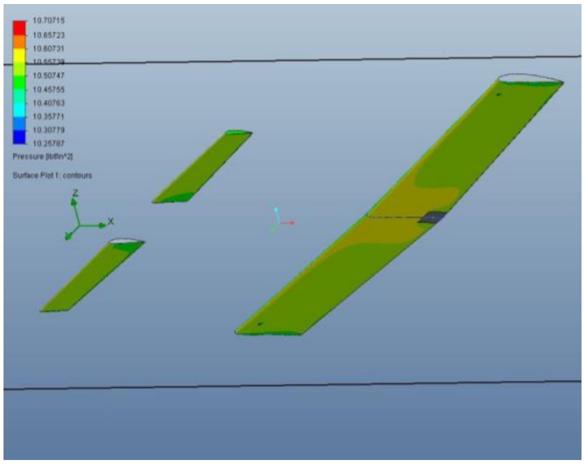


Figure 26 - Bottom View of Pressure Gradient of Final Wing and Canard Configuration

5.2 FAA Guidelines and Regulations

FAA Technical Readiness Criteria		
1	The airframe must withstand anticipated aerodynamic flight loads throughout the completerange of maneuvers anticipated within the approved flight envelope with an appropriate margin of safety (+6/-4g's ultimate load).	We are within the limits.
2	The propulsion system must provide reliable and sufficient power to takeoff, climb, and maintain flight at all expected mission altitudes and environmental conditions.	We have enough power.
3	The electrical system must generate, distribute, and manage power distribution to meet the power requirements of all receiving systems.	Yes
4	The UA must safely and expeditiously respond to pilot commands necessary to avoid conflict or collision with other aircraft or ground obstructions.	Yes
5	Aircraft with an autopilot must ensure the autopilot keeps the aircraft within the flight envelope and any other appropriate flight limits for autopilot enabled operations under any foreseeable operating condition.	Yes
6	Software used to control critical aircraft functions must be developed with the appropriate software safety guidelines.	Yes

FAA Rules for Public sUAS Operation in the National Airspace System	
Operation in Class G airspace for a UAS weighing 55 pounds or less with a maximum speed of 80mph (70 knots).	Max of 33.7 lbs.
The proponent will publish a NOTAM (NOTice to AirMen) to alert non-participating aircraft of the operation.	Yes
Operations will be conducted within visual line of sight of the pilot/operator utilizing VFR weather requirements.	Yes
Each control workstation may only control a single UAV at a time during normal flight operations.	Yes
Night operations are not permitted.	Yes
Operations will be conducted over military bases, reservations or land protected by purchase, lease, or with express permission of the landowner. Operations will not be conducted over wildlife preserves; national parks or other traditionally protected airspace unless express permission is granted by the controlling authority.	We assume the challenge is presented to us with permission to search the area. If not, we are confident in our ability to work with local law enforcement to attain the necessary warrants. If we were to conduct this search elsewhere, we would need to work hastily to attain the necessary permission.
The UAS will remain outside of five (5) NM from any civil airport or heliport	Yes

Aircraft Constraints	
The sUAS will comply with RWDC FAA Technical Readiness Guidelines	Yes
A maximum gross takeoff weight (including fuel) of not more than 55 pounds per UAV. There is no minimum weight requirement.	Max of 33.7 lbs.
Antennas on-board the UAV must be separated by a minimum of 18 inches to avoid destructive interference.	Yes
Search operations are conducted at an altitude of 150 - 1,000 feet above local ground level (assume that ground level is equal to the ground station altitude, a constant 8,000 ft MSL).	1000 above local ground level
Your choice of flight control hardware, sensor selection, video datalinks and associated ground hardware is limited to cataloged items to be provided. A catalog of propulsion options is provided, but substitutions are allowed.	Yes, there were no modifications to the hardware given.
The aircraft must be able to take-off and clear a 50 foot obstacle within 300 linear feet from the starting position. This is demonstrated within one of the provided MathCad worksheets. A launch catapult and capture snag-line are provided.	We clear a 50 feet obstacle within 280.355 feet.

5.3 Acknowledgements

The Real Word Design Challenge presented us with a stupendous opportunity to put our STEMB skills in practice. Combining our passion for science and technology, we grew as people, coming together to collectively develop a great product. Every once in a while, a design so great is developed –it's almost magical. The past five months have come with a lot of highs and lows, yet our collective strength kept our spirits high and we stayed motivated. Our sUAS is optimized and ready to implement in real world scenarios and captures the true essence of a true Real World Design Challenge. Thank you for this opportunity.

5.4 Bibliography

"Market Intelligence." *Market Intelligence*. N.p., n.d. Web. 03 Apr. 2013.

"National Association For Search And Rescue." *National Association For Search And Rescue*. N.p., n.d. Web. 03 Apr. 2013.

"The UAV - The Future Of The Sky." *The UAV*. N.p., n.d. Web. 03 Apr. 2013.

"UAV Market Research." *UAV Market Research*. N.p., n.d. Web. 03 Apr. 2013.

"UAV Solutions | The Future of Unmanned Flight." *UAV Solutions | The Future of Unmanned Flight*. N.p., n.d. Web. 03 Apr. 2013.

"Uavs." *Popular Science*. N.p., n.d. Web. 03 Apr. 2013.

"Ventura County Sheriff's Search and Rescue Dive Team." *Ventura County Sheriff's Search and Rescue Dive Team*. N.p., n.d. Web. 03 Apr. 2013.