FY16 National Unmanned Aircraft System Challenge: Moisture Detection in Precision Agriculture

Xaverian Engineers

Xavier High School

181 Randolph Rd. Middletown, CT 06457

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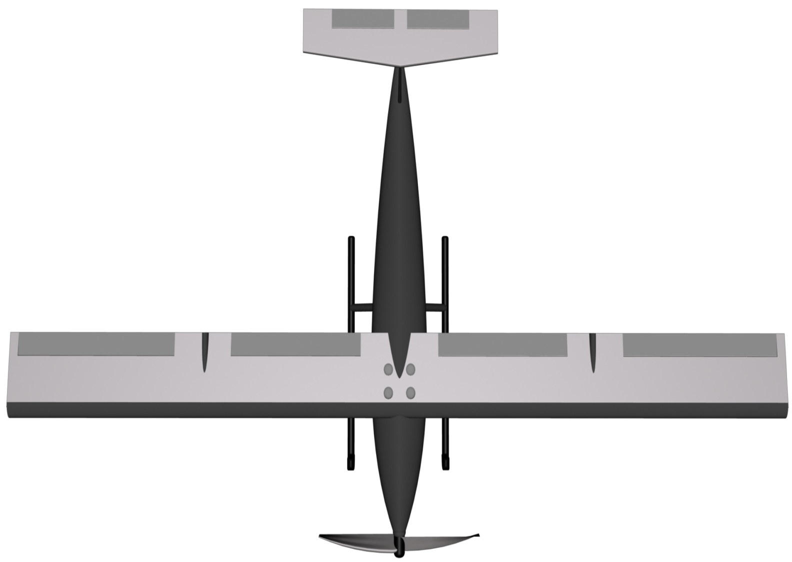
Objective Function: 0.8514

X181-KMR



Submitted in Response to the Real World Design Challenge

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ABSTRACT

By 2050, it is estimated that there will be an additional 2 billion people. In order to address the population growth, humans will need to produce 70% more food. Recent droughts particularly in the United States have shown the need for water conservation. The Xaverian Engineers were challenged to develop an Unmanned Aircraft System (UAS) capable of detecting the moisture content of the ground and crops. This information is to be provided at a reasonable price to farmers so that they can save money and help conserve water. The team was asked to design a solution where is a fixed-winged Unmanned Aerial Vehicle (UAV) is able to complete the mission efficiently while showing that is a profitable solution.

Due to their effect on Connecticut's economy and its abundance in the United States, the team chose corn and raspberries as the crops that would be detected. In order to detect corn and raspberries, the team decided to go with an Infrared Camera namely the X3000 camera provided in the RWDC catalog. This camera allows the UAV to collect accurate data about the field's moisture so that it can be used to help farmers conserve water. The team's autonomous design is equipped with a line of communication devices, flight controls, and onboard sensors. The team will employ an Operational Pilot, Range Safety/Aircraft, Launch, & Recovery/Maintenance personnel, and a safety pilot. These personnel have differing roles and titles but their main purpose is to execute the mission safely and efficiently. These personnel will remain near the ground control station and will take over the UAV in case the UAV malfunctions. If not, the UAV will fly autonomously using its pre-programmed autopilot and other sensors.

The UAS must scan for moisture over two one square mile field without exiting the parameters of the field or flying over the no-fly zone. Moreover, three detection missions must be accomplished over the growing season. Ground equipment is powered by solar panels, and a light truck is used to both transport and launch the aircraft. In total, the detection for each field takes under two hours. Moreover, the high winged design of the airframe allows for the greatest field of view for field detection.

The UAS must effectively determine the moisture content of a two square mile fields. Particular to the system, the UAS should be used by local farmers, unlike current large scale detection methods. Because of this, the demand for the UAS warrants low operating costs in order to compete with other detection methods, both current and future. The cost to detect a field's moisture with the UAS is one such that both possible revenue is limited while the operating costs must be limited.

Finally, it is important to note that UAS refers to the entire operating system. UAV, however, only refers to the aircraft. Therefore, the UAS is operated, detects moisture, executed a flight-plan, and reports data while a UAV is the airframe which is flying.

Keywords: [UAV, UAS, Moisture Detection, Agriculture, Connecticut]

1. Team Engagement

1.1 Team Formation and Project Operation

For the 2015-2016 competition, the team choose Mihir Khunte and Keith Cestaro as team project managers. It was decided to pick two leaders because it would allow the team to work more efficiently by having both members combine their approaches and expertise to develop a winning design. Due to the abundant interest from new members of the engineering club to take part on the team, last year's six person team decided to hold tryouts to fill the one remaining spot. The team asked each applicant to submit a resume with a list of his engineering experiences. In addition, the team gave a written test in order to measure aptitude and commitment. Using the data and information about these applicants, the team narrowed down their choices and discussed possible candidates. The team picked Roham due to his past experience with modeling, which the team felt was needed for another successful year.
Meet the members of the team:

Mihir Khunte, Project Manager (PM) [Junior]

Mihir Khunte is a junior at Xavier High School. He is taking all honors (H) and Advanced Placement (AP) classes including H Physics, AP Chemistry, H Engineering II, and H Pre-Calculus, and has received the distinction of high honors. In terms of extracurricular activities in addition to engineering team he is an Eagle Scout, participates on the math team, member of the Ryken service society, and rower on the crew team. He participated in the 2015 Xavier Engineering Team with research and development of the UAV. He has knowledge and experience with modeling software including Creo and Google Sketch Up. In addition, his leadership capabilities and time management skills will serve the team well. Considering his expertise, he will be a valuable member of the team as his role as Project Manager.

Keith Cestaro, Project Manager [Junior]

Keith Cestaro is a junior at Xavier High School. He has taken H Biology, H Chemistry, H Algebra II, H Engineering, and H Geometry before this year. He is currently in all honors and AP classes including H Engineering II, AP Chemistry, and H Pre-Calculus. Keith participates in many after school activities along with engineering team including junior firefighting where he has the role of being 3rd in command of the division. One of his major jobs in the division is keeping meetings on track and recording important information said during meetings. He has also taken a Physics and Philosophy class at Yale University over the summer. In addition to all of this, Keith is currently pursuing his EMT which requires a 300 hour long course in order to achieve. On top of all of this, Keith is fluent in many different programming languages including popular ones such as Javascript, HTML, and CSS. With the immense amount of leadership positions, he has held and currently holds, Keith will make a fabulous addition to the team as Project Manager.

Robert Larese [Junior]

Robert Larese is a Junior at Xavier High School. In addition to a team member, he is a Boy Scout, Class President, as well as the emeritus Project Manager of the team. He has stepped down to allow two new co-project managers take the lead, while still maintaining an active role in the team as the emeritus leader and a member. He has taken Honors Physics and Honors Geometry as a freshmen, as well as Chemistry and Algebra II as a sophomore. Currently, he is enrolled in Honors Pre-Engineering II, Honors Pre-Calculus, and AP Chemistry. In addition to this, he is a member of Xavier's Crew Team, and has demonstrated time management in his courses, sport, and Engineering Team. These skills have helped the team maintain a timeline and has kept deadlines on track. For example in the Real World Design Challenge two years ago, he was an essential component of the preliminary research. He has large amounts of experience in project management and leadership from leading the last few years challenges. In addition to this, he has assumed responsibility for the chief of research and development, coordinating the preliminary research to the modeling phase.

Vincent Salabarria [Sophomore]

Vincent Salabarria is the director of the Business Case for this year's challenge. He is a sophomore at Xavier High School. The experiences Vincent has in his honors and AP classes, including mathematics, English, and physics, are important to the success of the Business Case and the challenge in general. Vincent has also accumulated about sixty five hours of flight training, and has helped guide the team's design efforts through this experience. Furthermore, this is Vincent's second year leading the Business Case as part of the team. His prior experiences, both as a pilot and director of Business, have helped him develop a successful Business Case and advise the team on a course of action that leads to a profitable and successful UAS.

Noah McGuinness [Sophomore]

Noah McGuinness is the Director of Design and Modeling for Xavier High School's Real World Design Challenge solution. With one year of experience as a member of the team, his knowledge of the programs used for design and analysis have led to his ability to utilize the software in such a way that he can successfully model and test the theoretical design. As the leader of the design team, it is his responsibility to oversee many aspects of the development process using the skills he has acquired from his academic courses. In order to create an efficient and effective unmanned aerial system, he has applied these experiences and skills to the project with the goal of benefitting the team to the best of his ability.

Anthony Tedeschi [Sophomore]

Anthony Tedeschi is the assistant director of modeling for the RWDC team. He is a Sophomore at Xavier High School and takes Accelerated Geometry and Accelerated Chemistry. Anthony also takes Accelerated Spanish I and Introduction to Accelerated World Literature which gives him some of the writing skills necessary to write parts of the notebook. Alongside researching various aircrafts, he is also on the crew team and this is his second year in the Engineering Club. He is one of the people who is working on designing the model for the challenge.

Roham Hussain [Sophomore]

Even though this is Roham's first year in the program, his achievements in leadership, collaboration, and design make him ideal for the job. He has taken part in numerous engineering-based programs and has even been the proud recipient of the prestigious 2014 Scholar Leader award from the Connecticut Association of Schools, demonstrating his academic excellence. Currently, he is a sophomore at Xavier High School taking a number of Honors and AP courses (including Honors Pre-Engineering I, in which he is able to acquire hands-on "real world" experience). Furthermore, Roham participates in a multitude of clubs and activities including the Math Team, the Crew Team, and Model UN, while nicely balancing his time between academics and extracurricular activities. His effective management of time, leadership skills, and background experience make him a valuable asset for the team.

Figure 1: Xaverian Engineers

1.2 Acquiring and Engaging Mentors

The team found the mentors to be an invaluable resource in completing the project. The mentors provided their diverse backgrounds and years of work experience to help the team solve the complex problems this challenge offered. After winning the State Challenge, the team met with the mentors to discuss the judge's comments on our notebook and presentation. The team talked with the mentors and discussed strategies to meet the standards required for winning the national competition. The mentors and the team decided to split the project time line into two sections. The first section lasted from the release date of the National Challenge to March 7, 2016. This portion of the project consisted of planning and executing the project by completing the notebook. The team then entered into the second phase of the project: revision. The team leveraged the mentors by asking the mentors to review the notebook. The mentors provided suggestions and tips of how to improve our work. The team used the second phase to answer the feedback of the mentors and enhance the content. During the entire process, the team discussed with the mentors any issues that came up. For example, the team was not familiar with the terminology C_M and thus contacted the mentors in order to understand the concept.

In addition to helping the team with the project, the mentors helped the team find the necessary funds for the RWDC national competition registration fee. The mentors helped the team look for opportunities to raise the necessary money in order to attend the national competition. They contacted members of their own company and elsewhere to make sure the team could attend nationals. The following table shows a list of the mentors.

Mentor/Coach Name:	Role	Affiliation	Email
Andrew Burdick	Mentor	Pratt and Whittney	andrew.burdick@pw.utc.com
Frances M. Figueroa-Rodriguez	Mentor	Pratt and Whittney	frances.figueroa-rodriguez@pw.utc.com
Melanie E. Tibbetts	Mentor	Pratt and Whittney	melanie.tibbetts2@pw.utc.com
Arthur Salve	Mentor	Pratt and Whittney	arthur.salve@pw.utc.com
Kevin Zacchera	Mentor	Pratt and Whitney	kevin.zacchera@pw.utc.com

Table 1: Mentor List

1.3 State the Project Goal

This year's national challenge requires the development of a UAS, with the possibility of multiple aircrafts, designed to detect moisture in a field. According to the Challenge, the UAS must carry a payload that has the ability to detect moisture in two 1 mile x 1 mile fields that are growing two different food producing crops, where part of the area between the two fields is a No Fly Zone. A multitude of detection systems are suggested, with capabilities ranging from a visual to a full multispectral camera. The choice of detection system must be precise enough to properly detect a field's moisture (with resolution to a minimum of 10 feet) while also proving economical to the user. The UAS must also have the ability to support and utilize its payload while adhering to FAA's regulations on size, speed, and maximum altitude for operation. Therefore the UAS is limited to flying at 87 knots at 500 feet agl, while also weighing less than 55 pounds. The FAA also requires complete line of sight operation of the UAS. This alleviates the need for extensive study of long distance communication systems.

The Challenge requires that each team choose two food-producing crops specific to the team's region. There are also four, primary subjects that each team must document. They are "Task Analysis," "Strategy and Design," "Costs," and "Alternate Uses." The Task Analysis section requires that the team "analyze the mission/task to be performed." The "Strategy and Design" section discusses team structure and the structure of the UAS (how it will operate). "Costs" include development and operational costs, while "Alternate Uses" requires the team to identify alternate uses for their UAS in other industries. Therefore, the UAS cannot be task specific, but it must successfully complete the task that the Challenge presents. To further illustrate this point, the “Scenario” section says that the UAS cannot exceed four g’s in the moisture detection challenge but must have an ultimate load factor of 6 g’s. It also must be suited for continuous, repetitive operation: at least three detection cycles each year.

$$Maximize\left\{mean\left\{\begin{matrix} 1-\frac{W_E}{W_{TO}}, \\ 1-\frac{C_{AF}}{C_{UAV}}, \\ \left(\frac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}\right) \end{matrix}\right\}\right\}$$

The Objective Function discusses three parts of the aircraft’s design: the airframe efficiency, the airframe cost, and business profitability. By maximizing or minimizing these three sections appropriately, the mean Objective Function should be close to one. The airframe efficiency section relates the airframe weight to its maximum takeoff weight. A lighter airframe with a higher takeoff weight is more efficient, hence a greater objective function. Similarly, airframe cost relates the empty cost of the airframe to the total take off cost of the airframe. The cost of the energy source is included in the takeoff weight. Therefore, the Objective Function is maximized when the airframe cost is low compared to the takeoff cost. Business profitability, the final section of the Objective Function calculation, relates operating expenses to total revenue. The difference between total revenue and the operating expenses is the total profit. Therefore, operating expenses should be minimized while the revenue should be maximized. A profitable aircraft with a light and inexpensive airframe, and a high maximum takeoff weight maximizes the Objective Function.

Finally, the “Approach” states that the team is operating as a small business that is developing a prototype for agricultural moisture detection. Teams are required to use the PACE model of product development. Therefore, teams must “include information about acquisition cost and operations and support cost of the system to show that the product can be competitive in the marketplace.” Therefore, the team must prove that investing in their prototype UAS is a reasonable and desirable solution to agricultural moisture detection.

1.4 Tool Set-up/Learning/Validation

In order to successfully complete the project, the team had to use various softwares such as Creo, Autodesk analytic software, Microsoft Excel and Google Drive.

Modeling and Testing

Noah and Roham were chosen to work on the modeling and testing because of their past experience in 3D design. Experience from past years of the RWDC challenge, as well as the in-program tutorials included by PTC allowed the design team to easily operate the software. Unfortunately, due to issues with the license keys provided for Creo Simulate, other means of accomplishing the required analysis of the design were pursued. Autodesk's student account option allowed for full access to a wide range of softwares that proved to perform many of the required tests that allowed for the refining of the model. Programs such as flow design were used to make adjustments to the airframe and analyze the aerodynamic properties of the craft, while other functions of PTC Creo Parametric allowed for structural analysis of key members of the UAV.

Microsoft Excel

The team used Microsoft Excel for the Business case and objective function in addition to the creation of solution selection matrices and various calculations. The software was provided by the school and allowed the team to gain access to the mathematics functions already present in the program. The team chose to use Microsoft Excel over MathCAD because the team had more experience with Microsoft Excel and it fulfilled the team's needs. The benefit of Microsoft Excel is that it displays information very clearly and makes it easy to compare various items simultaneously. Also, one is able to repeat the same algorithm or equation several times which became extremely helpful during the creation of the solution selection matrices.

Google Drive

For the purpose of team collaboration, the team used the Google Drive service. This free service allowed the team to create a folder in the cloud and collaborate information. The team realized that similar services such as Microsoft Online did not perform as well when many individuals were working on the project at the same time. This was crucial as the team frequently took part in online conferences and worked together on the notebook and presentation. By using Google Drive, a service specifically designed for collaboration, the team was able to work together seamlessly. This allowed the team to work effectively and in harmony with other team members. The only issue the team noticed was that it was not as powerful as Microsoft Word and Microsoft PowerPoint but the team was able to solve this problem by converting the Google file into a Microsoft one and then editing a few things.

1.5 Impact on STEM

Xavier High School has supported STEM related interests for a many years. The school supports the Math Team, Robotics Team, and Engineering Team as well as a plethora of science classes that help its students prepare for college and work beyond.

Mihir Khunte, PM [Junior]

Since an early age, Mihir has been interested in math and science. Upon entering high school, he joined the engineering team within the first few weeks. While on the team he had the opportunity to experience and learn more about engineering, the career he had heard so much about. Mihir is enrolled in the engineering classes at his school and is taking rigorous math and science classes to feed his passion for science and engineering. This challenge has allowed him to apply his knowledge to solve real world challenges (as the name would suggest). It is has given him the opportunity to use the knowledge acquired from his classes and implement them in a real way. After speaking with the mentors and participating in this challenge, he has understood that engineering can be a enjoyable career. Mihir plans to carry on his interest for engineering by majoring in this field in college.

Keith Cestaro, PM [Junior]

For Keith, math and engineering have always been a part of his life. He has always enjoyed computers, even from a very young age. Keith could even take apart and repair his father's old laptops. He started creating my own small executable games when he was 13 years old through an extremely basic UI that involved minimal knowledge of language. That quickly evolved into fluency in Javascript, HTML, CSS, GML, Command Line, and soon PHP. Computers are Keith's passion. Whether it be networking, programming, hardware, it does not matter what as long as it is computer based. Keith is planning on majoring in a Computer Science or Networking. This project opened his eyes to other branches of engineering unrelated to computers, and Keith has found the challenge to be very enjoyable. Learning is something Keith enjoys, especially about topics he previously knew nothing about. This challenge has definitely accomplished that goal.

Robert Larese [Junior]

Since the genesis of Robert's life, he knew that he wanted to be in a field that designed airplanes. Captivated at such a young age by the wondrous jetliners and single engined Cessnas, Robert developed a keen interest in science and math. When he toured Xavier, once Robert learned about the Engineering Team and the RWDC Challenge, he knew that he wanted to go there to further his mathematical and scientific knowledge, while learning the in's and out's of engineering and, specifically, aeronautical engineering. So from building blocks to CAD modeling, Robert has maintained a keen interest. Within the first few weeks of school, Robert found the RWDC veteran Mr. Humphreys and signed up. As Robert displayed such an interest in the engineering club and curriculum, he was the obvious choice for the project manager last year. Robert has stepped up again to take on the task of developing the theory of operation, as he is fascinated with the math of field mapping. Robert hopes to pursue his love of engineering in college and in the career world.

Vincent Salabarria [Sophomore]

Science, technology, engineering, and mathematics have always interested Vincent. However, applying these topics is where he finds finds the most interest and value. The RWDC supports Vincent's interest in aircraft operation and design. As Director of Business, Vincent has the opportunity to thoroughly research and develop aviation technology. As Director of Business, Vincent primarily uses Microsoft Excel to calculate revenue, operating cost, and, finally, profit. This utilizes both technology and mathematics. Finally, the entire Challenge is conducted through the engineering design process, a form of the scientific method, in which the goal is to solve the scenario outlined in the Detailed Background. The opportunity to *apply* the four STEM topics through the RWDC is what draws Vincent to the Challenge. In the future, he would like to enter the field of aviation. Although this is a broad statement, a career in aviation education (flight instruction), as a commercial pilot, or as an air traffic controller are all rooted in the standards and goals of STEM.

Noah McGuinness [Sophomore]

The Xaverian Engineering team has allowed Noah to pursue interests in math, science, aviation, and computers that he has had since middle school. Upon becoming a member, Noah was able to take these preoccupations to a new level. The exposure to the workings of the engineering process allowed him to learn more about what the field really encompassed and the possibility of a career in it took on a new meaning to him. Through the work that Noah contributed to the project, and the experiences of functioning as a member of an engineering team he was introduced to not only design process, but Noah was able to expand my knowledge of flight and the intricate systems that must function properly and efficiently in order to achieve it. In doing so, Noah was able to combine this newfound knowledge with the previous experiences he has had working with various development softwares. The project's requirement for a tested and analyzed UAS model allowed Noah to increase my experience with the programs and become familiar with the workings of design and analysis. In conclusion, participating in the Real World Design Challenge has opened his eyes to many new concepts and has introduced an interest in the possibility of a future career in Engineering.

Anthony Tedeschi [Sophomore]

Ever since Anthony can remember, he has always had an interest for designing and building many different things. Anthony likes to work with his hands and craft different types of things for different projects, and also designing and testing the ideas that he has come up with. Anthony saw Xavier as a great way to expand upon this interest, and he knew that the Engineering Team would strengthen his abilities and help him really learn what the engineering process is all about. Anthony would also like to major in Mechanical Engineering and also have a career as an officer in the military that would revolve around engineering.

Roham Hussain [Sophomore]

As a child, Roham loved to experiment with building and designing things. He spent countless hours with LEGOs, creating his own buildings, landscapes, and vehicles. Roham even used to enjoy doing his own graphic design; whether it be with a logo, or a specific icon. Roham's experiences at various engineering summer camps have only furthered his passion for engineering. When Roham arrived at Xavier High School, he realized that the Engineering Team was the perfect way for him to continue doing what he loves to do. With the valuable experience gleaned from participating in the RWDC challenge this year, Roham hopes to one day become an engineer himself and fulfill the dreams he had as a child.

2. Document the System Design

2.1 Conceptual, Preliminary, and Detailed Design

The development of the UAS included in the final submission is the result of extensive research, design, and analysis. Following the model set by the engineering design process, the team began by breaking up the essential systems required for the function of the aircraft into sections to be researched. Initially the basic structural features were compared and contrasted based on their ability to conform to the design requirements. After the basic features, such as the aircraft type (tractor, pusher, or hybrid), tail type, and wing position were determined, the more specific details were investigated. Applying the specifics of the theory of operation and flight plan, the electrical systems were configured, accounting for proper flight time, endurance, and lift-off speed. Utilizing the design software at this stage to roughly model the aircraft based on the components of the baseline CAD models provided through the RWDC website allowed for the analysis of the UAS to make further adjustments. Due to the cyclical nature of the design process, the team repeatedly used this method to refine the design to its final form in order to record and document the necessary values regarding the aircraft's performance.

2.1.1 Engineering Design Process

The team created the engineering design process as shown below for the challenge.

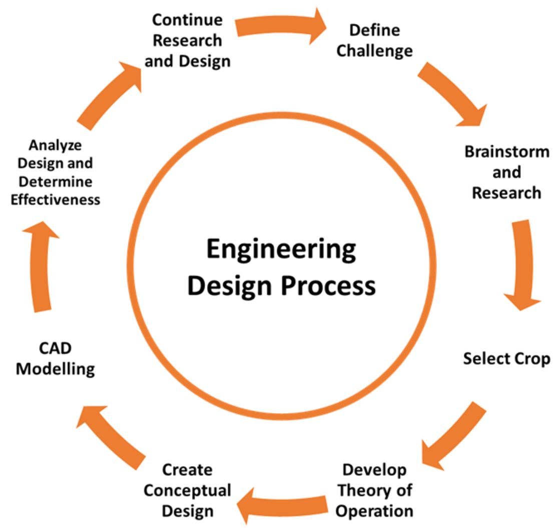


Figure 2: Engineering Design Process

In order to create the design process seen above, the team took a conventional design process and transformed it to fit the challenge better.

The step the team took first was to define the challenge. In order to define the challenge, each team member was responsible for reading both the detailed background for the state competition and challenge statement for the national challenge. Each team member was responsible for creating and presenting a small presentation that told the team what that part of the challenge entailed and possible suggestions to solve the task.

This presentation process led to the second phase in the engineering design process: Brainstorm and Research. In this phase, the team discussed possible solutions and researched their viability. Some ideas were absurd but were still considered hoping that they could possibly help us think of more viable options. The team drew diagrams on a whiteboard and discussed their ideas in the weekly meetings. The brainstorming was followed by research in order to back or refute our thoughts using information from reputable sources.

The next step the team took was to select a crop. Although this step is not found in your typical engineering design process, the team added this step into the custom the engineering design process. Because the team knew it would have to build a system that worked with the chosen crop, the team had to choose the crop first. Once the crop was picked, the team could then develop the flight path, design, and business case.

Upon the agreement of two crops, the team went on to develop the theory of operation. The theory of operation consisted of determining the flight path and operational considerations that needed to be taken into account. Using the flight path, the team was able to determine the type of UAV that needed to be designed in order to fulfill the needs of the theory of operation.

After determining the Theory of Operation, the team created a conceptual design. The referred to the solutions presented during the brainstorming phase and looked at existing UAVs on the market to assess what types of designs the team would consider. After creating several conceptual designs, the team began CAD modeling. The team began to build the team's conceptual design. The team used the testing software to determine the effectiveness of the UAV under the conditions presented by the challenge and the theory of operation.

Lastly, the team continued research and design. The team came across various obstacles that the team had to address. The team asked for support from mentors and learned of places potential improvement. In these situations, the team continued to create a better solution.

2.1.2 Conceptual Design

Initially the team referred to the detailed project background supplied by the RWDC and compiled a list of constraints provided for the UAV. The challenge stated the air vehicle must have a fixed wing and must fall under the category of either a pusher or a tractor. Pusher and tractor both refer to the organization of the propulsion components on the aircraft. The first implies an engine or motor attached to a rearward facing propeller or similar device used to generate thrust that "pushes" the body of the plane from behind. The latter performs its function on the other end of the airframe. The configuration is designed to "pull" the UAS forward with a frontward facing propeller, turbine, or similar device.

During the early stages of the design process, the team analyzed the various aircraft formats offered by the RWDC detailed background. Initially, a fixed-wing tractor was considered due to the increased efficiency supplied by the direct air to the propulsion system. Paired with a high wing configuration and a t-tail, the aircraft maximized potential airflow around the frame, allowing the craft to create a great deal of lift and travel at higher speeds. Between a fuel-based engine and an electric motor, the craft would have the capability to carry additional power plant equipment, allowing for longer runtimes and the ability to support an increased payload.

Next, a few members of the team presented a different design of high winged pusher. The main advantages of this design were present in the positioning of the camera on the nose of the aircraft, providing a clear and unobstructed view of the field below. In addition, the weight of the motor and battery supplies at the back of the craft would assist in balancing the center of mass of the UAS beneath the wings if more equipment was situated in the nose.

Lastly, the team also considered a hybrid (fixed-wing/quadcopter) design where the rotors would only be used for takeoff and landing. The advantages of such a design is that the UAS can hover in one spot or perform vertical take-offs and landings. This is particularly advantageous when there is little to no land present to serve as a runway for takeoff. Also, it is particularly helpful to take standstill pictures or video as it is able to hover in one place for extended periods of time. Its disadvantages include that it is costly and it is not the best choice for covering long distances as quickly and efficiently as possible.

In terms of powering the UAV, the team considered a gas powered engine. This engine would consume gas and combust it in order to form the energy needed to move the UAV. In terms of environmental sustainability, a gas powered UAV will emit greenhouse gasses which could contribute to issues concerning climate change. Although the team realized that the contribution of greenhouse gases would be low, the team wanted to incorporate the use of renewable energy in an effort to design the next generation of technology if it was economically and logistically viable. In addition to the release of harmful gases, one disadvantage for a gas powered engine is the additional maintenance needed in comparison to an electric-powered UAV. Gas powered engines are known to be less “clean” and therefore require more frequent maintenance routines. Knowing this, the team looked at potentially adopting a battery-powered motor. The team could charge the battery and power the UAV with electricity. This option would open the team to using renewable energy. In addition to the two conventional methods, the team considered using hydrogen, bio-fuel and vegetable oil.

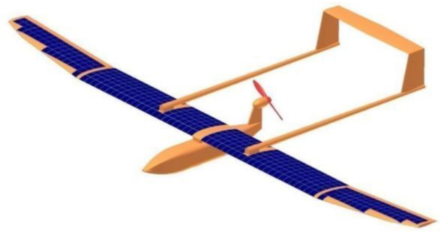


Figure 3: Solar Panel Winged UAV

For the conceptual design, the team thought of attaching solar panels to the wings of the aircraft. To make an accurate decision on whether or not this idea was viable, the team analyzed both the positives and the negatives associated with such a design. Not surprisingly, the advantage of having photovoltaic cells lies in energy production. This could power all of the internal workings of the UAV with just the rays of sunlight. However, there are some significant disadvantages with having a solar panel array. The two most important of these disadvantages is cost and practicality. Since the wings are designed by the team, no wings exist like them. For the solar panels, this means that they would have to be custom made to fit the wings, which would only make the already expensive solar panels even more costly. In addition, the ability of the solar panels to create power would be limited to the flight which lasts a little more than an hour. Because the UAV will be stored in the trailer most of the day, the solar panels will not be under sunlight for long periods of time and thus will not be able to create enough power for the design to be utilized properly.

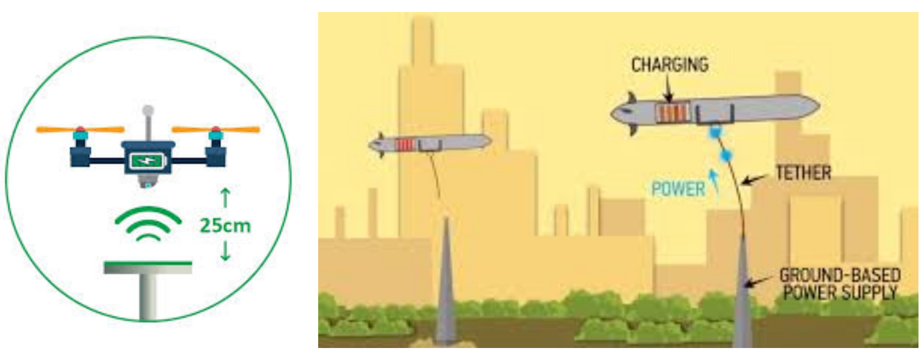


Figure 4: Wireless and Wired Charging Options

During the conceptual design phase, the team also thought of implementing either a wireless or wired charging design solution into the aircraft. The wireless design suggested wirelessly sending power to the UAV to maintain its ability to fly. This would allow the team to charge midflight and not have to land in the middle mission. The team quickly ruled this out due to the inefficiency of this design (as lots of energy would be lost during the wireless transmission). The team also looked at other possibilities on the opposite side of the spectrum of wireless charging. One of the ideas considered a wired charging solution that used a cable to power the UAV rather than a battery. The team quickly ruled out this design because it would require an unrealistic and impractical cable length of 1.54 miles.

2.1.3 Preliminary Design

The team ruled out the hybrid design right away. The main advantage of such a design was that the UAS can hover in one spot and perform vertical take-offs and landings. The disadvantages of the design include that it is very costly and more complex than the pusher or tractor. Also, it is not as well suited and efficient for traveling longer distances making it unsuitable for the challenge. Due to these disadvantages, the team ruled out the hybrid design and narrowed the search to the tractor and pusher configurations.

The pusher appeared to have significant advantages over the hybrid. The most promising aspect of this design was found in the open front of the aircraft, and the potential for ideal sensor and payload equipment layout. With the powerplant and propulsion system installed in the back of the fuselage, the added weight to the back allowed for a larger amount of detection machinery to be placed in the nose of the UAV. This would increase the ease with which the team could balance the center of mass beneath the wings. In addition, the open front would provide a clear, unobstructed view for any cameras or sensors placed there. Without a propeller, the ability of the equipment to successfully photograph the field would contain significantly less complications that would otherwise need to be accounted for with a tractor.

After extensive research and consideration, it was discovered that pushers have significant disadvantages that became evident as the design was compared to the tractor configuration. The pusher encounters issues with propeller efficiency and powerplant management, increasing the potential costs of repairs and maintenance. In terms of the propulsion system, air that comes in contact with a pusher's propeller has been significantly affected by the friction of the skin on the air. This decreases the overall efficiency and ability of the pusher to produce thrust. The tractor, however, does not experience this issue. In addition, the pusher's motor is not readily cooled by the smooth stream of incoming airflow like the tractor. This complicates the cooling of the powerplant, increases the probability of damage from overheating, and decreases the total life of the motor or engine.

After the team debated between the two configurations, it was determined that despite the field of view advantages of a pusher design, the requirements for the particular problem set by the Real World Design Challenge would be better suited for a tractor propelled aircraft. Despite the minor disadvantages of slip steam scrubbing drag from the wake of the propeller and the problems encountered with camera placement with a frontward-facing propeller, the multitude of disadvantages of the pusher outweighed the negatives of the tractor. The efficiency and ability to produce more thrust and lift on behalf of the tractor allowed for additional support equipment to be placed onboard, faster airspeeds, and more efficient use of power.

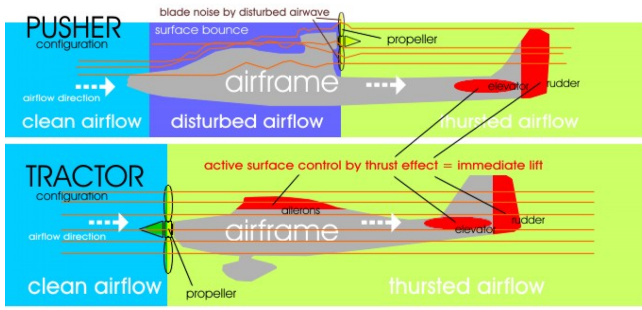


Figure 5: Airflow: Pusher vs Tractor Configuration

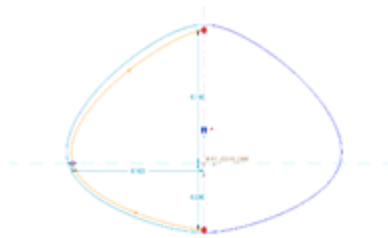
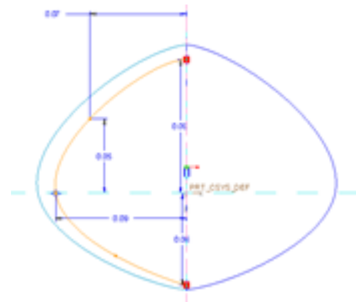
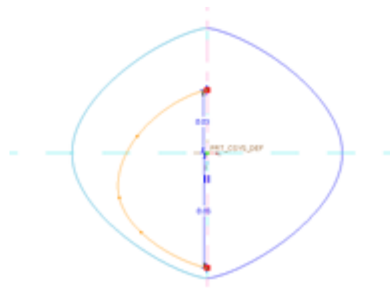
The team deliberated extensively over the use of solar panels on the wings of the UAV and came to the conclusion that it was not a worthy initiative because of its sheer cost and impracticability. Instead, the team decided that a solar panel fixture on the roof of the trailer would be far more useful. The team still wanted to factor an environmental consideration into our design but without it being too expensive. Since standard solar panels would be needed on the top of the trailer, the cost of purchasing the necessary photovoltaic cells would be far less. In addition, the existence of solar panels at the central base of operations would be able to power not only the battery of the UAV (when it was on land,) but also the various support equipments located in the area. As such, renewable energy would still play a crucial role in the flight of the aircraft, albeit in a way that is more cost-efficient.

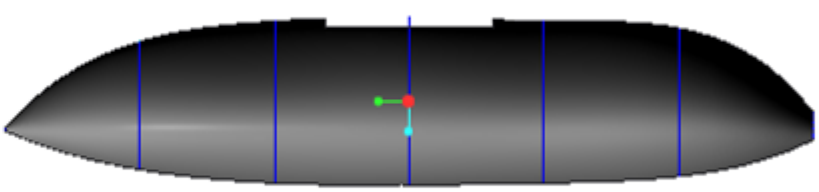
2.1.4 Detailed Design

PTC Creo 2.0 Software

The following chart is a representation of the processes used in the process of redefining various elements of the design in order to model the conceptual UAV as it was devised in the earlier stages of development. The table is designed to demonstrate one out of hundreds of steps and does not necessarily represent precisely an element of the final design and its respective dimensions.

Altering the Dimensions of a Rib

1	
2	
3	

Fuselage Efficiency Table		
F.1		**Drag Force: 4.63 N** (25m/s, T = 18)

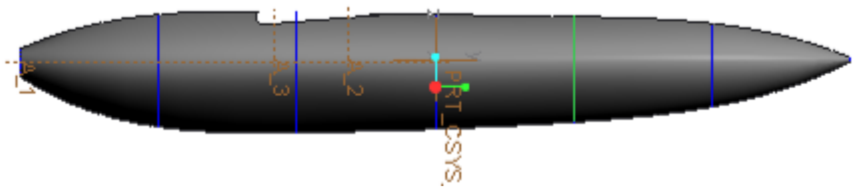
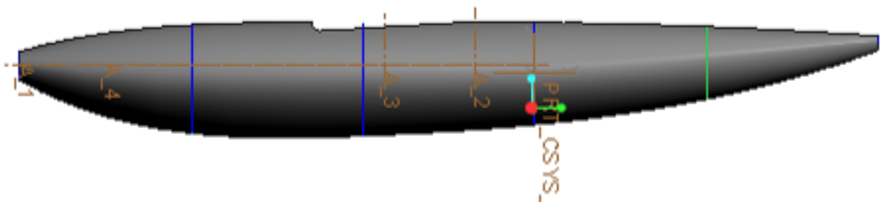
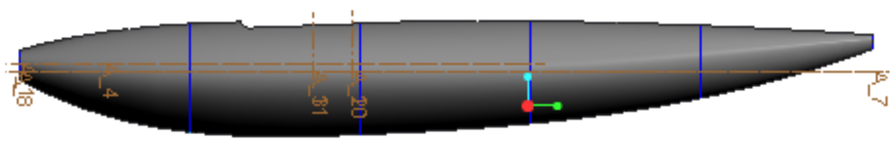
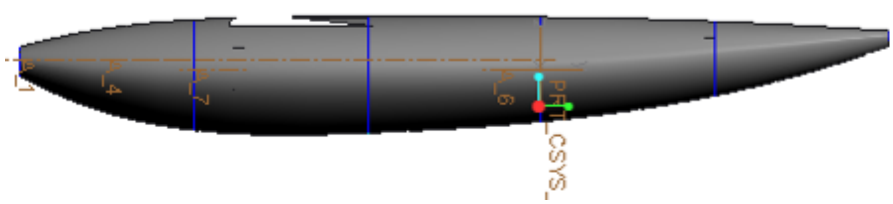
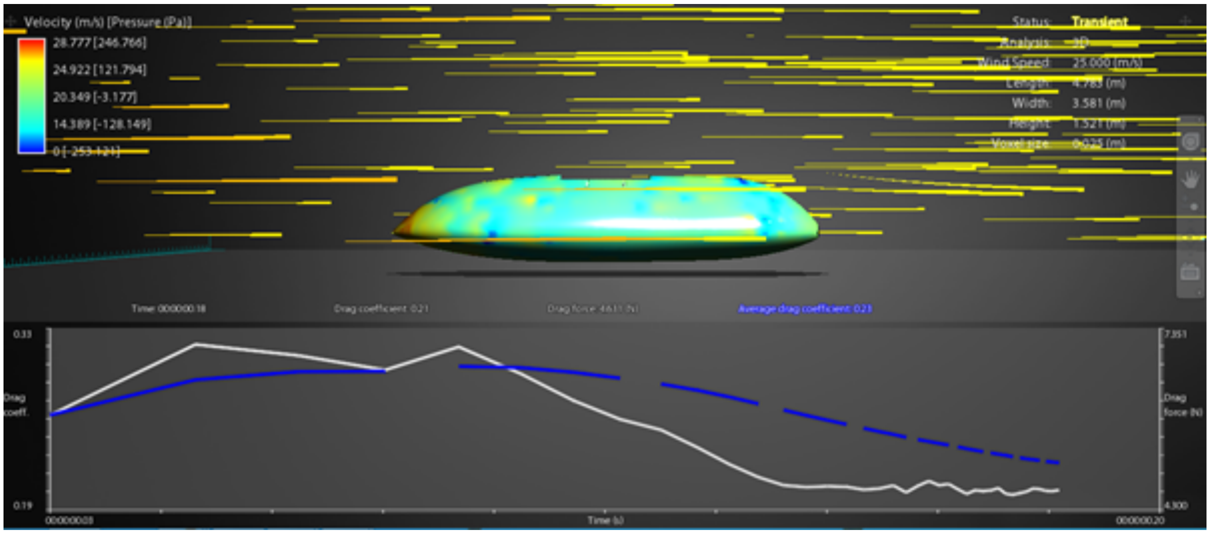
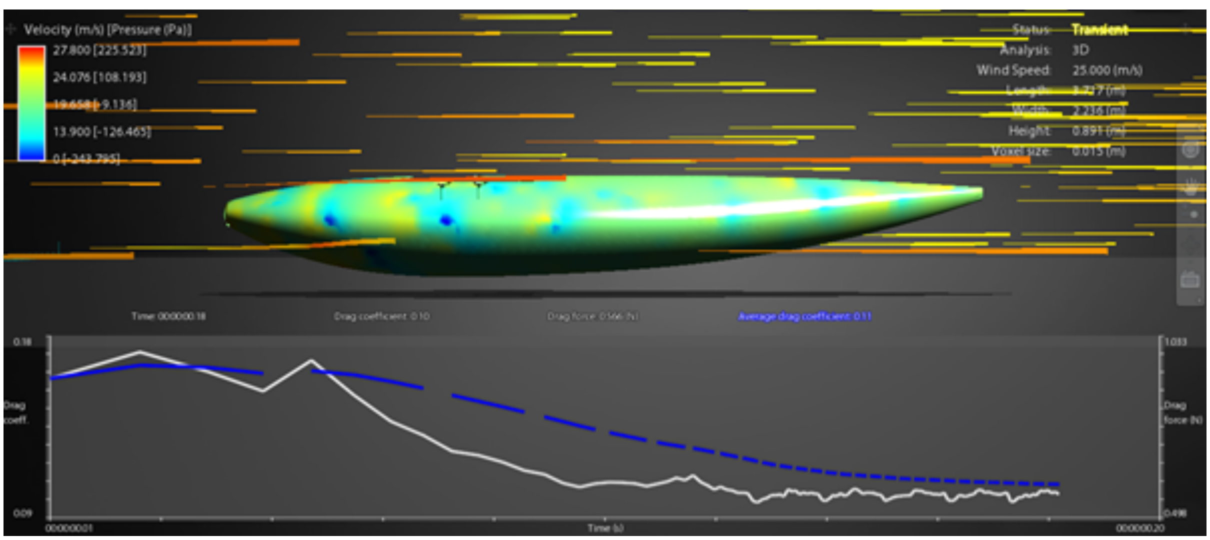
F.2		**<u>Drag Force</u>:** **1.23 N** (25m/s, T = 18)
F.3		**<u>Drag Force</u>:** **0.98 N** (25m/s, T = 18)
F.4		**<u>Drag Force</u>:** **0.70 N** (25m/s, T = 18)
F.5		**<u>Drag Force</u>:** **0.57 N** (25m/s, T = 18)

Table 2: Wind Tunnel



Time: 18 s
Drag Coefficient: 0.21
Drag Force: 4.631 N
Average Drag Coefficient: 0.23



Time: 18 s
Drag Coefficient: 0.10
Drag Force: 0.566 N
Average Drag Coefficient: 0.11

Figure 6: F.5: Wind Tunnel

-Figure F.1 in Table 2 represents the baseline model as the unaltered resource provided to all teams participating in the challenge.

-Figure F.2 in this table displays the initial dimension changes required to accommodate the payload.
-Figures F.3-F.4 are two iterations documented from the reformation and refinement process.
-Figure F.5 is the final design of the fuselage used.

2.1.5 Lessons Learned

In the first stage of the design phase, the team learned how to brainstorm quality solutions. The presentations by each team member helped facilitate a time for discussion. The presenter questioned the rest of the team on various ways to solve certain problems and the team was able to discuss methods to solve the challenges at hand. Although the solutions occasionally became far-fetched and unrealistic, the discussions allowed the team members to bring the ideas thought of by the group to do research on those solutions. Brainstorming was an important period for the team because it served as a medium to discuss the flaws of the team's state solution.

In the next step of the engineering design process, the team developed their research skills. The team primarily used the internet and books to learn important information in order to make solutions. The team learned how to adapt the information available to the scenario at hand. This is an important skill for engineers because although there is a plethora of information on the internet and in libraries, almost never do the resources provide the exact answer. The team learned how to piece loose pieces of information and use self-knowledge to create solutions to the challenge. The team used these skills during the entire project in places such as creating the flight plan or choosing the camera.

When it came to determining multiple solutions and picking the best solution, the team learned how to effectively use the solution selection matrix. The solution selection matrix is a Microsoft Excel spreadsheet that determines the effectiveness of a product using a weighted rating system in different categories. This method of down selecting possible solutions was suggested by the team's mentors. The team found the approach to very helpful and its use taught the team how to make decisions involving numerous variables.

In addition to learning numerous technical skills, the team learned time management skills, planning, and communication. During the state challenge, the team performed much of the work in the last few weeks which was problematic once issues came up. In order to prevent such issues, Mihir made sure everyone performed their tasks on a scheduled basis. This helped the team stay on track and not have to rush in the last minutes before the deadline. In terms of planning, the team planned the project beforehand giving each individual work to complete. Planning the project out more extensively than the state challenge helped the team work more efficiently. During the national challenge, the team used email and texting extensively. This helped send information very quickly and prevented the need for daily meetings. If a person had a problem, he could send a mass email to all the team members and receive an answer within minutes, maybe hours to his problem. This method of communication allowed the team to work more efficiently.

2.1.6 Project Plan Updates and Modifications

Initially the Xavier Engineering Team met after school on Wednesdays. Unfortunately, due to conflicts with other extracurricular activities the team changed the day of the meetings to every Monday instead. Monday was a better day, however, the meetings had to be brief due to sports and other activities. Since the Monday meetings had to be brief, the team also decided to hold meetings on Saturday around 2 PM. The Monday meetings were used to confirm each member knew their tasks while the Saturday meetings were used to discuss any issues team members were having with their tasks. When the team realized that it was hard to bring everyone together at the same time, people working on overlapping tasks scheduled meetings together on different days and conveyed their ideas to the rest of the team through email. Later on as the submission date neared, the team called meetings more frequently. Although many times all members could not attend the meetings, as long as a majority of the team was there the team worked on the project and discussed ideas.

In addition to holding frequent meetings, the team members communicated with each other through email and text. This was extremely vital for the design team because problems with the modeling software, and the design itself could be worked out. Because of great tools such as text messaging and email, the team was able to communicate quickly with each other. Some team members created group chats to quickly spread information which substituted for some in-school meetings during busy days.

During the course of the project, hundreds of iterations of the design were created. As engineering is an iterative process, the team adjusted the design and tested them using virtual wind tunnel testing. This part of the project was vital for the team's success. Although it is impractical to show every single iteration, the team covers the main iterations in Section 2.1.4.

2.2 Selection of System Components

The key items were selected by the team and then downselected by using the solution selection matrix. The solution matrix rated the key components based on things such as resources needed, complexity, the ability to eliminate current issues, the mistake proof level, possibility of new problems, price, and results. The ratings were calculated into a score and whichever item had the highest score was chosen. The team met whether in person or via google video chat to also discuss the key components selected and use the selection solution matrix. The following sections are based upon the team's research and score evaluations using the selection solution matrix.

2.2.1 Payload Selection

After researching methods of detecting moisture, the team found that a thermal imaging camera would allow the team to effectively accomplish the goal. Although the team found some other methods of accomplishing the same goal such as using cosmic rays, the team found that using thermal imaging would help provide the farmer with a clean and easy to interpret the thermal map in order to irrigate his/her crops properly. With this method, the farmer only has to distinguish between colors and understand that red or orange areas represent areas that need irrigation while blue or green areas represent areas that have sufficient moisture. This will save the team and farmer countless hours. The following is how a sample picture from a thermal imaging camera may look:

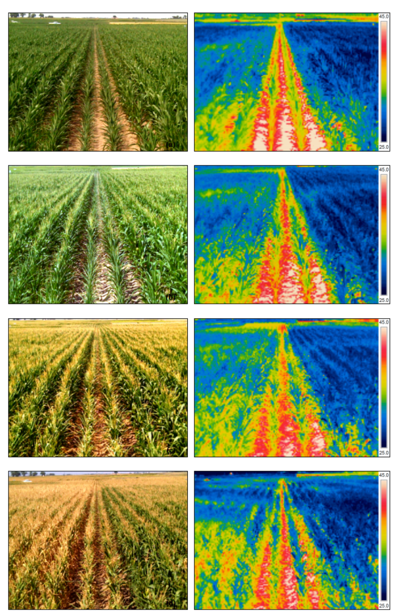


Figure 7: Colored Areas show where moisture is present and where it is not

The chosen camera was the X3000 camera system. The solution matrix helped the team select this camera as part of the UAS. This camera was selected because it had the best stability while also having a rating of excellent. The imager used is a thermal infrared and visual spectrum camera. The X3000 also has the best roll limits at 85 degrees pan left and right and pitch limits of 85 degrees tilt up and tilt down. In addition, the X3000 has a video format that takes JPEG images and MPEG-4 video that comes in at 25 frames per second. The camera also has a 4x continuous zoom IR and a 8x continuous zoom for visual images. The nominal power draw is 12 watts and has a maximum power draw of 16 watts and also has a voltage intake of 5 to 12 watts. The cost of the X3000 is $17,000, it is expensive but will repay itself when used as it is durable and is the most effective camera that was researched.

One of the aspects that secured the X3000 to be the camera of choice was the type of imager it offered. While cameras like the X4000 only offered thermal infrared cameras, the X3000 offered both thermal infrared and a visual spectrum camera. This essentially meant that the pilot of the UAS would have access to both types of cameras, a feature not available on the more expensive X4000.

2.2.2 Air Vehicle Element Selection

Airframe

Component	Quantity	Price	Weight
Airframe	1	$179.90	7.746 lbs
PowerPlant	1	$200.00	1.4 lbs
Li-Po Battery	2	$523.30	3.66 lbs

Figure 3: Airframe

PowerPlant
Cost per Unit: $200.00
Number Required: 1
Justification: The motor is necessary in order to convert the electrical energy from the batteries into mechanical energy used to propel the UAV.

Li-Po Battery

Cost per Unit: $523.30
Number Required: 2
Justification: The battery of our UAS was vital for the overall success of its profitability and flight. A Lithium Polymer battery, or LiPo for short, was selected due to its wide availability and low weight, compared to gasoline. Each battery weighs 3.66 lbs. LiPo batteries are commonly less rigid than normal, prismatic cells which makes it easier to store within the UAS. Another important aspect of the LiPo battery is the fact that it can be recharged. This will save money in the long run because the batteries rarely need to be replaced, and their lifespan is over five years.

Flight Controls

Component	**Quantity**	**Price**	**Weight**
Serial Servo Controller	1	$25	.35oz
Universal battery elimination circuitry (U-BEC)	1	$20	.26oz
Autopilot	1	$250	.81 oz
Multiplexer	1	$25	.53 oz
	Total	$320	1.95 oz

Table 4: Flight Controls

Serial Servo Controller
Cost per Unit: $25
Number Required: 1
Justification: This module provides a flight control alternative to the servo RX of a hobby radio. It will allow the pilot to control the UAS via the joystick.

Universal battery elimination circuitry (U-BEC)
Cost per Unit: $20
Number Required: 1

An alternative power regulation module for protection of the control system. It provides power to the servo controls, without requiring an addition power source. When the available power for the system has diminished to no longer sustain powered/motored flight, the system will shift power solely to the flight controls (i.e., servos) to enable to the operator to perform a controlled descent (e.g., glide or autorotation). This is necessary in case of an emergency to prevent the plane from crashing.

Autopilot
Cost per Unit: $250
Number Required: 1
Justification: Device onboard the UAV, autonomously controls servos/actuators, can be switched ON/OFF or dynamically reprogrammed with uploaded parameters from GCS. The autopilot is needed to autonomously fly the marked area.

Multiplexer
Cost per Unit: $25
Number Required: 1
Justification: This option provides an interface that can be used to switch control of up to seven (7) servos or ESC from two independent control sources. This is needed to satisfy the need to send data.

Sensors

Component	**Quantity**	**Price**	**Weight**
Digital compass sensor (,)	1	$45	.03 oz
9-Degree of freedom (DOF) Inertial measurement unit (IMU)	1	$40	.02 oz
Global Positioning System (GPS) Sensor	1	$50	Negligible
X3000	1	17,000	3.5 lb (56 oz)
	Total	$17,135	56.05 oz

Table 5: Sensors

Digital Compass Sensor
Cost per Unit: $45
Number Required: 1
Justification: Measures magnetic heading (single-axis) with 0.1 degree resolution (three to four degrees accuracy). This provides the UAS direction of travel.

9-Degree of freedom (DOF) Inertial measurement unit (IMU)
Cost per Unit: $40
Number Required: 1
Justification: A device used to measure the velocity, orientation, and gravitational forces. This option is a primary component of an inertial navigation system that is typically used to provide data to an autopilot or ground control station. The unit provides the autopilot data needed to conducts it role to lead the UAS in the correct direction.

Global Positioning System (GPS) Sensor
Cost per Unit: $50
Number Required: 1
Justification: Device that receives GPS signals to determine position on the Earth. This helps the autopilot determine the exact position of the UAV.

X3000
Cost per Unit: $17,000
Number Required: 1
Justification: A Thermal Infrared and Visual Spectrum Camera which will be used to detect moisture content in the designated field. The camera includes both infrared as well as visual capabilities allowing the camera to record not only the information needed to detect moisture but also allows the collection of visual content that will allow the pilot to see the ground and surroundings of the UAS when connected to a video transmitter. The camera has excellent stabilization which allows for accurate moisture detection.

2.2.3 Command, Control, and Communications (C3) Selection

The Command, Control, and Communications section concerns the team's plan regarding interacting with the UAS on ground. The team had to keep in mind costs and logistical issues when considering this section.

Component	Quantity	Price
ArduPilot (Command)	1	$0
PC Laptop Control (Control)	1	$3000
Data Transceiver Set (900Mhz) – High Range (Communication)	1	$135
900MHz Video System –High Power (1500mW) (Communication)	1	$120
Patch Antenna (900 Mhz)-Ground Based (Communication)	1	$55
	Total	$3310

Table 5: Command, Control and Communications (C3) Selection

Command/Control-

The team chose the PC Laptop Control which costs $3000. This system will be able to communicate with the UAS and control it by via the multiplexer and autopilot. Although the UAS will be autonomous with a preprogrammed flight plan, the control system will allow the pilot to monitor the UAS while in the air and confirm that the UAS maintains its flight plan. The control serves as GCS system for capture of user input (control commands), capture and interpretation of telemetry data, and display of vehicle state. In addition, the USB joystick is good for user control inputs from the pilot which allow the pilot to take over during any mishaps. The computer will be helpful to program the flight plan by using the application called ArduPilot.

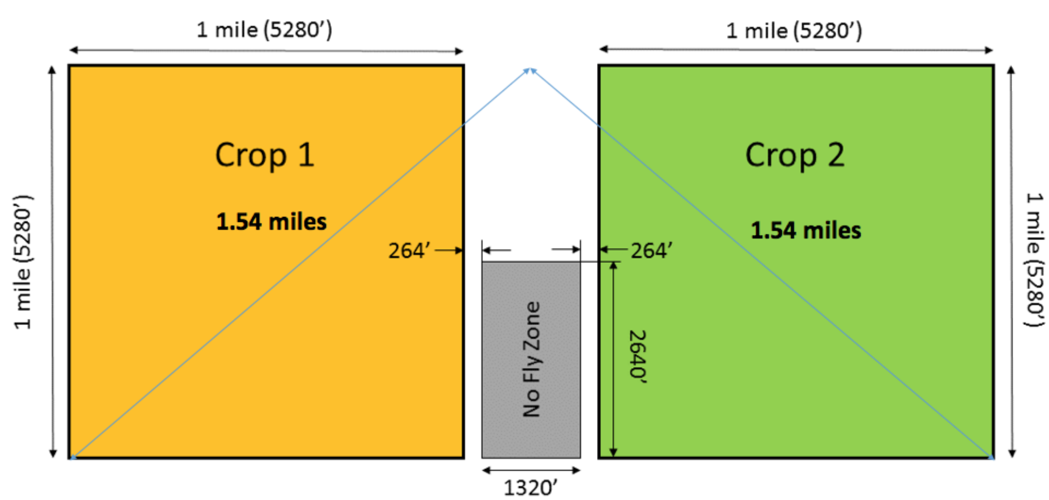
Figure 8: PC Laptop and ArduPilot Screenshot

Communication-

The team needed to design the last aspect of the C3 which is communication. In other words, design how the UAS and ground control system communicates and interacts with one another. It was decided to utilize the Data Transceiver Set (900Mhz) – High Range system, which costs $135. The long range option was selected for the transceivers because it allowed for sufficient transmit distance, which is vital for a proper performance of the overall system . The team calculated that the farthest distance the UAV would fly from the Ground station is 1.54 miles. In compliance with FAA regulations the team must add a 1.5 safety factor. Thus, the transceiver must be able to transmit data over a distance of 2.31 miles. The Data Transceiver Set (900Mhz) – High Range can send data over a distance of 6.3 miles while the Data Transceiver Set (2.4Ghz) – High Range can send data at least two miles. The team chose the Data Transceiver Set (900Mhz) – High Range because it has better range, which is crucial in maintaining contact with the UAS if it goes off course. Another advantage of this system is that it has a higher transmit power which allows for more immediate and faster data transfer. Overall it was more effective than the Data Transceiver Set (2.4Ghz) – High Range despite the higher price and higher sensitivity. These transceivers will allow the pilot on the ground to monitor the UAS via Laptop by sending it the needed data.

The next section concerning communication is video communication. The team was limited in the sense that the video system has be at the same frequency (900 Mhz) as the Data Transceiver Set. That limited the choice between the 900MHz Video System –Low Power (200mW) and 900MHz Video System –High Power (1500mW) which cost $60 and $120 and have a transmit distance of .5 miles and 1.8 miles respectively. As mentioned before, the farthest distance between the UAV and the ground station is 1.54 miles assuming the UAS does not escape the boundaries of the field. According to FAA rules, the control data link must provide sufficient link performance margin at 1.5 times the maximum allowed range specified in the system operating manual under normal meteorological and RF interference, environmental conditions, and aircraft configuration. Thus, the team must be able to maintain a range of at least 2.31 miles. Because neither of the video systems provide the needed range of 2.31 miles, the team was required to use an antenna. The team had two choices for antennas: the Patch Antenna (900 Mhz)-Ground Based which boosts the range by approximately 100% and the YAGI-Directional Antenna (900MHz) – Ground Based which boosts the range by approximately 300%. The antennas cost $55 and $60 respectively. Because none of the antennas could extend the range of the 900MHz Video System –Low Power (200mW) to 2.31 miles, the team dropped the option. The team chose the 900MHz Video System –High Power (1500mW) with the Patch Antenna (900 Mhz)-Ground Based which extends the range from 1.8 miles to 3.6 miles and costs a total of $175. The team chose the Patch Antenna (900 Mhz)-Ground Based over the YAGI-Directional Antenna (900MHz) – Ground Based because it is less costly and does not need to be aligned with the opposing unit like does the YAGI-Directional Antenna (900MHz) – Ground Based.

In summary, the system communication updates consists of the use the PC Laptop Control costing $4000, the Data Transceiver Set (900Mhz) – High Range costing $135, the 900MHz Video System –High Power (1500mW) costing $120, and the Patch Antenna (900 Mhz)-Ground Based costing $55. This results in a total of $4310 for all communication devices. The following is a chart that illustrates the purpose of each component.



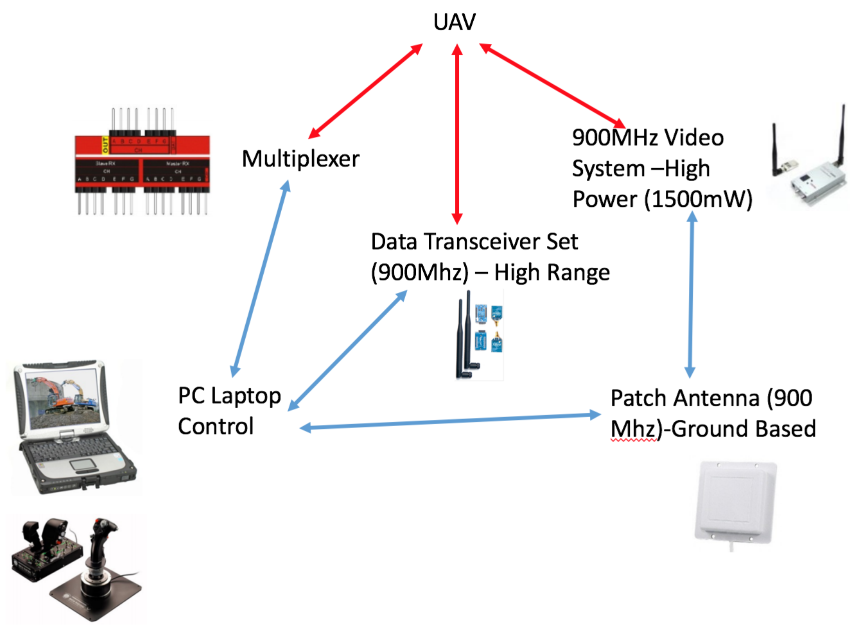


Figure 9: Field View and Communication System

2.2.4 Support Equipment Selection

Below are the support equipment needed for this mission:

Item	Quantity	Cost per Unit
Streamline Trailer	1	$5,000
Used Ford F-150 Truck	1	$11,000
Honda EU2000I 2000 Watt Super Quiet Inverter Generator	1	$899.00
AC/DC Battery Charger	1	$150.00
Post-Processing PC Desktop	1	$1617.10
Agisoft (Professional Edition)	1	$3499.00
Car Top Launcher	1	$3000.00
Solar Panel (L*W*H) (64x44x49 inch)	2	$900.00
Inverter	1	$150.00
	Total	$26,215.10

Table 6: Support Equipment Selection

Streamline Trailer
Cost per Unit: $5000
Number Required: 1
Justification: Essentially a mobile office and workshop, the trailer will provide the desk space for the workstations, as well as room to transport the aircraft, tools, fuel, generators, and other support equipment. The trailer can be connected to external power (30A 120V) to power lights, air conditioning, and equipment which is great because the solar panel will be able to directly connect to the trailer and no additional wiring will be necessary.

Used Ford F-150 Truck
Cost per Unit: $11,000
Number Required: 1
Justification: In order to haul the trailer containing the UAS and other equipment, the team decided to invest in a light truck. The truck will be able to haul personnel and equipment to the work site. Although the the team briefly considered services such as Uber or Lyft, the team realized that in the long run the team would benefit by buying a truck because services such as Uber and Lyft are unreliable and costly. In order to save money, the team decided to buy used trucks knowing that new cars depreciate in value by about 11% once they are driven out of the lot. Thus, the team chose to look for a truck that contained less than 100,000 miles and was less than six years old. The team felt that taking these measures would help the company on the business side especially in the first years when the company does not have much starting cash. The intent is on buying newer models once the company is established with a strong customer base and has enough revenue to take on such expenses. The truck can also be utilized to mount the car top launcher, which launches the aircraft for flight. The truck has a towing capacity of up to 9,600 lbs and fuel efficiency of 23 miles per gallon.

Honda EU2000I 2000 Watt Super Quiet Inverter Generator
Cost per Unit: $899.00
Number Required: 1
Justification: The team will need a generator to charge the UAS batteries and provide power to the computer set-up and trailer in case the solar panels fail or the sun is not out.

AC/DC Battery Charger

Cost per Unit: $150.00
Number Required: 1
Justification: Device used to balance and charge up to two batteries simultaneously. Needed to charge batteries for the UAV.

Agisoft Photoscan (Professional Edition)
Cost per Unit: $3499
Number Required: 1
Justification: The program will be needed in order to stitch together images according to its geographical location. Even though two options were available-Professional and Standard- the team had to go with the professional version because of its GIS (Geographic Information System) capabilities which were not available in the Standard version.

Post-Processing PC Desktop
Cost per Unit: $1617.10
Number Required: 1

Component	Item	Price
CPU	Intel Core i7-5820K Haswell-E 6-Core 3.3GHz LGA 2011-v3 140W Desktop Processor BX80648I75820K	$424.95
CPU Cooler	Cooler Master Hyper 212 EVO - CPU Cooler with 120mm PWM Fan (RR-212E-20PK-R2)	$29.44
Motherboard	MSI Computer ATX DDR4 3000 LGA 2011-3 Computer Motherboards X99A SLI PLUS	$211.06
Memory	Crucial 32GB (8GBx4) Desktop Memory Kit DDR4-2133, PC4-17000, UDIMM, 288-Pin CT4K8G4DFD8213	$139.99
Storage	WD Blue 1TB Desktop Hard Disk Drive - 7200 RPM SATA 6 Gb/s 64MB Cache 3.5 Inch - WD10EZEX	$53.99
GPU	EVGA GeForce GTX 780 Ti, 3GB, 3072MB,GDDR5 384bit	$399.99
Case	Corsair Carbide Series SPEC-01 Mid Tower Gaming Case CC-9011050-WW	$49.99
Power Supply	Sentey Xplus Power Supply 725 Watt (XPP725-HS)	$44.99
Optical Drive	Asus 24x DVD-RW Serial-ATA Internal OEM Optical Drive DRW-24B1ST (Black)	$21.89
Operating System	MICROSOFT Windows 10 KW9-00140	$116.90
Monitor	HP Pavilion 21.5-Inch IPS LED HDMI VGA Monitor	$99.99
Keyboard	AmazonBasics Wired Keyboard	$12.72
Mouse	AmazonBasics Wireless Mouse with Nano Receiver	$11.20
	Total	**$1,617.10**

Justification: The team needed a system able to run the Agisoft Photoscan software. The team found the system requirements to run the program on the Agisoft's website. The PC desktop provided in the state challenge was very expensive costing the team $6000. Thus, the team decided to build its own PC according to the system requirements provided by Agisoft in order to save money. The team shopped on Amazon, an American electronic commerce and cloud computing company, to buy the parts. Because some team members have experience building desktop PC, the team does not need a professional technician to construct the PC. Due to the team's ability to build its own gear, the team saved $4382.90. In addition to saving money right away, anticipating some potential part failures, the team will be able to easily replace the broken part rather than having to replace the entire PC. This will save money in the long run.

Car Top Launcher
Cost per Unit: $3000
Number Required: 1
Justification: The team needs a car top launcher in order to launch the UAV into the air. Most farms will not have a runway for the UAV thus launcher seems most appropriate. The bought a truck so the UAV would launch from the truck.

Solar Panels (500W)
Cost per Unit: $900.00
Number Required: 2
Justification: The team needs solar panels to charge the UAS batteries and provide power to the computer set-up and trailer. This will allow the workstation to be mobile and free of the need to plug into some wall outlet. Also, this method it emissions free and works to protect the environment. The solar panel will be mounted (permanently) on top of the trailer so that it can be charged during the day. The team made sure that the solar panels could stay on the roof while the trailer was moving.

Inverter (1000W)
Cost per Unit: $150.00
Number Required: 1
Justification: The team will need an inverter in order to convert the DC power from the solar panels into AC power.

2.2.5 Human Resource Selection

Operational Pilot
Cost per hour: $35.00
Number Required: 1
Justification: In the case of autonomous or semiautonomous operations, the operational pilot is responsible for monitoring aircraft state (attitude, altitude, and location) to adjusting aircraft flight path as required for success of the application task. The pilot will typically spend most of the operation looking at a screen at the ground control station monitoring the telemetry from the aircraft's on-board flight control computer, and adjusting the aircraft's programming as necessary. The operational pilot will be responsible for navigating the UAV in case the UAV's autopilot stops functioning properly. The FAA requires a minimum of a recreational licence to operate the UAS.

Range Safety/Aircraft, Launch, & Recovery/Maintenance:
Cost per hour: $35.00
Number Required: 1
Justification: This individual can be assigned multiple non-concurrent roles, and is typically a highly qualified technician. Range safety includes ensuring frequency de-confliction prior to and during application execution as well as airspace deconfliction. This individual will be trained in the use and operation of a spectrum analyzer to ensure that the communications and aircraft operations frequencies are not conflicting with other potential operations in the area. This individual will also monitor air traffic channels to ensure that the airspace remains free during the task. This individual will be responsible for coordinating with the air traffic management personnel in advance of the operation to ensure that the appropriate airspace restrictions are communicated to piloted aircraft operating in the area. This individual may also be responsible for aircraft launch and recovery operations as well as any required maintenance (e.g. refueling or repairs) in between flights.

Safety Pilot
Cost per hour: $35.00
Number Required: 1

Justification: This individual is responsible for bringing the aircraft safely in for recovery. For this competition, line-of-sight (LOS) operation is required at all times, meaning that the safety pilot will need to be able to observe the aircraft at all times during flight. During semi-autonomous flight operations, the safety pilot is responsible for immediately taking over command of the aircraft and bringing it safely to the ground should it exhibit unanticipated flight behaviors, or in the case of piloted aircraft entering the flight operations area as communicated by the range safety officer. This role is also referred to as the "Observer", responsible for maintaining VLOS with the aircraft.

Data Analyst
Cost per hour: $50.00
Number Required: 1
Justification: This person is responsible for being able to use the Agisoft Software and Post-processing computer in order to provide the farmer with a map that indicates water stress. In order to create this map, the person is responsible for stitching the images taken from the thermal imaging camera based on the geographical location of the photo taken. This should not be labor intensive because all the data analyst has to do is input the images into the Agisoft Software and make sure the software properly maps the field. The data analyst will be responsible for sending the farmer with the map of the field by email so that the farmer can take the appropriate actions in irrigating the field. Although the areas that need irrigation will be be clearly marked with a red/orange color, the data analyst will be required to answer any questions the farmer has regarding the data collected.

Summary

The team will need to employ one Operational Pilot, one Range Safety/Aircraft, Launch, & Recovery/Maintenance personnel, and one Safety Pilot. Thus, the total cost per hour of mission is $155.

2.3 System and Operational Considerations

The proposed FAA regulations result in both operational and structural considerations that affect both the flight-plan and airframe. The regulations limit the operational altitude to 500 feet above ground level (agl). Because of this, the aircraft detection span of the aircraft is limited. Had the aircraft had the ability to fly higher, a higher resolution camera could have been used to detect the moisture of the entire field at once. However, the operational limitations imposed by the FAA require the UAS to make multiple passes over the field.

Furthermore, the aircraft is limited to flying at speeds less than 87 knots. However, over each one square mile pass, this limitation is not unreasonable, nor does it greatly affect the operational considerations of the aircraft. Flying any faster would result in turns that require a greater bank angle, which would also impose greater load factors on the aircraft's wing. The RWDC limitation of four g's in the operation of the aircraft could easily be breached with an aircraft traveling 87 knots while detecting the field and conducting turns. A lower airspeed allows for tighter turns to be established (a smaller turn radius). In the event that the field was longer, the greater speed may have been useful. However, considering the frequency of the the aircraft's maneuvering in the one square mile field, the 87 knots is not a reasonable airspeed for the aircraft to fly at because of the load that would impose on the aircraft in a bank and its wider turning radius.

Line of sight operation is also required for the operation of unmanned aircraft. Because of this, the operator must physically have visual contact with the aircraft. Over one square mile with the aircraft flying at 301.8 ft AGL, visual contact should not be lost. Had the aircraft flown lower, it could have been possible for line of sight operation to be lost, while it is also an FAA requirement to fly at or above 301.8 ft AGL for the operation. Once again, this limitation is not unreasonable for the operation of moisture detection over the one square mile field.

The FAA also requires that the UAS be registered. There is a $5.00 fee associated with this which is payable to the Federal Aviation Administration. Once registered, the registration must be displayed on the aircraft at least 12 inches in height or as large as practical. It also must be applied so it can only be removed with paint strippers or thinners.

2.4 Component and Complete Flight Vehicle Weight and Balance

Two major factors needed consideration in the calculation of the center of gravity of the UAV: The center of the empty frame, and the center of the distributed payload. In order to determine the overall center, weighted averages of the two points were taken to determine its location. For the first component, Autodesk Inventor was used to calculate the initial position and distribution of the mass.

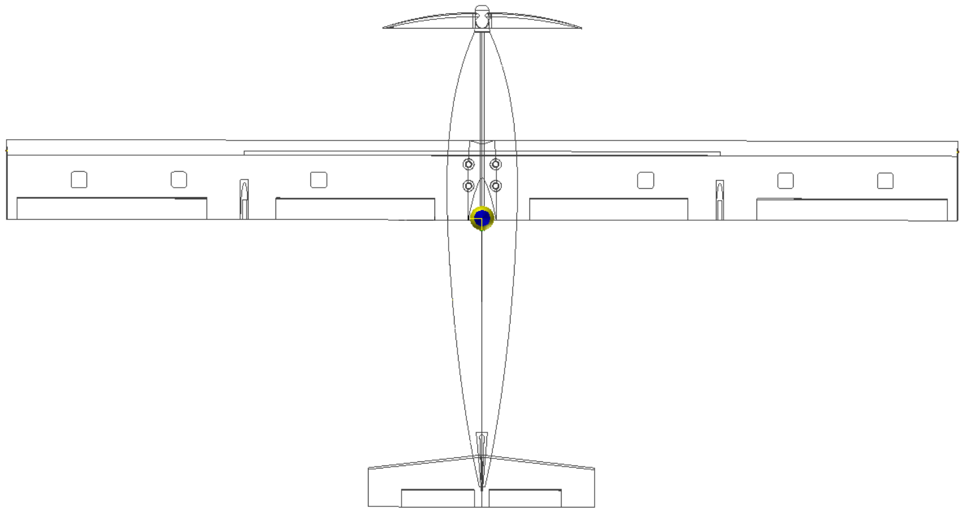
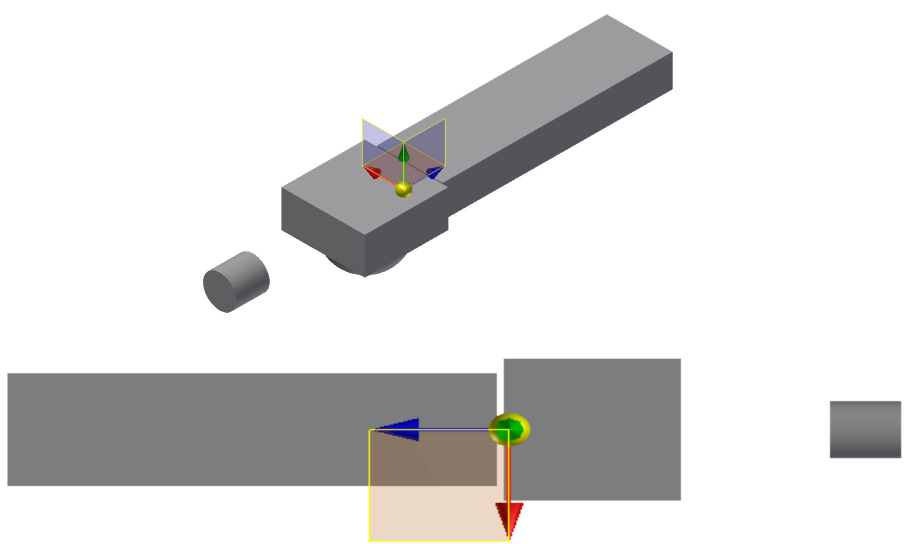


Figure 10: Top View of UAV

Following this calculation, the positioning of this coordinate was translated to a measurement along the length of the fuselage. In order to determine the weight distribution of the payload, a separate part was modeled in PTC Creo to represent the major components that rest within the body of the aircraft. This model, represented below in Figure 11, is not a completely exhaustive depiction of payload items. Components with either negligible weights (in comparison to the mass of major components) or potentially shifting positions (such as wires and other components of connectivity) are excluded in this calculation. In addition, support braces and other elements of the design used to secure and store these items safely and effectively are included in the simulation of the main frame of the UAV.



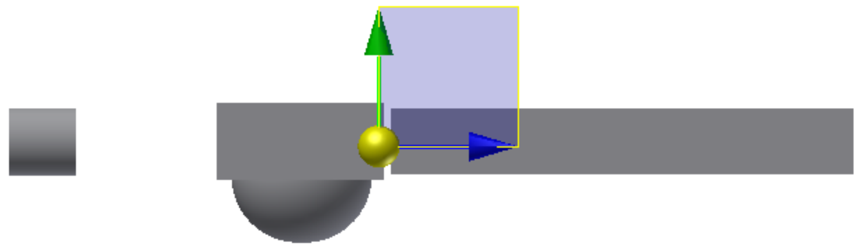


Figure 11: Depiction of Payload Items

The positioning of this coordinate along the length of the fuselage was recorded following the program's simulation. WIth the knowledge that the total, empty weight of the UAV is 9.36 kg, and the total weight of the payload alone is 3.5 kg (the total weight resting at 12.86 g), and the location of both centers relative to the length of the frame, a weighted average can be calculated. With the airframe center of gravity located 39.87 cm from the nose, and the payload center located 31.00 cm from the nose, the following expression may be used to determine the average of the two. [(9.36/12.86) * (39.87)] + [(3.5/12.86) * (31.00)] = 37.46 cm from the nose of the aircraft. This location is ideal, as it rests solidly beneath the wings of the UAV, near to the center of lift. (CM is depicted below by the green rhombus)

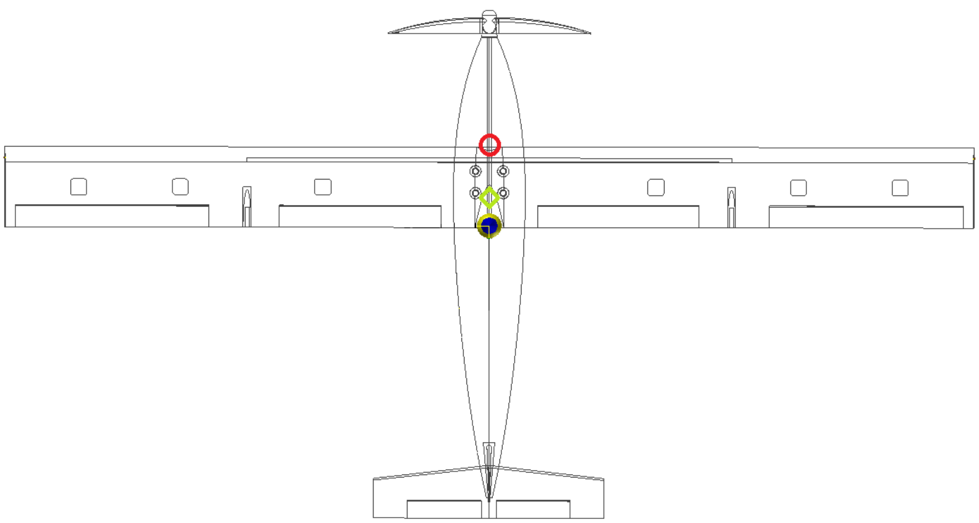


Figure 12: Depiction of CM

2.5 Design Analysis

Aircraft

FAA Requirement	Team's Design

1. The airframe must withstand anticipated aerodynamic flight loads throughout the complete range of maneuvers anticipated within the approved flight envelope with an appropriate margin of safety (+6/-4g's ultimate load)	Refer to Section 2.7: Operational Maneuver Analysis
2. The propulsion system must provide reliable and sufficient power to takeoff, climb, and maintain flight at all expected application altitudes and environmental conditions	The X181-KMR is powered by a electric brushless motor which can produce 19 HP. This provides enough power to accomplish the mission. Refer to section 2.2.2: Air Vehicle Element Selection.
3. The electrical system must generate, distribute, and manage power distribution to meet the power requirements of all receiving systems.	In order to meet this requirement, the team is using a Universal battery elimination circuitry which is an alternative power regulation module for protection of the control system. It provides power to the servo controls, without requiring an addition power source. Refer to section 2.2.1: Payload Selection.
4. The UAS must safely and expeditiously respond to pilot commands necessary to avoid conflict or collision with other aircraft or ground obstructions.	The UAS is equipped with a Data Transceiver Set (900Mhz) – High Range which has data transfer speeds of 250kbps which will allow the UAS to safely and expeditiously respond to pilot commands when the pilot reprograms the auto-pilot, adjusts the altitude or direction set in the 9-Degree of freedom (DOF) Inertial measurement unit (IMU), or takes full control of the UAV. Refer to section 2.2.3: Command, Control, and Communications (C3) Selection.
5. UAS 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	The autopilot is pre-programed by the operational pilot using the application ArduPilot which determines a specific flight plan and sets specific boundaries to prevent the UAS from escaping.
6. Software used to control critical aircraft functions must be developed with the appropriate software safety guidelines	The software is from a known and trustworthy source and is confirmed to follow the appropriate software safety guidelines. It has shown that it is able to properly perform on other similar UAVs.
7. Air vehicle Element/UAS maximum gross weight (fully loaded) should not exceed 55 lb.	Max Weight: 13.8lb

8. Antennas on-board the vehicle(s) must be separated by a minimum of 18 inches to avoid destructive interference	Antennas on board the vehicle are separated by at least 18 inches.
9. Any designs must comply with FAA guidelines and regulations, in addition to local/state legislation	Refer to section 2.3: System and Operational Considerations.

Control Data Link

FAA Requirement	**Team's Design**
1. The control data link must provide sufficient link performance margin at the maximum allowed range specified in the system operating manual under worst case meteorological and Radio Frequency (RF) interference, environmental conditions, and aircraft configuration	The team will use the Patch Antenna (900 Mhz)-Ground Based to provide more than 1.5 times the needed range of 1.52 miles. The current system is able to handle lengths of 3.6 miles. In addition, the team used the Data Transceiver Set (900Mhz) – High Range which is capable of transmitting data up to a distance of 6.3 miles.
2. The control data link must provide sufficient link performance margin at 1.5 times the maximum allowed range specified in the system operating manual under normal meteorological and RF interference, environmental conditions, and aircraft configuration.	The team will use the Patch Antenna (900 Mhz)-Ground Based to provide more than 1.5 times the needed range of 1.52 miles. The current system is able to handle lengths of 3.6 miles. In addition, the team used the Data Transceiver Set (900Mhz) – High Range which is capable of transmitting data up to a distance of 6.3 miles.
3. A human operator will be required to take control of an unmanned system in an emergency.	At the site, a safety pilot will be present. The Safety Pilot is responsible for bringing the aircraft safely in for recovery. The safety pilot is responsible for immediately taking over command of the aircraft and bringing it safely to the ground should it exhibit unanticipated flight behaviors
4. The radio frequencies used for control must be appropriate for the operation of UAS and approved by the appropriate government agency.	The team's radio frequencies are in compliance with FAA regulations. The radio frequency will operate at 900MHz.
5. Communications must be maintained with ALL remote vehicle elements	The team has sufficient communication equipment to maintain communication with all remote vehicle elements.

6. The control data link and aircraft system must continue to operate safely or perform the appropriate predictable contingency procedure in the presence of intentional or unintentional RF interference	In the case of intentional or unintentional RF interference where the data link is entirely lost and no fix can be made right away, the UAS will navigate back to trailer as programmed in the autopilot. The UAS will navigate back to the trailer once two continuous minutes of lost connection occur.

Navigation and Orientation-

FAA Regulation	**Team's Design**
1. System must provide positional determination	The UAS is equipped with a global positioning system capable of determining latitude, longitude, and altitude.
2. Must consider how your onboard navigation systems will remain in communication with your ground control system and operating crew.	The onboard navigation system will remain in contact with the ground control system and operating crew via the Data Transceiver Set (900Mhz) – High Range.

Control Station/Pilot Interface-

FAA Regulation	**Team's Design**
1. The control station layout and organization must allow the pilot to safely perform the functions necessary for safe flight.	The control station will be placed in the middle of the two field at the farthest end away from the no-fly-zone.
2. Any information necessary for the performance and maintenance of safe flight operations must be clearly displayed to the pilot and easy to identify and interpret.	The information necessary for the performance and maintenance of safe flight operations will be clearly visible on the PC Laptop. The PC laptop will receive data from the UAS through the transceiver which will then be displayed on the screen.
3. Aircraft control and input devices must allow the pilot to safely operate the aircraft without unusual pilot skill or concentration, be intuitive and logically implemented, and have the necessary labels for proper identification of function	The aircraft control will allow the pilot to safely operate the aircraft as it is very easy to use. The pilot will be able to preprogram the UAV's route prior to the flight while receiving video footage during the flight. The software used to pre-program the autopilot is very straightforward. The pilot will be able to operate the aircraft using the easy to use joystick while looking at the video footage coming from the UAV.

4. Aircraft control and input devices must be designed to minimize human error.	In order to minimize human error, the team will make full use of the autopilot feature. By being able to pre-program the flight path, one minimizes the need for human intervention and thus error.
5. Critical control inputs that could cause an undesirable outcome if inadvertently activated.	The team can not completely get rid of these critical controls because they all serve important purposes when properly used. Thus, in the software the team will incorporate password restrictions and dialogue messages that alert the user what he/she intends to do. The password restrictions and alert messages will prevent accidental or undesirable outcomes.
6. The system must provide the necessary cautions, warnings, and advisories to the pilot to allow the pilot to troubleshoot and properly respond to abnormal and emergency situations	The UAV's autopilot will be programed to return to ground base if the UAS loses contact with the control station for a certain amount of time. Additionally, if components such as the fuel gage and gyroscope detect undesirable conditions, the pilot will be notified by some message or alert on the PC laptop. Depending on the issue, the pilot may be able to solve it via the joystick and PC Laptop while for other issues may force the pilot to call the UAS to the control station.
7. The control station must have a primary power source suitable for rugged field operations.	The team will use the solar panels as a primary power source for rugged field operations.
8. The control station must have a backup power source in the event of a loss of primary power.	The team will have a backup generator in case the primary source malfunctions (Ex. little to no sunlight) in order to power the operation.
9. If applicable, the control station must allow a transfer of aircraft control to another airworthy control station without causing an unsafe condition.	The multiplexer will allow the transfer of control from the autopilot to manual. SImilarly it will allow the change in control between control stations.

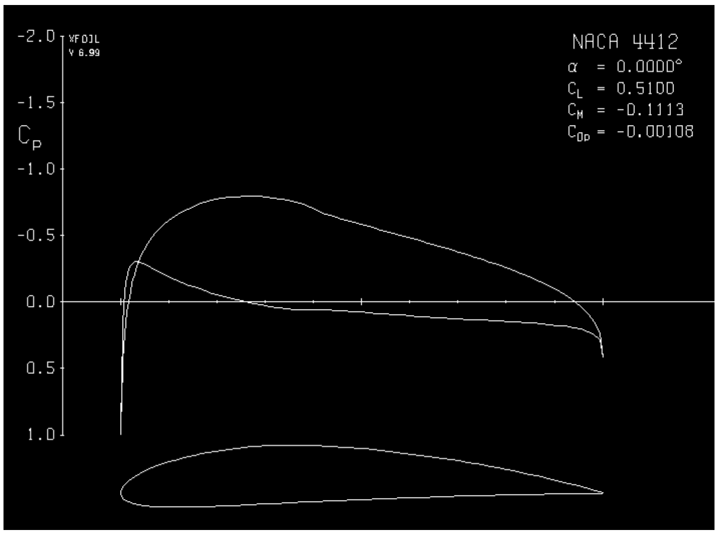
Contingency Response:

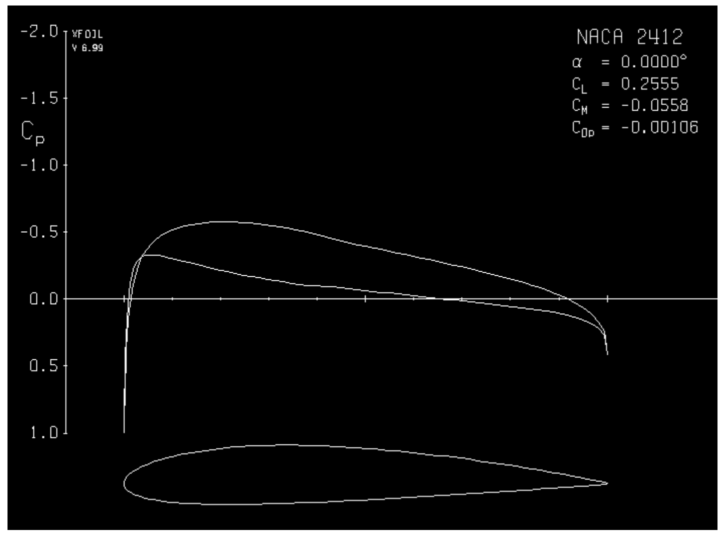
FAA Regulation	**Team's Design**

1. The UAS must provide, or must allow the pilot to perform, a safe and appropriate response to the unanticipated loss of the primary propulsion system	In response to the possibility of an unanticipated loss of the primary propulsion system, the Operational Pilot and Safety Pilot will have to oversee that the UAV glides to the ground safely. The ground crew will then be able to administer the cause of the issue and perform any necessary repairs.
2. The UAS element must provide sufficient back-up power for safety critical systems in case of a loss of the primary power source sufficient to safely recover the aircraft.	There are two batteries on board meaning that if one fails the UAS will be able to depend on the other to fly the UAS to ground base.
3. The UAS element must perform a predictable and safe flight maneuver in response to a loss of control link (lost-link) during any phase of flight.	In the case of loss of control link during any phase of the flight, the UAS will return to ground base as is programmed in the autopilot.
4. The UAS element must have a means to perform an emergency flight recovery, when appropriate, with both an active control link and during lost-link.	The UAS is programmed to return to ground base after two minutes of lost-link. If the control link remains active but another incident occurs, the UAS is programmed to return to the ground base.
5. The UAS element must be capable of continued safe flight and landing with an inoperative primary navigation sensor.	The UAS consists of an autopilot, digital compass sensor, and 9-Degree of freedom (DOF) Inertial measurement unit (IMU). Because of this, in case the autopilot (primary navigation sensor) becomes inoperative the use of digital compass sensor and 9-Degree of freedom (DOF) Inertial measurement unit (IMU) will be sufficient to allow the UAS to fly to the control base and land safely.
6. The UAS element must be capable of continued safe flight and landing with the loss or malfunction of a single propulsion source in a multiple propulsion source configuration.	The UAV is programmed to return to the ground station in the case that something malfunctions.

As you can see, not only does the team's UAV have a great design, it also follows FAA requirements.

As a result of research, the team procured a list of airfoils that would best suit the needs and size of the UAV. Upon narrowing the list down to two ideal selections, the program X-Foil was utilized to determine exact values and coefficients associated with the respective lifts and drags of each foil. The analysis demonstrated that between the NACA 2412 and the NACA 4412, the latter produced a greater lift for the speeds and angle of attack required for the execution of the flight plan. The final coefficient of lift for the craft was determined to be .5100 (shown below). From this point, the lift force was calculated. Following these calculations, the team experimentally determined the coefficient of drag, and proceeded to find the Moment Coefficient.





Calculating the Lift Force:

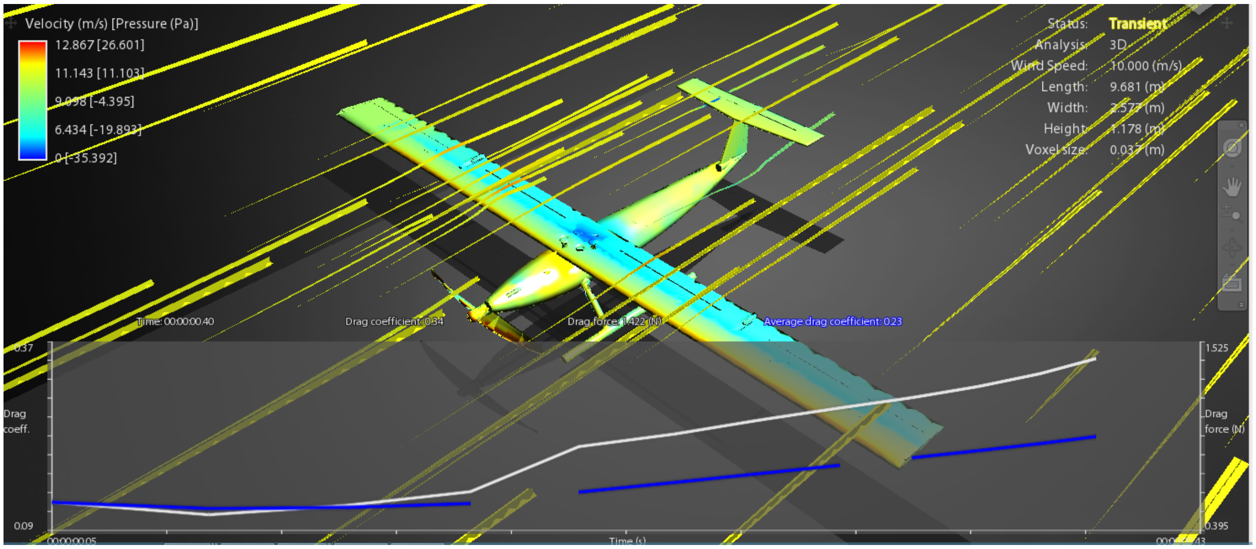
Using the lift equation: L = Cl x (((density) x V^2) /2) x A, the lift of the UAV was determined. L = (0.5100)((1.225(25^2)/2)(0.8) = 156.2 Newtons of lift force.

C_L = 0.5100

Figure 13: Lift Force Calculation

Determining Coefficient of Drag:

Using software provided by Autodesk, “Flow Design,” the team determined the drag coefficient of the entire frame experimentally through the simulation. Below, a screen-capture of the program in progress displays the process.



Average Drag Coefficient: 0.23

Drag Force (T=40): 1.422 Newtons

$$C_D = 0.23$$

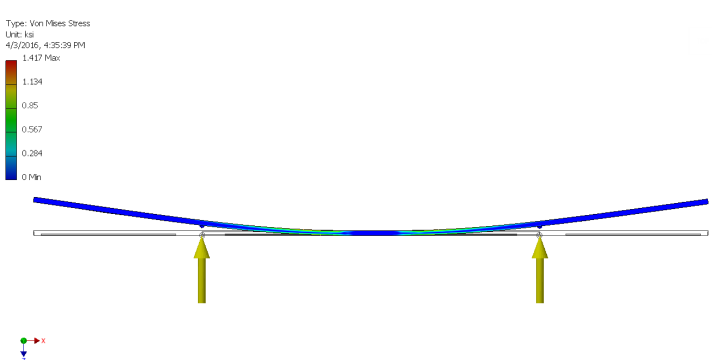
Figure 14: Flow Design Drag Coefficient Calculation

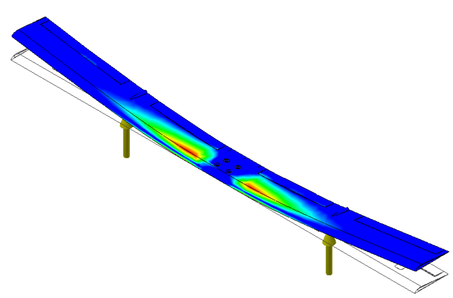
Determining Moment Coefficient:

The X-Foil software used in the analysis of the airfoil provided a variety of Aerodynamic coefficients, including the values involved in the calculation of the pitching moment of the UAV.

$$C_M = -0.1113$$

2.6 Structural Analysis





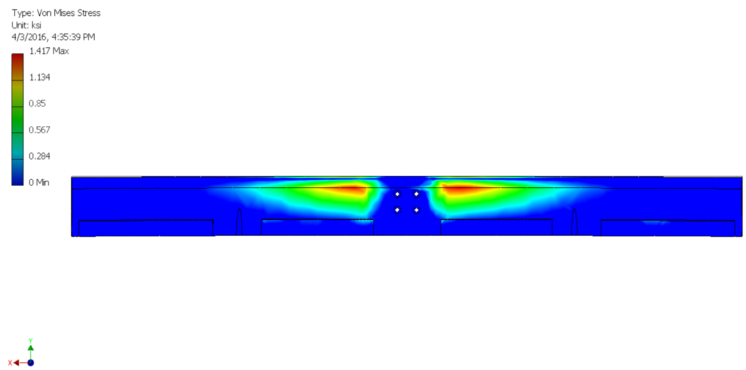
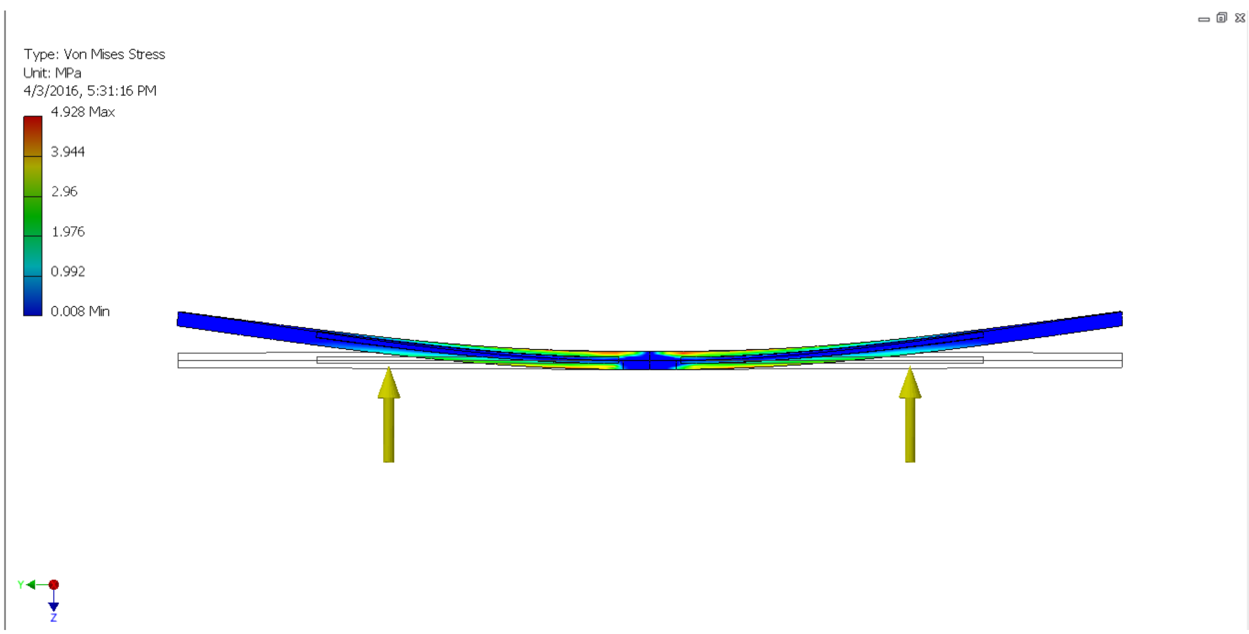


Figure 15: Maximum Load (6Gs - 78.0 equivalent lbs) on Wings

In the above models, the colors indicate how close the model is to its breaking point (dark red showing the parts of the model under the maximum amount of stress). The orange is not ideal, however it shows that it can at least withstand the absolute maximum stress. In the flight plan established by the team, the aircraft does not exceed 1.4 Gs in any given turn, guaranteeing that the craft will be able to withstand the normal stresses of flight, in addition to the safety factor (6 Gs).



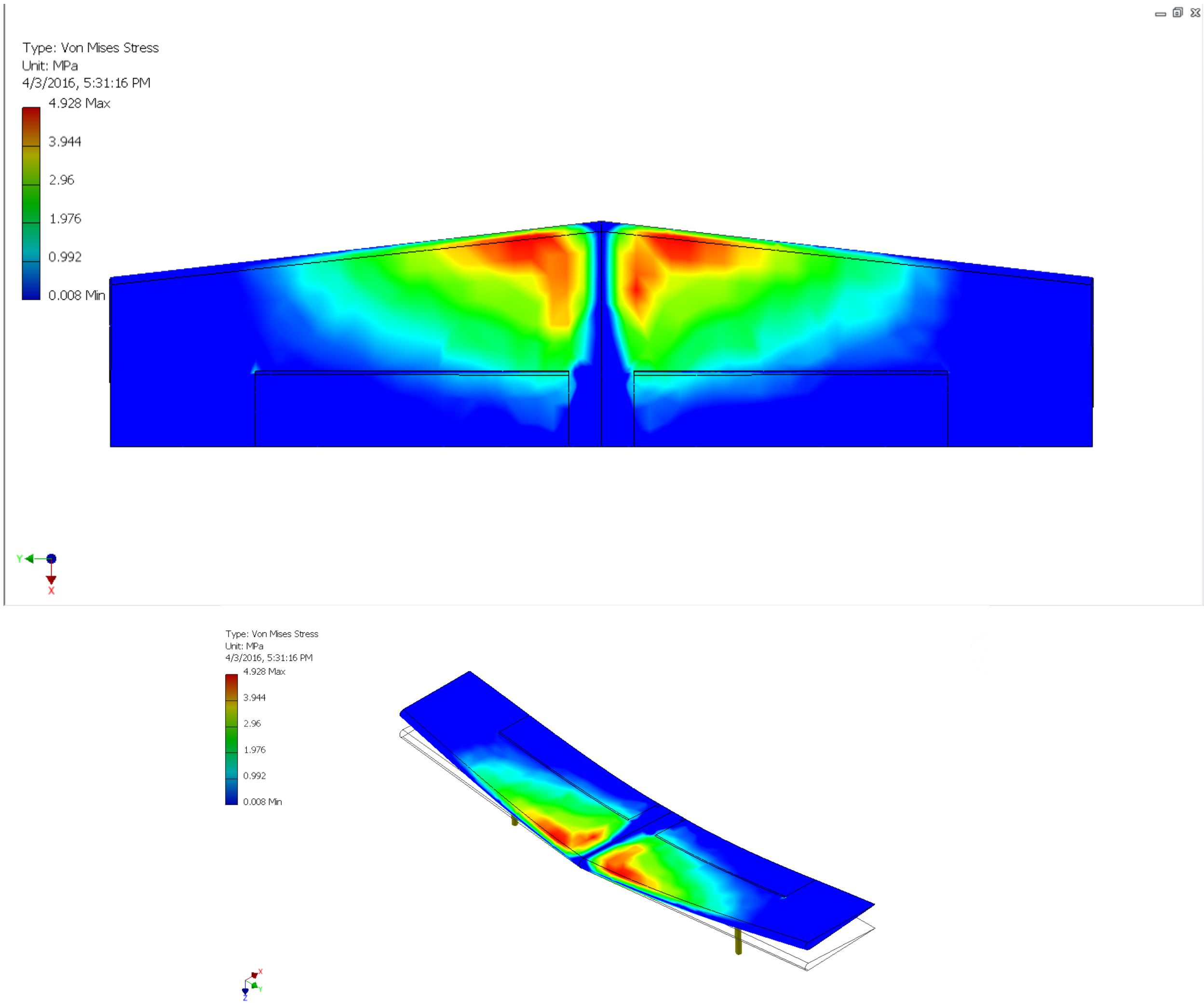


Figure 16: Stress on Tail

2.7 Operational Maneuver Analysis

During the flight, the UAV will be flying at 46 mph at an altitude of 301.8 ft. (This height was determined as the most advantageous height for the camera resolution.) The aircraft will travel for approximately 66.59 minutes along 51.05-mile flight path (outlined in section 3.2). As shown below, the aircraft will be able to maintain flight at 46 mph and will be able to perform the various turns in the flight path.

Aircraft Speed Entering Turn	46 MPH 39.974 KTS
Aircraft Rated Stall Speed	23 MPH 19.987 KTS
Turn Bank Angle	45 °

Turn Radius	142.1	Feet
Turn Diameter	284.2	Feet
Turn Diameter	0.0	NMiles
Turn Diameter	0.1	Miles
G Load	1.4	Gs
Increase In Stall Speed	1.2	Factor
Increased Stall Speed	24	KTS
Increased Stall Speed	27	MPH
360° Turn Time	13.2	Seconds
360° Turn Time	0.2	Minutes
180° Turn Time	6.6	Seconds
180° Turn Time	0.1	Minutes
90° Turn Time	3.3	Seconds
90° Turn Time	0.1	Minutes

2.8 CAD models

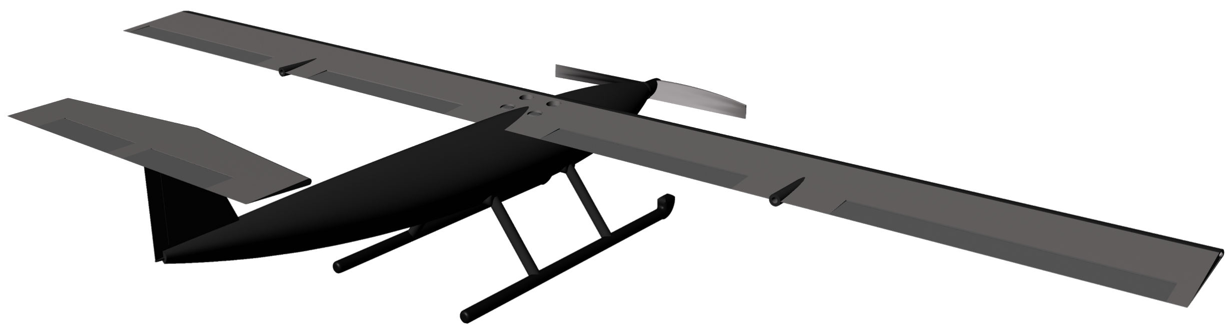
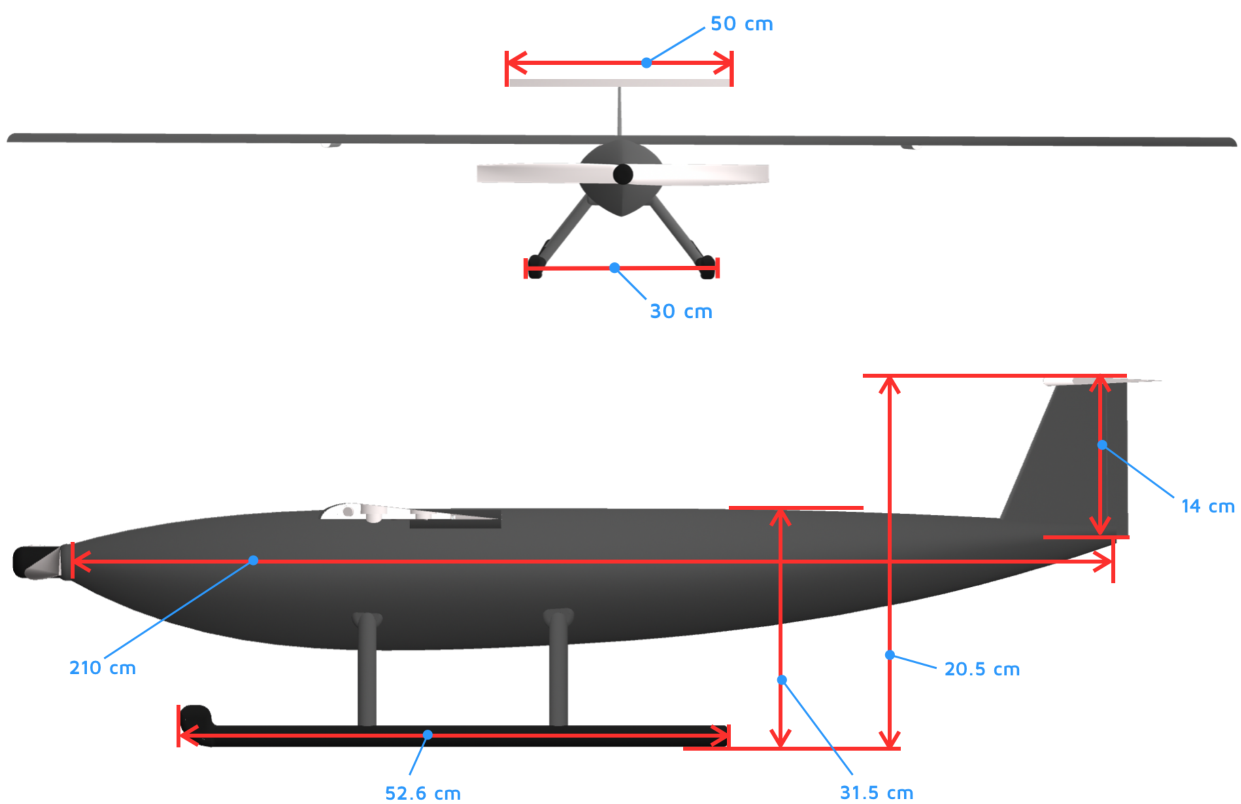


Figure 17: CAD Models

2.9 Three View of Final Design

The following, Figure 1, depicts the three view of the final unmanned system design.



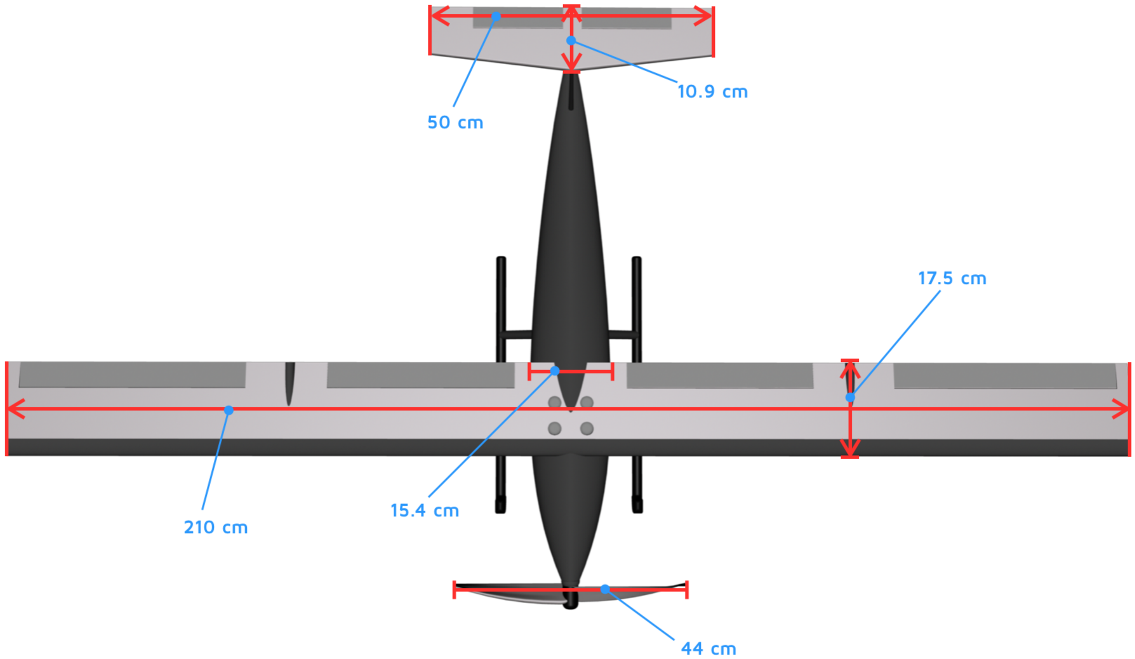


Figure 18. Three View of Final Unmanned System Design

3. Document the Detection Plan

3.1 Moisture Detection Pattern

Throughout the preliminary research, it was determined that a creeping line flight pattern would be most advantageous for this year's challenge. A cyclical pattern was also considered, but, as shown below, it does not cover a rectangular field in an ideal way. A creeping line pattern fits the square field best, as it is linear and could follow the natural shape of the target fields without large complications. However, considering the constraint that the air vehicle can not leave the outer border of the two fields, a modified circumcision/creeping line pattern was determined to be the team's best option. This design allowed the team to function from a single command center, which was most advantageous for communication and logistics, as shown below in the visual flight path representation. Subsequently, the team designed a full flight path with these two design components in mind.

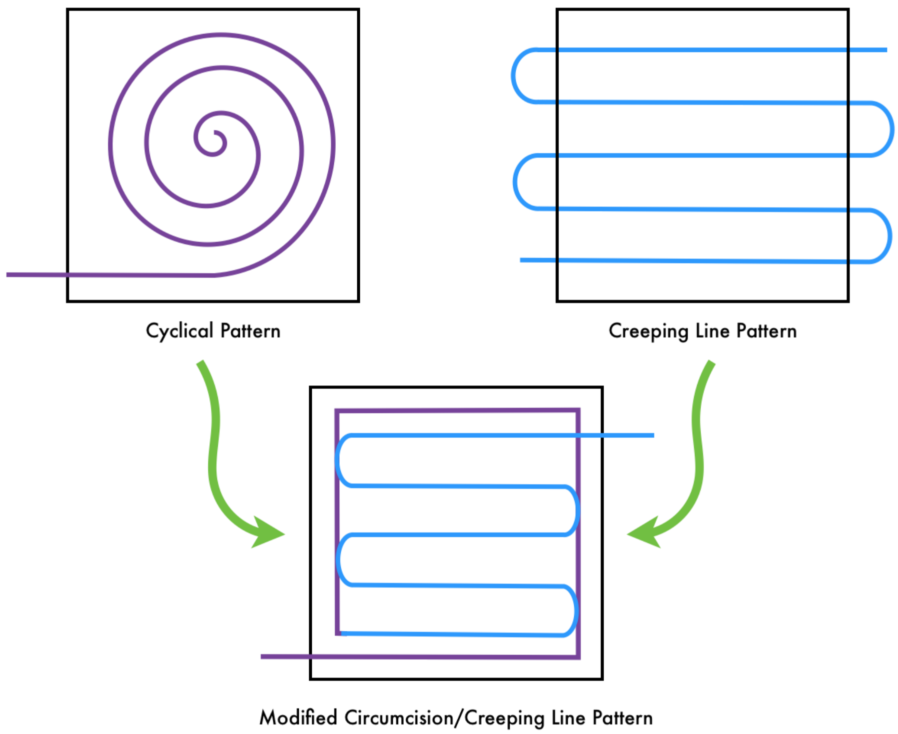


Figure 19: Modified Circumcision/Creeping Line Pattern

The creeping line pattern has an inherent problem if applied within the boundaries of the subject field. The semicircles at each end have "blind spots" which ignore certain portions of the field with the camera sensor. The inscribing pattern accounts for this major creeping line folly. Additionally, the No Fly Zone further complicates the flight path. However, the team opted for a simplistic approach, with minimal interaction between the individual paths in each field, to minimize the obsolete complexities associated with creating a single pattern followed across both fields as one unit. The airspeed chosen for the UAV is 46 mph (miles per hour) and the flight altitude is 301 ft. Seen below is a visual representation of the flight path:

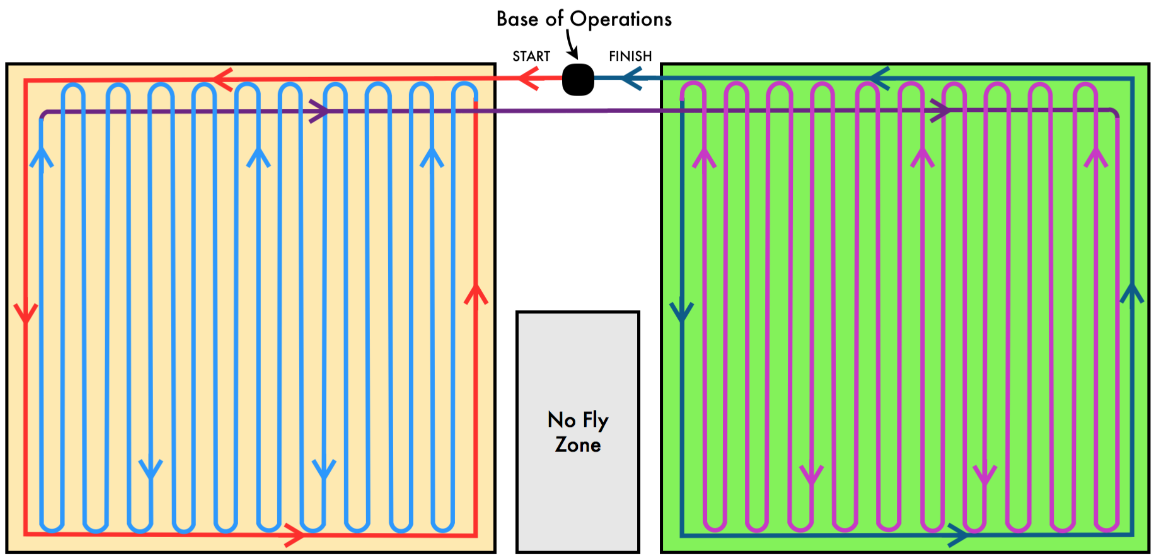
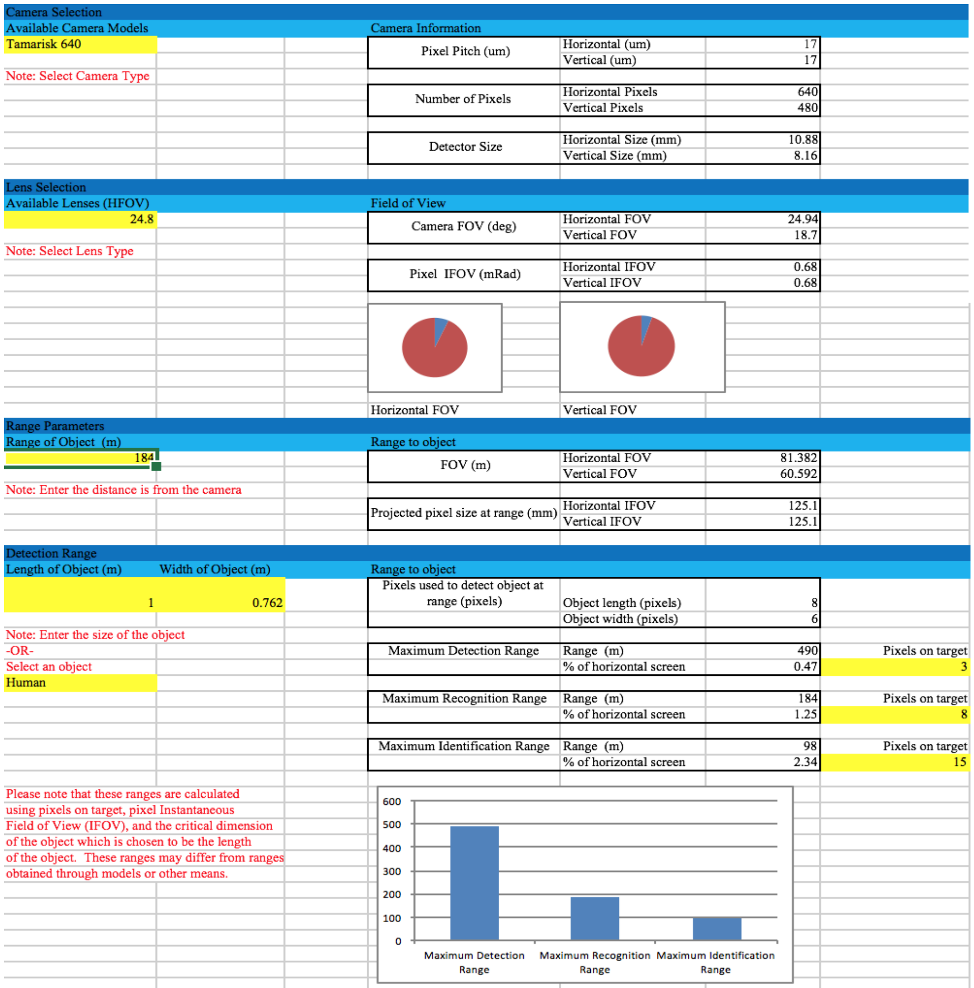


Figure 20: Flight Plan

Seen above, the flight path itself can be classified as a mirrored double circumcision creeping line pattern. The flight path is as follows: The UAV takes off and begins the first circular inscription of the field to the left, arbitrarily labeled the red, then blue, path, following the path along the outer edges on the first field, and then begins a second go around along the upper edge, as depicted. At the conclusion of this second leg, the UAV begins the series of eighteen passes, vertically along the creeping line portion of the path. Again, this pattern is most advantageous in a rectangular, linear fashion, as is these two subject fields. Subsequently, the aircraft flies an exit pattern adjacent to its entry path, and then begins the second phase of the flight path.

The second phase of the flight path includes the same elements, however, they are applied differently, as to not cause problems with the UAV re-adjusting course to follow the perfect mirrored pattern. This means that the UAV begins the series of twenty vertical passes, in accordance with the creeping line design, and subsequently complete the circumcision of the field, thus “filling the holes” in the creeping line pattern, adequately covering all parts of the field with the camera filming.

A constant altitude is held throughout the pattern, which was determined through pixel analysis to determine the ideal flight altitude given our sensor, pattern, etc. As seen in the table below, the team used a set of multiple parameters including camera specifications to determine the field of view (FOV).



Camera Selection			
Available Camera Models	Camera Information		
Tamarisk 640	Pixel Pitch (um)	Horizontal (um)	17
		Vertical (um)	17
Note: Select Camera Type	Number of Pixels	Horizontal Pixels	640
		Vertical Pixels	480
	Detector Size	Horizontal Size (mm)	10.88
		Vertical Size (mm)	8.16

Lens Selection			
Available Lenses (HFOV)	Field of View		
24.8	Camera FOV (deg)	Horizontal FOV	24.94
		Vertical FOV	18.7
Note: Select Lens Type	Pixel IFOV (mRad)	Horizontal IFOV	0.68
		Vertical IFOV	0.68
	Horizontal FOV	Vertical FOV	

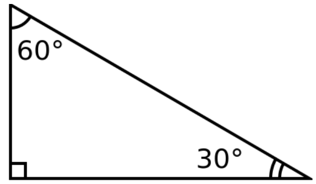
Range Parameters			
Range of Object (m)	Range to object		
184	FOV (m)	Horizontal FOV	81.382
		Vertical FOV	60.592
Note: Enter the distance is from the camera	Projected pixel size at range (mm)	Horizontal IFOV	125.1
		Vertical IFOV	125.1

Detection Range					
Length of Object (m)	Width of Object (m)	Range to object			
1	0.762	Pixels used to detect object at range (pixels)	Object length (pixels)	8	
			Object width (pixels)	6	
Note: Enter the size of the object		Maximum Detection Range	Range (m)	490	Pixels on target
-OR-			% of horizontal screen	0.47	3
Select an object		Maximum Recognition Range	Range (m)	184	Pixels on target
Human			% of horizontal screen	1.25	8
		Maximum Identification Range	Range (m)	98	Pixels on target
			% of horizontal screen	2.34	15

Please note that these ranges are calculated using pixels on target, pixel Instantaneous Field of View (IFOV), and the critical dimension of the object which is chosen to be the length of the object. These ranges may differ from ranges obtained through models or other means.

Figure 21: UAV Height Calculation

After calculating the maximum range that the UAV could fly, the team found that the Maximum Recognition Range of the Camera was 184m (603.68 ft). This means that at this distant the camera is able to focus 8 pixels on the target. The team choose to mount the camera at a pitch of 60^{o} in order to prevent the camera from looking straight at the ground and measuring the moisture of the soil instead of completing the intended task of measuring the moisture of the crop. By giving the camera this 60^{o} pitch up, more accurate data collection is possible. In terms of calculating the altitude, the team performed the simple mathematical operation 184*sin(30).



In the triangle above, the hypotenuse represents the Maximum Recognition Range of the camera, which is 184 m. Using the equation mentioned above, 184*sin(30^{o}), the team found that the UAV must not fly at an altitude greater than 92 m (301.8 ft). The team checked if this calculated altitude fit into FAA requirements which mandated that the UAV fly under 500 ft. Evidently, the team met the requirements set by the FAA.

Being that both fields will be filmed with the same infrared camera sensor, there is no variation from field to field. Thus, there are no differences in detection strategies from field to field. During the process of choosing crops, the team wanted to pick crops that would need similar detection strategies so that the mission could be as straight-forward as possible. The team knew that designing an efficient flight plan would save many costs.

The camera chosen for this year's challenge is the X3000. This camera offers a full visual spectrum camera for no extra charge along with the infrared camera. The X3000 has a roll and pitch limit of 85°, larger than all other competitors of this product. The X3000 also has a field of view of 25° horizontal and 19° vertical. These are all very powerful aspects, especially when combined with its $17,000.00 price tag.

This camera was chosen mainly for its relatively low price and good ability to function under a variety of circumstances. It offers a better value than many of the other cameras on the market simply due to its inclusion of a visual spectrum camera along with a thermal imaging camera. Its weight of 3.5lb is slightly higher than its competitors, but it was decided that this was negligible when compared to the many positive aspects it offers, through use of a solution selection matrix. This spreadsheet allowed the team to objectively determine the X3000 to be the team's ideal sensor/camera for this year's challenge.

	A Solution Selection Matrix for Determining the Best Camera					
	Solution Description	Complexity	Detection	Price	Results	Score
		1 = Very Complex	1 = Less Precise	1 = Expensive	1 = Less Precise	Low = Poor
		100 = Less Complex	100 = More Precise	100 = Inexpensive	100 = More Precise	High = Good
	Weight	0.1	0.2	0.3	0.4	1
1	X250	90	45	100	40	64
2	X500	80	50	90	45	63
3	X1000	75	65	70	60	65.5
4	X2000	70	70	55	65	63.5
5	X3000	70	80	50	75	68
6	X4000	60	80	35	80	64.5
7	X5000	65	85	68	50	63.9
8	X6000	65	90	30	80	65.5

3.2 Theory of Operation (Example Detection)

The theory of operation is as follows:

The equipment, delivered by the support trailer/truck, arrives at the two fields. Specifically, it is stationed between the two fields, directly above the no-fly zone, when looking at the map given in the national challenge background, vertically. Once it has arrived arrived, the communication, command, and control devices and equipment are set up. There are also the solar panels on the trailer that facilitate the charging of the batteries when the UAV is not inflight. The analysis computer is also set up, which functions to receive the UAV camera data and analyze it for the moisture levels in the two subject fields.

The personnel are the following along with their job description:

- Operational Pilot: In the case of autonomous or semiautonomous operations, the operational pilot is responsible for monitoring aircraft state (attitude, altitude, and location) to adjusting aircraft flight path as required for success of the application task.
- Aircraft Mechanic Technician: This individual can be assigned multiple non-concurrent roles, and is typically a highly qualified technician. This individual may also be responsible for aircraft launch and recovery operations as well as any required maintenance (e.g. refueling or repairs) in between flights.
- Safety/Redundancy Pilot: This individual is responsible for bringing the aircraft safely in for recovery. This role is also referred to as the “Observer”, responsible for maintaining VLOS with the aircraft.

- Data Analyst: This person is responsible for being able to use the Agisoft Software and Post-processing computer in order to provide the farmer with a map that indicates water stress.

Also before the preflight inspection, the wings are attached to the aircraft. The wings can be unbolted from the fuselage for easier transportation. Once the support systems are adequately prepared for the flight as well, the UAV is given a preflight inspection, checking basic components such as:

- motor and propeller
- fuel systems
- control surfaces and linkages
- communication systems

The aircraft is then prepared for flight, payload checked, and camera calibrated.

After the pre-flight inspection, the aircraft must be loaded into the car-top launcher, which provides the necessary acceleration and thrust to make the UAV airborne. The aircraft is then subsequently launched into the air and climbs to the flight altitude of 301.8 ft. Obviously, it makes the most sense to launch the aircraft in the direction of the first field, so the trajectory of the launcher is directly in line to intersect with the first pass around the field to the right.

A custom coded program was considered to run alongside the Ardupilot software. This program would allow Ardupilot to recognize and carry out our proposed flight plan. It would be written in either C++ or Python. After extensive research, it was found that a custom coded program would be inferior to the built-in Mission Planner of Ardupilot due to the time and effort put in for little gain. The Mission Planner was found to accommodate the functions we required for our UAS to work properly and thus made the idea of a custom built script inferior.

As the two fields are filmed, the camera records the data, which is sent directly to one of the support computers which reviews and compiles the footage as the aircraft is in the air filming. At the conclusion of the flight path, the UAV reduces power back, and slowly descends from the flight altitude of 301.8 feet to the ground, and lands on its skis.

The aircraft is packed up, support systems dismantled and packed up, and the truck/trailer leave the premises. At this point, the infrared data is analyzed through the data analysis computer (computer and components are outlined in section 2.2.4).

3.3 Detection Considerations

For the challenge two crop were selected that had were popular in the northeastern region of the United States. The chosen two crop are raspberries and sweet corn. Most farms grow more than one crop, which meant that the team had to modify the the detection strategy and flight path in order to have a successful flight and to also have an effective UAS system. The team had to select two crops that are important to agriculture and that have the same harvesting seasons.

The first crop selected was sweet corn. Sweet corn is one of the most common crops in the northeast and in Connecticut. This crop was chosen, in part, because it is harvested from August 1 to September 20. Since this crop is harvested in the summer, the X181-KMR would be crucial to the health of the crops, especially regarding moisture detection (preventing mold or allowing for proper irrigation to be carried out). In Connecticut, many farms grow more than one crop. The X181-KMR is an effective solution to agricultural moisture detection because of its ability to easily and effectively detect moisture in a variety of different crops. In Connecticut, sweet corn is vital to the state and nation's economies. In 2012, corn made $67.3 billion which is 17% of all U.S. agricultural sales, and there were 369,332 farms that were harvesting corn.

The second crop that was chosen was raspberries, since they harvested at about the same time as corn. This crop is harvested from July 5 to September 30. In the United States, raspberries have an average retail price of $6.98 per pound fresh and $4.45 per pound frozen, and yearly production is 64,773 metric tonnes. The U.S. is number four in annual raspberry production around the world.

The moisture detection system is a thermal imaging system that is able to detect the difference between the temperature of areas with a healthy amount of moisture and areas where there would need to be more water for the crops, along with over-watered areas that are subject to mold. The UAS would fly over both fields in one continuous flight path and would collect the data to show the client where there needs to be more water for the crop, along with the crop's status. This would also check the crops for any irregularities such as deformities and certain pests that plague these crops. In terms of sweet corn, the UAS would be able to help the farmer in irrigation. When the farmer properly irrigates the crop, his/her yield will increase by 20-30%.

Being that our thermal imaging uses an infrared camera, and thus can penetrate through the crops to adequately determine the heat associated with the given plants, the multiple detections throughout the time period are not a large problem.

Having two different crops is a result of the diversification that farmers maintain in their crops. This also means that the UAS must be able to have a flight path that would fly over two fields with two different crops in one flight. This means that the power source of the UAS must be able to use the thermal imaging for the two different crops.

This UAS also needs multiple passes to get the most accurate measurements and to be able to provide the customer with the most credible and reliable information. This means that there would have to be three different detection periods to be able to increase the effectiveness of the UAS. This means that the UAS would need to be able to have the endurance and reliability for three different time periods of detections each year. The UAS uses two Li-Po batteries that powers the electric brushless motion and that are recharged at the command and control station when needed in between flights. The thermal detection system would generally be used in the summer for the detection for moisture in the field would make the thermal imaging even more accurate.

Being that the team decided to use an infrared moisture detection camera sensor, an appropriate flight altitude to allow adequate sensing greatly influenced the flight path and detection pattern. The flight pattern is dependent on the altitude, to determine the camera footprint, through the pixel analysis previously explained. As far as the design, the modeling team had to design a fuselage that incorporated the X3000 camera, streamlining the body, and allowing the camera to utilize its maximum field of view. After this was accounted for, the team refined the flight path to be most effective, attempting to keep costs as low as possible, designing the most economic flight plan, the best moisture detection pattern and strategy.

There were major considerations that the team discussed in meetings regarding the efficiency of the UAS, the cost of a UAS with this specific task and also the profitability of the UAS. The team discussed on how to make the aircraft very efficient in order to complete the task. The team discussed what kind of powerplant and propulsion system would be effective and be able to make multiple flights in the crop field. The lithium ion battery would be able to be the most efficient and effective powerplant that would suit the purpose of the UAS and what it will be used for. The brushless electric motor was selected because of its excellent efficiency and how it will be able to conserve power and battery life while in flight. The team also discussed a reliable, strong and affordable airframe that would suit the purpose of the UAS. The material selected for the airframe was carbon fiber. This lightweight, affordable and strong material was the best airframe that would suit the purpose of the UAS as it will be needed to withstand the conditions in the field.

The current method of moisture detection on the market is placing stations that are positioned in fields to take regular soil samples, to then be picked up and tested with the proper agricultural equipment. A UAV system is quite costly comparatively over a small area, but the advantages of a UAS over manual collection of soil samples from ground units are plentiful, especially over a large field. For one, the UAV provides a more comprehensive and full scan of the entire subject field, versus sporadic and separated, isolated soil samples from stationary ground units. Additionally, the UAV provides the ease of multiple scans without the requirement of constant maintenance of those ground stations or the alternate of owning the equipment to take the soil samples and test them for moisture manually. Moreover, the number of detectors needed to detect moisture over two square miles would require much more money than a single UAS.

3.4 Detection Time and Resource Requirements

Below outlines the flight time break down into the several components:

Flight Path Component	Length (in ft)	Number of Passes	Total distance (in ft)	Total time (in hours)
Circumcision circles	39039	2	78078	N/A
Creeping Lines Turns	30197	N/A	30197	N/A
Creeping Lines	89400	2	178800	N/A
Passes between fields	1320	2	2640	N/A
Second Inscribed Line	5013	2	10026	N/A
Total	N/A	N/A	269544	1.109782609

Table 7: Flight Time Breakdown

And below is the human resource elements for a given mission:

For brief descriptions of their roles, see above section 3.2

Position	Cost per hour	Number of hours worked	Total Cost

Operational Pilot	$35.00	2	$70.00
Safety Pilot	$35.00	2	$70.00
Data Analyst	$50.00	2	$100.00
Mechanical Technician	$35.00	2	$70.00
Total Cost	N/A	N/A	$310.00

Mission Profile

1. Launch UAV and begin search

   After setting up the ground station, the UAV will be assembled. The removeable wings will be bolted to the body and UAV will be tested for any deficiencies. Once the testing is successful, the UAV will be launched into the air via a car top launcher. The UAV will ascend to the flight altitude of 301.8 ft and fly at its cruise speed of 46 mph. After reaching the set altitude and cruise speed, the UAV will begin detecting moisture content in the field. The pilot will be monitoring the progress of the UAV in flight.

2. During the Flight

   In flight, the UAV will fly at the preprogrammed cruise speed while collecting data concerning the moisture. The autopilot in conjunction with other sensors onboard the UAV will allow the UAV to follow its autonomous flight plan.

3. After the Flight

   Upon the conclusion of the pre-programmed flight, the UAV will descend in altitude to the ground control station. The operator will disassemble the UAV by separating its body from the wings. Both will be stored in the trailer along with any other equipment. The data concerning the moisture content taken during the UAV's flight will be processed by the data analyst. By using the Post-Processing computer created by the team and the Agisoft Software, the Data analyst will create a map of the field outlining locations needing irrigation and areas that don't require it. This map will be given to the farmer, either electronically or physically (depending on his/her preference), so that he/she can take any further action.

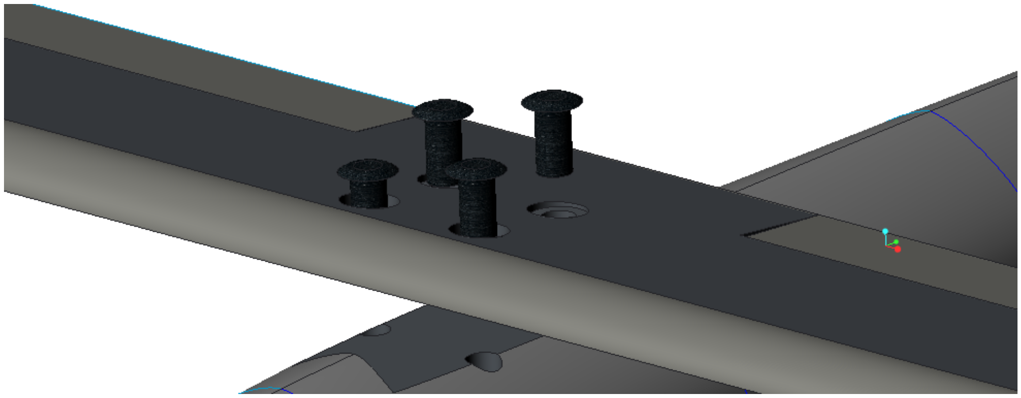


Figure 22: Removable Wing Design

4. Document the Business Case

4.1 Regulatory Restrictions

The proposed FAA regulations result in both operational and structural considerations that affect both the flight-plan and airframe. The regulations limit the operational altitude to 500 feet above ground level (agl). Because of this, the aircraft detection span of the aircraft is limited. Had the aircraft had the ability to fly higher, a higher resolution camera could have been used to detect the moisture of the entire field at once. However, the operational limitations imposed by the FAA require the UAS to make multiple passes over the field. Furthermore, the aircraft is limited to flying at speeds less than 87 knots. Line of sight operation is also required for the operation of unmanned aircraft. Because of this, the operator must physically have visual contact with the aircraft. The FAA also requires that the UAS be registered. There is a $5.00 fee associated with this which is payable to the Federal Aviation Administration. Once registered, the registration must be displayed on the aircraft at least 12 inches in height or as large as practical. It also must be applied so it can only be removed with paint strippers or thinners.

The X181-KMR, though designed for agricultural detection, can be used and adapted for other commercial needs. Moreover, unmanned technology could vastly improve the operations of many companies that rely on manned aircraft. Because of this, the X181-KMR can be used for fast transport of light payloads.

Medical supplies or organ transplants, which today are transported by helicopter to hospitals, could be transported by the X181-KMR. As long as the distance the aircraft has to fly is less than thirty minutes away, about 25 miles, it could effectively be used for immediate transport. Furthermore, because of its small size, current hospital configurations could be used for takeoff and landing of the X181-KMR. Organ transportation may require a slight reconfiguration of the fuselage, for sterility and freezing purposes. Although the range would need to be increased, this retrofit would be a matter of improving infrastructure and spending money for overall medical improvement.

The X181-KMR could also be used for search and rescue operations, both inland and at sea. Its visual sensing capabilities could be effectively utilized to search for a lost person. This information could be immediately transmitted to search crews who could then attend to the person. Using a UAS is much less expensive and less resource intensive than using a manned aircraft. In addition, because the X181-KMR uses batteries, it reduces fuel costs.

Another possible, and cost effective, use of the X181-KMR is for animal herding (primarily cattle). Traditionally, helicopters are used for herding the cattle, while other aircraft are used for locating the herd. Helicopters are much more expensive than the X181-KMR, which, excluding the camera (which would not be used for actual herding procedures), is only $29032.29. With a lower resolution camera (since herds would be detected instead of moisture), the expense would still decrease. Although range boosting equipment may be necessary, this cost is offset by the lack of camera. Because of this, the X181-KMR is a financial improvement. Helicopters also produce large amounts of dust when flown near the ground. This reduces visibility and could disturb the herd rather than muster it. Since the X181-KMR is a fixed-wing aircraft, the UAV will not create dust clouds. Herding animals is not affected by the size of the machine (as both helicopters and dogs are used to herd the animals). Hence, although the X181-KMR is smaller than a helicopter, it can still effectively herd animals. Moreover, sheep and goats also must be herded. Mustering animals is global, so the X181-KMR could be commercially utilized worldwide.

Finally, the X181-KMR, in its current moisture detection configuration, can also detect moisture on other crops. Cabbage and onions can be also be evaluated for moisture content. The X181-KMR can be used for a range of agricultural and other civil applications.

FAA regulations would have to be changed slightly to facilitate additional commercial applications. The most limiting regulation is the maintenance of line of sight (LOS) operation throughout the flight. Because of this, great distances cannot be traversed. Licensure and communication is not an overbearing regulation, as flying in controlled airspace requires this anyway. Also, if the UAS were to fly in controlled airspace, it would need to fly over 500 ft agl. In fact, for medicine or organ transplant, it would need to fly higher than 500 ft agl per current FAA regulation. In fact, it would need to fly 1000 ft over the highest obstacle if the hospital were in a populated or congested area (which is not unlikely because many hospitals are in urban areas). Although FAA regulations need to be eased for some operations, the result of their easing would be neither dangerous nor hazardous if the UAS was in controlled airspace.

4.2 Amortized System Costs

The amortized system costs help to offset the acquisition costs of the system and the cost per individual mission. Because of this, the total cost of the system is not instantly needed but, rather, can be paid in full over a span of time. Five years are allotted to pay for the entire UAS, along with its operating costs. Therefore, the development of a successful Business Case ensures that the entire system is paid for over the five year period, its operational costs are defrayed, and a profit is produced.

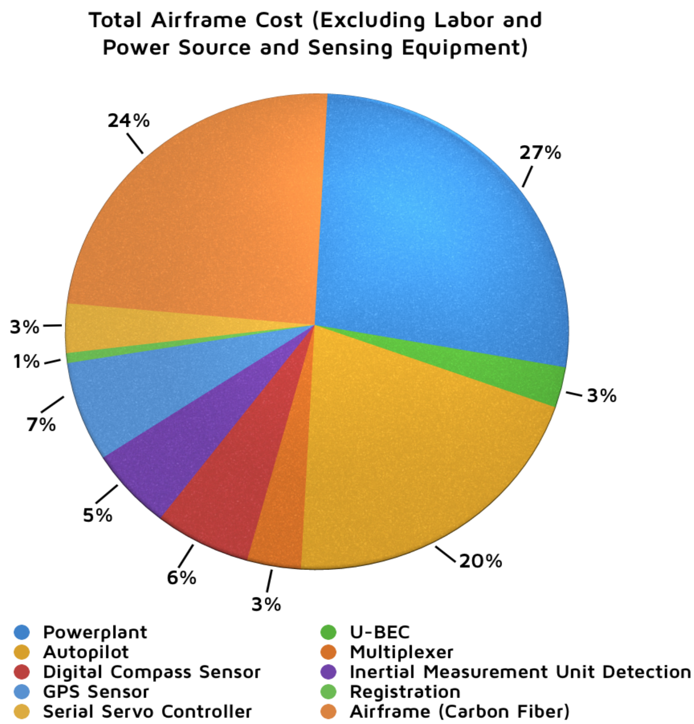
4.2.1 Initial Costs

The X181-KMR, as a UAS, is a combination of three main systems and the labor to build and design the aircraft. The airframe and powerplant are essential to the fundamental operation of the UAS, the LiPo batteries are fuel (although they are a single cost to the system, they are not included in the "initial" cost of the airframe itself), while the sensing equipment is mission specific. The airframe's total cost is outlined below (sensors and batteries are excluded).

Component	Cost
Powerplant	$200.00
U-BEC	$20.00
Autopilot	$150.00
Multiplexer	$25.00
Digital Compass Sensor	$45.00
9-Degree of freedom (DOF) Inertial measurement unit (IMU)	$40.00
GPS Sensor	$50.00
Registration	$5.00
Serial Servo Controller	$25.00
Airframe (Carbon Fiber)	$179.90
	Total: $739.90

Table 8: Initial Costs

The cost of the two batteries used in flight is an additional $1050.60. Therefore, the total cost of the system with fuel is $1790.50. The components of that make up the initial costs of the system can also be broken down into percents of the total initial cost. This is useful for future reference for the buyer. In the event of a crash, the owner can more easily determine whether or not to replace the entire system, or just the damaged components.



The sensing equipment used to complete the moisture detection mission is the X3000 camera. This camera is a $17,000 expense. However, because of the X3000's capabilities, no other detection equipment is needed. Therefore, both infrared and visual detection are included in the $17,000 cost of the camera.

The cost of designing and assembling the system, unlike purchasing materials, is incumbent upon the amount of time needed to build the system. Therefore, the more complicated the system is, the more expensive it is to build. Spending less time using more expensive materials could, in fact, be more cost effective than spending more time assembling a series of less expensive materials. This can be displayed by a linear relationship in which x is one hour, the coefficient of x is the total pay of labor per hour, b is the fixed materials cost, and y is the total cost of labor. It was necessary for the team to combine ease of construction with cost of each material.

The assembly personnel needed to construct and design the X181-KMR result in a total expense of $5340. An assembly technician that works with carbon fiber is needed to construct the fuselage, wings, vertical stabilizer, and horizontal stabilizer along with the control surfaces for flight (aileron, elevator, etc.). Working for 30 hours at 23 dollars per hour results in a $690 total paid to the assembly technician. The electronics technician, certified by the Federal

Communications Commission (FCC) or an electronics technician with an Aircraft Electronics Technician (AET) certification would be paid $1450 at 29 dollars per hour for fifty hours. This technician's responsibility includes the complete development of electrical systems for the aircraft. Finally, the aircraft maintenance technician repairs inoperative components of the aircraft. A critical member of the aircraft's development team, the aircraft maintenance technician is paid $3200 for 100 hours of work at 32 dollars per hour.

Labor Expenses			
Role	Hours	Cost Per Hour	Subtotal
Assembly Technician (Carbon Fiber)	30	$23.00	$690.00
Electronics Technician	50	$29.00	$1450.00
Aircraft Maintenance Technician	100	$32.00	$3200.00
			Total Assembly Cost: $5340.00

Table 9: Labor Expenses

Section 2.2.4 outlines the support equipment costs related to the operation of the X181-KMR. The total cost is $27,115.10, which consists of a trailer, pickup truck, generator, battery charger, desktop computer, data collection software, a car top launcher, and two solar panels.

The total acquisition cost for the entire X181-KMR UAS is $55,555.60. Thirty four percent of the cost is made up of the vehicle itself, eight percent of the total cost is made up of C3 elements, forty nine percent of the total is made up of support equipment, and ten percent is made up of the engineering labor costs. The addition of all four elements is outlined below.

System Costs	
Total Vehicle Cost	$18,790.50
C3 Cost	$4,310.00
Support Equipment Cost	$27,115.10
Engineering Labor Cost	$5,340.00
Total Acquisition Cost	$55,555.60

Table 10: System Costs

4.2.2 Direct Operational Cost per Mission

The manpower for an example mission is a team of four employees, each with a distinct role. This example mission is 2 hours in length, approximately 66 minutes in flight, and 54 minutes for equipment and support systems set up. The manpower requirements followed the RWDC Crew Requirements. The following is the human resources/manpower required to operate the system:

Position	Cost per hour	Number of hours worked	Total Cost
Operational Pilot	$35.00	2	$70.00
Safety Pilot	$35.00	2	$70.00
Data Analyst	$50.00	2	$100.00
Mechanical Technician	$35.00	2	$70.00
Total Cost (Per mission)	N/A	N/A	$310.00

Table 11: Human Resources

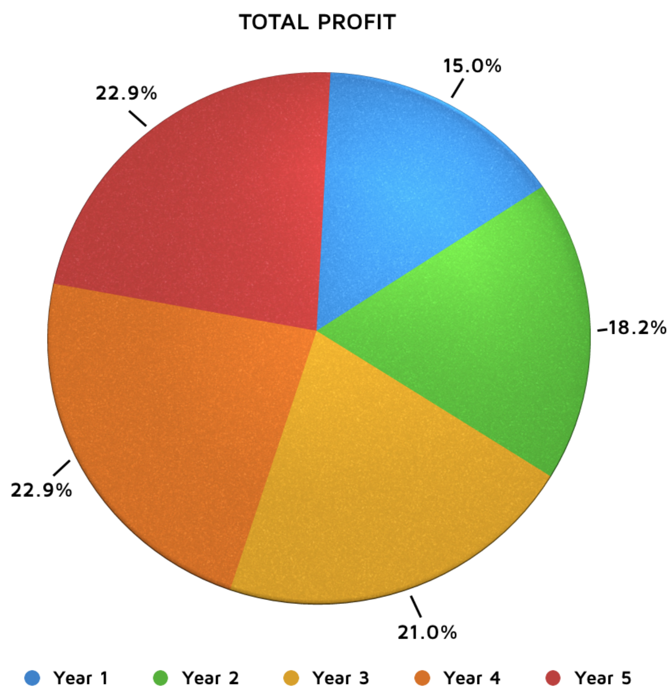
An operational pilot, maintenance technician, and safety pilot are all needed for safe and legal operation of the UAS. Each is paid $35 per each hour of work. The data analyst sorts and analyzes data after the flight concludes. The data analyst, who also must both operate software and sort data, is paid $50 per hour. In total, for a two hour mission, $310 must be paid to operational personnel.

Because of the LiPo batteries selected for the mission, the cost of consumable items are mitigated. Electrical power on the ground is provided by a series of solar panels. However, for cloudy days, a generator with gasoline will be needed. According to the U.S. Energy Information Administration, in the month of March in 2016, the national average for the cost of gasoline was $2.00 per gallon. Given fluctuations in the market, it is safe to assume that over the next few years the price of gas will have an average of around $2.00. Therefore, $20 is spent per hour on gasoline costs and thus $40 per 2-hour mission. As previously mentioned, this number is subject to rising and falling, though even doubling the price of gasoline would result in only $80 per mission of gasoline use. This is far less than the total expense for operational personnel for each mission.

4.2.3 Amortization

One acre of raspberries is worth about $7000 and one acre of corn is worth about $950. Therefore, in total, each mission farm could potentially result in $7950 in revenue for the farmer. However, additional costs from fertilizer, equipment maintenance, and manpower result in about a $1000 profit per acre of raspberries and a $350 profit from the corn per acre. Therefore, for each two square mile area of farm, the farmer could expect a little over $80,000 profit in an extremely successful year of farming. However, because raspberries are a high-risk crop, the actual expected profit per acre of raspberries is commonly lower. However, because of the sensitivity of both crops to water, the X181-KMR can result in profits at the higher end of the potential profit that the crops could produce. Consider that a year in which there is a draught would normally result in a waste of about 1.2 million gallons of water. In Connecticut, the cost for water is about $0.006 per gallon. That would be a loss of $7200 to water alone. Therefore, the farmer would hardly break even, just after water costs. In reality, the farmer would probably lose about $1000 per acre after accounting for the little revenue produced by the crops and the other costs to operate the farm.

If the X181-KMR were to be used in a season and save the farmer $7200 in a year, then it is reasonable to assume that the farmer would be willing to pay about $5000 for use of the system. That would leave a $2200 margin for the farmer to profit off of. However, in order to establish the X181-KMR as a system to reduce overwatering, it would be more reasonable to begin by charging farmers $4700 to detect each mission. Then, over time, the $5000 charge could be reached (hopefully by the fourth year). Moreover, the first year, fewer missions would be done, as business must be built over the time period. Therefore, assuming twenty five fields, seventy five detections would be accomplished. At a total of $4700 of revenue per mission, seventy five missions, and about a $53000 operational cost, the first year would yield just under $300,000 in profit for the X181-KMR. By the fifth year, with thirty five fields and 105 detections, the total profit is about $455,000 per year. The following chart breaks down the profit per year compared to the cumulative net cash flow:



By the fifth year, the X181-KMR would have produced a total of a little under two million dollars in profit.

These profits and costs per year assume a constant $11000 payment each year for the system. This offsets the initial costs of the system by the fifth year of payment. The acquisition cost per hour the first year of flying is the most, about $73, because the fewest number of missions, and therefore hours, are flown. This number decreases to $52 per flight hour by the fifth year, when more missions are flown. In total, for the farmer, at $5000 revenue, $3.91 per acre is paid for moisture detection (assuming two square mile fields).

4.3 Market Assessment

The agriculture industry is a very large and competitive. Everyday, there are new innovations that result in the improvement of agricultural technology. Because of this, the X181-KMR needs to be more productive than its competition that detects crop moisture. By saving farmers money by helping them conserve water, the X181-KMR is an effective solution to agricultural moisture detection.

A competing system is the the Stevens HydraProbe soil detection system. Farmers buy a number of these probes and insert them into their fields. The probes then send data to the farmer regarding soil moisture content. However, this system is expensive and imprecise. One probe costs between $400.00 to $745.00. However, to detect moisture in a one square mile field, many of these probes must be purchased. In fact, if the farmer was interested in detecting moisture at each *acre* of land, the total cost would be $256,000. These probes also relatively easily lost, since they are small and would be placed all over the field (moreover, there would be 640 of them over a square mile field). These probes also have to be calibrated for the soil there being placed in individually. Furthermore, computer programs must be purchased to analyze and retrieve the farmer's data. Therefore, using soil probes are only useful for smaller fields when looking for general trends in moisture content.

The PrecisionHawk is another moisture detection and surveying drone. The aircraft itself is $25000, though additional items can increase its cost. Furthermore, it has a payload of only 2.2 lbs. Therefore, unlike the X181-KMR, its uses are extremely limited. Moreover, sensor options for the PrecisionHawk can cost up to $60000. Initial costs of this system are higher than those of the X181-KMR, and it is not nearly as versatile as the X181-KMR either.

Assuming identical conditions, the X181-KMR is less expensive for the farmer to use per acre than both the PrecisionHawk and the HydraProbe. The farmer pays $3.91 per acre to use the X181-KMR for moisture detection. With comparable equipment that could produce results similar to those of the X181-KMR, the PrecisionHawk costs about $65000 initially. The PrecisionHawk detects a field in about the same time as the X181-KMR. In total, the PrecisionHawk cost about $4.01 to operate per acre. Therefore, the X181-KMR is $0.10 less expensive to operate per acre, or $128 less expensive to operate per year. Similarly, for the much more expensive HydraProbe system, the X181-KMR saves $8.59 per acre.

4.4 Cost / Benefits Analysis and Justification

The X181-KMR is, at its core, a very cost effective aircraft. The aircraft itself is $739.90, including the airframe, powerplant, and flight controls. Because of this, more can be invested into additional components on the airframe, such as a more precise camera, or batteries with a longer life and greater output of electricity. The cost effectiveness of the X181-KMR's airframe helps allot more money for additional components and helps improve the business objective function.

The airframe cost objective function relates the airframe cost (CAF) to additional components (total cost of the vehicle), (CUAV). Therefore, to maximize this function, a lower CAF must be established to allow for a higher CUAV. The greater the disparity between the two values, the better the objective function (since the CAF is always less than or equal to the CUAV). As the X181-KMR demonstrates, a lower CAF and a higher CUAV results in an objective function near one. A higher CAF and a lower CUAV would result in an objective function value much lower than one.

UAV 1	
Airframe Cost, CAF	$739.90
Total UAV Cost, CUAV	$18,790.50
AF Cost 1	0.9606237194
Number of vehicles	1

Carbon fiber is used for the X181-KMR's airframe. Although the X181-KMR does not have a large surface area, carbon fiber is lightweight and strong which helps to improve the performance of the aircraft. In total, the airframe costs only $1429.90 for materials and production. Assembling the airframe is an additional $4650 for the electronics technician and aircraft maintenance technicians' pays. Batteries were selected that could complete an entire mission on one charge. This decreases the time needed to fly the mission and thereby increases lifetime profit and the objective function.

Finally, the camera chosen (the X3000) provides moisture detection capabilities, both infrared and visual, for $17,000. This is an additional component (payload), but because the airframe costs are are, the X181-KMR can be specialized for each mission with precision detection or, depending on the application, generally more precise instruments could be affixed to the airframe without inordinately increasing the overall UAS cost. Because the X3000 provides both infrared and visual detection, only one pass is necessary over each field to detect moisture. This also reduces mission times and increases profit.

The overall goal of the X181-KMR is to allow for maximum profits with minimum revenue. Low operational and initial costs allow for this goal, which is also reflected in the objective function. The result of mitigating airframe costs while maximizing other expenses allowed for a Business Case objective function of $0.86.

To calculate the total, final objective function, three formulae are used. The business objective function is a function of total operational expenses to total operational revenue. Thus, to find the business objective function, the difference in these two expenses is found, and then their average is taken. Using the $320,995.60 as the five year expense and $2,310,600.00 as the total revenue, a business objective function of $0.86 is calculated. The airframe efficiency objective function relates the airframe's maximum takeoff weight to its empty weight. Therefore, if the aircraft has a lower empty weight and a higher maximum takeoff weight, this part of the objective function is higher. Using an empty weight of 9.36 pounds and a maximum takeoff weight of 35.0 pounds, an airframe efficiency objective function of 0.73 is calculated. Finally, airframe cost is related to total cost of the UAS for the mission. A lesser airframe cost and greater equipment costs results in a higher airframe cost objective function. The X181-KMR, without mission specific equipment, costs $739.90. With mission equipment, however, it costs $18790.50. This results in an objective function for the airframe cost of 0.96. As a combination of all objective function factors, the final objective function is 0.85.

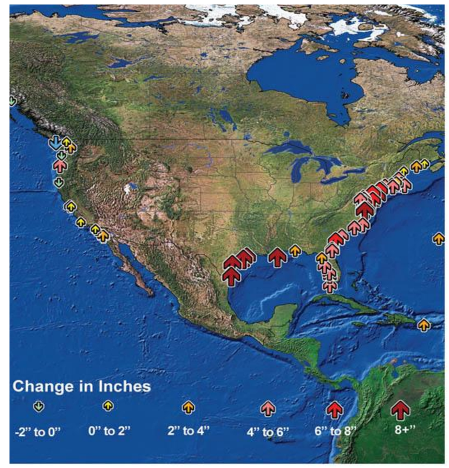
4.5 Additional Commercial Applications

Moisture detection on golf courses and tobacco fields along with erosion monitoring on shorelines can all easily be surveyed by the X181-KMR. Each one of these additional applications will help the UAS continue producing revenue even when it is not detecting moisture content in corn and raspberry fields.

In the United States, there are over 1.1 million acres of golf courses that need to be irrigated. Between 2001 and 2005, over 8000 new acres of grass were irrigated on golf courses in the northeast. $6300 of water were used in the northeast per year to irrigate golf courses. However, it is important to note that golf-course superintendents still need to conserve water. Most use schedules in order to try to appropriately irrigate the grass. According to the United States Golf Association (USGA), “approximately 35 percent routinely utilize evapotranspiration data” (*Golf’s Use of Water*, 15) and three percent use soil moisture sensors to aid in irrigation schedules. Evapotranspiration is the measurement of how much water has evaporated from the land to the air. In order to conserve water, 92% of courses use wetting-agents, 78% use hand watering, and 69% simply keep the turf drier (by not watering it). 28% of golf courses in the northeast have strict irrigation allocation restrictions, and must use limited water, even in dry seasons. Because of the drought in California, the USGA has done an extensive case study of water savings in the state. It was found that 45% less water could be used when extensive study of moisture content in soil was conducted. This was a result of very careful detection and reports from golfers, as well. A permanent system, the X181-KMR, would benefit golf courses because of its dedication to the job and accuracy. In the northeast, using 45% less water translates into a $2835 savings each year. Using one third less water saves $2100. That means that, for $1100 a year, the X181-KMR could detect moisture on a golf course, and the golf course would still make a $1000 profit that it would not have had otherwise.

Per hour, the X181-KMR costs $280 to operate. An eighteen hole golf course is about thirty acres, or one half of a square mile. Therefore, for set-up, execution, and break-down of the mission, it is reasonable to allow one hour of time. Because the golf course saves $1000 in water costs, the X181-KMR can charge about $580 to detect moisture at each golf course. Therefore, about $300 profit can be produced from each golf course moisture detection. Although detection moisture on golf courses is not as lucrative as detection crop soil moisture, it takes less time and only requires couple detections, as the grass is never harvested. Therefore, three detections are not necessary for each golf course, and golf course moisture can truly be detected when the soil-moisture detection business for crops is not in demand.

Erosion detection is another potential use for the X181-KMR. According to the Environmental Protection Agency (EPA), 23 of the 25 most densely populated counties in the United States are located on the coast. The EPA also states that, between 1900 and 2000, the sea level in the eastern United States rose by one foot. This one foot rise in sea level led to $94 billion of damage in Boston, Massachusetts, alone. By 2100, it is expected that the sea level could rise an additional four feet globally. The EPA warns that, "In the Northeast, even higher sea level rise is possible, due to the combined effects of warming waters and local land subsidence (sinking). Sea level rise and coastal flooding are likely to disrupt and damage important infrastructure, including communication systems, energy production, transportation, waste management, and access to clean water" (Climate Impacts on the Northeast: Precipitation and Sea Level Rise Impacts). Assuming that both the private sector and government are interested in ensuring the safety of their infrastructure, $460 million could be used for erosion and sea level rise impacts. That $460 million represents a mere one half percent of the damage done by a one foot rise in sea level. The current camera that the X181-KMR offers would be more effective than a satellite because of its ability to detect the responses of the coastal ecosystem. Trees and crops respond to changes in moisture and temperature, just like the sea does. Therefore, when the X181-KMR detects changes in crop or tree success and patterns, it could be an early indication of sea level rise. In southern New England, the success of oak and hickory trees over maple, beech, birch, spruce, and fir trees could indicate a higher temperature and sea level. These trends could help notify industries on the shore about an imminent sea level rise. Crop success will also change when the temperature changes, another indicator of potential sea level rise. Therefore, the notifying industries of sea level rises and trends could result in more revenue for the X181-KMR, even in the winter season. Typically, in Connecticut, waterfront houses and businesses are worth over $500,000. However, because most of these properties have limited waterfront, detection would take very little time. Assuming two detections per year, and one hour per detection, the X181-KMR would cost $560 to operate per property. Flood insurance in Connecticut is about $3000 for residential houses on the shoreline that are not elevated. Therefore, for two detections for a residential property, about $860 can be charged. This is a $300 per year profit for each residential property detected. For commercial properties, flood insurance is over $5000 per year. Therefore, about $1400 can be charged to detect erosion and flood threats for commercial clients. This results in an $840 profit per property for the X181-KMR. Erosion detection could also be extended to insurance companies in order to set rates for specific areas depending on the threats in those regions. The X181-KMR's use for erosion detection is especially useful in the winter months when no crops grow.



Finally, tobacco is a very important crop in Connecticut's economy. However, over 25% of Connecticut tobacco is damaged by mold annually, according to the *Connecticut Valley Tobacconist*. As a result of this, tobacco from Connecticut costs between $24 and $40 per pound, and production costs are $20,000 per acre. According to bulletin 564 from The Connecticut Agricultural Experiment Station in New Haven, Connecticut, overwatering tobacco crops can have disastrous effects. It can lead to bed rot, mildew, and reduced nitrogen content in the soil. Moreover, it can make the leaves tender and easier to tear and useless for cigar wrapping. Tobacco beds must also be properly ventilated (since tobacco fields are covered). The X181-KMR could also use its infrared camera to ensure that the fields do not reach 95 degrees Fahrenheit, which results in a failed crop. Tobacco farms in Connecticut range from around twenty acres to 100 acres per farm, while about 2000 acres of tobacco farms are maintained in Connecticut. The Windsor Shade Tobacco Company produces about one million pounds of tobacco each year.

Damaged tobacco results in a loss of about $875,000 annually per one million pounds of tobacco successfully produced. Therefore, moisture and heat detection for tobacco farms could potentially save $875,000 per million pounds of tobacco crop. Because of the value of tobacco, detection moisture in fields of tobacco can easily produce revenue.

Assuming that there are 2100 pounds of tobacco in each acre, and the X181-KMR detects moisture in 1280 acres of tobacco per year (two square miles), farmers could save up to 2.2 million dollars if two square miles of tobacco are saved. Obviously, in two square miles of tobacco fields, two square miles of tobacco are not lost. About 25% of Connecticut shade tobacco is damaged because of heat and moisture each year. Therefore, for two square miles of tobacco farm, about $560,000 is lost because of moisture and heat.

It would be reasonable to detect moisture in the tobacco field twice each year. The first detection would be before the plants are covered. This detection would only be analyzed for moisture content, as the temperature of the leaves would simply be the same as the ambient temperature of the air. The second detection would ensure that the tents (and underneath each tent), are not excessively moist nor over 95 degrees Fahrenheit. With this knowledge, the crops should be safe from being damaged.

It would take about four hours in total to do two detections of a two square mile field of tobacco (as both moisture and temperature must be detected). Therefore, at $280 an hour to operate the X181-KMR, $1120 would need to be spent to operate the aircraft. However, the amount of money that the tobacco farmers could save with by using the X181-KMR would allow for substantial revenue to be produced. Because $560,000 is at stake, even charging $84,000 to detect moisture in the field is only 15% of the new revenue for the farmer. Considering that the X181-KMR is the only reason that this portion of the field is successful, it is not unreasonable to charge a relatively high price for the detection. The farmer would have fertilized, watered, and maintained the 25% of the field that would have failed anyway. Therefore, the X181-KMR is simply making that labor worthwhile. Because of this, an $82,880 profit could eventually be made by the X181-KMR by detecting moisture and temperature in a tobacco field.

5. References

"Aircraft Mechanics and Service Technicians." Bureau of Labor Statistics. 30 March 2016. Retrieved from: http://www.bls.gov/oes/current/oes493011.htm

"Aircraft Turn Information Calculator." CSGNetwork. Retrieved from: http://www.csgnetwork.com/aircraftturninfocalc.html

Anderson, P.J. "Connecticut Experimental Station Bulletin 564." January 1953. Retrieved from:

http://www.ct.gov/caes/lib/caes/documents/publications/bulletins/b564.pdf

"Assembly Technician Salaries." Indeed. Retrieved from: http://www.indeed.com/salaries/Assembly-Technician-Salaries

"Aviation Maintenance Technician Salaries." Glassdoor. 15 March 2016. Retrieved from: https://www.glassdoor.com/Salaries/aviation-maintenance-technician-salary-SRCH_KO0,31.htm

"Avionics Technician Salary (United States)." PayScale. Retrieved from: http://www.payscale.com/research/US/Job=Avionics_Technician/Hourly_Rate

"Climate Impacts in the Northeast." Environmental Protection Agency. 23 February 2016. Retrieved from: http://www3.epa.gov/climatechange/impacts/northeast.html

"Climate Impacts on Coastal Areas." Environmental Protection Agency. 23 February 2016. Retrieved from: http://www3.epa.gov/climatechange/impacts/coasts.html

Danneberger, Karl. "EIG Study: Water Use on Golf Courses." The Ohio State University. Retrieved from: http://buckeyeturf.osu.edu/index.php?option=com_content&id=186&Itemid=170

"Electrical and Electronics Engineering Technicians." Bureau of Labor Statistics. 17 December 2015. Retrieved from: http://www.bls.gov/ooh/architecture-and-engineering/electrical-and-electronics-engineering-technicians.htm

English, Jean. "Raspberries: Challenging but Potentially Profitable." Maine Organic Farmers and Gardeners Association. 2016. Retrieved from: http://www.mofga.org/Publications/MaineOrganicFarmerGardener/Spring2005/Raspberries/tabid/1223/Default.aspx

"Golf's Use of Water." USGA. 2012. Retrieved from: http://usgatero.msu.edu/v11/n12.pdf

HydraProbe Field Portable. Retrieved from: http://www.stevenswater.com/products/sensors/soil/portable/hp_field/

Shrader, Brian. "Raleigh Drone Company Looks to Farmers for Business." 14 November 2014. Retrieved from: http://www.wral.com/raleigh-drone-company-looks-to-farmers-for-business/14181272/

The Luddy/Taylor Connecticut Valley Tobacco Museum. "About Us." Retrieved from: http://www.tobaccohistsoc.org/#!about_us/csgz

"The Tobacco Story." The Connecticut Valley Tobacconist. 2002. Retrieved from: http://www.cvtobacco.com/tobacco_story.html

Vaughan, Mark. "Surprise in Connecticut." Cigar Aficionado. Retrieved from: http://www.cigaraficionado.com/webfeatures/show/id/Surprise-in-Connecticut_7833/p/1